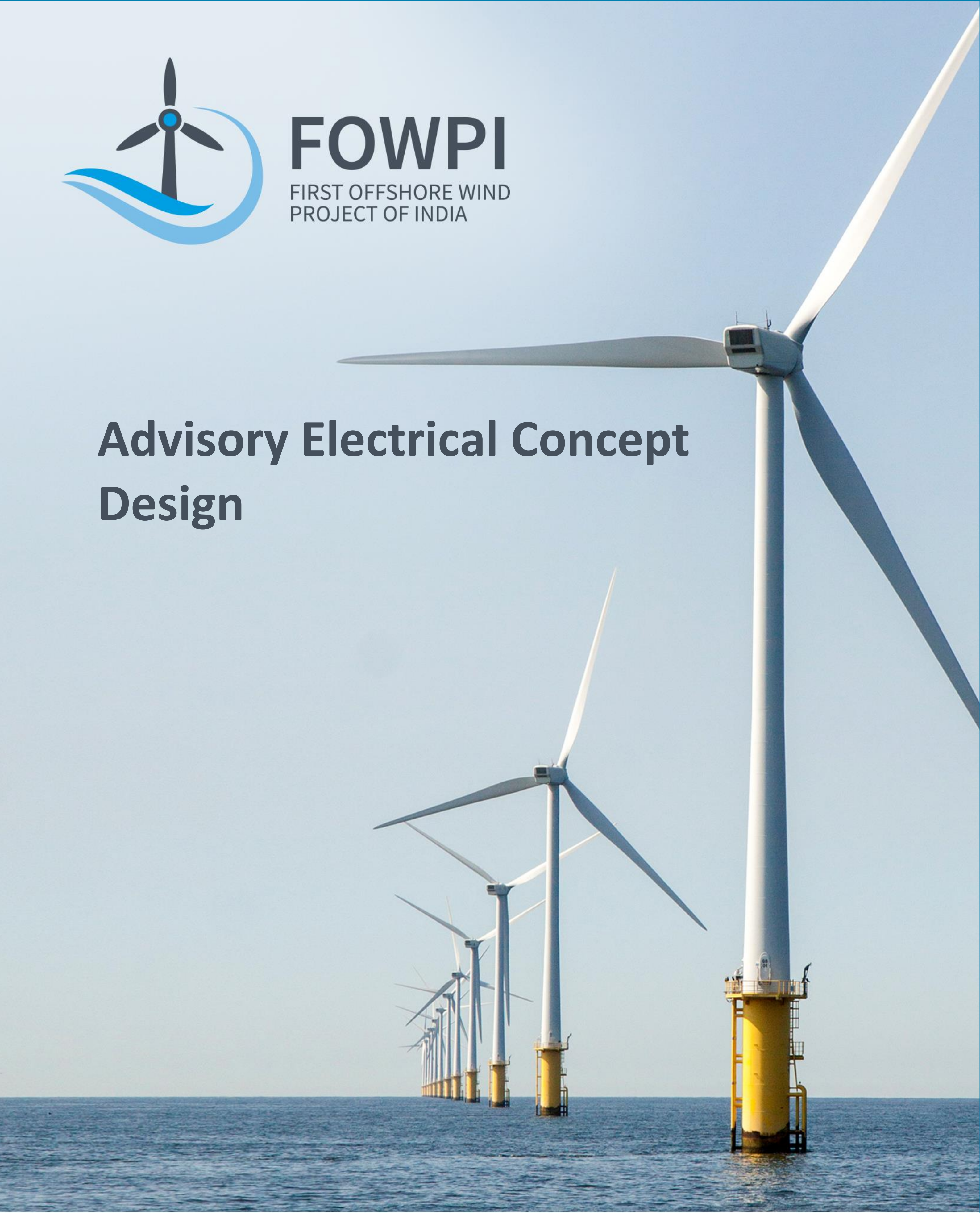
FOWPI

FIRST OFFSHORE WIND PROJECT OF INDIA

Advisory Electrical Concept Design



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This Project is funded by The European Union

1 About FOWPI

The First Offshore Wind Project of India (FOWPI) is part of the "Clean Energy Cooperation with India" (CECI) programme, funded by the European Union (EU). The programme aims at enhancing India's capacity to deploy low carbon energy production and improve energy efficiency, thereby contributing to the mitigation of global climate change. Project activities will support India's efforts to secure the energy supply security, within a well-established framework for strategic energy cooperation between the EU and India.

FOWPI is defined as a 200MW offshore wind farm near the coast of Gujarat, 25km off Jafarabad. The project scope focus is on preliminary investigations and advisory for the windfarm including wind turbine foundation, electrical network, environmental scoping, financial modelling and other relevant technical studies. FOWPI uses the outputs from Facilitating Offshore Wind in India (FOWIND) project (2013-2018) also supported by the European Union. FOWIND and FOWPI bring the vast experience of European countries in offshore wind, to support India with the creation of a national knowledge centre and with technical support for setting up the first offshore wind-farms.

FOWPI is led by COWI A/S (Denmark) with key support from WindDForce Management Ltd. (India). The project is implemented in close collaboration with the European Union, the Ministry of New and Renewable Energy- India (MNRE) and National Institute of Wind Energy- India (NIWE).

Contract: No 2015/368469 Start 01-2016 Duration: 42 months

2 Disclaimer

3 Copyright statements

4 About the European Union

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The 14th annual Summit between India and the European Union (EU) was held in New Delhi on 6 October 2017. Both sides adopted a Joint Statement on Clean Energy and Climate Change, reaffirmed their commitments under the 2015 Paris Agreement, and agreed to co-operate further to enhance its implementation. India and the EU noted that addressing climate change and promoting secure, affordable and sustainable supplies of energy are key shared priorities and welcomed the progress on the Clean Energy and Climate Partnership, adopted at the 2016 EU-India Summit, and reiterated their commitment to its implementation and further development. In particular the EU is committed to continue cooperation in view of the cost-effective development of offshore wind in India.

5 Acknowledgements

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Advisory Electrical Concept Design

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1 Introduction

Under the EU-funded project "First Offshore Wind Farm Project of India" (FOWPI), an offshore wind farm is planned and advisory technical documentation to support a tender call is prepared. This document addresses the power system infrastructure interconnecting FOWPI to the existing power grid.

FOWPI is a 200 MW wind farm, situated in Gujarat in the Gulf of Khambhat, approximately 25 km off the coast, near the harbour and container terminal of Pipavav. FOWPI location, within development Zone B, is illustrated in Figure 1.

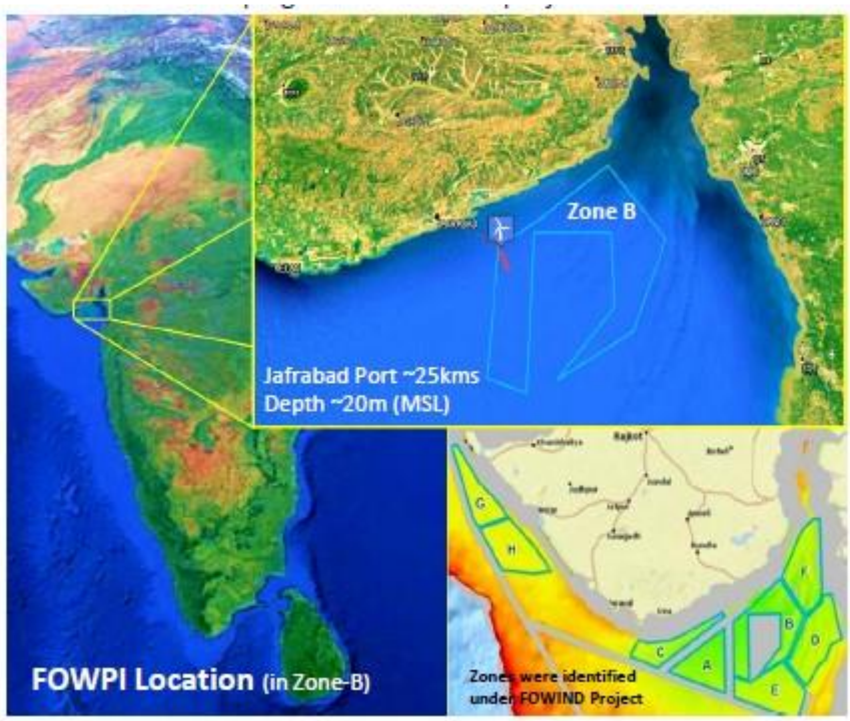

Figure 1 Wind farm location in Gulf of Khambath, Gujarat, in a sub-area of Zone B identified by FOWIND studies.

This document explores a number of possible power export configurations and grid connection possibilities for the interconnection and integration of FOWPI. The designs for electrical infrastructure offshore and onshore present possibilities that may be used for this specific project, but which may also provide inspiration for coming offshore projects in India.

The illustrative layout for FOWPI is shown in Figure 2 with three rows perpendicular to the predominant wind direction and export cable(s) from the wind farm to the shore.

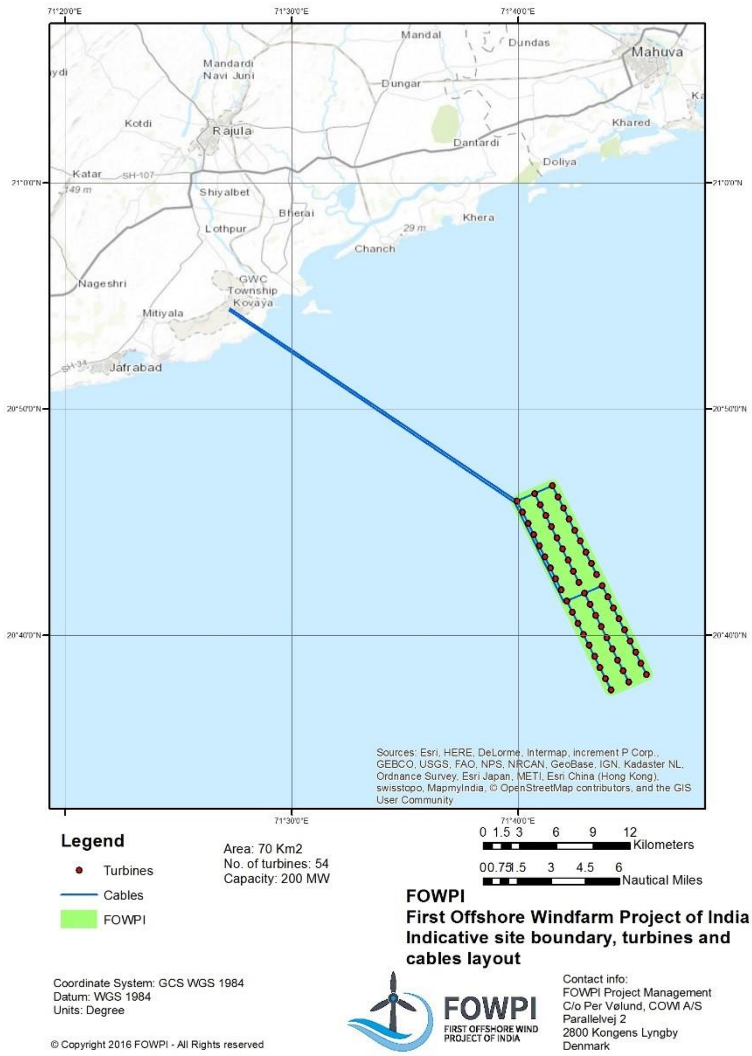

Figure 2 Wind farm layout in the Gulf of Khambhat, Gujarat – 25 km off Pipavav Harbor

As part of the study, Gujarat Energy Transmission Corporation Limited (GETCO) has been consulted for grid integration evaluation for different grid connection possibilities. The results of this study provide a basis for the evaluation and potential selection of the grid connection point for FOWPI at one of the GETCO owned substations.

2 Summary

The conceptual design of the electrical systems for FOWPI offshore wind farm in Gujarat, India, is presented in this report.

General project related references as well as technical standards are presented in *Section 3*. All standards are used as guidelines and design basis for similar projects in Europe, and are broadly used by most designers and manufacturers.

The conceptual design assumptions are described in *Section 4*. It includes i) the requirement to fulfil the local grid code with respect to grid connection point and power quality, ii) layouts of the of the wind farm depending of the Wind Turbine Generator (WTG) sizing, i.e. 3 or 6 MW, iii) considerations for the offshore export cable routing and location for the landfall and iv) potential onshore cable routing and points of connection (PoC) to the grid - further supported by a GETCO study presented in the Appendix.

The design challenges and concepts are approached in *Section 5*. Different cable types are listed and the basic design requirements with respect to load, losses, cable routing, installation, etc. are described. Different types of high voltage (HV) and medium voltage (MV) switchgear equipment, including types of sub-marine and land cables are presented. Installation techniques for both land and sub-marine cables are highlighted, and off-shore route engineering along with different cable-laying systems are described. Section 5 also approaches different supervisory control and data acquisition systems (SCADA), communication systems, including fibre optic network, Tetra- and Very High Frequency (VHF) radios and IP telephones.

A number of different possibilities for the electrical system topologies have been considered in *Sections 6 and 7,* and in more detail in the Appendices. Four solutions (Options) have been chosen and further evaluated.

A windfarm consisting of 3MW WTGs offers two possibilities for the power system topology:

- **Option 1** - 6 export cables 33 kV and no off-shore substation (OSS).
- **Option 2** - 1 export cable 220 kV with a 33/220 kV OSS.

A windfarm consisting of 6MW WTGs solution also offers two solutions with or without an OSS:

- **Option 3** - 4 export cables 66 kV and no OSS.

- **Option 4** - 1 export cable 220 kV with a 66/220 kV OSS.

Option 1 is a solution with 66 WTGs of 3 MW interconnected in 6 strings with 33 kV array cables. For each of the 6 strings a 33 kV export cable is connected to a new on-shore substation (ONSS). There is no OSS for this solution. The 33kV offshore export cables are connected via cable joints at landfall, and then routed on via 33 kV onshore export cables buried in the ground. The onshore 33 kV export cables are then connected to a new 33/220 kV ONSS located close to an existing grid substation operated by the TSO. The point of common coupling (POC) is located in the TSO grid sub-station.

Option 2 is also a solution with 66 WTGs of 3 MW interconnected in 6 strings with 33kV array cables. However, for this solution the 6 strings are connected to an offshore substation (OSS). The electrical requirements for the OSS is described in Appendix B. On the OSS the 33 kV array cables are connected a transformer converting the voltage level to 220 kV. From the OSS a single 220 kV offshore export cable is then routed to shore, and via a cable transition joint at landfall the 220 kV cables is routed on land (buried) to be connected to a new 33/220 kV ONSS located close to an existing grid substation operated by the TSO.

Option 3 is a solution almost similar to Option 1 but with larger 6 MW WTGs and 66kV array - and export cables. The 33 WTGs – 6 MW are interconnected in 4 strings. For each string a 66 kV export cable is connected to the new on-shore substation (ONSS). As for Option 1 there is no OSS for this solution. The 66 kV offshore export cables are connected via cable joints at landfall, and then routed on via 66 kV onshore export cables buried in the ground. The onshore 66 kV export cables are then connected to a new 66/220 kV ONSS located close to an existing grid substation operated by the TSO. The point of common coupling (POC) is located in the TSO grid sub-station.

Option 4 is a solution almost similar to Option 1 and have only been investigated in respect to cost comparison.

An indicative economical comparison between the power system options is presented in *Section 8*. The comparison is based on the CAPEX and capitalisation of energy losses, primarily for the cables with the summary budget figures shown in Table 1.

	Option 1	Option 2	Option 3	Option 4
	66x3MW 6x33kV Exp. Cab. 6x Array Cab.	66x3MW OSS+230kV Exp.Cab 6x Array Cab.	33x6MW 4x66kV Exp.Cab. 4x Array Cab.	33x6MW OSS+230kV Exp.Cab 4x Array Cab.
WTG Components	11,7	11,7	10,8	10,8
MV Cables, Offshore	132,4	38,6	90,0	25,8
MV Cables, Onshore	0,9	0,0	0,5	0,0
HV Cable, Offshore	0,0	29,7	0,0	29,7
HV cable Onshore	1,1	1,6	2,9	2,3
Offshore Substation	0,0	61,6	0,0	62,1
Onshore Substation	7,1	2,5	7,8	2,5
Energy Loss Capitalisation	23,3	10,5	16,9	8,0
Total [Eur x10^6]	**177**	**156**	**129**	**141**

Table 1 High level cost summary for base options

The cost comparison indicates that Option 3 *(6 MW WTG, 66 kV export cables and no OSS)* is the most cost attractive solution for FOWPI.

The table also indicates that:

- A power system topology consisting of 220 kV export cable, OSS and 33 kV array cables is cost attractive to a solution with six 33 kV export cables and no OSS when 3 MW WTGs are installed.

- A power system topology consisting of 220 kV export cable, OSS and 66 kV array cables is not cost attractive to a solution with four 66 kV export cables and no OSS when 6 MW WTGs are installed.

It should be noted that the above cost assessment is only indicative, as just a few, or minor, changes to the wind farm layout, the number of WTGs and/or cable lengths, will change the preconditions.

For comparison and in order to present possible optimizations, a number of derived versions of each option were evaluated including changes in the number of array cables, changes in array cable conductor material and cross-section. The following table defines the optimisation alternatives that were considered:

	Base Case	**Alternative 1**	**Alternative 2**	**Alternative 3**
Option 1	Six 33kV Export Cables	Five 33kV Export Cables	Four 33kV Export Cables	
Option 2 (With OSS)	Six 33kV Array Cables	Four 33kV Array Cables		
Option 3	Four 66kV Export Cables	Three 66kV Export Cables	Three 66kV Export Cables (Straight Radial)	Two 66kV Export Cables
Option 4 (With OSS)	Four 33kV Array Cables			

Table 2 Base Cases & Alternatives Analysed

Cost assessments in respect to less cable circuits (imposing larger cable conductor sizes) indicate that a cost optimisation could lead to further savings as illustrated in Figure 3.

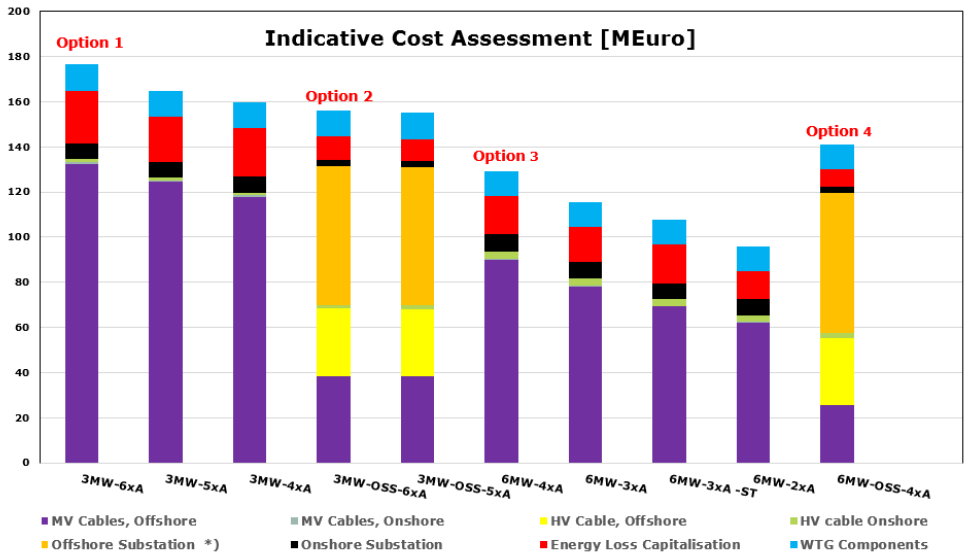

Figure 3 Indicative cost comparison with reduced export/array cable strings

However, the limitation for such optimisation would be:

- The maximum cable size that can be installed in the WTGs
- The developers risk assessment on the park's availability when more WTGs are connected to each array cables radial

Section 9 provides an overview of potential suppliers of HV and MV submarine cables and land cables, and suppliers of OSS. All suppliers of submarine cables and OSS are European. No Indian supplier of these components have been identified. For HV and MV land cables and sub-station components, a number of Indian suppliers have been identified as well as several European.

Section 10 includes comments of the results from the GETCO grid study. The study identifies three substations operated by GETCO as potential Point of Connection (PoC) and a Power System Analysis (PSA) on Dhokadva SS preferred by GETCO (situated 45km from preferred offshore landing point) has been carried out. The PSA confirms that the grid capacity can absorb the power generated by the 200MW wind farm. A future OWF developer is advised to approach both GETCO and operators of other private 220kV substations situated nearby the preferred offshore cable landing point aiming at identifying the most cost attractive concept for the grid interconnection. It is also recommended that GETCO is approached in respect to establishing a new 220kV substation that can connect direct to existing 220kV transmission lines. The GETCO Grid Study report is enclosed in Appendix F.

3 References, abbreviations and definitions

3.1 References

Ref. /1/ FOWIND Consortium, Pre-feasibility Study for Offshore Wind Farm Development in, May 2015.

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Ref. /3/ Prysmain Conference Paper, Dynamic rating of submarine cables – Application to offshore windfarms, November 2013.

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Ref. /5/ ABB Cables, XLPE Cable Systems, User's Guide, Rev 2.

Ref. /6/ ABB Cables, XLPE Submarine Cable Systems, Attachment to XLPE Land Cable Systems, User's Guide, Rev 5.

Ref. /7/ Nexans, Submarine Power Cables - Brochure.

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Ref. /11/ Institute of Electrical and Electronics Engineers, IEEE std 519-2014 - IEEE recommended practice and requirements for harmonic control in electric power systems, 2014.

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GERC-Draft Gujarat Electricity Grid Code, 2013 Posted August 2, 2013

3.2 Abbreviations

The main abbreviations and symbols used in the present report are listed below.

ACSR	Aluminium Conductor Steel Reinforced
AIS	Automated identification System
AT	Station Auxiliary Transformer
BAS	Burial Assessment Study
BoP	Balance of Plant
CAPEX	Capital Expenditure
CLV	Cable Laying Vessel
CPS	Cable Protection System (Bending Restrictors)
CRS	Cable Route Study
CTW	Crew Transfer Vessel
DoB	Depth of Burial
DP2	Dynamic Positioning (DP) vessel (DP1, 2 or 3)
DTMS	Distributed Temperature Measurement System
EPDM	Ethylene Propylene Diene Monomers
EPCI	Engineering Procurement Construction Installation
EPR	Ethylene Propylene Rubber
EU	European Union
FAS	Fire Alarm System
FAT	Factory Acceptance Test
FES	Fire Equipment Services
FOC	Fibre Optical Cable
GETCO	Gujarat Energy Transmission Corporation Limited (TSO)
GIS	Gas Insulated Switchgear
Grid SS	Grid substation (PoC identified)
HDD	Horizontal Directional Drilling
HMI	Human Machine Interface
HSE	Health and Safety Executive
HV	High Voltage 132 - 220kV power system operational voltage
ICC	Interconnection Cable, between WTGs
IED	Intelligent Electronic Device (IEC61850 reference)
IEGC	Indian Electricity Grid Code
LV	Low Voltage <1kV
MBR	Minimum Bending Radius (for cables)
MV	Medium Voltage 33 - 66kV power system operational voltage
nm	Nautical Mile
O&M	Operation and Maintenance
OPEX	Operational Expenditure
OSS	Offshore Substation
OWF	Offshore Wind Farm
PLB	Post Lay Burial
PoC	Point of Connection
PPA	Power Purchase Agreement
RAMS	Risk Assessments and Method Statements
SAP	Senior Authorised Person
SAT	Site Acceptance Test

SCADA	Supervision & Control System
SCS	Substation Control System
STATCOM	Dynamic Reactive Compensation
SVC	Static Var Compensator
TJB	Transition Joint Bay
TR	Thermal Resistivity
TSO	Transmission System Operator
UI	User Interface
UPS	Uninterruptable Power Supply
UXO	UneXploded Ordnance
WFD	Wind farm Developer
WF ONSS	Wind farm onshore substation
VHF	Very High Frequency (radio)
WTG	Wind Turbine Generator
XLPE	Cross-linked polyethylene

4 Design assumptions

4.1 Grid code requirements

The power delivered by the prospected wind farm shall be in accordance with the requirements from the Indian Electricity Code Ref. /20/. Further specifications are summarized below:

- **Voltage level**
  The voltage range at the point of connection shall be within the operating range as specified in the Table 3:

Voltage — (kV rms)		
Nominal	Maximum	Minimum
220	245	198
132	145	122
66	72	60
33	36	30

Table 2 Voltage range at point of connection

N.B. It is noted that this report will use the term 33kV nominal voltage even if it would be an advantage to operate some circuits within the windfarm at 34kV nominal. This is due to the conceptual nature of this study.

- **Power Quality**
  Wind farms connected to the grid PoC at 66kV and above shall be capable of supplying dynamically varying reactive power support, so as to maintain the power factor within limits of 0.95 lagging to 0.95 leading from no-load to full load production.

  Reactive power compensation must be installed in order to reduce losses in the export cable(s) to shore to an absolute minimum.

- **Harmonics**
  India has not yet established its country specific requirements on allowable harmonic disturbance from wind farms. The prevailing IEGC refers to IEEE Std 519 (Ref. /11/), which states the noise level requirements presented in Table 3.

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{sc}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 25[c]	1.0	0.5	0.38	0.15	0.1	1.5
$25 < 50$	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.0	1.5	1.15	0.45	0.22	3.75

Table 3 IEEE Std 519 (Ref. /11/) noise level requirements

- **Frequency**
  The frequency must remain within the frequency band of 48.5 to 50.5Hz in continuous operation and 47.5 to 52Hz for short durations.

- **Fault ride through requirement**
  The wind farm and the WTGs shall be able to remain connected to the power grid and support the voltage during fault events occurring elsewhere in the power grid until the cause of the fault has been determined and normal operational conditions has been re-established. Thus the WTGs and the wind farm park control management system shall maintain 15% retained voltage for 300 ms, increasing linearly to 85% over 3 s (Ref. /10/). This is illustrated in Figure 4.

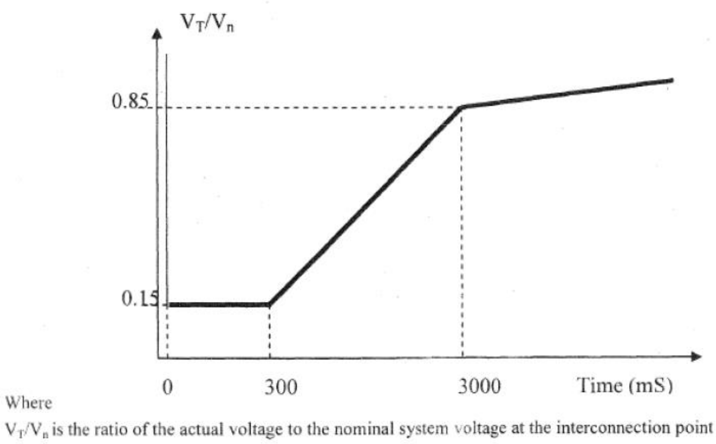


Figure 4 Fault Ride through requirement

4.2 Wind farm outline

4.2.1 Wind farm layout

This conceptual design document is based on two different wind farm layouts:

- 66 WTG units each rated 3.0 MW resulting in 198 MW installed power
- 33 WTG units each rated 6.0 MW resulting in 198 MW installed power.

The total installed wind farm capacity shall be agreed between the project developer, the transmission system operator (TSO), and other national/regional stakeholders in the power purchase agreement.

It is noted that some developers in Europe for particular sites have obtained permission to install one or two additional WTG units that may serve as operational spare to improve the park availability. This approach is in compliance with the maximum power connected to the grid being respected. However, such additional units can contribute to the park production when other WTGs are out for maintenance/repair. The wind farm business case could be further improved if the developer is allowed to produce up to a maximum agreed power at the PoC and is not restricted by a number of units / installed capacity.

The final number of units / installed capacity obviously cannot be determined until the developer has completed the feasibility study and negotiated a solid power purchase agreement with the TSO.

The assumed wind farm layouts for the two WTG types are based on the conclusions from the preliminary FOWPI wind studies, Ref. /19/, and form the basis for the power electrical infrastructure design.

The layout will cover an area with a length of approximately 10 km and with a width of approximately 3 km. For both layouts there will be three rows facing the prevailing wind direction. The wind farm option with 3 MW WTG units is assumed to have a distance of 0.5 km between wind turbines, whereas the 6 MW WTG units are placed with a distance of 1.0 km between them. The two base layouts are illustrated in Figure 5.

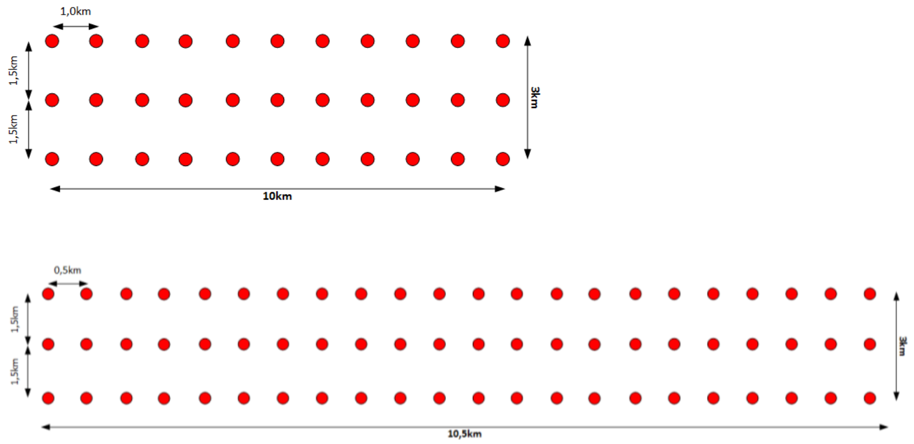


Figure 5 Assumed wind farm layouts: 33 x 6 MW (Top) and 66 x 3 MW (Bottom)

4.2.2 Wind turbine generators

The present advisory design focuses on reference wind turbines of sizes 3MW and 6MW respectively. Both WTG sizes are of the electrical type 4, which has a variable speed generator with a full-scale power converter. The full-scale power converter utilises a synchronous or induction generator effectively separated from the grid via a full-power converter. The wind turbines are also assumed to be with variable speed regulation by means of blade pitch control.

4.2.2.1 Reactive power control and voltage regulation

The wind farm shall comply with the prevailing grid code set up by the TSO, thus the entire wind farm must be equipped with a reactive power control function capable of controlling the generated active and reactive power.

The SCADA system for the wind farm shall be designed to control the WTGs individually so that it is possible to obtain the required voltage quality specified in the grid code at the Point of Connection (PoC) for the full power range.

The WTGs shall be designed so that it is possible to operate the wind farm in the following operation modes:

- Reactive power control
- Power factor control
- Voltage control

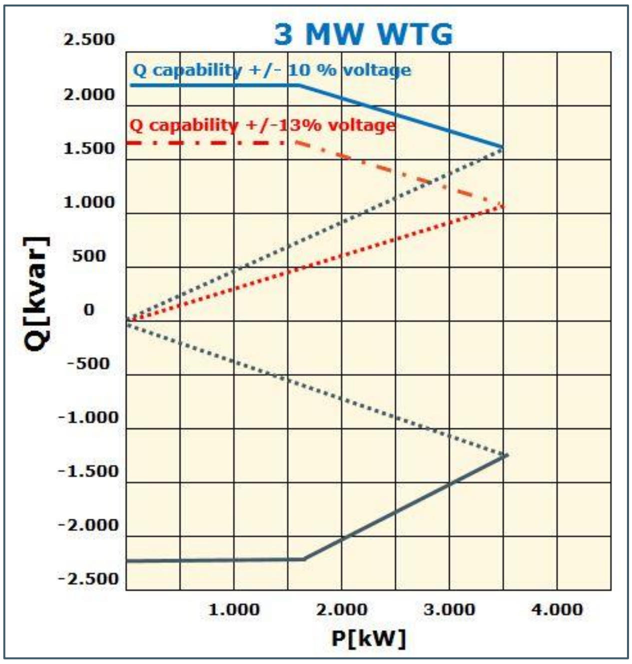


Figure 6 Typical Q and P operation mode characteristics

Figure 6 shows the typical Q and P operation mode characteristics for a 3MW sized WTG (6MW will have similar characteristics), which shall be used for the power grid studies based on the supplier's specific P/Q curves for his offered design.

Modern wind turbines with full-scale converters are typically able to deliver reactive power with a power factor of ≈0.9-1.0 at full load in the whole operating range usually with only a few limitations. The full converter type WTG can also to some extent absorb reactive power from the grid and will be able to maintain the reactive power capability at low wind where no active power production occurs. This is very useful and will reduce the need for centralized compensation facilities at the wind farm onshore substation (implying that STATCOMs may be rated smaller).

4.2.2.2 Cable connection box in the WTGs

It is assumed that the WTG foundations will be designed with T-connection units. The units should be pre-installed onshore, thus enabling the laying of array cables and pull-in to foundations prior to the transition piece and WTG tower/nacelle installation. This will enable a more solid and accelerated installation programme for the entire wind farm.

In addition, the T-connection units will also eliminate the current restriction imposed by the WTG supplier's standard MV switch gear (630A) and thus allow larger array cables and more WTGs being connected to each MV radial string.

The high-level topology of the MV-radials is illustrated in Figure 7.

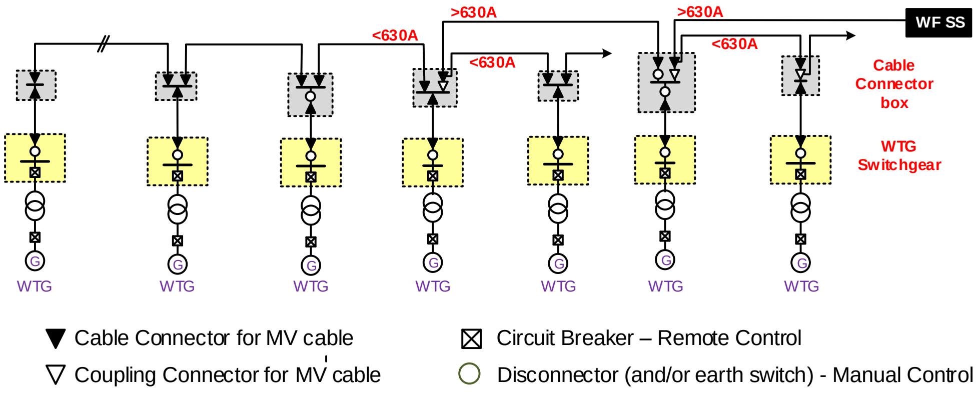


Figure 7 High-level topology of the MV-radials

Downstream in the MV-radial from the OSS or the ONSS towards the WTGs, disconnector and earth switch devices could be designed in the cable connection box, but this is not mandatory for the operation of the wind farm. Disconnection of the array cables during operation will be very rare and would be done manually. A cost efficient design could involve that disconnection of the array cables is done manually simply by extracting the cable connector from the termination point and securing the cable safety by earthing the conductors to designed earthing terminals. This operation naturally involves personal safety hazards, and therefore such disconnection/reconnection of cables shall be carried out only by certified and trained personnel with specific training and instruction in accordance with appropriate and agreed safety rules.

4.3 Landfall location

The selection of the landfall is one of the cornerstone decisions determining the basis for the power system design and cost impact, and it must be selected as soon as possible by the wind farm developer. The proper selection should consider numerous factors including:

- Export cable route lengths onshore and offshore shall be as shortest possible
- A flat coast line, which may result in horizontal directional drilling (HDD) not being necessary
- Easy access for construction machinery
- A location as close as possible to available PoC
- Low population in the area for landfall and along the cable track
- Shipping routes, navigation channels
- Other services e.g. tele communication cables, pipelines etc

The situation map in Figure 8 indicates potential PoCs and the assumed location of the landfall.

Figure 8 Assumed landfall

4.4 Grid connection point

The Point of Connection (PoC) to the existing power grid constitutes the metering point and the interface between the wind farm and the power grid. This point and technical requirements stated by the TSO must be identified as soon as possible in order for any developer to understand the basis for the costs of design and construction related to the grid interconnection. The prevailing grid code defining the technical requirement basis for the wind farm with respect to operational performance shall be fulfilled at the PoC.

A 200MW production facility should be connected to the grid at a voltage level above 132kV. The solutions presented in this report all connect to grid at a voltage level of 220kV.

The area assumed for landfall of the sea cable already offers different options for grid connection given that heavy electricity consumers already exists in this area (Pipavav port, Kovaya Cement Plant). This indicates that the area has a strong grid supported by the Utrateck power plant and GSPC Pipavav Power Company's facilities situated immediately south of the area assumed for landfall.

Based on the data procured and the understanding that heavy reinforcement of the power grid is previously investigated to receive up to 500MW generation capacity in the region, it is assumed that a new 220/500kV substation may be established. The assumed location is shown in Figure 9. This connection point forms the basis for the advisory design and it is anticipated to offer a solid connection point in respect of voltage fluctuation. It is possible that the 200MW wind farm can be connected to the outdoor switchyards identified in the area. A more comprehensive assessment made in dialogue with the TSO could reveal that one of the existing switchyards could constitute a suitable PoC.

The landfall location shall be determined based on comprehensive assessments of access to grid substations, conditions at the coastline and routing of the sea cable(s). Consequently, it is considered appropriate that the advisory design assumes that the PoC is located onshore at a distance of approximately 2.5 km from the shore as indicated in the situation map in Figure 9.

Figure 9 Situation map – assumed location of the PoC

Update: GETCO has carried out load flow studies in order to identify possible grid connection points for the FOWPI wind farm assuming that the generated power will be consumed within the Gujarat only. Results indicating connection possibilities with GETCO facilities are presented in Chapter 10 and Appendix F.

4.5 Environmental conditions

4.5.1 Design basis data

Temperatures	
Soil onshore	30ºC
Soil offshore - seabed	25ºC
Air temperature	10-45ºC

Native soil thermal resistivity, [moist/dry]	
Onshore, up to 2 m depth	1.0/3.0 km/W
Offshore and at beach	0.7/0.7 km/W

Dry-out of soil will not be considered offshore, but shall be considered onshore.

Installation assumptions	[burial /min. separation]
Offshore cable circuits	1.0 - 2.0/10 m
Onshore cable trench, HV cable	1.5/2.0 m
Onshore cable trench, MV cable	1.0/3.0 m
Landfall, open cut, cable trench	1.5 /5.0 m

4.5.2 Seabed conditions

An early determination of seabed geotechnical conditions is important for the selection of the export cable route and could even impact the micro siting (location) of the WTGs at the wind farm. Further, the geotechnical conditions will also form the basis for selecting appropriate cable installation methods to achieve an acceptable cable burial depth offering protection against mechanical damage during the lifetime of the wind farm.

Figure 10 Geotechnical investigations at location 25 km south of the coast

Recent geotechnical investigations in March 2017 at a single location situated 25 km south of the coast, as indicated in Ref. /12/, indicate that "the material in this stratum up to 4.0 m depth comprises very soft to soft greyish silty clay with high plasticity and SPT N value varying from 1 to 4". No boulders are anticipated in the region.

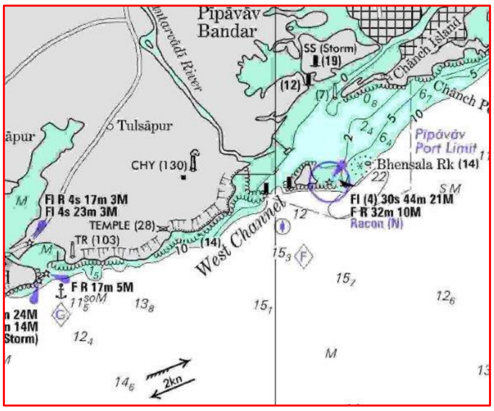


Figure 11 Water depth indications

The water depth within the wind farm is between 14 - 18 m LAT. The nautical chart of the coastline and towards the wind farm position along the assumed export cable corridor indicates a relatively flat seabed profile. Thus, no large slopes are anticipated. It is also verified that the water depth is rapidly increasing from the shoreline. E.g. 10 m water depth is expected already at a distance of 200-300 m from the shore.

The tide table for Pipavav port indicates a tide spectrum highest 4.0 m/lowest 0.5 m.

The Pipavav port is one of India's main hubs for bulk container ship transport and will be a major stakeholder since the shipping lanes to/from the port should be disturbed as little as possible during installation and operation of the export cable(s). In particular, any plans for future dredging activities across the export cable corridor shall be clarified and taken into consideration during the design activities. Thus it is important at an early stage to consult Pipavav port in order to assure a design of the offshore export cable which meets the requirements of the port.

The preliminary suggested offshore cable corridor and feasible installation methods are addressed in section 5.9.

4.5.3 Crossing of existing services

Oil exploration is ongoing or planned in the gulf of Khambhat and oil subsea pipelines, communication cables are reported but not identified in the area. This must be clarified when the cable route planning commences. Crossing agreements with the operators and technical alignments on the crossing design/outline shall be obtained prior to the cable installation.

The most widely adopted approach is placing a 0.5 - 1.0 m separation layer approx. 20x10m (rock beam) above the existing cables/pipelines and surface lay the latest cable at the top when crossing. Mechanical protection of the subsea cable (against anchor damage) can then be obtained by applying a cover layer of around 1 m consisting of rocks in a suitable size offering a stable construction but without damaging the cable during the rock dumping operation. This design shall be prepared as early as possible by the developer since operators and marine authorities very likely will set out strict requirements to be taken into account for the cable route design. In addition, scour effects shall be investigated if significant water currents exists. With the water depth > 10m the influence from waves on the rock beam design is considered insignificant.

4.6 Power Grid Analysis

4.6.1 General Concepts

It is important that a framework for power grid analysis is established with details on regulatory aspects on responsibilities and interfaces between the TSO and the developer. Please refer to Ref. /2/ issued by FOWIND in April 2017, where the situation today and suggested initiatives in an Indian context is discussed in detail.

The grid interconnection cannot be executed unless a comprehensive power system analysis have been completed. Proper sizing and rating of electrical components shall be identified and need for reactive compensation and harmonic interference at the PoC shall be agreed between the wind farm developer and the TSO. Further, it shall be established to what extent the existing power grid shall be reinforced and agreements on responsibilities/cost spilt shall be aligned. On such agreed basis the developer can commence his design/engineering and committed procurement of the electrical components and the TSO can kick-of his planning, design, and installation of e grid reinforcements.

Table 4 outlines the nature and range simulations required and mark out the studies implemented as a part of this advisory design. The studies completed are preliminary and must be redone when the WTG type and PoC have been identified by the wind farm developer.

Simulation method	**Description**	**Included**
Load-flow calculations	Simulation of currents in all cable sections. The load flow study for the wind farm shall: › verify that the rating on cables is sufficient on components, › justify that the voltage criteria is not violated and › determine if any additional components are needed to deliver the generated power at the PoC.	Yes

Power loss calculations	Simulation of the active and reactive power losses within the wind farm power distribution system to the PoC typically at no-load and full load.	Yes
PQ-capability diagrams for the wind farm in PoC	Simulation of how the generated power from the wind farm is dependent of the ratio between P and Q.	Partly
Short circuit current behaviour	Simulation of the short circuit (SC) current contribution of the wind farm into the transmission network under different fault conditions. The short circuit study shall ensure the design according to reliability, protection and short circuit levels › maximum level › minimum level › 1 phase short circuit › 3 phase short circuit	Yes
Harmonic assessment	A dynamic harmonic study of the behavior of the harmonics.	No
Low voltage fault ride through capability	Simulation of the capability of the generators in the wind farm to stay connected in short periods of a lower electric network voltage.	No
Dynamic stability study	The important part of the power system with the dynamic wind study, is to investigate if the voltage can stabilize after a failure affecting the wind generation and no oscillation with power schemes happens. This is in principle the same as for a total study done with all configurations of the power system where large loads are lost or outage of power lines means changes in power flow.	No
Dynamic frequency regulation	A dynamic study, which shows the wind farm's availability to control the regulation of the frequency of the generated power.	No
Protection coordination study	Wind farm equipment such as transformers, reactors, capacitor banks and cables must be protected against damage from fault currents and short circuit currents. The protection coordination study: › helps reduce unnecessary downtime. › provides recommended settings for adjustable trip circuit breakers and relays. › focuses on coordination (selectivity) between devices. › identifies deficiencies in system protection. › provides recommended solutions to help correct problem areas. › implements the use of system devices with respect to National Electric Code requirements, and appropriate IEC, ANSI/IEEE standards. The protection coordination study also defines the protection zones and provides an overview of protective devices such as measuring devices, breakers, disconnectors and earthing switches.	

Table 4 Power System Analysis Topics

4.6.2 Reactive power compensation requirements

The following grid simulations are recommended to assess the need for power compensation in the following situations:

- Idle mode "WTGs connected - no-production"

- Full production

Regardless, there will be a need for reactive power compensation to fulfil the grid code, to balance out the capacitance and charging current in the relative long 33/220 kV cables used for export or as array cables between the WTGs.

Experience from European offshore wind farms shows good experience with placing a shunt reactor for reactive power compensation both for the export and the array cables at the OSS.

For options, which doesn't have an OSS, the equipment will be placed in a newly built onshore substation situated as close as possible to the landfall of the offshore export cable(s).

Techniques
The compensation of the reactive power can be realised with one or several shunt reactors connected either via separate switchgear or direct to the HV export cable. (If not connected via a dedicated circuit breaker then the shunt reactor is terminated direct on the cable feeder and will be disconnected together with the cable. The shunt reactors can be equipped with on-load tap changers for regulation purposes. The fine-tuning of the reactive power balance, particular at low production scenarios, is often supported by STATCOM’s or SVC’s, that also assist with correction for voltage flicker and harmonic currents.

4.6.3 Harmonic assessment

Even if it is recommended to use WTGs of electrical type 3 and 4, which are known to deliver power with a sinusoidal curve with very few harmonics, it is still recommended to do the following two types of grid simulations at the point of connection for the wind farm:

- Frequency scan analysis
- Harmonic load flow analysis

The assessment of the harmonic distortions caused by the wind farm should be evaluated in two steps.

- First, a frequency scan analysis is performed to get information about possible series or parallel resonance frequencies. A parallel resonant phenomena is characterised by a significant increase in harmonic impedance at the resonant frequency. Harmonic currents will tend to create large harmonic voltages if they coincide with the parallel resonant harmonic impedance. A series of resonant phenomena is characterized by a significant drop in harmonic impedance at the harmonic resonant frequency. Harmonic voltages will tend to create large harmonic currents if they coincide with the series resonant harmonic impedance. Generally, for a WF the most relevant issue is the search for parallel resonance as this potentially can course harmonic voltage distortions for other consumers. The frequency scans should be calculated as the impedance seen from the PoC 220kV busbar at full load of the WF.

- In addition to the frequency scan also harmonic load flow calculations should be performed. The harmonic load flow calculations will evaluate the harmonic voltages and currents at the PoC 220kV busbar at full load of the WF. The results from the harmonic load flow are used for assessing the grid code compliance.

The harmonic spectrum as according to IEC61400 for the WTG types selected shall be used.

The assessment shall be made, with the wind farm running at full load with all HV/MV transformers in service. The initial sub transient short circuit power of the external network at the 220kV busbar is adjusted to an estimated medium value of Sk=2500MVA based on the indicated maximum and minimum values.

The harmonic assessment rest on data provided from the TSO who shall provide accurate information on the harmonic impedance load, harmonic background level and short circuit level at the PoC. Further, planned harmonic impacts from future production plants and the TSO’s improvement initiatives in the power grid shall also be factored into the harmonic study.

The output of the harmonic study shall determine the necessary number and rating of filters installed at the WF ONSS to obtain grid code compliance.

5 General design challenges and concepts

5.1 General Electrical Rating

Operational voltage	**220kV**	**66kV**	**33..34kV *)**
Basic Insulation Level (IEC60071)			
Highest voltage for equipment, U_m	245KV	72.5kV	36.0kV
Short duration power-frequency withstand voltage	$460kV_{rms}$	$140\ V_{rms}$	$70kV_{rms}$
Lightning impulse withstand voltage, (1.2/50μs)	1,050kV	325kV	170kV
System Earthing	Direct	High resistance	High resistance
3 phase short circuit capability	31.5kA, 1s	31.5kA, 1s	31.5kA, 1s
1-phase earth fault	31.5kA, 1s	1.0kA, 5s	1.0kA, 5s

*) *33kV operational voltage is suggested with array cables from ONSS.*
34kV operational voltage is suggested with array cables from OSS

Table 5 General Rating Electrical Systems

5.2 Cable system type and sizing

The optimisation of the export and array cable systems adopted is a technical-economic approach being straightforward and following the high level simplified process illustrated in Figure 12.

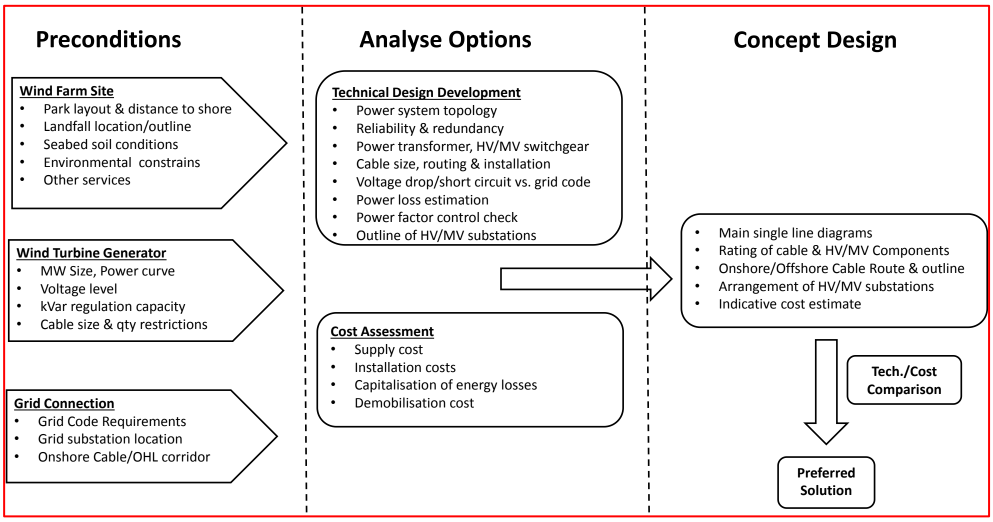


Figure 12 Indicative high level power system high optimisation approach

The selection of cables conductor type/size should be based on most optimal cross-section in respect to load capacity, voltage drop, short circuit capabilities and cost/capitalised energy losses over the operational lifetime.

The WTGs' production pattern shall be considered when sizing the cables, since a continuous load profile will impose larger conductors than needed. Wind farm production is not constant over time, and a significant fluctuation of wind farm production will prevail. Consequently, a dynamic rating factor must be included in the ampacity design when the cable sizes are determined, otherwise too large conductors will be selected. Different approaches have been developed recently and are discussed at international workshops/seminars. No common accepted or aligned approach has been established yet, thus wind farm developers (and power utilities) uses internal guidelines on dynamic cable load design. The derating factor "Continuously vs. dynamic load" range from 105% to 115%. Ref. /3/, Ref. /4/.

As a simple design approach this advisory design assumes the peak of the cyclic/dynamic load current allowed for in the cables is up to 110% of the continuous maximum load current that gives permitted maximum conductor temperature 90ºC with the site conditions defined. *(This approach can only be adopted for cables being buried – not for cable systems installed in air where the cable surface temperature will vary more dynamic due to a smaller thermal capacity of the surroundings).*

The array cables and the export cables shall be designed in respect to load capacity and mechanical performance during installation and operation at different environments imposing different requirements.

- WTG
  - Connection to WTG switchgear
  - Free hanging cable section in tower/foundation
  - Cable transition from seabed to foundation

- OSS
  - Connection to HV and MV switchgear
  - Routing at cable deck
  - Free hanging cable section in J-tube
  - Cable transition from seabed to J-tube

- Seabed
  - Surface layer at seabed – covered with rock beam.
  - Buried in seabed (Simultaneously buried or post lay buried)

- Landfall
  - Cables installed in open trench either pre or post excavated
  - Cable installed in HDD

- Onshore

- Cables installed in standard trenches
- Cables crossing roads
- Cables crossing other power lines

5.2.1 Cable Load Capacity

The ampacity design for any cable circuit takes basis in a simple relationship since load currents generate power losses heating up the conductors from the ambient temperature. Thus a maximum permissible temperature raise "θ_{con_max} - θ_{soil} must be respected.

For the Indian context this temperature increase could be θ_{con_max} (90°C) – θ_{soil} (25°C) → 65 °C defining the band width of permissible temperature increase for the cables. This permissible temperature raise must not be exceeded in any section of the cable route. The ampacity design process shall consider all sections and identify the bottleneck that constitutes the most stringent requirement and will determine the minimum allowed conductor cross-section.

The conductor temperature increase also will depend on several installation factors as per listed below:

- Buried
  - Soil temperature
  - Mutual heating from other power cables
  - Burial depth
  - Thermal resistivity of soil/sand bed/concrete embedding
  - Thermal resistivity of ducts, (air or with bentonite to improve air derating)

- Installed in air
  - Air temperature
  - Ventilation
  - Solar radiation

Any supplier will provide current loading tables for the cable types offered based on an assumed standard installation for one single cable. Rating factors for installations deviating are also provided. The most common rating factors [4,5] against a standard installation *(soil temperature 20°C, soil thermal resistivity 1.0 Km/W, Burial depth 1.0m, distance between single cores Dcab+70mm)* combined with the above installation rating factors are illustrated in Figure 13.

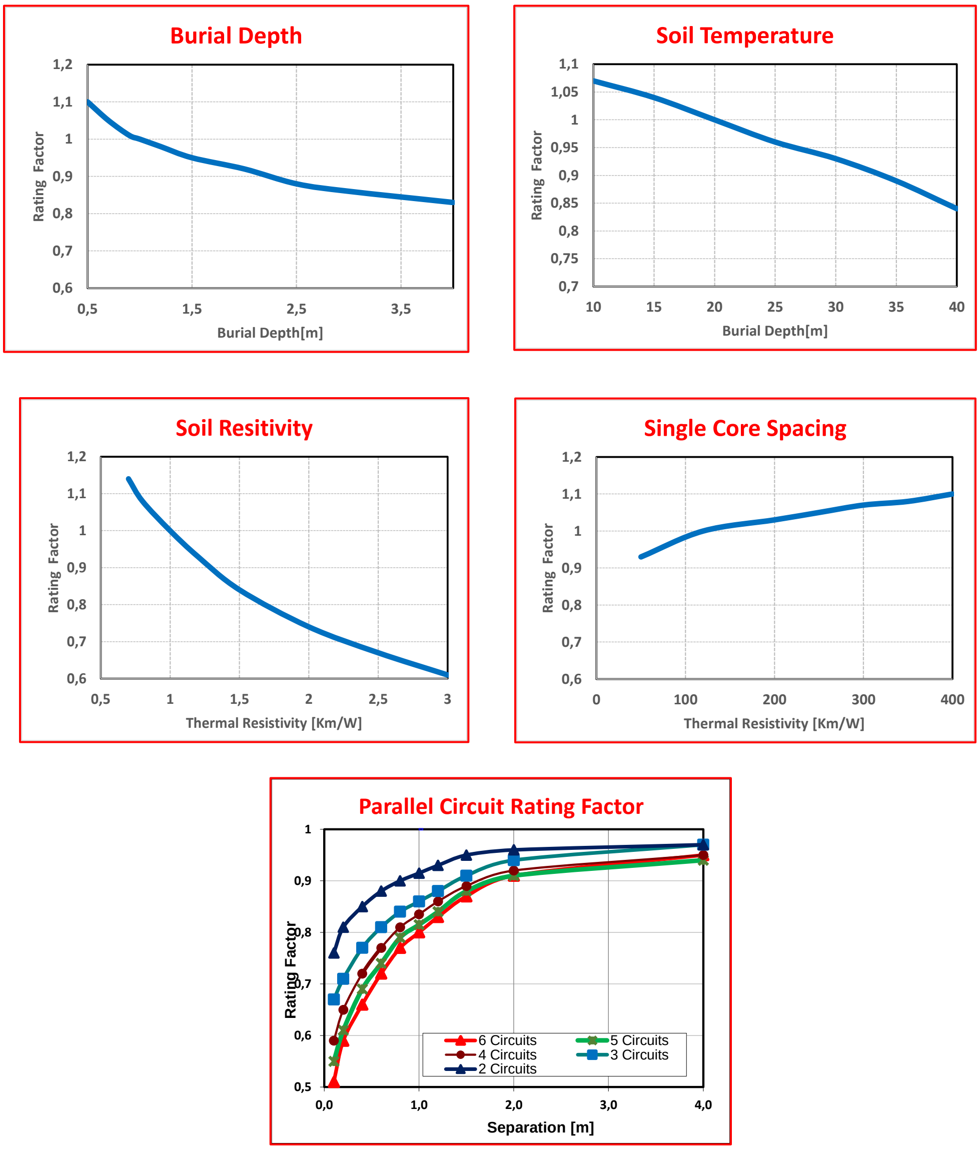


Figure 13 - Common rating factors

Selecting the site specific installation parameters will give a good assessment for selection of adequate conductor size. As an illustrative example three 36kV XLPE-AL cable circuits (1.3m – 25°C – 1.5Km/W – 2m distance – 200mm separation) can be computed as:

$Imax = 755A \times F_{dym} \times F_{depth} \times F_{soil\ temp} \times F_{soil\ TR} \times F_{parallel} \times F_{sc\ space} = 755A \times F_{res} = 655A$

Soil Thermal Resistivity

The overall most important environmental rating factor is the thermal resistivity for soil and the sand zone close to the cable. It is highly depending on the moisture content where the dry figures could raise 3 - 5 Km/W in a completely dry situation. This will be critical if not addressed properly in the design basis since the high loaded cable circuits will dry out the soil. *(It can improve the moisture later during low load periods).* This drying out phenomena can commence at a soil temperature above ≈50ºC and could provoke a thermal run away resulting in overheating the conductor and provoking permanent damage to the insulation leading to a breakdown. It shall be mentioned that the drying out phenomena is not anticipated to occur offshore or below the ground waterline close to the shore.

It is normal practise that geotechnical soil investigations are done both onshore and offshore. Thermal resistivity (TR) figures can be measured in situ, but must be supported by sample tests in laboratories.

The resulting soil resistivity (thus the ampacity of the cable circuit) can be significantly improved if the cable zone approx. 30 - 50 cm around the cable is installed with selected backfill with low TR figures and being thermal stabile against the moisture content. Also an embedding of the cable (and ducts) with a weak concrete could offer better resulting soil thermal resistivity).

Cable Ducts

In addition to the above, the increased thermal resistivity caused by eventual ducts shall be factored into the ampacity design. The reduction factor will be ≈0.9 but can be improved if the air between the cable and the duct inner surface is injected with e.g. bentonite (0.4 – 0.9 Km/W).

5.2.2 Cable short circuit performance

The permissible conductor temperature at the end of a short circuit is 250ºC for both XLPE and EPR insulation material. The conductor temperature will rapidly increase until the fault is cleared of by the protective relay systems. Modern solid state and computerised protective systems makes a maximum trip response time less than 1 sec is achievable, and constitutes the basis for conductor sizes in respect to short circuit capability. The short circuit current will be largest at the OSS busbars and will decrease down-stream against the WTGs. Figure 19 indicates the minimum conductor size that can be selected close to the OSS for the array cables for 31.5 kA 1s disruption.

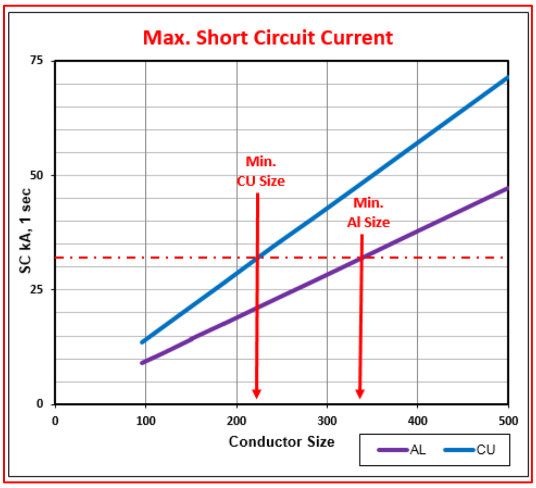


Figure 14 - Max Short Circuit Current

5.3 Offshore Cable Systems

This section presents a brief introduction of the cable design used for offshore export and array circuits. Preliminary reflections on possible installation methods are also addressed for the entry to WTGs/OSS, installation in the seabed and at the landfall.

Illustrations shown have been collected from general brochures, leaflets and presentations released by:

- Cable installation contractors: Van-Ord, Jan de Null, VBMS, DeepOcean, JD Contractors
- Suppliers: Tekmar, Prysmain Cables, Nexans Cables, NKT/ABB cables
- and selected photos from Ørsted OWF (Walney 1+2, West of Dudon Sand, Walney Extension)

The above list is only a fraction of qualified suppliers and installation contractors. Reference is also made to Section 9.1.

5.3.1 Offshore Cable Characteristics

Offshore cables today have been designed, tested, installed and proven in operation as 3-core design that can be offered up to 400kV voltage level with solid insulation design. A robust cable construction is needed, since the offshore cable shall be able to withstand high mechanical stresses during laying and an eventual recovery from the seabed should a fault repair be necessary.

Typical characteristics of the design are given in Table 6:

Description	**Details**	**Comment**
Phase Core		
Conductor	Stranded AL or Cu MV cables: 95..1000mm^2 HV cables: 300…1600mm^2	Longitudinally water tight designed with swellable powder between strands
Insulation	Inner semi conducting layer XLPE or EPR insulation **1)** Outer semiconducting layer	XLPE is not watertight and will deteriorate should water penetrate
Metallic Screen	HV cable: Lead alloy MV cable: Lead alloy or laminated al/cu tape	Shall offer vertical water tightness and be sized for the 1ph earth fault currents
Core sheath/Jacket	Semi conductive PE	
3-core assembly		
Fillers	Extruded polypropylene shaped profiles	Contains the Fibre Optic Cable (FOC) tube(s)
Core & armour binders	Polymeric tape and/or yarn	
Amour bending	Polymeric tape and/or yarn	

Amour layer	One or two layers – Galvanised steel wires **2)**	Offer mechanical protection against damage during installation and provides adequate pulling force.
Severing	Polypropylene yarn with bitumen	
Optical fibre optical cable	One or two FOC placed in the filler profile.	Mono-mode fibres are required for long export cables. Multi-mode fibres could be applied for the shorter array cables

Table 6 Typical offshore cable characteristics

1) Insulation material

Ethylene propylene rubber (EPR) design is proven for 36kV cables and recently for 72.5kV insulation level and offers different performance as briefly listed below:

Permissible conductor temperature

Nominal operating temperature is 90°C as per the XLPE, but the physical properties of EPR will not be severely affected before 130°C compared with ca. 100°C applied for XLPE. Thus the short duration overload capabilities are improved.

Water trees

EPR is not sensitive to ingress of water to same extent as XLPE, thus EPR cables are not designed with radial water barriers as commonly applied for XPLE.

Die-electric losses

Due to a lower die-electric loss factor (0.0004 vs. 0.002) XLPE has significant better performance in respect to die-electric losses. Table 7 indicative but illustrates the trend for the different cable types.

Operational Voltage	XLPE	EPR
33kV *Die-electric loss* *Percent of full load losses*	 ≈0.05 W/m ≈0.1%	 ≈0.26 W/m ≈0.3%
66kV	≈0.17 W/m ≈0.2%	≈0.87 W/m ≈1.0%
220kV	≈1.6 W/m ≈1.0%	≈4.6 W/m ≈4.6%

Table 7 HV cable die-electric loss comparison

The overall impact on the full load cable losses is insignificant for the 33kV cables. However the EPR 66kV cables have ≈1.0% die-electric losses and 220kV cables up to 4.6%.

The loading capacity of the 33kV and 66kV cable systems will be of insignificant importance and will not impose larger conductors for the EPR cables compared with the XLPE type. This outcome can't be ruled out for the 220kV cable circuits.

Based on negotiated supply cost the most attractive cable type and conductor cross-section can be identified taking the capitalized losses in to consideration.

- EPR insulated cables offer superior mechanical performance and are often a more suitable choice when the cables can't be installed in a fixed positon but will be exposed to dynamic movements through its operational lifetime.

2) Armour design

Subsea cables are traditionally offered with a single layer galvanised armour wire coated with bitumen to counteract corrosion. This design is cost efficient from a manufacturing and supply perspective. The main purpose of the amour wires is protecting the 3-core assembly against mechanical damage during the spooling operation prior/during to the cable laying vessel (CLV) loading the cable and the unspooling/laying/burial at the seabed. Further, the armour shall allow sufficient permissible longitudinal pulling force when the cable is installed to the WTGs/OSS or to the landfall from the CLV. (The total pulling force will be distributed between the conductor cores and the armour wires and transferred to the cable via either cable pulling stocks or customised pulling head).

Double armoured design can be necessary for export cables if the seabed couture don't allow the CLV to approach the landing point at a short distance thus demanding high pulling forces.

The armour imposes challenges for the installation since it makes the cable stiff and difficult to handle. The minimum bending radius (MBR) is increased (3 - 5m until the armour have been stripped off) that in particular adds concern at the OSS cable deck when the cable ways are designed.

The armour wires also have a considerable contribution to the power losses in the cable and can be reduced by: i) Replacing galvanised wires with stainless steel (more expensive); ii) Substituting 30 - 50% of the galvanised steel wires with polymer wires (shall be balanced out with minimum pulling force).

It is further noticed that the theoretical calculation methods embedded in prevailing IEC standard 60287 forming a key design basis for ampacity calculations will result in galvanised armour losses being conservative and to high. The cable manufacturer shall be asked to inform his guaranteed full load armour losses being justified by measurements of the cable during the FAT.

Table 8 indicates the power loss distribution in 220kV cables with galvanised single armour (SA) design and stainless steel double armour design for a UK windfarm project.

Cable Losses	3x500SA	3x1200SA	3x1600SA	3x1600DA
Conductor	73.5%	59.5%	64.0%	65.2%
Die-electric	1.0%	1.3%	1.7%	1.8%
Screen	8.6%	18.1%	27.1%	18.5%
Armour	16.8%	21.1%	7.3%	14.5%
	100.0%	**100.0%**	**100.0%**	**100.0%**

Table 8 HV cable power loss comparison - typical

The double armour (DA) cable design was selected to achieve sufficient pulling forces at a landfall. *(The CLV was beached 2-3 km from the shore line and a long pulling to the transition joint bay via ≈500m HDD was designe*d). The HDD burial depth (6—7m) imposed unacceptable temperatures in the conductors, thus stainless steel wires have been selected to counteract the higher power losses.

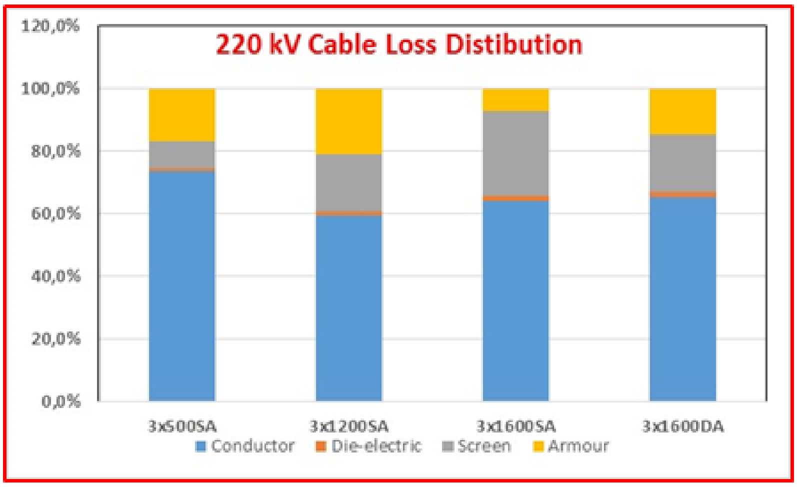


Figure 15 220kV Cable Loss Distribution

Figure 15 perfectly illustrates the complexity in designing the offshore cables since a sound design shall be an engineered solution taking into consideration the mechanical performance, ampacity and the cost impact as well. Consequently, the installation conditions, methods and pulling calculations shall go hand in hand before the cable design is frozen and contract arrangements are closed.

3) Fibre Optical Cable Design

Offshore cables are designed with integrated optical fibres for communication between the WTG, OSS and WF ONSS. Single-mode fibres are commonly prescribed in a number of 24 – 96 fibres depending on the communication network requirements. If the transmission asset is owned/operated by a TSO – dedicated fibres can also be required.

One or two fibre steel reinforced and water tight tubes are common. It is advised that the fibre tubes are protected by a semi-conducting PE sheath being earthed in both ends to avoid induced voltages that could damage the PE sheath and HV cable component.

Depending on the cable length stainless steel wires (non-magnetic thus having less circulating currents can be considered).

The optical fibres can also be utilised for distributed temperature measurements. This feature is standard approach for export cables and enables online measurement of the fibre temperature along the cable with a resolution +/- 2°C within 1 - 3 m. The distributed temperature measurement system (DTMS) will give accurate online measurement of the cable condition and can locate hotspots along the cable route *(mitigation can then be implemented to secure loading capacity)* and enable a more dynamic operation of the export cable(s) if two parallel cables are installed and one is out for maintenance

The DTMS requires racks (sized as typical relay/control panels) placed at the OSS and the WF ONSS.

5.3.2 Pre-qualification and type test

HV cable systems compared to MV cables are not standardised to the same extent. Project specific comprehensive and strict requirements on qualification- and type test addressing both electrical and mechanical properties for the cable component, cable terminations, factory joints and rigid offshore cable joints shall be incorporated in the supply contract agreement. A sound test regime can be established from:

- IEC6206 Power cables with extruded insulation and their accessories for rated voltages above 150kV (Um = 170kV) up to 500kV (Um = 550kV) - Test methods and requirements
- Cigre, Recommendation for mechanical test on submarine cables, ELEKTRA No 171, January 1997
- Cigre, Recommendation for testing of long AC submarine cables with extruded insulation for system voltage above 30(36) to 150/170kV, ELEKTRA No.189, April 2000

5.3.3 Mechanical performance

The offshore cables shall be designed with sufficient mechanical properties that will make installation possible and offer adequate protection against damage from external sources.

HV offshore cables with XLPE insulation are designed with lead screen surrounding the cable phase cores that also serve as radial water barrier. Since lead is fragile to fatigue, long-term vibrations and movement should be avoided during the installation process and operation. Typical points of interest are:

Transition from seabed to OSS J-tube
The vertical distance between the seabed and J-tube bell-mouth could be up to 3 - 5 meters if proper design and scour protection have not been implemented. Even though the cable section is protected against over-bend the water current could provoke periodical and consistent movement of the cable. This can be avoided by limiting the horizontal distance from the seabed and potential rock dumping to shorten the free span and fix the section as much as possible.

Free hanging cable in WTG
The WTG nacelle will experience horizontal movement during operation. This will provoke the MV cable to swing significantly in the free hanging section. MV cables are often designed with al or cu laminated foil around the phase conductors thus the lead topic is solved, but proper design of the hang-off arrangement should be considered to avoid long-term damage to the cable just below the WTG cable platform.

Free hanging cable in OSS/J-tube
The vibrations and movement of the OSS is insignificant and does not constitute any danger to the cables.

Catenary from CLV cable chute to seabed
The cable laying operation could be stopped during installation (must likely by adverse weather conditions). The cable will then be hanging in a free-span and could be subjected to repeatedly movements caused by the waves that could cause fatigue issues at the seabed touchdown point. The most common mitigation is "paying out and recovering" a few meters from the CLV that will release the stress on a single point. The same approach must be taken during an offshore cable jointing operation (typically lasting 5 - 7 days) with two cable catenaries.

Cable transfer
The number of spooling operations/bends during manufacturing, cable loading and laying operation could have an upper limit. This should be detailed with the cable supplier prior to contract agreement in his cable handling parameter specification.
Array cables can be designed as coilable cables having a maximum of ca. 4 - 6 coil operations to be defined by the cable supplier.

Armour birdcages
The cable industry occasionally experiences armour birdcages (armour deformity) occurring during cable laying, landfall pulling, or loading operations. The phenomenon is a result of cable rotation/twist combined with bending causing the armour to open up or work itself into the interior part of the cable. The root cause for these failures are different from case to case, and not yet fully understood due to the large number of physical parameters in respect to the cable and installation conditions. Consequently, agreed test standards are not yet developed and cable suppliers recommend guidelines based on own experience. However, the cable should be designed as a balanced cable “cable cores and armour wires with opposite lay rotation” to limit rotation behaviour as

far as possible. Also the laying length and armour wire diameter should be considered.

The cable handling parameters in respect to 2-bending (MBR, distance between two nearby bends, loading speed, and cable surface temperature) should be detailed and carefully considered for any transfer of the cable during CLV loading and cable laying.

The mechanical behaviour of the cables should be proven in the test program set up for qualification of the design.

5.3.4 Offshore sea cable transport

The transportation logistic from the manufacturer's production facilities to the wind farm site constitutes an important planning task for the project.

Export cables often > 20km will be delivered in one continuous length and be loaded directly from the manufacturer's production turntable after FAT has been successfully achieved. This interface needs careful planning since the cable load-out often defines the risk transfer between the manufacturer and the cable installation company. Comprehensive method statements and risk assessments shall be timely elaborated and aligned between the parties to avoid unintended damage to the product or delays. If not properly addressed this may incur significant standby cost for all parties involved.

Export cables will be picked up by the cable laying vessel. The CLV is often already mobilised with a suitable installation spread appropriate for the route length and prevailing seabed conditions.

Figure 16 Left: Loading of cable into CLV turntable. Right: Transfer of cable from quayside chute to CLV chute.

The turntable size at the CLV will determine if the full cable length can be loaded in one section or if offshore expensive cable joints shall be planned. Today several contractors in addition to the cable suppliers can source in CLVs with large turntables that can contain up to 4000 - 9000 t cable being sufficient for approx. 30 km. The loading operation and transit to factory and site is time consuming and add cost to the CAPEX. The developer shall scan the market for available CLVs that can be utilised with as few vessel days as possible. 30km 220kV export cable surely can be accommodated in one loading perhaps two or three. 33kV or 66kV cables with smaller diameter also could be loaded in one operation.

Array Cables can be supplied either on individual cable drums (up to approx. 1km depending on the cable dimensions) or as longer continuous cable lengths up to 3 - 5 km.

- Short lengths delivered on cable drums
  The array cables between the majority of WTGs are well defined in length and short enough to be delivered on cable drums suitable for shipment with transporters that easily can be hired on the market. The logistic is straightforward and could give the lowest supply cost from the manufacturer. Depending on the drum size the transportation from the cable supplier to the loadout port (should he not have his own quayside) can be implemented on a heavy load trailer. The approach with cable drums transported to an installation port nearby the wind farm location offers flexibility for the cable installer that can be necessary should the WTG foundation installation be delayed. It is recommended that a spare cable drum for the largest and the smallest cable size respectively is procured and stored at a port nearby the windfarm site.

Figure 17 Transport rigging of array short length on cable drum

- Long lengths delivered
  The cables interconnecting the OSS with the nearest WTGs are often significantly longer than the other array cables and cannot be delivered on drums. These cables must be loaded unto the CLV in its turntable in a similar operation as the export cable. Some array cable manufactures producing MV cables don't have direct access to a quayside but can offer transportation to a loadout port by use of rail wagons as shown beside, Ref. /7/. Due to this, the array cable must be designed as a coilable design. Offshore joints are not expected for long MV array cables or even the 30km export cables. However it is recommended that 2-4 sets of

Figure 18 Transport arrangement of long array cable in train wagon

spare repair joints are procured to be prepared for eventual damages during installation or 3rd party "typically anchor damage".

5.3.5 Offshore cable accessories

- **Factory joints**
  Long cable lengths above 15 km (production facility dependent) will be manufactured in two or three sections. Flexible factory joints will be installed prior to FAT and give same handling parameters as the cable component in respect to pulling forces, MBR and radial squeeze/crush load. Thus the cable laying from the CLV shall not have particular awareness during the operation and can lay out the joint in-line as the cable. It is however normal practice that such factory joints are clearly marked by the supplier allowing the cable installer to plan his installation methodology for the passage of the factory joint through the LV cable way/desk tensioner and chute since the outer dimension is slightly enlarged.

  The factory joints may also be applied to connection of different conductor sizes and transition between single and double armour design. The cable system load capacity will not be compromised by these flexible factory joints.

- **Offshore repair - cable joint**
  The relatively short length of export cable <30km does not give reason to design for an offshore cable joint. However, the project must be prepared to mitigate cable damages caused by installation failures or third party damage during operation lifetime. Failure on an operational export cable will impose a significant revenue loss *(in particular for the HV cable interconnected to the OSS).*

  A repair operation will typical involve cutting out the damaged cable section, recovering cable ends to a suitable cable repair vessel/barge, assembling joints, over-boarding to seabed and inserting approx. 75 - 150m new export cable in-between two new cable joints. The cable repair vessel/barge shall be mobilised with assembly containers, cable winches, cranes, cable chutes etc. and adequate accommodation. 24/7 working scheme shall be planned for due to vessel cost and in order to reduce the costly down time.

  The repair of a damaged offshore cable will have a duration of approx. 1½-2 months involving the high-level activities listed in Table 9.

1-2 Weeks	Home port mobilisation of CLV with jointing container, cable handling rigging, burial tools etc.
1-2 Weeks	Transit to site
1 Week	Mobilisation of cable drum & cable joints from windfarm storage facilities
1 day	Cut and recovery of damaged cable end to repair vessel
5-7 days	Jointing of 1st offshore joint
1-2 days	1st joint over-boarding – surface laying approx. 100m cable – recovery of 2nd cable end
5-7 days	Jointing of 2nd offshore joint
1 day	2nd joint over-boarding
1-2 days	Burial of joints and cable section
1-2 weeks	Transit and demobilisation of CLV

Table 9 Offshore cable joint repair – possible time line

Weather down time due to adverse weather conditions is not included and may add 2-4 weeks to the offshore campaign depending on the operational criteria offered by the CLV. The availability of a suitable repair barge/vessel may also contribute with additional time to the total duration of the operation.

The lead-time for supply of the rigid offshore joint is 3-4 months and for supply of the cable 4-8 months. Consequently, all offshore cable projects include supply of spare joints and cables for export cables being transferred to the operator's storage facilities at a nearby port to make a fast repair possible in case a cable damage occur.

Figure 19 and Figure 20 indicate possible deck layout and over boarding of an assembled offshore cable joint to the seabed.

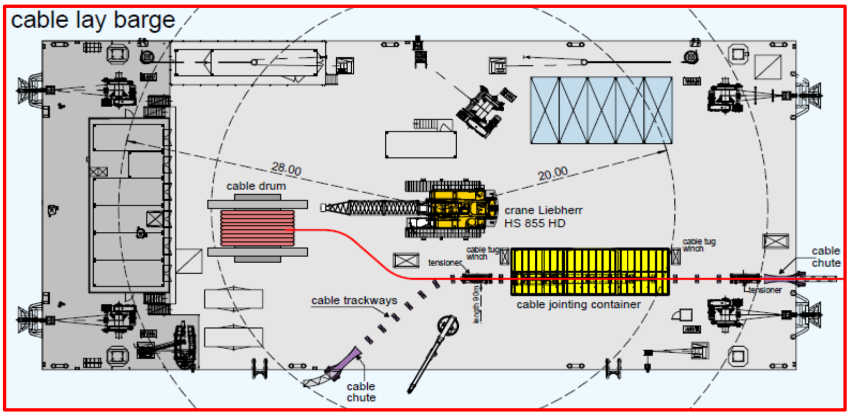


Figure 19 Cable jointing barge deck lay-out

Figure 20 HV cable joint over boarding from cable jointing barge

- **MV Cable Terminations - Offshore**
  Cable terminations shall be installed at the WTG either in the WTG MV switchgear or in the T-connector units and will have a similar outline as onshore cable systems. Cable terminations are only relevant in the two cable ends in the WTG or at the OSS since no offshore cable joints should be planned for due to the high cost and installation risk they introduce. (Even if a cable failure occur in the seabed during/after installation the preferred approach is a full replacement rather than a repair utilising one or two offshore joints).

  Figure 21 illustrates the outline are from Euromold and Nexans, several other suppliers can offer similar and type proven products.

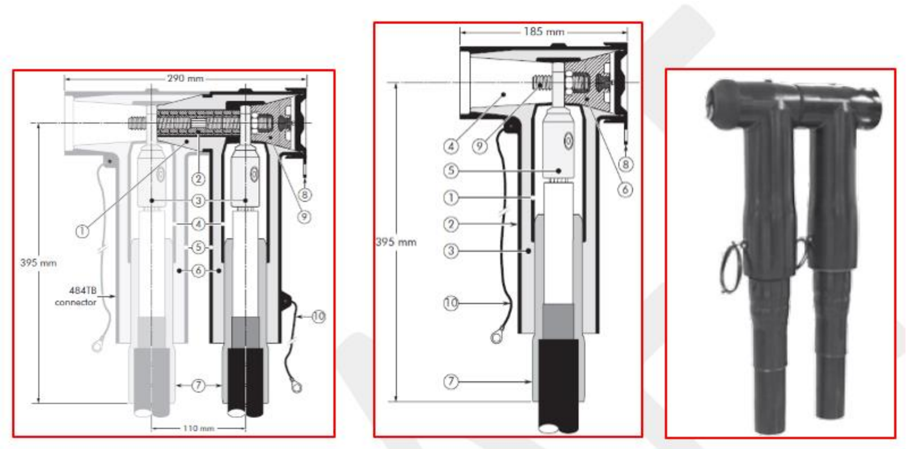


Figure 21 - Cable outline illustration

The industry has delivered well-proven standard solutions for 36kV cable systems for decades and recently for the 72.5kV voltage level with particular focus on the current offshore wind farms being planned with 6-10MW WTGs which are designed to cable systems with 66kV operational voltage. With the development of the 66kV inter-array cable, also a full range of bushings, connectors, surge arresters, terminations, joints and special alloy contacts for large cross-sections has been developed. The connectors are based on the outer cone standard and the piggy-back principle. Besides the easy mounting conditions of a plug-in connector, they are also easy to use in an environment of 2 or more cables for one phase. Surge arresters can be plugged into the connector.

The cable terminations (bolted type) commonly used are

- separable tee shape connector designed to connect polymeric insulated cable to equipment (transformers, switchgear), or

- coupling connectors that can be installed picky-back, thus either two/three conductors per phase or a simple busbar without disconnecting devices can be utilised.

Both types consists of EPDM[1] or jacket that provide a total safe to touch screen which ensures safety for personnel

Common rating up to 1250A and 800mm^2 conductor size depending on voltage level and supplier.

- **HV Cable Accessories – Offshore**
  Two different approaches exist for terminating the sea-cable(s) to the HV GIS at the OSS. The 3-core cable will be pulled from the CLV to the OSS cable deck and secured with a hang-off by where the armour wires are fixed to the OSS structure preventing the free hanging cable to fall back to the seabed. The stripped cable will be laid at horizontal and vertical cable ways/ladders from the hang-off via a floor penetration to the 220kV GIS room.

  Aiming at reducing the assembly work offshore an internal 220kV cable section with single core cables (with conductors) can be installed and terminated to the HV GIS at the fabrication yard. Then all cable termination, support structures and floor penetrations can be completed at the OSS prior to sail-away. This however will impose that three single phase straight joints shall be assembled offshore after the cable have been pulled on to the OSS.

[1] Ethylene Propylene Diene Monomers - EPDM

- GIS termination
  The sea cable can be connected directly to the HV GIS at the OSS. Cable termination for offshore application will not differ from traditional design used by transmission companies worldwide. The 3-core sea cable will be stripped (armour and plastic profiles are removed) and the cable cores can be laid up and handled as onshore 1-core cables.

Figure 22 33-66kV Male terminations

- The interface between the manufacturers of the GIS and the cable respectively is of paramount importance and shall be considered thoroughly to meet the interface standards adopted by the industry. The illustration in the above figure from ABB shows the outline of the 'male' part of the HV GIS termination consisting of pre-moulded stress cone that shall assembled at site and injected into the 'female' part consisting of the GIS supplier's cable box.

- <u>Straight Joint</u>
  The three 1-phase straight cable joints can be assembled on an approx. 2.5x8m horizontal balcony build along the cable way at the cable deck and be necessary since the cable MBR will impose the cable being raised 2-3m above the deck level. Also the arrangement of congested cable ways for array cables and export cable(s) at the cable deck requires different vertical position of the various MV and HV cables.

  The straight joint design is almost identical to onshore HV straight joints. The cable joints (and the single-core cables) shall be fixed to the cable ladder by suitable cable clamps to counteract dynamic mechanical forces provoked if a short circuit failure occurs in the circuit.

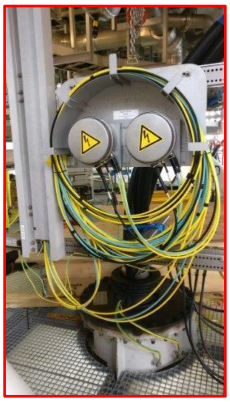
220kV cables prepared at with male parts ready to be plugged in GIS	220kV cables pulled to GIS ready for assembly of termination
	
220kV Straight Joints assembled offshore at OSS cable deck	**FOC splice boxes at cable deck**
	
220kV cable attachment with cleats	**220kV & 33kV cable hang-off assembly**
	

Table 10 OSS Cable deck photos

5.4 WTG - Cable system interface

The cable installation design and methods for the WTGs constitute one of the most important challenges since different foundation designs exist and no common standards are agreed within the industry. However, the vast number of OWF implemented worldwide have revealed well proven solutions based on the lessons learned in the early days.

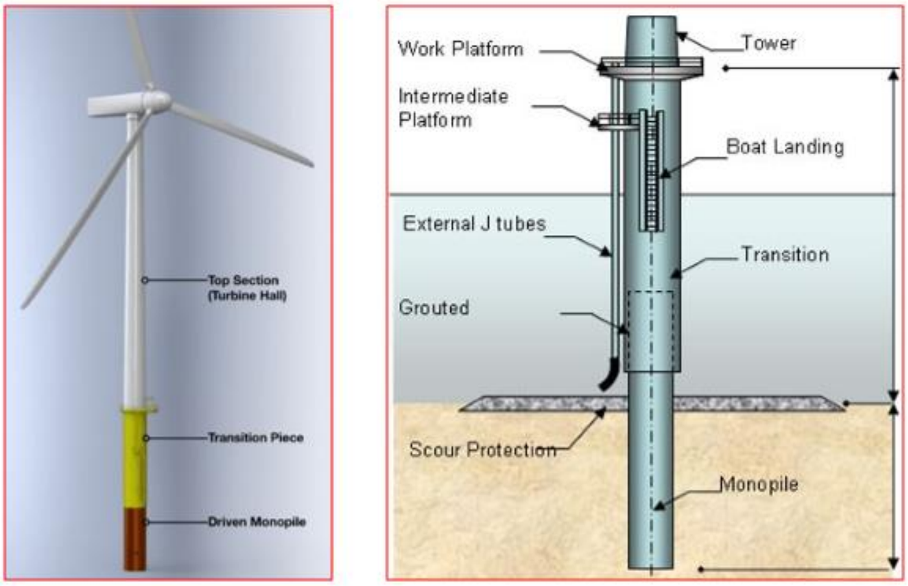


Figure 23 Right: WTG foundation and transition piece general outline. Left: WTG General Outline.

The challenge is further complicated since this interface shall be coordinated in between:

- WTG supplier.
- Foundation supplier / Installer.
- Cable supplier/ Installer.
- MV switchgear supplier/installer.
- Cable protection system (CPS) supplier.

The following sections briefly summarises components forming part of the cable system interface in respect to outline and installation.

5.4.1 Cable entry

The sea cables enter the WTG structure at the bottom of its foundation direct from the seabed. It will be free hanging from the entry point to the cable deck platform where it is fastened by a hang-off arrangement. The foundation design shall consider installation with up to three cables in some selected WTGs, but the majority of WTGs will have two and some only one MV cable installed. The design challenges are:

- Cable Hang-off at WTG top
  - Tension in cable
  - Vibrations *)

- Cable Entry point at seabed level
  - Pulling forces
  - Bending forces, side wall pressure, bending requirement

    - Reduction of cable ampacity

- Transition seabed / foundation
    - Tidal and wave current impact
    - Scour development exposing the cable
    - Fatigue if large free hanging section occur.

**) The monopile foundations transfer their movement to the cables hung-off freely in the interior of the piles. For certain lengths and tension of cables there is a possibility for resonance, i.e. the vibrations of the cables increase in magnitude. This could lead to clashes between the cables or to fatigue damage in hang-off.*

The WTG foundation can be designed either as monopiles or jacket structure as per indicative illustrations bellow:

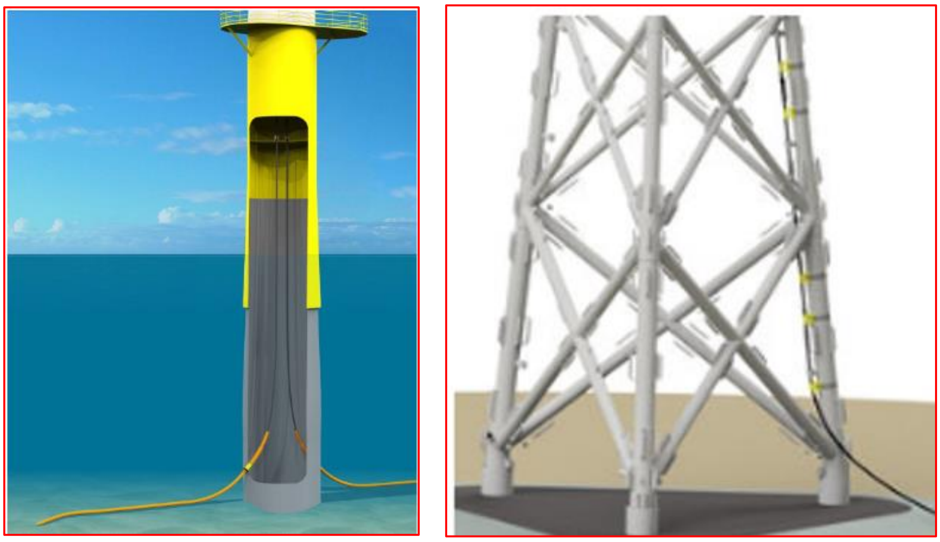


Figure 24 Illustrative concepts with cable bending restrictors

- **J-tube**
  External or internal J-tubes can be chosen for monopile foundations, but will be mandatory for the WTG foundation jacket structures. The J-tube shall be designed with a bell-mouth at the seabed oriented with an adequate angle to horizontally accommodating the cable MRB requirement. The bell-mouth shall also be designed with an interface fitting with the CPS solution selected. The cable load capacity will be de-rated in the J-tube compared with a cable hanging in free air. The cable losses within the J-tube will heat up and circulate the enclosed air, thus the upper sections potentially could overheat the cable conductors. This phenomena is well understood and can be analysed by conservative analytic formulas suggested by IEC60287 or by more accurate final element calculations. The cable rating design must be based on the air temperature within the J-tube added contribution from the solar radiation

"heating up the J-tube", that in an Indian context is worse than in a European environment.

The overheating can be counteracted by designing ventilation holes in the J-tube in a suitable size and number, should it be required with the cable conductor size selected. It shall be mentioned that this section in the J-tube seldom is the designing factor for cable sizing, and the high wind occurring at max production also will tend to cold down the J-tube surface. Anyhow, this topic shall be addressed prior to selecting the conductor sizes.

Monopile foundations are often designed without J-tubes, then having the cable hanging in a free span directly from the hang-off to the CPS entry in the foundation.

› **Cable Protection System**

Engineered solutions and appropriate equipment preventing damage to the sea cable during its installation and operational lifetime shall be identified. All foundation designs will require a CPS that will guide the cable from the seabed to the WTG without compromising the MBR.

Customised and special designed bending restrictors for cables and umbilical's have been developed within the oil & gas offshore sector for decades. The range of products and suppliers has increased significantly lately due to the aggressive market expansion for OWFs. Thus, well proven and mass produced CPS can be offered from a number of suppliers.

These CPS will be installed during the cable pulling operation from the CLV.

Figure 25 CPS overboarding

The main installation approach involves:

- Fitting of the CPS on the cable at the CLV prior to pull-in
- Guiding the cable and CPS to the foundation entry
- Positioning the CPS correctly at the J-tube bell-mouth
- Pulling through the cable from the CPS to the WTG service platform
- Engaging and fixation of the CPS at the bell-mouth
- Eventual rock-dumping above the CPS *(damage to cable/CPS shall be considered)*
- Post lay burial of the CPS and cable outside the WTG scour protection zone approx. 15 m from the WTG foundation.

Figure 26 CPS and J-tube with bell-mouth

The installation process is designed as a diver-less operation as the normal/standard approach. Diving operations (costly and very weather dependent) will only be required in mitigation initiatives should the installation fail.

- The hang-off shall position the cable on the service platform deck and provide a reliable fastening of the cable armour wires to secure the cable hanging and avoid tampering or any possible slip of the wires. The entire securing flange is often filled by resin as an additional safety mitigation.

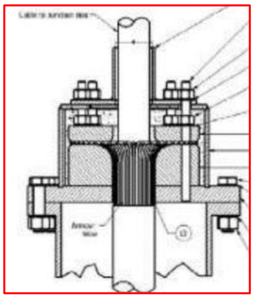


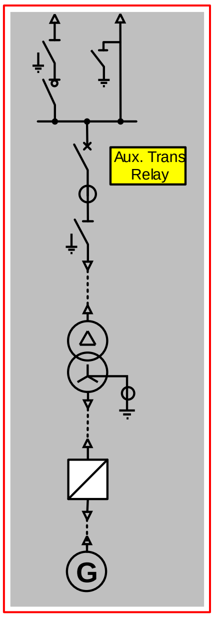
Figure 27 Cable hang-off - GA

- If J-tubes are designed the hang-off shall be designed according to the J-tube flange diameter for a proper
centralisation and matching. Hang-offs can be manufactured in carbon steel or stainless steel.

5.5 WTG switchgear

Today all WTG suppliers offer solutions with 66/33kV power transformers and switchgear integrated in the nacelle or tower as a standard concept.

The WTG and MV switchgear are typically standard solutions based on compact design either suitable or tailored to the requirements set out by the WTG manufacturer. The limited access defined by the door opening and need for safe manoeuvring of the switchgear is a challenge to overcome within the WTG tower. Consequently, should the standard solutions not be accepted, possible special requirements shall be addressed already before a contract is entered into with the WTG supplier.



The compact MV switchgear could consists of either SF6 or vacuum type circuit breakers towards the power transformer, a load break switch/disconnector for the downstream cable to the next WTG in the radial and a direct connected termination for the upstream cable to the previous WTG against the main MV busbar in the OSS.

The two cable feeders in the MV switchgear constitute the interface between the WTG supply and MV cable supply/installation works. Furthermore, the interface includes a fibre optic communication cable in each WTG unit where a wall box shall be installed to connect the WTG with the windfarm SCADA system.

5.5.1.1 33kV Switchgear

Various designs exist in the market for switchgear in the voltage range 10-40.5kV. A compact switchgear with remote operated circuit breakers and manual/local operated load switches and earth switches are recommended.

All major international suppliers (ABB, Siemens, Schneider, etc.) offer modular design. The trend within the offshore wind farm segment also have pushed forward for a more slim design that can be incorporated in WTG towers with restricted space.

Two possible designs are indicated in Table 11.

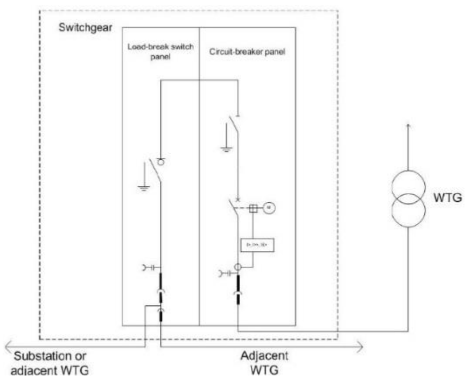
ABB Safeplus Rated current, In 630A SC Ik: 25kA, 1s • 1xTransformer circuit breaker • 2xLoad breaker (remote operation) • 1xcable connection box facilitating up to three MV cables	 
Siemens: NXPlus Wind Rated current, In 630A SC Ik: 25kA, 1s • 1xTransformer circuit breaker • 1xLoad breaker (manually) "Optional" • 1xCable connection box facilitating up to two MV cables	 

Table 11 Two types of 33kV modular switchgear

5.5.1.2 66kV Switchgear

The increased size of WTGs with 8MW, or larger units now available on the market, imposes that the next distribution level 66kV must be adopted for the array cable systems. Several leading manufacturers of MV components are already able to deliver 66kV switchgear and have implemented trail projects on prototype WTGs. 66kV distribution level is anticipated to be standard in European OWF over the next few years. High level characteristics of developed 66kV switchgear is indicated in Table 12.

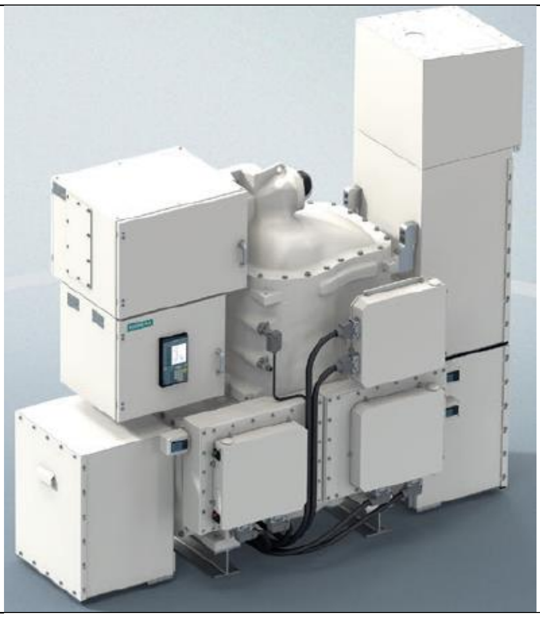
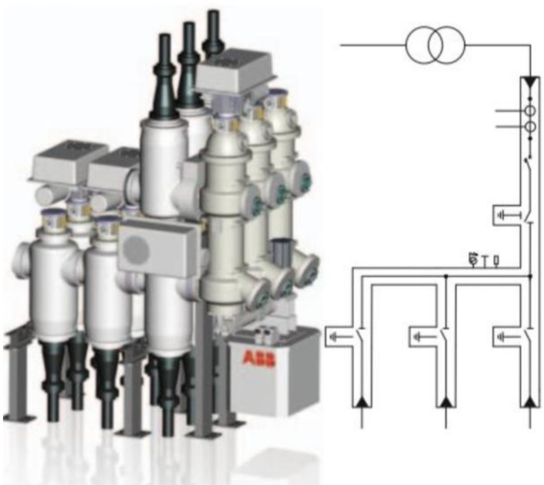
Siemens, 8DM1 switchgear Vaccum breakers with similar benefits as the SF6 technology. Rated current: 1250A SC: 25kA, 1s ▪ Transformer feeder with circuit breaker and disconnector ▪ Standard 1-3 direct cable connections ▪ Optional two remote load breakers for cable connection Dimensions 1.2 x 2.1 x 2.8m	
ABB, PAS M00 Switchgear ABB's PASS series of hybrid switchgear modules combines the advantages of traditional air-insulated switchgear (AIS) and advanced SF6 gas-insulated switchgear (GIS) technologies. Rated current: 2000A SC: 31.5kA, 1s ▪ Transformer feeder with circuit breaker and disconnector ▪ Optional 2-3 direct cable connections via common disconnector	
Worldwide established Alstom and Schneider Electric also have developed similar compact switchgear	

Table 12 Two types of 66kV GIS switchgear

The 66kV switchgear can be placed either in the foundation structure/transition piece or as a part of the WTG delivery. The industry have not yet converged into standardised design approach on this matter.

5.5.2 T-connector box

The main benefit of introducing a T-connector box is that it allows a completion of the full array cable system radial prior to installation of the WTG tower and nacelle commences. This enables a more robust overall program for the offshore operations and a more rapid energisation of the WTGs when they have been erected. Introducing the T-connector box offers a cleaner interface between the WTG supply and the cable installation works in respect to dependencies and delay damages between the parties.

Figure 28 T-connection box outline

The T-connector boxes can be installed at the foundation units onshore, thus saving offshore installation work since the cable installation to the WTG switchgear then only shall be done for one MV cable.

In addition, the cable installation at the WTG foundation is easier since the cable termination of the array cables and export cables in the WTGs or the OSS can be done in one operation.

The outline of a T-connector box (Disitek) used on several OWF in the UK is shown in Figure 29.

Details indicating cable connector bushings (suitable for the cable and coupling connectors) and cable entries can also be seen in the figure.

The box further can be equipped with earthing rod and adaptors/bars.

Figure 29 Dimensions – example W0.6 x H1.1 x D1.2m, Weight 125 kg

5.6 HV – MV cables at OSS

Design, fabrication and installation of the OSS is on the critical path of the overall programme due to the long manufacturing time of the steel structures and supply of long lead items (power transformers, reactors, HV & MV GIS and protective relay panels).

A traditional OSS is designed with:

- Substructure (Jacket or Monopile) equipped with J-Tubes for the sea-cable installation.
- Topside with cable deck, main deck, utility deck, top deck.

A critical activity will be determination of the dimensions of the main components (incl. radiators and coolers) since this is a precondition for the detailed design and arrangement of rooms at the OSS. This must be done very early to allow detailed design which takes 4-6 months, fabrication of OSS steel structure 3-8months, and installation of M&E equipment 4-6 months.

The installation of MV and HV offshore cables at the OSS cable deck constitutes one of the most important interfaces at the OSS. The arrangement of the cable ways (respecting the MBR of the cables during cable pulling) requires detailed 3D modelling of the primary steel structures, floor penetrations, location of the J-tubes/cable hang-offs, and HV/MV plant to prevent clashes. The work scope split between the OSS and cable supply/installation contractors need to be well defined otherwise expensive offshore delays could occur.

The sketch in Figure 30 aims at illustrating this interface.

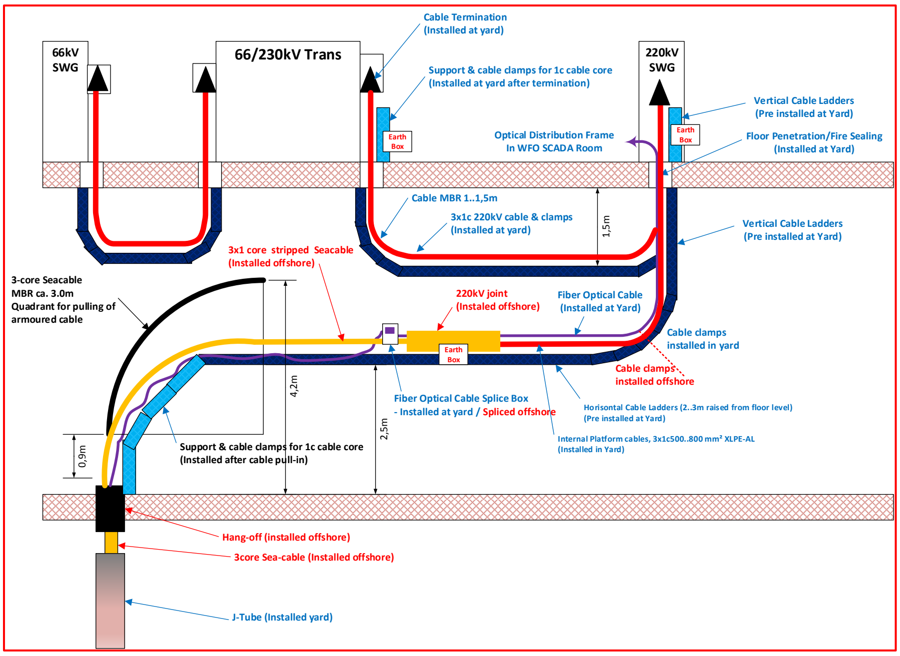


Figure 30 Cable interfaces and scope split at the OSS

Some reflections are given below:

- The internal MV & HV cable connections between GIS and apparatus should be installed by the OSS contractor in his fabrication yard. *(Alternatively, MV & HV bus ducts could be considered – cost is higher, but reliability and robustness is better – they also could be more easy to repair compared to a faulty HV/MV cable circuit).*

- <u>Cable deck joint</u>
  The sea cables can be pulled to the cable deck, stripped into three single cores and guided to the MV/HV GIS rooms for termination to the respective feeder. Benefit will be that a clean/controlled environment for the assembly work is given by the rooms. Drawback is that the floor penetrations and the vertical cable supports below the equipment shall be done offshore.
  An alternative approach could involve that the OSS contractor at his yard installs a short cable terminated at the GIS and attached to the cable ladders ready for jointing offshore after the sea-cable have been pulled in.

  A cable joint for 33kV and 66kV is often selected and recommended. This, however, is not always the case for 220kV cable systems where concern on additional cable joints in respect to cost and risk of failure during operation could be raised.

  As a general advice it is recommended to design and plan for as little offshore work as possible and also to close the GIS rooms at the yard.

- Scaffolding
  The cable ways at the cable deck will be raised approx. 2-3 m above the floor, thus scaffolds shall be used offshore for the below listed operations:

  - Preparation for sea-cable pulling (cable quadrant/ rigging of suspensions and wire etc./temporary modifications of cable ways/supports to give space for operation).
  - Sea-cable pulling, stripping and arrangement of cables on cable ladders.
  - Demobilisation of cable pulling arrangement / reinstatement of cable ways.
  - Assembly of HV/MV cable joints.
  - Fixation of cables with cleats to cable ladders.

  It is advised that the developer carefully considers the planning of the works since HSE requirements for these works could cause unintended delay and postpone the energisation of the platform if not timely and properly planned when entering contract agreements with the OSS and cable contractors.

5.7 Sub-marine-cable installation

This section aims at giving a very brief introduction to the challenges and commonly used methodologies adopted in the industry. The description is not detailed. Prudent contractors will on request in a tender process provide a comprehensive and project specific proposal detailing the appropriate installation methods.

It is mandatory for a timely construction that the wind farm developer upfront defines his procurement strategy in respect to engineering, consent and construction activities.

The most common split is that the developer prepares the route engineering and obtains consents/approval from relevant authorities. The supply & installation works are then contracted either combined or divided into a supply and an installation package. Adopting a multi-contracting approach will require comprehensive interface management since both technical solutions/deliverables and programme dependencies shall be considered. The wind farm developer will be exposed to unforeseen cost caused by the knock on effect from one contractor's none-performance or delay, and will be liable for mitigating the gaps by issuing variation orders. The benefit with design-build contracts involving supply and installation is a limitation of the interfaces. These will be managed by the contractor who will price in his risk for program delay caused by sub-contractors. Experienced wind farm developers have success in multi-contracting approach, but it is not recommended for inexperienced developers since mismanagement of program and interfaces easily can provoke significant additional cost and delays that would harm the business case significantly.

The most important interfaces are:

- Cable entry and installation in the WTGs.
- Cable entry and installation in the OSS.
- Transition joint bay (onshore/offshore).
- Crossing agreements with offshore service operators.

5.7.1 Route engineering

The offshore cable installation engineering commences with the wind farm developer's design basis, which is established prior to approaching cable suppliers or EPCI contractors.

The route planning and design for offshore cable systems are based on:

- Wind farm layout.
- Location of the OSS (if relevant).
- Export cable corridor to shore.
- Landfall location.

The route engineering is a fundamental building block of the project and will comprise a complete and thorough desktop study including:

- Cable Engineering and Survey Documentation
  - Straight Line Diagrams (SLD).
  - Route Position Lists (RPL).
  - Survey Charts (Bathymetry, Geomorphology).
  - Obstruction Reports/Crossing Matrix.
  - Burial assessment study.

- Route Planning Tools
  - Databases and Geographic Information System for detailed route planning.
  - Documentation/Charting Tools.
  - Cable database indicating installation handling parameters.

Engineering Survey Studies

Reliable and cost effective route and cable engineering is crucial for the success of the project. Consequently, the wind farm developer must initiate several investigations and studies to establish a reasonable detailed basis for the cable route design. This is a pre-condition for any installation contractor’s detailed tender design and cost proposal for the installation work. The list below shows a recommended minimum of topics to be addressed prior to issuing tender documents to potential bidders.

- Soil investigations (1-4m depth only) with sampling at discrete intervals along the route. (Identifying the seabed topography and giving seabed soil data by sampling and in situ testing of the seabed sediments)
- Bathymetry survey carried out with multi-beam echo sounder, side scan sonar and sub-bottom profiler equipment for anticipated cable export cable corridor (500m width recommended). The bathymetry survey done within the wind farm for positing the WTGs will cover the array cable installation as well, unless large couture deviations occur
- Seabed mobility survey "Pre- & post installation"
- Burial assessment survey - comprising sampling "grabs or cores" and cone penetration tests (CPTs)
- Boulder survey
- UXO survey
- Environmental assessment and consents applications
- Permits and right of way from relevant authorities
- Alignment with third party stakeholders (fishing organisations, port authorities, shipping lane operators, crossing of existing cables/pipelines to be passed, etc.)

Reference to a more comprehensive description of suitable surveys (Pre- and post-construction) are given in Ref. /15/.

Cable Route Study (CRS)
The CRS is essential to determine the optimum route for the cable with respect to the integrity of the cable during its installation and operational life. It also determines whether a route is acceptable and comprises a design basis composed of:

- Mapping of seabed bathymetry in anticipated cable corridor
- Assessment of seabed morphology and geology
- Mapping of natural hazards e.g. seismic events, submarine volcanism
- Oceanography and meteorology
- Mapping of human activities e.g. mineral extraction, oil & gas activities, and fishing.
- Probability assessment of man-made hazards e.g. anchoring and dredging

- Detailing of other cables and pipelines
- Detailing of eventual exclusion zones for the corridors
- Preliminary Route Position List (RPL)

Burial Assessment Study (BAS)
The CRS establishes the starting point for the BAS that accurately determines whether it is possible to bury a cable along the route. In addition to the soil investigations, a burial assessment can be carried out using a burial assessment tool. The BAS will recommend an acceptable burial depth along the cable route that with an acceptable probability will give sufficient protection of the cable against third party damage or exposure due to seabed movement in the operational lifetime. BAS guidelines are detailed in Ref. /14/.

It is clearly not possible to avoid all hazards. The most significant hazard is fishing activity, which by its nature covers a wide area of the seabed, and accounts for about 40% of all cable faults. The second most significant hazard is anchoring which accounts for about 18% of faults in all water depths, but is most significant in water depths of less than 50m. To achieve a secure cable system, some form of protection must be provided. This essentially falls into the categories of burial and/or armouring.

Fishing activity damage is often caused by trawling operations having a soil penetration of up to 30-50cm depending on the hardness of the seabed. Anchor damages will depend on the anchor type and size. Cable damages caused by anchor penetrations into the seabed up to 3-4 m have been reported. This naturally highly depend on the soil characteristics. Penetration in hard clay naturally will not be as deep as in a sandy seabed. Stiffer clays and denser sands provide more protection to a buried cable than softer clays and looser sands, hence such soil conditions require less burial to provide the same level of protection.

The overall tendency is therefore straightforward, hard seabed requires less burial depth than soft seabed.

The BAS constitutes the baseline for the installation contractor's selection of proposed cable laying and burial tools methods. In this respect it is observed that no common standards exist and the developer should not issue strict requirements on the installation methods (unless environmental conditions prevail). He should rather issue a tender specification with functional requirements "minimum accepted burial depth along the cable route" open to the contractor's suggested methodology based on his experience, capability, availability of vessel and burial tools. Different methods at different cost and time frames will exist for any offshore cable project.

General requirements stipulating an equal minimum burial depth along the whole offshore cable route should not be required, since it will impose unnecessary demands and high installation cost. The BAS must be conclusive on the acceptable burial depth, which will vary along the cable corridor.

5.7.2 Preparation, Pre Lay Grapnel Run

Pre Lay Grapnel Run (PLGR)

The offshore installation campaign will commence with cleaning up the cable route for any debris on the seabed such as old trawler nets, disposed wires or chains that can damage the installation tools or in worst case the cable.

Each of the cable routes will be prepared with a PLGR, within sufficient time before cable installation. The PLGR involves a vessel towing a grapnel train over the seabed. The vessel follows the cable route to hook in and recover small debris like lost fishing nets, ropes and wires from the seabed. Continuous measurement of the towing tension of the grapnel line gives an indication if something is caught by the grapnel. Depending on the size and type of debris, it will be either removed from the route or recovered to the vessel deck (not including wrecks). A typical PLGR grapnel train suggested by cable installer is shown in Figure 31.

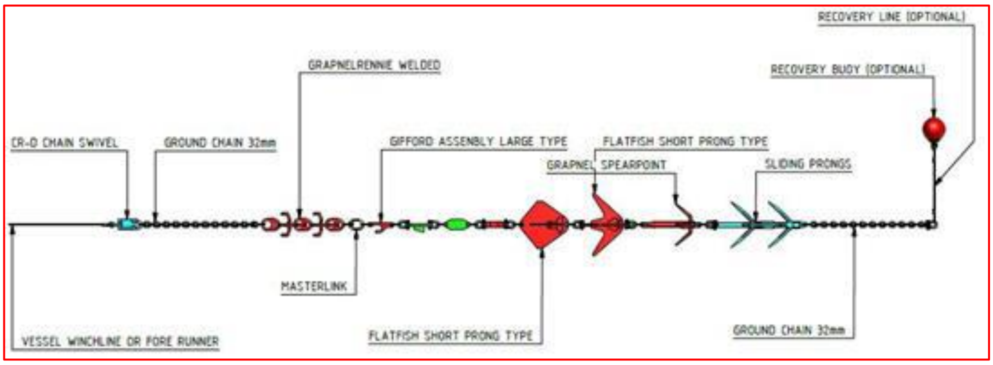


Figure 31 Example of a grapnel train for PLGR

Boulder removal

Cable routes may pass areas congested with boulders in the seabed. The detailed cable routing should allow for alter course and bending requirements caused by the cable laying and burial tools that could not be fulfilled without implementing a pre-cable laying boulder removal campaign.

Typical alter course limitations are:

- Maximum 15° for plough buried sections
- Maximum 15° for post lay buried sections
- Maximum 25° in surface laid areas
- Clearance to boulders approx. 50 m.

Figure 32 - Boulder removal tool

The detailed route engineering (utilising a geographical information system software tools complemented with Eg. AutoCad or the like) will suggest the most appropriate cable route through the boulder zones and identify eventual boulders obstructing a safe cable installation, which should be removed if there is no possibility of rerouting the cables around them. The installation contractor will determine if a separate removal campaign utilising a special vessel is feasible or if the CLV should be mobilised with a suitable grab for removal prior to commencement of the cable laying operation.

5.7.3 Cable laying/burial methods

The most optimal cable laying and burial methodology may be suggested by a cable installation contractor based on his available CLV, burial tools and supported by the BAS and CRS provided by the wind farm developer.

Several solutions exists:

- Cable laying in pre-excavated trench (natural backfilled or backfilled by contractor).
- Surface laying, no burial (not appropriate at water depths <100m).
- Surface laying, protected by post lay rock beam installation.
- Surface laying, protected by post lay mattresses.
- Surface laying, post burial.
- Simultaneously laying and burial (ploughing).
- Surface laying with cable protection by manufactured cable ducts.

Figure 33 Mobilised CLV

Cable Laying Vessel (CLV)

Figure 34 Mobilised CLV

The market can offer several CLV's either as constructed cable laying ships or mobilised barges. The variety of type, size and capabilities are wide since all sea cable projects have unique challenges that require a project specific mobilisation aligned with the selected installation methodologies. The cable installers often have a mix of own CLVs and long-term hired CLVs being mobilised with a basic cable installation spread. Different CLV's are used for the array and export cable installation since the long export cables, and the landfall pulling operation requires a larger turntable and deck space, than the array cable installation where individual drums normally are placed on the cable deck.

The selection of the most suitable array cable CLV shall take basis in the prevailing site conditions but also the cable supplier's capability to deliver long cable lengths direct to the CLV shall be factored in. CLV's with 1-3 small turn tables 1000-2500t or one large turn table can pick up long continuous cables thus the cable drum logistic will be eliminated and cost savings could be achieved.

The export cable CLV shall be suitable for shallow water operation since the CLV should do the landfall pulling operation as close to the beach as possible. If large tide difference prevails and an intertidal zone exists it will be required to beach the CLV at 1-3 km shore distance. (Otherwise the maximum pulling force will be compromised)

The basis CLV mobilisation will comprise of the following:

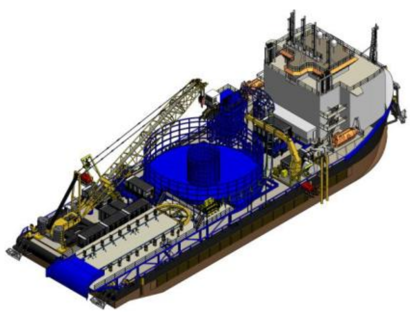


Figure 35 CLV cable deck outline

- DP2 subsea support.
- Accommodation and associated facilities.
- Firefighting and safety equipment.
- Turntable/carousel.
- Cable tensioners.
- Cable counters.
- Rigging workshop container.
- Electrical stores and workshop containers.
- Crane.
- Cable chute.
- Sliding frame with quadrant.
- Pulling winch & power pack for winch.
- Various cable highways, bollards and tugger winches.
- Deck lights for night time working.
- Survey equipment/tools.

Pre-trenching

Pre-excavation of a cable trench can be a suitable approach for seabed with clay and water depths 10-20m. The durability will depend on the seabed condition. If the seabed is too soft the cable trench will likely collapse prior to the cable laying, if hard soil prevails very slowly excavation performance will occur.
The solution could benefit from being a robust and easy planned operation, not involving complex burial tools.
Drawback could be collapsing or backfilled trenches prior to the cable laying operation is carried out (could require clean-up campaign and programme challenges) and mobilisation of a separate vessel for the dredging work. Further, post lay backfilling operation shall be implemented for sections where natural backfilling does not occur.

Figure 36 Example of pre-trenching vessel

Surface Lay

This is by far the quickest approach and does not require post-lay burial (PLB) tools mobilised. The cable is laid directly onto the seabed from the CLV either from a static coil or a revolving turn carousel/turntable depending upon the characteristics of the cable. The cable is led via a cable pick-up arrangement and an associated cable trackway through linear cable engines and is led over board through a cable chute usually mounted at the stern of the vessel.

Surface Lay and Post-lay Burial

Where simultaneous lay and burial of the cable cannot be carried out in one combined operation, e.g. restricted soil conditions, restrictions by client/owner or restrictions as a result of cable characteristics, the cable can be laid on the sea bottom and be buried subsequently using ploughing, water jetting or soil cutting techniques later. With the exception of shorter routes, the post burial option is usually a more expensive operation (subject to soil conditions) than simultaneous lay, and burial as a second pass (if water jetting operation is implemented) will be required over the cable, either by the cable lay vessel or another cable burial vessel. Water jetting is not suitable for burial of surface laid cables at the near shore section where shallow water operations shall be implemented thus a cutting technique could be more feasible as indicated in the figure (Jan de Null). Several other tools can be offered by different installation

Figure 37 Example of post burial method

contractors. Post lay trenching with excavators mobilised on a suitable barge could also be an alternative. *(Pre-trenching is recommended only if the soil characteristic can secure the trench does not collapse prior to cable laying).*

<u>Simultaneously laying and burial</u>

When the cable is required to be buried over a greater part of its route to provide protection and, if this can be achieved in one pass, it can be laid and simultaneously buried during the installation. Burial can be achieved either by towing a plough which effectively cuts a trench depositing the soil back onto the cable or by jetting or cutting which lowers the cable below the seabed. Figure 39 illustrates a vertical injector designed with cutting/jetting facilities suitable for hard clay.

A very common approach is using a cable plough that can be designed with jetting facilities as well to loosen up the soil and reducing the pulling forces required thus the speed can be improved. The ploughing operation is often performed from a CLV barge utilising an anchor spread to achieve sufficient pulling force.

Figure 38 shows a post lay ploughing operation in an intertidal zone after the landfall pulling operation have been finalised.

Figure 38 Cable ploughing operation - low tide at beach

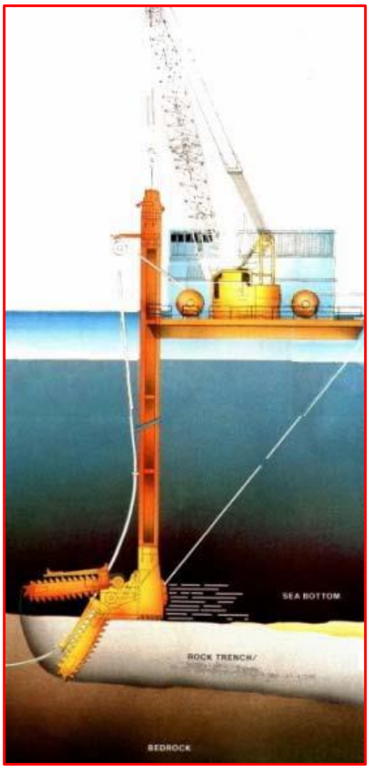


Figure 39 Vertical Injector burial approach

5.7.4 As built verification – Post construction surveys

The installation contractor can verify the achieved depth of burial (DoB) with instruments built on the plough or the cutting tools used for simultaneously cable laying/burial operations. These measurements are reasonably accurate but require a calibration of the tools prior to any operation commenced.

PLB with water jetting or cutting tools cannot offer accurate measurements of the burial depth. The installation contractor's work scope should include a PLB burial survey to establish the as laid position and soil cover for the cable in the seabed. The industry has developed a range of survey tools for PLB depth of burial surveys that can be employed either on floating/flying remotely operated underwater vehicles (ROV) or on sledges driving at the seabed. These systems can be rented by the installation contractor from the manufactures who will provide tools and experienced survey team on the vessel mobilised. Particularly, full survey contracts with specialised offshore survey companies are also an option, in particular for the wind farm developer if he wishes to perform third party DoB verification surveys against the DoB reported by the cable installer.

- Cable tracking survey
  A leading manufacturer is Teledyne TSS offering two solutions.
  The measurements are based on either pulse induction technology (TSS440) or on detection of an AC tone injected on the cable (TS350). TSS350 is used for cable systems < 1.2m and TS440 for cable systems up to 10m burial depth. The accuracy of TSS 350 is improved compared with TSS440, but will require that the tone is injected to the conductors or at the fibre metallic tube. TSS DoB survey with tone injection seems to be the most reliable method and should be planned already at contract signing with supplier and installer. (Fibre optic arrangement in pulling head should be clarified). If tone injected DoB surveys are implemented the wind farm developer shall do a robust planning since the cable may not be allowed to stay in operation since the access to either the conductors or the fibre tube is restricted. The DoB survey will take 1-3 weeks excluding possible weather down-time. This could have severe consequences on the overall program for energisation date if not properly addressed in the planning stage.

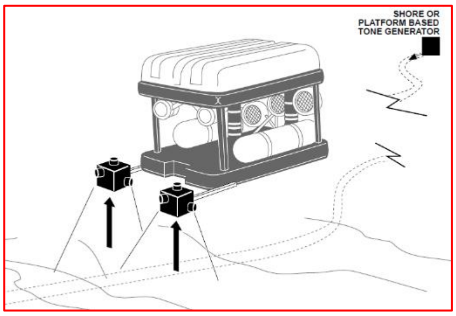


Figure 40 Cable Tracker – ROV outline

- Acoustic inspections by sub-bottom profiler or pinger can also be used to determine the DoB. This principle is based on the sensor crossing the cable perpendicular to the cable corridor at an agreed distance. Thus not offering a full plot of the DoB.

- Sub-bottom Imager (SBI) Ref. /17/
  A relative new survey approach is SBI developed by Pangeo Subsea. SBI offers 3D images of the cable burial in the seabed with 10cm x 10cm resolution with the sonar flying approx. 3.5m above the seabed. This, however, causes complication for sections with water depths in the range of 5-10m where the vessel selection and deployment shall be considered since a flying ROV approach is impractical.

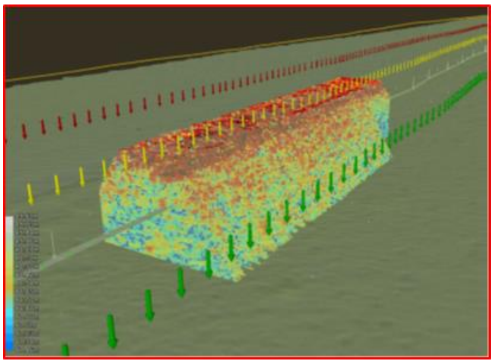


Figure 41 3D image of seabed and cable position

Figure 42 Mobilisation of sonar at survey vessel

- Spot check can be implemented by divers if required to verify the accuracy of the survey tools used. (Large DoB deviations can occur when different methods are implemented, thus a challenge will be establishing a reliable DoB aligned and agreed between the parties).

The PLB survey shall be planned as a separate offshore operation with a vessel mobilised with tracking sensors or on a sledge or ROV. The DoB results may be disturbed since the seabed above the cable may not be settled/levelled to undisturbed seabed within a timeframe of 1-2 months. This is a complication factor adding to the inaccuracy of the survey tools resulting in measurements not always offering comparable DoB data when different methods are used and compared. The common understanding of the DoB is illustrated in Figure 43, Ref. /16/.

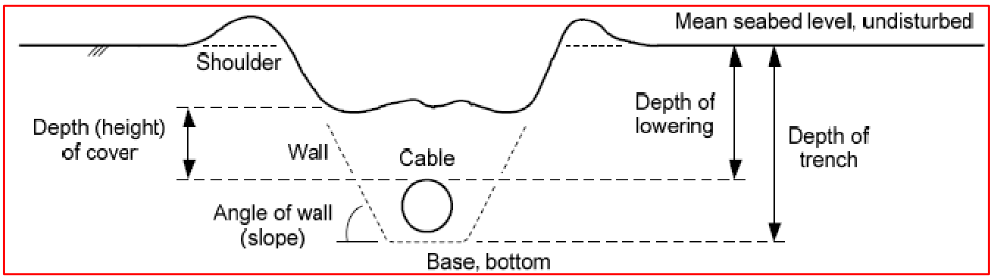


Figure 43 Example of DoB and terms used

It is important that the actual burial depth (in particular for the export cables) is established firmly before the cable is taken over from the installation contractor. This will be a starting point in insurance cases should the cable suffer damage from external matters during its operational lifetime. It is suggested that the wind farm developer organises a third party survey in parallel with simultaneous lay/burial operation since this allows for an immediate comparison against the DoB informed by the contractor and offers a chance for making possible new calibration of his measurement tools/burial equipment in the field.

5.7.5 Post installation monitoring

The wind farm developer often will be required to implement periodical survey campaigns during the operational phase. See Ref. /15/.

The purpose of a post-installation survey is multi-fold, and includes the following:

- To assess the burial status of the cable and determine cable exposure/ free-spanning or monitor existing exposures / spans
- To identify cable damage
- To assess the burial depth of the cable
- To assess scour in the vicinity of the substation or rock beams
- To assess mobile sediment movement and sediment level changes (scour / erosion / accretion) from previous surveys
- To update the ground model to review sediment level changes and trends
- To assess the condition of existing remedial works
- To identify hazards / potential hazards in the vicinity of the cable / offshore substation
- To monitor any previously-identified sensitive habitats
- To monitor any previously-identified areas of archaeological interest

- To inform any maintenance works required

5.8 Landfall / sea defence / beach

5.8.1 General

The location and conceptual outline of the landfall where the offshore cable(s) are routed to shore and interconnected to an onshore cable system is vital for the planning of the export cable systems. It does affect the overall routing of both the offshore and onshore cable systems thus having significant impact on the solutions and cost. Consequently, the determination of the landfall position shall be considered very early in the planning process and is closely linked to the selection of the PoC if different options exist.

The most apparent selection criteria for the cable landing are listed below:

- Location nearby available PoC
- The CLV can easily access to the beach
- Access for beach works and usage of heavy machinery
- Seabed topography, material and condition
- A remote location from existing plant, utility services should be preferred
- Locations with man-made sea defence constructions should be avoided
- A location enabling an open cut cable trench shall be preferred above locations where HDD ducts shall be installed
- Distance to other cables, pipelines in the nearshore seabed shall be avoided
- National park, coastal reserves, environmental sensitive zones etc. shall be avoided

Furthermore, the conceptual outline of the landfall will have an impact of the overall power system concept since the export cable design will depend on the following considerations:

- Cable ampacity design
- Pulling force from cable laying vessel to shore
- Pre-installed cable duct (in excavated trench or as a HDD
- Soil characteristic in respect to soil hardness and thermal resistivity

A pre-installed cable duct at a large burial depth will require larger cable conductor sizes to maintain the load capacity and could even provoke that more 33kV or 66kV export cable circuits are necessary.

The most common alternative concepts are briefly discussed in Table 13.

	Concept	**Depth**	**Impact on cable ampacity**
A	Sea cable pulled in open excavated trench and directly buried. *(The cable trench also can be excavated after cable pulling)*	1-2 m	› Civil work consideration The open cut of an eventual sea defence could cause consent issues but can be overcome with robust methodology. Excavation in the beach is uncomplicated. Excavation in the 1-5 m water depth section can be done by either land based excavators or from a suitable mobilised barge with very low draught. › Pulling operation This option give less pulling forces on the cable and will leave the cable either in a pre-excavated trench or surface laid for later burial. › Cable load capacity Conductor temperature raise in soil low. Dry out of soil to be considered above water line. Can be counteracted with concrete embedding offering low thermal resistivity. › Post-lay burial › The cable can easily be buried by same land based and offshore equipment used for the excavation works.
B	Cable pulled in open excavated trench with post installed duct at the beach.	1-2 m	› Civil work consideration Prefabricated half ducts can be procured and installed around the cable at site after it has been surface laid. The purpose of the duct will be offering additional protection of the cable should the soil/sand cover be washed away overtime. The post installed duct is not a durable option for the cable laid in the 1-5m water depth section. Offshore PLB equipment (jetting/cutting tools) must be mobilised from a small barge. › Pulling operation Will be similar to concept **A** › Cable load capacity The cable duct will provoke additional thermal resistance in between the cable surface and the duct composed of air space between cable/duct and the duct itself. This will impose an increased conductor temperature. The unfavourable air space can be eliminated by injection of bentonite or grout offering lower resistivity. *(Sealing of the duct at sea and risk of grout material entering the sea will be a challenge to overcome).* The moderate burial depth up to approx. 2m combined with low resistivity grout material could result in no derating of the cable circuit occurring at this section. › Post lay burial The beach work can be implemented with land based equipment.
C	Cable pulled in duct placed in pre-buried trench	1-2 m	› Civil work consideration Burial of the duct can be done with same methods per concept **A**. The duct "PE approx. Ø600/500mm" can be delivered in short lengths 15-20m that shall be connected at site with tight connections to avoid ingress of sand etc. prior to cable pulling operation take place. Connection can be done by suitable designed prefabricated connectors or welding at site. The connection of the duct sections can be done at the beach and then float out to the sea until it is lowered down to the seabed

			for later burial. › Pulling operation The cable duct will add additional friction significantly higher than cable rollers during the landfall pulling operation. This will increase the pulling forces that shall respect the handling parameters defined for the cable. Any prudent contractor or design engineer can provide pulling calculations at a conceptual stage of the project. The maximum pulling force incl. properly selected safety factors must be aligned with the cable supplier prior to the cable design freeze of the armour wire construction and contract agreement. › Cable load capacity Same as concept **B**. Should a more heavy armour wire design be imposed then the armour losses will increase and could result in an additional derating of the cable. › Post lay burial Beach work will be uncomplicated. Diving operations and/or use of offshore ROV jetting/cutting tools will be required at the duct sea end for burial and sealing of the duct + cable section entering the duct.
D	Cable pulled in duct installed by horizontal directional drilling (50-400m).	4-8 m	› Civil work consideration Benefit could be › solid protection of export cable at beach › opening of a sea defence construction is avoided › construction work in environmental sensitive areas avoided › the beach/nearshore zone is prepared to receive the offshore cable › Pulling operation Similar to concept **C**. The larger burial depth is not considered to add significant higher pulling forces. › Cable load capacity The extended depth of the duct will provoke a significant larger thermal resistivity of the soil. This will imply that the maximum allowable cable conductor temperature is overpassed unless a larger conductor size is selected. › Post lay burial The HDD duct will be starting just next to the transition joint bay (TJB) thus backfilling and reinstatement can be done together with the TJB. The seaside of the duct shall be handled as concept **C**.

Table 13 Common alternative concepts for landfall

A very indicative outline of a HDD duct concept is shown in Figure 44.

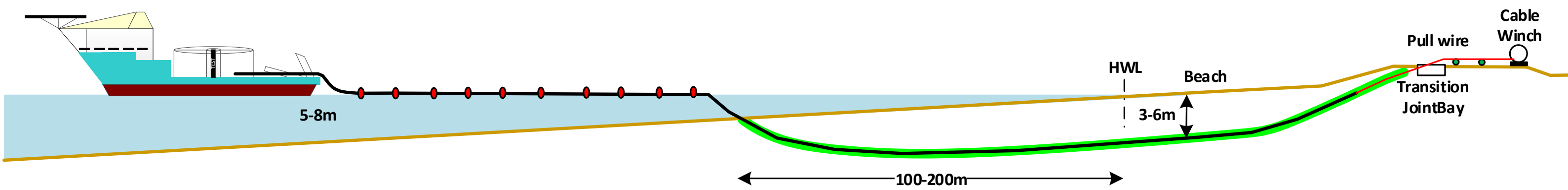


Figure 44 Example of landfall pulling operation with HDD

The cable sizing at landfall will determine the design of the full export cable from the beach to the first connection point at the offshore wind farm (at OSS or first WTG for MV export cable systems). It is possible to choose a special cable design for the first ≈1km of the sea cable with larger conductor size. The transient between the nearshore and offshore cables can be connected with flexible factory joints to accommodate the two different cross-sections. Flexible factory cable joints are developed and tested by all experienced submarine cable suppliers. The cost impact for the flexible factory joint is considered insignificant. The cost impact from production of the short length with larger conductor size could be significant.

The design freeze related landfall can only be done when an optimisation process based commercial negotiated costs are available for the different cable designs and the HDD duct installation have been completed. *(For the MV export cable alternatives this will be complicated by the number of export cable circuits in question).*

5.8.2 Landfall pulling operation

The limiting factor for the design landfall installation will be the distance from the shoreline to the CLV and the maximum pulling forces allowed for the cable.

The sketch in Figure 45 below illustrates an assumed methodology with the CLV approx. 300-500m from the beach (as close as possible).

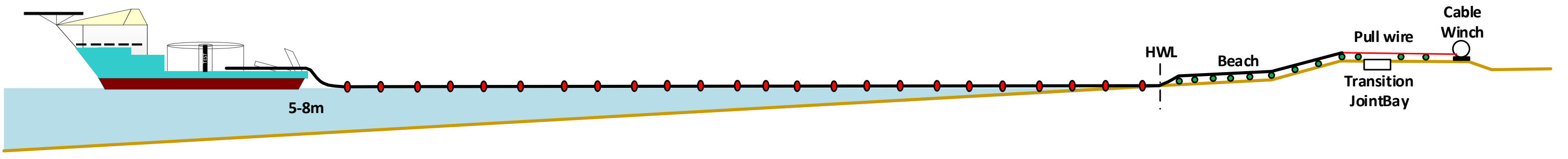


Figure 45 Example of landfall pulling operation without HDD

The operation involves floating in the cable (with pontoons) guided by the pulling wire connected to the winch approx. 10m behind the transition joint bay.

The landfall pulling operation consists of an offshore and onshore team working closely together during the pulling operation to secure a safe land-intake without compromising the cable handling parameters specified. The offshore team will use approximately 2 weeks to mobilise the site and prepare the TJB (protecting the onshore cable(s)) followed by approx. 7 days for mobilising the cable winch. The cable pulling operation can be completed within one day given good weather conditions and 1-2 days for removal of the pontoons/placing the cable at the seabed. If the current along the shoreline is heavy it will be necessary to deploy small vessels to keep the floating cable in a straight line.

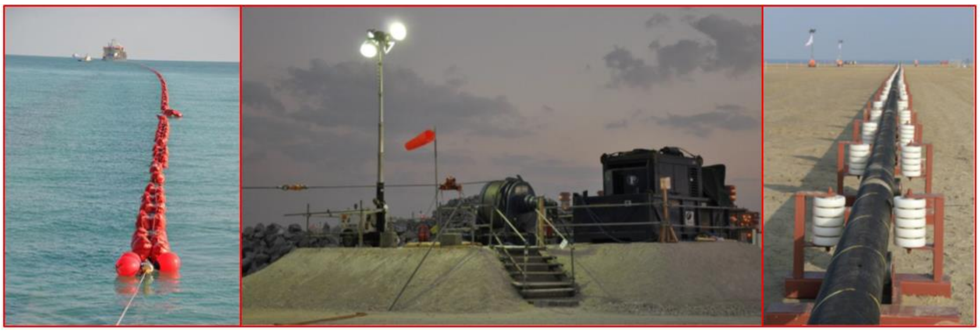


Figure 46 Landfall pulling operation – arrangement

Figure 46 is from a beach landing implemented by Jan de Null with the cable being floated in. In the photo beside, a landfall pull in an approx. 2km intertidal zone on pre-placed cable rollers at the UK west coast performed by DeepOcean is illustrated.

The transition joint bay (TJB) houses the cable joint between the 3-core offshore and 1-core onshore cable systems. It is assumed to be located as close as possible to (or even at) the beach with the cables buried well below the waterline. This will guarantee that the soil and sand bed around the 3-core sea-cables will remain moist, thus no drying out of the soil and overheating of the cable due to increased soil thermal resistivity will happen.

The TJB interfaces the onshore and offshore cable systems. A prudent overall program will secure that the onshore cable systems are laid and ready to receive the offshore cable in the TJB. This demands that the TJB shall be constructed and ready with the onshore cables placed in the TJB ready for jointing assembly commencing just after the offshore cable have been pulled into the TJB. An indicative design of a TJB for a 220kV cable transition joint (approx. 1.5m deep) is indicated in Figure 47.

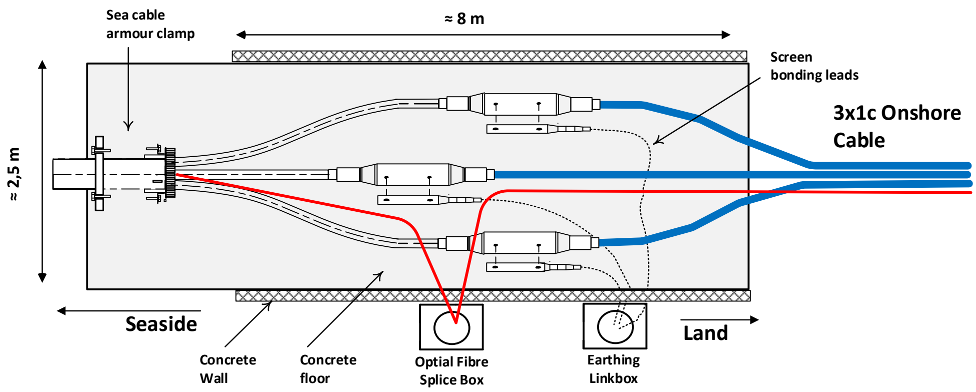


Figure 47 Example of transition joint bay (TJB) lay-out

The TJB shall be designed to accommodate the three single phase joints, cable screen bonding cables and link box, fibre optical splice box and the anchor clamp for the sea cable. A proper and clean working space should be planned for by constructing a concrete base and supporting walls for the cable supplier's mobilisation of his jointing container. The concrete wall also secures collapse of the soil during the large duration is shall stay open.

The TJB shall be backfilled with selected sand fill or a weak concrete mixture approx. 0.5 m above the cable/joints to ensure proper thermal behaviour of the surroundings. The top layer can be reinstated to its original conditions in alignment with the landowner's requirements. It is suggested building in a small polymer housing with a top cover to contain the link and fibre splice boxes provided and installed by the cable supplier. The access to the link and fibre boxes shall also be considered. Thus this shall be agreed with the landowner.

Below photos are showing possible outlines of the TJB.

Cable armour clamp against sea	**Earth link box arrangement**
	
Transition joint located at beach	**Sea cable armour clamp and entry to duct**
	

Figure 48 Pictures of transition joint bay (TJB)

5.9 Installation methods – suggested for the 200MW OWF

Based on the seabed conditions available a preliminary suggestion for offshore cable installation to the GULF OF KHAMBHAT -200MW OWF can be given as per below:

Export cable(s)

The availability requirement for export cable(s) is higher than for the array cables (in particular if only one HV cable is connected to an OSS). Consequently, the requirements to cable burial for the India project are higher since the export cable corridor passes one of the most used shipping lanes in India, which will increase risk of anchor damage.

- **Offshore**

  The seabed favours a simultaneous laying/burial operation very likely with a plough set-up as the most cost attractive method.

  Over the last twenty years, ploughing has become the preferred method for burial of cables. Ploughing is an efficient burial method, operating at speeds of up to 500m per hour in most soil conditions and achieving good burial in the range 0.5-2.0m depending on soil conditions.

- **Nearshore/beach**

  The seabed profile indicates that the CLV can approach the shore at approx. 500m distance. The beach also appears flat and without any man-made sea defence construction. No significant tide seems to occur, thus a cable pulling from the CLV utilising a winch situated at the beach and involving floating pontoons to guide in the export cable is a reasonable approach.

  The cable can be laid in a pre-excavated trench at the beach, surface laid at the shallow water zone until approx. 500m where the ploughing operation towards the offshore section can commence. Post lay burial with a suitable jetting spread will then be required between the high water mark and the location where ploughing operation commences.

  Topics to be considered in a more elaborated phase:

  - If high current exists this shall be factored in when planning the floating operation
  - Seabed mobility/movement at the shallow section shall be investigated to determine minimum burial depth of the cable and eventual pre-buried duct for the first approx. 100m
  - Cable duct installed with HDD technology is not recommended since it will result in large burial depth and derating of the cable loading capacity (Will most likely require larger cable conductors)
  - Perhaps the ploughing operation can take start already from the beach with the surface being pulled through the plough mobilised at the beach. (Contractor to detail and develop such methodology heavily dependent on the seabed profile).

Array cables

The installation of the array cables will be done in a sequence as indicated below:

A. WTG foundation preparation "cable pulling rigging" *)
B. Recovery of messenger wire in WTG at the seabed.
ROV operation to connect messenger wire with cable
C. CPS installation & 1st end pulling
D. Surface laying to next WTG
E. Recovery of messenger wire in WTG at the seabed.
F. CPS installation & 2nd end pulling
G. Cable burial
H. Termination work in WTGs
MV cable stripping, hang-off assembly , termination, fibre optical cable splicing and testing
I. Demobilisation of cable rigging equipment

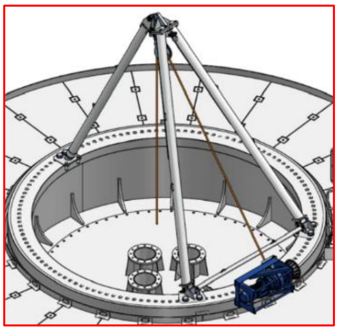


Figure 49 Example of 3-pod for array cable pull-in

*) The timespan between cable pulling to the WTG foundations and the installation of the WTG tower/nacelle will typical be more than one month and shall allow for cable installer's termination of the cable ends to the T-connector box. This assembly work shall be done in a clean environment both for HSE and quality issues. Consequently, the WTG foundations shall be designed with a cover (tent or the like) that are installed by the foundation contractor and handled by the cable installer. It is essential that the cable installation contractor's requirements for cable pulling is considered and designed for by the WTG foundation package. A typical rigging for cable pulling to the WTG is shown beside.

Figure 50 Transfer from CTV to WTG monopole

The access to the WTG foundation is essential for achieving installation works as per schedule. These assembly works are implemented on the foundation unit before an eventual helicopter transfer facility is established. Thus, the weather limitations for transfer from the CTV to the WTG foundation is of utmost importance and shall be a focus point when the CTVs are specified. Several solutions with movable/flexible gangways are on the market and may be adopted to minimize contractor's standby due to adverse weather conditions.

The most economical way to install the cable is to surface lay it. However, as discussed above, external threats exist which can damage the cables. Thus a PLB operation is suggested for all cables.

The seabed “soft silty clay” will be suitable for a jetting operation with a ROV tool illustrated beside from Fugro.

The jetting campaign is often planned to be executed when all array cables are surface laid. The campaign could also be included in the jetting of the export cables at the OSS that will be surface laid the last 300-400m.

The importance of proper burial for the last array cables in the strings is less than for the first one at the OSS and the export cables. The developer can consider a risk vs. cost assessment if some of the last array cables can remain surface laid.

Figure 51 Jetting ROV

Crossings The cables are surface laid at crossing with eventual existing pipelines/cables on a pre installation rock dumped separation layer and covered with post laid rock beam to protect against damage from anchors and fishing trawls.

5.10 Onshore cable system

5.10.1 Cable characteristics

The predominating design for onshore MV and HV cable systems are XLPE insulated in either single or three core design. The choice between Cu or Al conductor will be a cost optimisation since the electrical/mechanical properties are almost similar for an Al cable having one or two increased standard conductor size. In general, Al cables are most cost efficient, but this will depend on the metal cost and local market preferences.

In general, manufacturing/supply of 1-core cables for a given conductor size is cost attractive compared with 3x1core cables. Thus MV 3-core cables mostly used for distribution systems.

The 3-core cables can also be more attractive in respect to the transport and pulling operation but could due to cable drum limitations impose shorter distance between cable joints (approx. 400-600m) where single core cables can have up to 1.000m distance. Drawback selecting 3-core design could be reduced load capacity (since the cable cores are very close and will heat up the conductors), and larger MBR that could impose challenges for route design. 66kV and 220kV land cables are most often selected as 1-core cables since they will make longer sections possible between the expensive cable joints.

Single core cable will be the preferred design for the onshore export cable circuits since the available conductor size can go up to 2,000mm^2 should it be required. Typical designs, Ref. /8/, are shown in Figure 52.

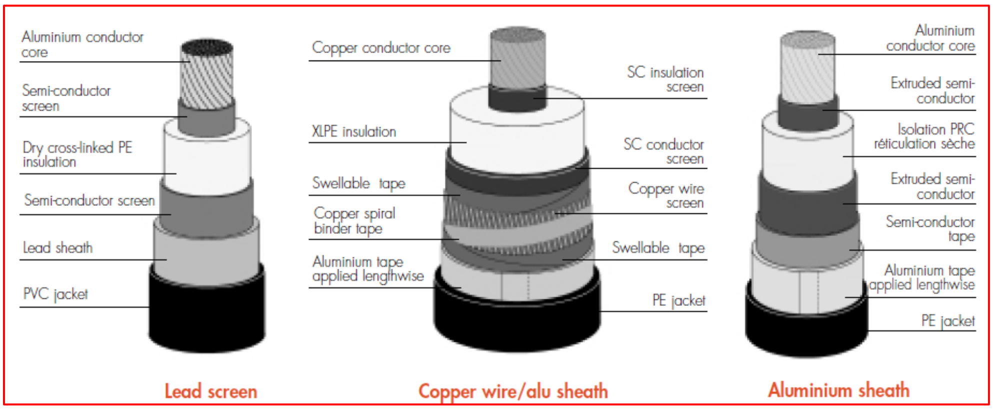


Figure 52 60-220kV single core cables

All onshore XLPE cables are typical required as longitudinally and radial watertight. The 33kV cables having less electrical stress can be released from this requirement. The cable jacket should be designed with an outer semi-conducting layer since this will ease fault finding and 10kV sheath testing before and after the installation.

5.10.2 Cable Installation Concepts

Onshore cables shall be installed in a pre-excavated cable trench and pulled out from the cable drum in one end and the winch in the other end between the cable joint bays. The cable route should be planned as straight as possible to enable as long as possible (up to 1.0 km) distance between the cable joint bays. Limiting factors on the cable length will be drum size, transportation of drum (height restrictions on land transport to be considered), and permissible pulling force during cable laying.

A typical onshore cable trench appropriate for MV and HV cable circuits are shown beside. Different burial depth can apply due to local regulations and the environment the cable circuit passes. E.g. in farming land an increased depth up-to 1.3m may be chosen to prevent damages from heavy machinery during ploughing or drainage work.

The cable jacket should not be damaged during installation, thus pre-lay 10kVdc testing is often carried out before the cable trench is backfilled. The jacket very often is damaged from stones in the cable zone, sand fill not being properly removed prior to compaction of the sand fill.

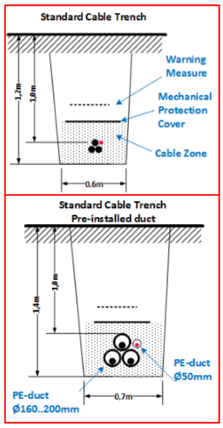


Figure 53 Typical Cable Trenches

In general, it is recommended selecting the cable conductor size for a trefoil formation since this will make it possible to do a separation of the cable cores at eventual crossings of existing services. The spacing could also be required at road crossings where the soil temperature increases due to the heating of the asphalt surface.

220kV cable systems often are installed in pre-laid ducts that offer the following benefits:

- The cable trench can be opened, backfilled and reinstated in a continuous flow independent of the cable pulling operation. The civil work savings (challenges to maintain an open trench) will balance out the additional cost to ducts and installation.
- A more easy cable pulling operation can be planned since the number of rollers and risk of collapsing cable trenches can be avoided.
- Additional protection against 3rd party excavator damage is obtained.
- The cable jacket will not be exposed to damage from eventual stones, rocks, etc. not intentionally left in the cable zone during installation (they can penetrate the jacket when soil compression is implemented).

Drawbacks will be reduced load capacity for the cables that could impose a larger conductor size.

Underground cable systems also crosses roads and other services (power cables, communication cables, water pipes, gas-pipes, drains, etc.). The detailed route planning shall identify these and make crossing design aligned and agreed with 3rd party operators. Road crossings can be implemented at open trenches with pipes laid in horizontal position. The pipes to secure mechanical protection and horizontal spacing to allow better load capacity, since the asphalt road surface due to solar radiation very likely will increase the ambient soil temperature. Horizontal spacing is also common practice when other power cables are crossed since the load capacity in both cable systems will suffer from the mutual heating.

When crossing large roads, railways or other facilities making an open trench is not allowed (could also be an environmental sensitive zone), but then HDD can be implemented. Three individual ducts (up to 300-500m length) at a depth 3-6m can be installed. The large burial depth and the missed opportunity to improve the thermal resistivity of the cable zone will often define these HDD crossings as the bottle neck for the cable system. Only spacing or injection of bentonite in the duct after the cable laying will improve the loading capacity. It is mandatory to address this in the detailed route design, but should also be addressed before the cable conductor cross-section is selected. Special design tools based on IEC/ANSI standards are available and 3D finite element analyses can also be offered by engineering companies and cable manufacturers.

The final and detailed layout of the cable trenches cannot be optimised before the cable route is agreed with the private landowners and other stakeholders.

5.10.3 Ampacity optimisation options

When the cable route is finalized there will be several possibilities for doing an optimisation of the onshore cables. A few of them are mentioned below:

- With several parallel circuits the mutual heating between the parallel circuits can be decreased with an enlarging of the distance between the circuits.

- With single cores in flat formation the mutual heating between the cores can be decreased with an enlarging of the distance between the three single cores in the flat formation

- Load capacity derating caused by circulating cable screen currents (approx. 10% of cable losses) can be counteracted by:

    a. <u>Long cable systems > 2km</u>
    Implementing a cross bonding of the screens in at the cable joints. Thus screen currents will be almost eliminated.

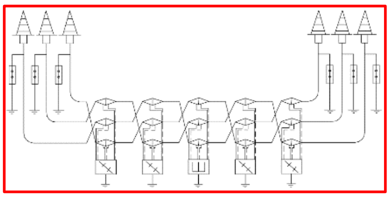


Figure 54 Cross-bonded screen arr.

    b. <u>Short cable systems (less than two cable joints)</u>
    Connect the screen in one end only and disconnect the screen from earth in the other end that will eliminate screen currents. A parallel cu wire shall be designed to ensure a path for earth currents during fault conditions. Figure 56 shows the concept for single point screen earthing arrangement. Ref. /9/.

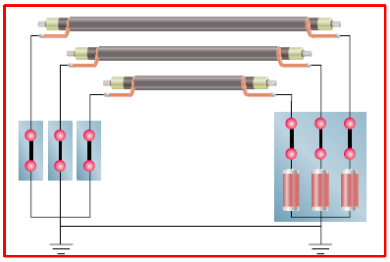


Figure 55 One side screen arr.

- Embedding the cables in an approx. 40x40cm weak-concrete mix with selected stable thermal resistivity in the range of 0.6-1.0Km/W that will surround the 50ºC isotherm and prevent drying out of the sand bed in the cable zone.

5.10.4 Onshore cable accessories

5.10.4.1 Cable joints

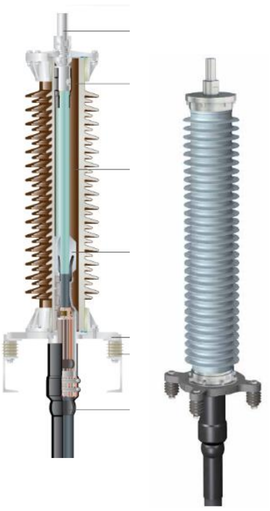
Both the MV and HV cable joints shall be assembled at site in a cable bay prepared in advance of the cable laying operation. These joints will constitute a risk for the cable circuit should a proper and type tested unit not be installed.

Figure 56 Screen Link box

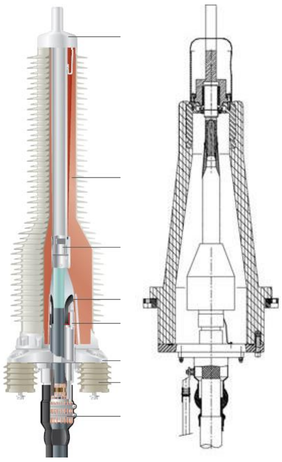
Prefabricated design today is a preferred solution since it offers the benefit of a factory tested elastomer body that will maintain sufficient pressure between the cable and joint section thus ensuring reliable electrical conditions during its lifetime. The cable screens shall be taken out and connected either to earth or separated from earth in a control manager by use of bonding cables connected to a link box. Skilled workmanship and clean working environment should be planned for the site assembly lasting between 3 and 10 days depending of the joint type and voltage level. The jointing bay will have a footprint of approx. 1.0-2.5m width and 5-8m length. A possible arrangement is shown in Figure 57 (overpressure should be maintained in container for HV joints).

Figure 57 Onshore cable jointing container - arrangement

The cable installer may also suggest a tent solution that is lighter.
It is recommended to design a HV cable joint bay with concrete floor for improved working conditions and walls for supporting a container mobilised by the cable installer/supplier. The HV joint assembly process will require power supply for lighting, tools and ventilation. Thus gen-sets should be organised. A stainless steel link box is also shown above. Ref. /9/.



5.10.4.2 Cable terminations



HV onshore cables can be connected to transformers, reactors and GIS by sealing ends as described in the offshore cable section. The connection to outdoor switchyards will be implemented by self-supporting cable terminations on raiser poles/structures and are offered in a variety of different design.

- Oil filed porcelain housing.
- Oil field composite housing.
- Dry type (Silicone).

Porcelain type is well proven technology but having the drawback that should and internal short circuit occur the risk of personal/equipment damage due to the explosion is increased compared with the newer alternatives. All types have been well type tested and demonstrated satisfactory operational performance.
The cable termination often will constitute the interface between a cable- and a substation project that shall be considered carefully.

5.11 STATCOM/SVC

The wind farm project will be required to install compensation equipment to comply with the prevailing grid code both in normal, dynamic and fault conditions both in relation to the regional power grid and the wind farm power system infrastructure. The wind farm power system can be designed not to affect the power grid performance, but also to support the grid during abnormal operational conditions to support grid stability. The grid code compliance can be achieved with a combination of shunt reactors, centralised SVC/STATCOM and features offered by the WTG (Type 4 full converter type).

This section only introduces the basis and concepts. Detailed recommendations will depend on comprehensive power system studies with the grid code demand defined and the characteristics of the grid, the WTGs and the length/voltage level of the cable systems. Further, the requirements and detailed concept of the centralised compensation systems also depend on the conditions negotiated by the wind farm developer under the power purchase agreement.

The centralised compensation systems shall be designed for the task of:

- Improving power quality and plant reliability.
- Increasing network stability and transmission capacity.
- Securing necessary grid compliance when connecting renewable energy.
- Provide damps disturbances and oscillations in critical system configurations.

Typical features include:

- Power factor control.
- Voltage regulation.
- Flicker compensation.
- Harmonic current compensation.
- Active resonance damping.
- Multiple system parallel control.
- High and low voltage ride through.

STATCOM and SVC plants are typically designed for 10-20kV and will require either dedicated step up transformers to deliver at 33, 66 or 220kV. An optimised design could involve that the STACOM/SVC plant is connected to a tertiaries of a 220/33(66) kV transformer since it could save switchgear, cable and space.

A generic brief description is given by STATCOM RXPE provider who have delivered several systems to the Indian TSO's and also is established with local production facilities in India.

SVC	STATCOM
SVCs are part of the Flexible AC Transmission System (FACTS) genre of equipment. They provide variable inductive and capacitive reactive power using a combination of thyristor controlled reactors (TCR), thyristor switched reactors (TSR) and thyristor switched capacitors (TSC). These are connected to the AC network using a compensator transformer or via a transformer tertiary winding. *An SVC can provide a continuously variable reactive power range using TCRs, with coarser reactive control provided by TSRs and TSCs. The reactive power (MVAr) output of the SVC can be configured for direct or automatic voltage control.*	*The SVC / STATCOM is a voltage source converter (VSC) using insulated gate bipolar transistors (IGBTs) or insulated gate commutated thyristors (IGCTs) to achieve reactive power compensation.* *Compared to traditional SVC technology, the SVC / STATCOM offers faster response, stronger flicker restrain capability, lower harmonic content and a wider range of operation. SVCs / STATCOMs also have a more balanced ratio between capacitance and conductance than SVCs, which enhances their constancy. And as well as having a smaller footprint, they have fewer internal components, reducing maintenance requirements.*

Table 14 Comparison of SVC and STATCOM

Several manufacturers (such as ABB, Siemens, COMSYS, General Electric, and RXPE) offer a full product range including detailed engineering and supply as turnkey solutions. STATCOM are most often delivered as a package solution to be integrated with the wind farm substation interconnecting the grid. The interfaces usually civil work, installation and cable work are done by the substation contractor and supply/commissioning of the STATCOM is implemented by the supplier.
The pictures in Figure 58 show some STATCOM plants delivered by RXPE to UK OWF projects implemented by Danish wind farm developer Ørsted.

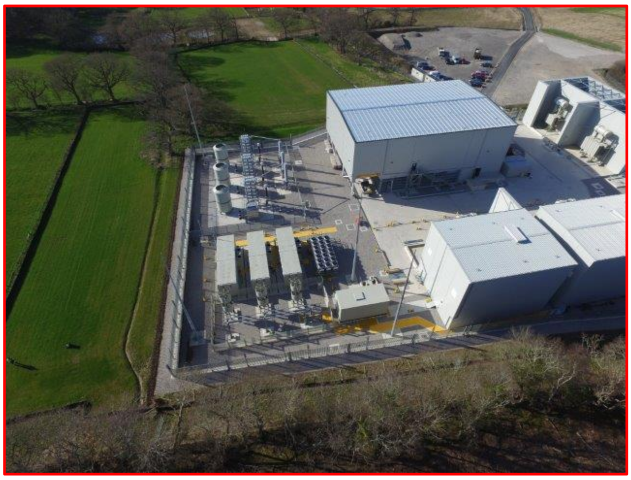
2xSTATCOM +/-50MVar Burbo Bank OWF

2xSTATCOM +/-50MVar Burbo Bank OWF


Figure 58 Examples of STATCOMs

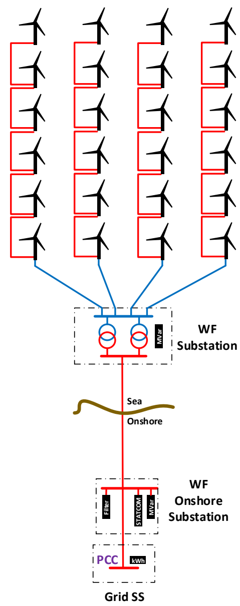
Indicative arrangement layouts and single line diagrams are presented in later sections of this advisory design report.

5.12 Onshore substations

The wind farm shall interface with the grid substation either direct as an extension to the existing grid substation or via an individual substation inter-connected via a HV overhead line or cable circuit. Two possible generic outlines are illustrated in Table 15.

OWF with offshore substation and 220kV export cable circuit

- **MV cable systems** interconnecting the WTGs to the OSS
- **OSS** located offshore where the power transmission is stepped up from 33 (66)kV to 220kV level. The OSS will typical be equipped with MV switch gear, power transformers, 220kV GIS and shunt reactors installed to compensate for the cable system capacitance
- **One 220kV export cable circuit** consisting of an offshore & onshore section
- **Onshore substation**, (situated nearby the PoC) equipped with 220kV switchgear, harmonic filters and STATCOM
- **220kV cable or overhead line,** interconnecting the onshore substation with the PoC



OWF with MV export cable circuits & onshore substation

- **MV cable systems 33(66) kV** interconnecting the WTGs
- **MV cable systems** interconnecting the wind farm with an onshore substation
- **WF ONSS** situated nearby the sea cable landfall equipped with MV switchgear, power transformers, shunt reactors, onshore nearby the land in-take equipped with 220kV switchgear, harmonic filters and STATCOM
- **220kV cable or overhead line,** interconnecting the onshore substation with the PoC

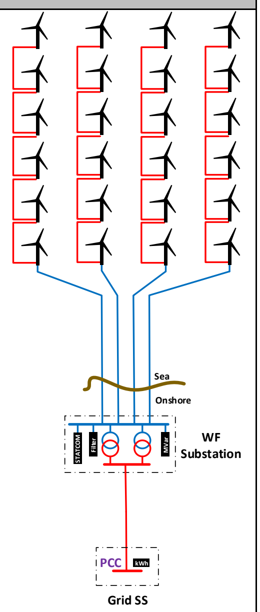


Table 15 - Examples of OWF with- and without OSS

The design of the onshore substation shall fulfil already adopted design standards and practice prevailing in India and must be aligned with the TSO's requirements stated in the grid code and power purchase agreement. Thus, this advisory design do not detail the specifications of the various components but only outline main concepts by indicative single line diagrams and arrangement/layout proposals.

It is anticipated that a suitable detailing of the technical requirements can be drafted by Indian engineering companies when the power system analysis against prevailing grid code is established. The STATCOM suppliers also can offer engineering services that can be very useful in the conceptual phase.

Complete and compacted modular designed GIS are recommended for the indoor 33kV or 66kV switchgear. The cost may be slightly higher, but it is essential that eventual internal faults (that will be fatal for the operation) is contained in the compartment and not cause damages to other compartments. Thus a continued operation with the other parts of the switchgear can take place. The repair also is anticipated only to be necessary on the GIS apparatus and not building structures, cables, panels etc. since the occurrence of a fire will be limited. An example from Siemens is shown in Figure 59 (several other suppliers can provide the same).

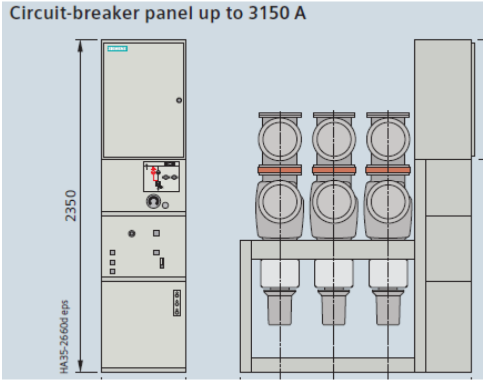


Figure 59 Example of 33kV modular GIS

5.13 Control (SCADA) & communication

Descriptions given in this section are based on best practise obtained during the maturing of offshore wind farm installation and operational requirements. Additional measures for adaptation to regional/national requirements are assumed.

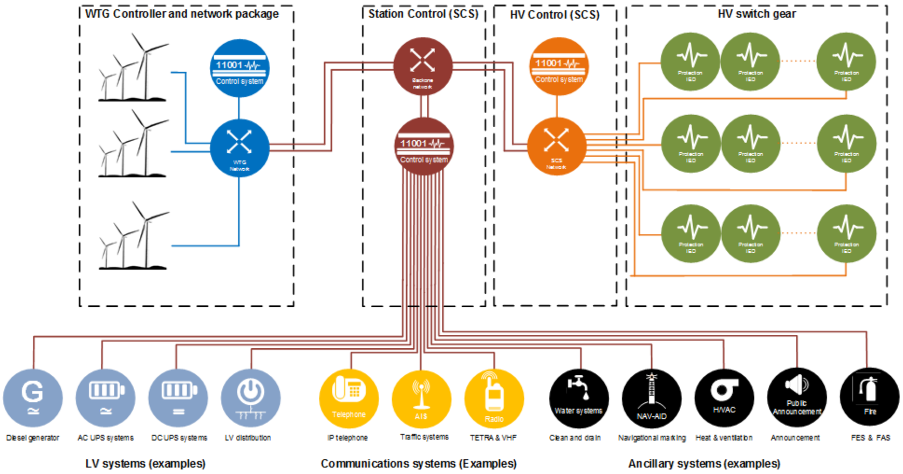


Figure 60 Generic control system principle diagram

5.13.1 Control systems

Several designated control systems are normally expected in a wind farm. This section describes the main plant level systems.

5.13.1.1 Station Control System (SCS)

The main purpose of a SCS is to provide remote monitoring and control of HV and main LV assets in the wind farm. For this reason the system is considered highly critical and should be designed as a redundant system encapsulated in a safe network zone.

It is assumed that ancillary systems are procured and installed as standalone systems with embedded closed loop control. In this way the main purpose of the SCS is to collect data and issue commands in order to control and monitor the asset at plant level. Relevant data must be forwarded to higher level SCADA systems such as a central monitoring centre or relevant stakeholders such as the TSO.

The control system user interface (UI) must as minimum include HV and MV single line diagrams including dynamic states, preferably including first level LV breakers. It should be possible to access the SCS – UI by simultaneous client sessions to facilitate installation of clients both locally and remote. As a guideline 5 clients should be specified

Operation of HV equipment implies a risk of major damage if not handled correctly. Thus, it is imperative that the system supports a log-in hierarchy and audit trail which reflects the authorisations given in regard of operating HV equipment (SAP function).

Station level (upstream) communication interfaces should comply with the protocol requested by the TSO to ensure that the OWF interface towards the TSO is compliant. Best practise in Europe would be a redundant IEC 60870-5-104 protocol or a Microsoft OPC-protocol.

For process level communication with HV assets the general recommendation is to utilize the IEC 61850 protocol in combination with simple hardwired interface or a ModBus for less complex interfaces such as transformers, reactors etc.

The IEC 61850 standard suggests the substation network divided in two parts.

- One domain is the process bus, which consists of the interface between the process equipment such as intelligent protection relays (IED's).

- The second domain is the station bus which comprises the interface to the UI and SCADA.

The standard defines the protocols for communication between the Process Bus and Station Bus as follows:

- MMS (Manufacturing Message Service) Protocol - Reporting services (Alarms/Events) are messages which are vital to the operation of the substation. This message type contains all of the necessary information for supervision of the control and monitoring signals. It is a lower priority messaging and is usually located between the control/protection equipment (IEDs) and supervision systems such as a Data concentrators, local HMIs and SCADA systems.

- GOOSE (Generic Object Oriented Substation Events) is often used to replace the conventional hardwires for intra-relay interlocking, trips, failure breaker and blocking. GOOSE messages communicate horizontally and travel peer to peer between IEC 61850 IEDs or servers. At this level they pass commands and status data amongst protection relays (IEDs) transmitted within a time period of 4 millisecond. GOOSE conveys both binary and analogue data.

The network design requirements should comply with the overall design philosophy of the SCS system and by this redundancy is required.

This is achieved by implementing either a Parallel Redundancy Protocol or a High-availability Seamless Redundancy Protocol (HSR) – standardized as IEC 62439-3 providing network redundancy with no data loss. These high reliability Ethernet protocols guarantees no packet loss for a single point of network failure with no network recovery time.

To assure a fault tolerant and robust network design, the network must be broken down into multiple subnets hereby ensuring that faults cannot migrate on large scale and to simplify trouble shooting.

It is feasible to include monitoring and control of all utility and ancillary systems into the SCS such as LV systems, diesel generators, FES/FAS systems etc. Alternatively a programmable logic controller (PLC) based control system could be considered, having a protocol interface to the SCS system for exchange of relevant signals. The main driver for considering of a secondary control system the procurement sourcing strategy is relevant since contractual interfaces should be avoided.

5.13.1.2 WTG control system

The WTG control system is normally a proprietary control system delivered under the WTG contract as a standard package. The system includes a control module and a SCADA module. The control module would normally be installed close to PoC whereas the SCADA system would be installed where optimal physical accessibility is assured (onshore).

The control module is calculating and distributing park level set points to each WTG and possibly to third-party equipment such as STATCOMs.

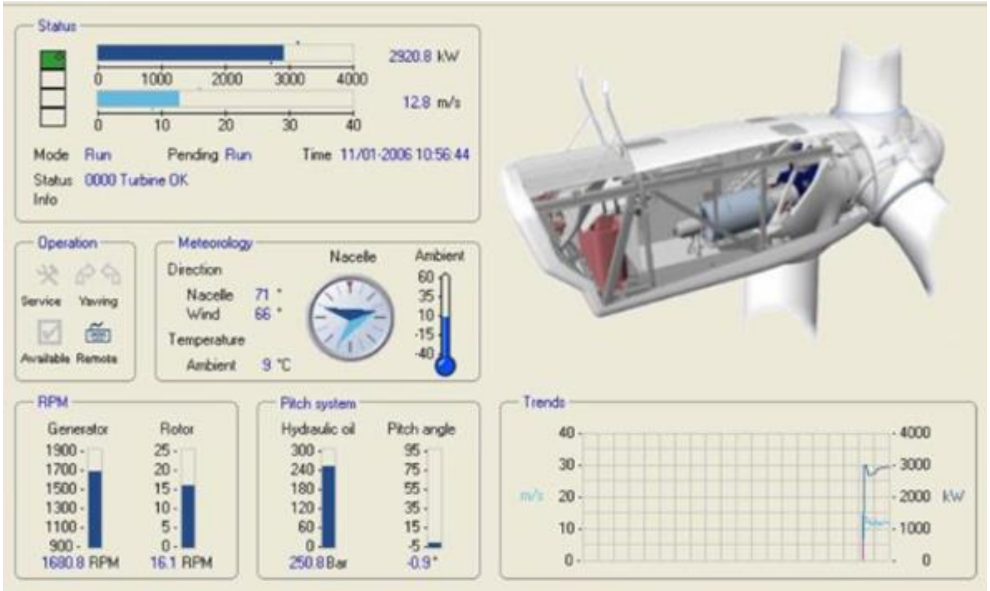


Figure 61 Possible WTG presentation on SCADA console

The control module is managing all control functions relevant for the OWF grid code compliancy.

The WTG SCADA system is the operator's UI for monitoring and control of the WTGs either at park level or at the individual WTG. The application is normally accessible via remote connection.

The SCADA system provides several tools for the owner by accessing various data streams from the WTGs or SCS interfaces.

These data may be available for the operator by being displayed online in a table or as a graphical presentation. The data would normally be accessible by export to an Excel spread sheet for further analysis.

5.13.1.3 VTMS, HSE and planning

An integrated solution for wind farm management is normally not mandatory but is recommended for managing marine traffic, site logistics and HSE.

Depending on complexity a vessel traffic management system (VTMS) may include radar, AIS[2], closed-circuit television (CCTV), VHF radiotelephony to provide navigational safety of marine traffic in a limited geographical area. For this project, a less complex solution is recommended, including only AIS and VHF coverage.

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[2] Automatic Identification System

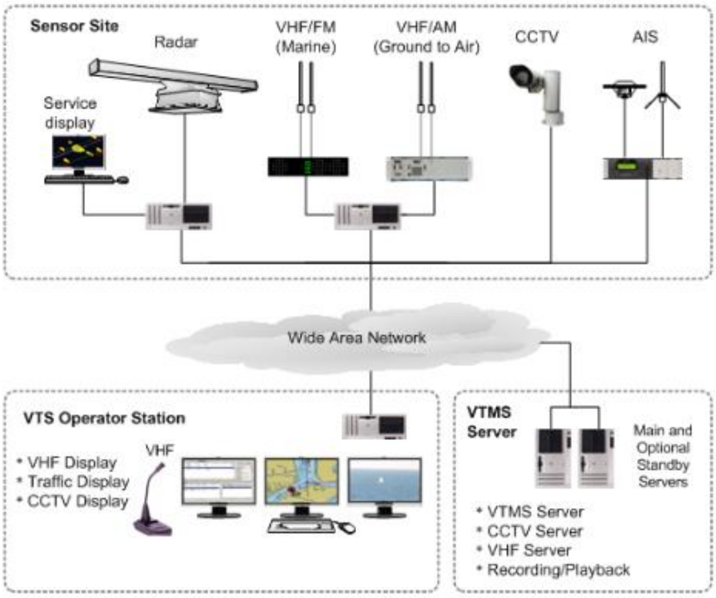

Figure 62 Generic solution setup from VisSim Webpage

The system must as a minimum cover a 10nm range outside the offshore construction site in all directions including the export cable route(s) and the transport route to and from port

The system must automatically detect, plot and track all vessels within the defined working areas and indicate risk of collision, closest point of approach (CPA) and time to closest point of approach (TCPA). This information should be calculated for all or selected targets and on all vessels in a range of minimum 10nm outside the offshore site.

The UI must present the vessel traffic on the background of a vectorised navigational chart of proven quality for real-time tracking, including display of personnel location. VHF conversations must be saved and stored by a voice recorder system.

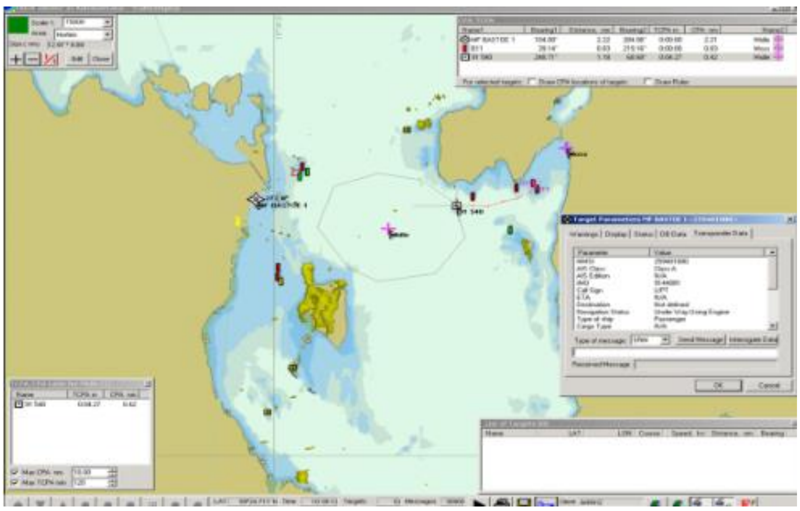

Figure 63 Traffic display from VisSim Webpage

A permit to work system should be included preferably integrated in the VTMS to manage next of kin data, certificates and RAMS for all works on site, primarily during construction but it is highly relevant in the operational phase as well.

The VTMS should allow for planning of crew transfers offshore including on-board crew transfer terminals. This people tracking feature is not to be mistaken for access control but should purely provide people tracking and recording of successful and unsuccessful transfers. Any transfer should be verified against personnel certification already at planning phase.

5.13.2 Communication systems

The wind farm communication systems include both voice based communication systems and data communication infrastructure.

5.13.2.1 IP telephone system

The IP telephone system should connect all IP telephones on site. Depending on contractual setup any telephones to be installed in the WTG are normally delivered under the WTG contract. The telephone system should be specified to require full integration of all WTG telephones.

The telephone system should be considered mandatory for the offshore substation in order to allow simple communication without loading the radio transmitted communication such as TETRA.

In the WTGs the telephone system works as a fall back communication link in case the TETRA system fail or coverage inside the WTG is not assured (especially in the tower).

Each PABX[3] shall be connected to the public switched telephone network via an ISDN line.

5.13.2.2 TETRA system

The TETRA system which is short for Terrestrial Trunked Radio, is a professional mobile radio system with a two way transceiver (duplex) specification.

TETRA was specifically designed for use by government agencies, emergency services (police forces, fire departments, ambulances etc.), and for public safety networks, such as train radio communication, other transport services and for military service.

TETRA uses Time Division Multiple Access (TDMA) with four user channels on one radio carrier and 25kHz spacing between carriers. Both point-to-point and point-to-multipoint transfer can be used.

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[3] Private Automatic Branch Exchange

In addition to voice and dispatch services, the TETRA system supports several types of data communication. Status messages and *short data services* (SDS) are provided over the system's main control channel, while packet-switched data or circuit-switched data communication uses specifically assigned traffic channels.

The TETRA System is used for enabling voice and data communication within the wind farm, sail route and at the O&M/harbour facilities. The TETRA system is used for verbal communication between internal and external technical crews servicing the wind farm.
It is recommended to install the TETRA system in all crew boats and at marine coordinators office onshore.

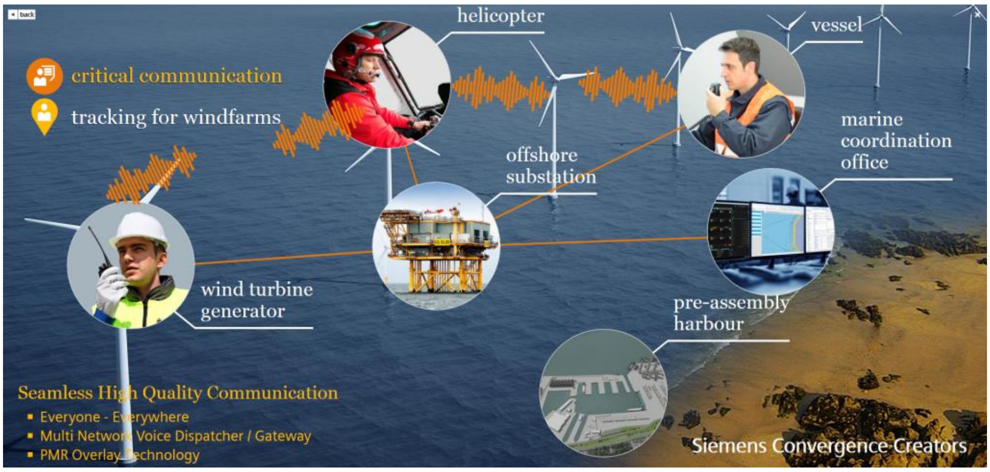

Figure 64 From Siemens Convergence Creators – Webpage

It can be accepted that part of the sail route between the onshore facility and the wind farm is without coverage by TETRA in case specific geographic limitations may apply. In these areas standard marine VHF will prevail.

The TETRA system is considered to be the primary system carrying voice communication for the personnel working on site (offshore), by this the WTG coverage must include the entire tower and the entire nacelle area.
This requirement is underlined if the WTG tower is defined as a muster place in case of emergencies.

It is recommended to include TETRA repeaters in the scope to be installed in each WTG. The actual configuration of the repeaters may differ with the selected WTG type and manufacturer

As a base case scenario approx. 50 mobile radios and approx. 10 fixed radios should be considered. This will in most cases cover the need for a standard site in the operation phase. Additional units may be required during installation and commissioning. The radios are designed for optimum reliability in harsh environment. The casing must be robust and lightweight and allow for superior audio quality.

It should be observed that the approval process for the frequency application process may be additionally complex by having Pipavav port in the vicinity.

5.13.2.3 VHF systems

It is recommended to include a redundant VHF radio infrastructure as the primary communication between vessels and marine coordination. Depending on geographical limitations it is assumed that an onshore based infrastructure should be able to provide full coverage. An initial coverage analysis/calculation will reveal this.

The VHF coverage should as minimum cover the complete offshore site with a further addition of minimum 10nm. This will provide a response time of ~30min before a potential collision.

Marine radio equipment is normally expected to be installed in all ships, commercial as well as leisure. It is used for ship to ship communications as well as communication to coastal stations in regard of rescue services and communicating
with harbours, locks, bridges and marinas.

A marine VHF set is a combined transmitter and receiver and operates on standard, international frequencies known as channels. Channel 16 (156.8 MHz) is the international calling and distress channel.

Modern-day marine VHF radios offer not only basic transmit and receive capabilities. Permanently mounted marine VHF radios on seagoing vessels are required to have certification of some level of "Digital Selective Calling" (DSC) capability, to allow a distress signal to be sent with a single button press.

In order to operate a VHF radio a VHF certificate is required.

The VHF System is used for enabling voice communication between Marine Coordinators and the ships working within the wind farm including sail routes. The VHF systems are also first line of communication if any vessel is approaching the site on a collision course.

The VHF base stations should be designed to listen on minimum 2 channels.

It should be observed that applying for private channels may be additionally complex by having Pipavav port in the vicinity.

5.13.2.4 AIS

AIS is an identification system making it possible to exchange ship-to-ship information by electronically exchanging data with other nearby ships, AIS base stations, and satellites. When satellites are used to detect AIS signatures then the term Satellite-AIS (S-AIS) is used.

The AIS should be installed to broadcast information on position and type of the offshore substation for offshore vessel traffic. Based on best practises for offshore structures, the use of Class B transponders is recommended.

AIS AtoN (Aid to Navigation) is designed to be installed on navigational hazards, offshore wind farms, oil and gas platforms/pipelines etc. The AtoN system supplement other fixed or floating aids to navigation such as buoys and markers, enhancing their operation by alerting any AIS equipped vessels that are within range.

AIS AtoN stations will broadcast their presence, identity (9-digit Marine Mobile Service Identity (MMSI) number), position, and status at least every three minutes or as needed. Local notices to mariners will announce the exact content, location, and times of these broadcasts.

Unless specified by local authorities, AIS AtoN is normally not included in the supply scope.

5.13.2.5 Backbone IT network

An IT backbone network should be included as a part of the BoP scope.

This network is to be considered as an internal network or LAN, managing all internal dataflow in the wind farm.

The network should be designed based on the principles given in the Open Systems Interconnection model (OSI model). This model is a conceptual model to standardize the communication functions of selected levels to assure interoperability of diverse communication systems. The original version of the model defines seven layers.

The model is a product of the Open Systems Interconnection project at the International Organization for Standardization (ISO).

The IT network exists on a physical layer as well as a logical layer. The latter should be designed according to the guidelines given at corporate level normally given by the Employers IT department. These guidelines should describe ICS guidelines and other relevant information to make sure remote connections for monitoring, control and diagnostic is possible.

The IT network is to be terminated to the Internet or WAN by a connection allowing sufficient bandwidth, redundancy and support from the public network operator. Typically a MPLS[4] connection is preferred.

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[4] Multiple Protocol Label Switching

To assure a fault tolerant and robust network design, the network must be broken down into multiple subnets whereby ensuring minimum recovery time for the spanning tree protocol and prevent faults to migrate on a larger scale. Smaller subnets domains will simplify trouble shooting as well.

In most cases the IT network for the WTG communication is included in the WTG contract.

At the physical level all IT equipment such as routers, switches, wireless controllers, etc. must be built into ventilated enclosures based on 19" frames. At least two panels should be considered for installation in separate rooms in order to ensure redundancy.

The network cabling should be done using stranded cables which are more flexible and thus suitable for pulling in a complex and narrow environment on the substation. The category of the cables should be decided based on cost and expected technical level of the workmanship on the construction site.

5.13.2.6 Optical fibre network

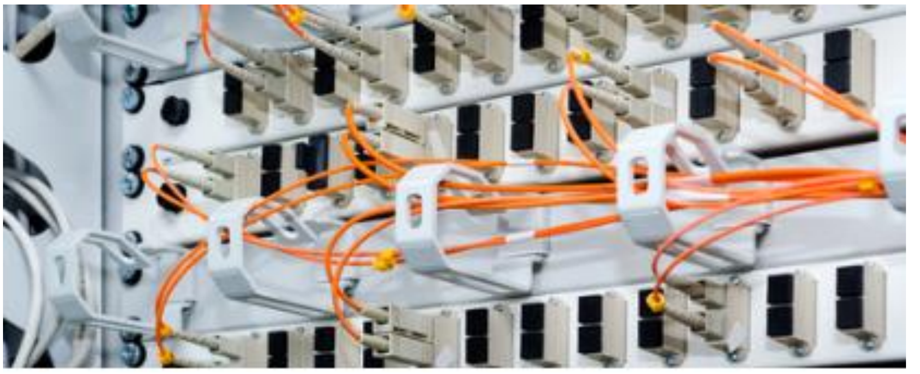
For all subsea cables pulled into either the WTGs or the substation, various number of Single mode optical fibre cores must be embedded. These are used to form a highly available and reliable communication network route from the WTGs to the offshore or onshore substation via the export cable(s).

To allow required flexibility in interconnecting fibre optical cores, all fibre optical cores shall be terminated in a 19" Optical Distribution Frame (ODF). (In the WTG foundations another solution than 19" may apply).

As reference, array cables include 24 fibre optical cores per cable. The optical fibre cores shall be terminated with Square Connector Ultra-Polished Connection (SC/UPC) fibre optical pigtails. All connectors shall be connected to duplex bulkhead adapters and carefully installed in the fibre trays of the patch panel.

For overall connection configuration a splice plan must be delivered, showing both fusion splices and patch connections. The splice plan is normally expected to be delivered by the cable installation contractor.

Splicing works shall be made in accordance with ITU-T L.12 (03/2008) recommendations for optical fibre fusion splice works. Maximum measured insertion loss for individual fusion spliced pigtails shall be < 0.3dB.



The installation of the fibre optical network is normally divided between the cable termination contractors (array and export cable) and the substation contractors (onshore and offshore). As a denominator the following guidelines should apply.

All splices shall be mounted in splice cassettes. Capacity for splice cassette shall be for minimum 48 fibre optical cores.

Fibre optical works shall be verified and documented in form of quality inspection and photo documentation of performed works. Documentation shall be provided to the Employer when fibre optical splice work and termination have been completed for each individual location.

OTDR (Optical Time-Domain Reflection) tests shall be performed to verify the quality and consistency in fibre optical splice termination works and patch lead installation.

The patch panel cabinet shall be provided with embedded key lock to prevent unauthorized access. The IP classification shall be according to specified environmental requirements in which the patch panel shall be installed.

5.13.2.7 Line of sight - LOS (micro-link)

A line of sight data link are normally considered as a fall back solution to the export cable optical fibre infrastructure. By this, LOS systems are relevant for projects having only one export cable.

For this project a line of sight solution should be considered as an option which is only relevant if an offshore substation is installed.

LOS technology is limited by distance due to the curve of the earth, however a sufficient bandwidth of 100+ Mbps for a distance of ~50km is expected. However this estimation relies on site specific data primarily installation height of the antennas. Another consideration is the CAPEX and especially the OPEX cost for installation the onshore installation point.

When assessing the cost of the LOS system, the project schedule should be taken into consideration as well. Depending on the planned milestone for termination of the export cable fibres, a LOS may present a good business case for earlier start of commissioning activities by being able to communicate with the offshore substation systems prior to export cable optical fibre termination.

Since the LOS system is installed offshore it should be considered that when there are no waves, the sea works like a mirror to reflect the radio beam and reflection may affect the transmission. By this, it shall be considered to use a combination of space diversity and/or frequency diversity, which are supported by leading manufacturers.

It should be observed that the approval process for the frequency application process may be additionally complex by having Pipavav port in the vicinity.

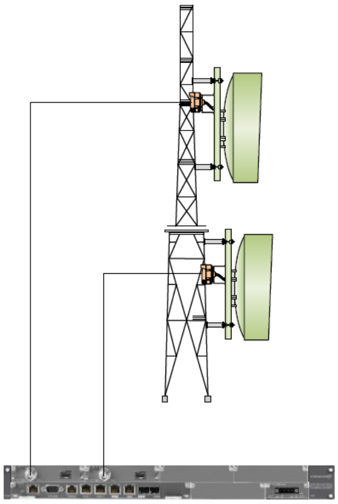


Figure 65 LOS concept with antenna

6 Conceptual design options

The number and size of offshore wind farms on a worldwide basis is increasing rapidly and the development of technologies and solutions aiming at reducing energy cost have improved significantly during the last decade. This establish a sound basis and possibilities to design the overall concepts for the electrical power distribution systems. This advisory design focuses on some solutions found appropriate with highest relevance for the first Offshore Windfarm Project in India. The advisor design does not address all possible solutions that might have relevance and only includes temporarily technical data on parts of the components. The layout of the power system infrastructure will depend on the selected WTG type (size & voltage level) and of the layout of the wind farm.

This report addresses solutions already existing on the European offshore wind farm market. It is assumed that the offshore wind farm will be connected to the onshore grid at 220kV level and considered as one 200MW power plant unit.

Concepts investigated comprise:

- 33- and 66kV cable system interconnecting the individual wind turbines.
- A collection substation for the windfarm “WF substation” that step up the medium voltage to the transmission voltage 220kV (can be located offshore or onshore).
- Export cable system(s) connecting the OWF with onshore substation.
- HV cable/overhead line to the PoC.
- Reinforcement of the PoC.

This advisory design does not address reinforcements necessary in the existing power grid. The following options for the power system infrastructure concepts have been investigated:

1. Power infrastructure option 1
   3MW WTGs, 33kV array cables, 33kV export cables connected to a collection substation onshore.

2. Power infrastructure option 2
   3MW WTGs, 33kV array cables connected to a collection substation

located offshore, 220kV export cable connected to an onshore substation.

3. Power infrastructure option 3
   6MW WTGs, 66kV array cables, 66kV export cables connected to collection substation located onshore.

4. Power infrastructure option 4
   6MW WTGs, 66kV array cables connected to a collection substation offshore, 220kV export cable connected to an onshore substation (cost comparison only).

The two first options have proved their sustainability from operation during the last 10 years. The other solutions with 66kV array cable systems still need more operational experience to proof equal performance in respect to availability and reliability. The ongoing tendency with increasing WTG size will soon result in future 6-10MW WTGs that all are prepared for 66kV distribution level as standard solution.

Already today, WTGs with 66kV equipment are offered by some suppliers, and the installation of first commercial OWF with 66kV technology projects in Europe have commenced.

7 Recommended Design Options

7.1 Option 1: 3MW WTGs – 33kV cables to shore

This concept offers a solution with an onshore substation but no offshore substation. A number of 33kV submarine export cables from each radial/string are connected via transition cable joints at landfall, and 33kV land cables are then routed to the new ONSS. On the ONSS the power is then stepped up 33kV to 220kV, and following this transferred via a 220kV land cable to the existing TSO Grid SS.

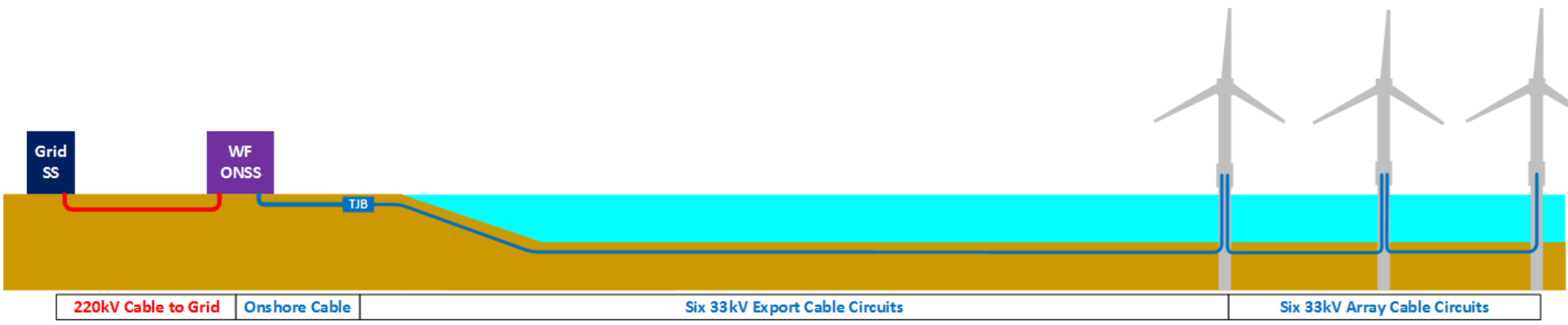


Figure 66 Power System Components - High Level Option 1

The analysis indicates that the most optimal technical solution comprises six 33kV export cables. This allows even distribution of loads in the cables, and an equal load on the two 33/220kV ONSS transformers.

This option will consist of:

- 66 WTGs 3MW in 6 strings each consisting of 11 WTGs
- Each of the six strings will consist of ten 33kV array cables each approx. 500m, i.e. a total of 60 array cables with a total length of approx. 30km.
- Six 33kV submarine export cables of either approx. 25- or 31km, with a total length of approx. 168km.
- A transition joint bay (TJB) at landfall with six 33kV cable joints, including provisions for fibre optic cables.

- Six parallel 33kV underground export cables of approx. 0.5km, with a total length of approx. 3km.

- One new ONSS consisting of 33kV and 220kV switchgear, two 33/220kV power transformers, reactors, STATCOM, harmonic filters and aux. systems. The ONSS will also include the windfarm SCADA system, necessary buildings, structures, roads etc. The 220kV switchgear will be outdoor, and the 33kV switchgear will be indoor.

- One 220kV underground export cable of approx. 2.5km between the new ONSS and the existing TSO Grid SS

- One new 220kV bay in existing TSO Grid SS including kWh metering. This work will be carried out by the TSO.

A proposed layout of the new 33/220kV ONSS are shown in Appendix A.

7.2 Option 2: 3MW WTGs - OSS with 220kV export cable

Similar to Option 1, the concept in Option 2 includes 66 3MW WTGs and 33kV inter array cables. In this option, however, the 33kV array cables are connected to an offshore sub-station (OSS) which transforms the 33kV up to 220kV. One 220kV submarine export cable from the OSS is connected via a cable joint at landfall and a 220kV land cable to the new ONSS. From the ONSS the power is exported via a 220kV land cable to the existing TSO Grid SS.

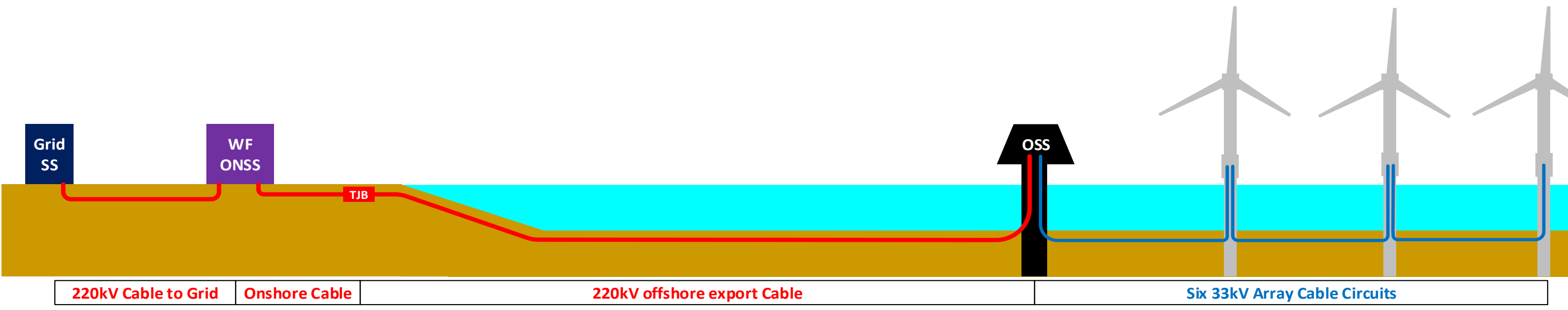


Figure 67 Power System Components - High Level Option 2

The analysis indicates that the most optimal technical solution is six 33kV strings each containing 11 WTGs. Each string is connected to the OSS.

This concept will consist of:

- 66 WTGs 3MW in 6 strings each consisting of 11 WTGs

- Each of the six strings will consist of ten 33kV array cables each approx. 500m, i.e. a total of 60 array cables with a total length of approx. 30km. The 6 array cables between the last WTG in a string and the OSS may be up to 4km long, i.e. the total length of array cables are approx. 45km.
- One OSS containing 2 power transformers (33/220kV), 220kV GIS and 33kV GIS switchgear including SCADA and all low voltage auxiliary systems. The OSS includes mechanical systems, as well as utility systems including aviation, navigation and communication systems. The OSS is equipped with boat landings and helicopter platform.
- One 220kV submarine export cable with a total length of approx. 30km.
- A transition joint bay (TJB) at landfall with one 220kV cable joint, including provisions for fibre optic cables.
- One 220kV underground export cable with a length of approx. 0,5km.
- One new ONSS consisting of 220kV switchgear, shunt reactors, STATCOM, harmonic filters and aux. systems. The ONSS will also include the windfarm SCADA system, necessary buildings, structures, roads etc. The 220kV switchgear will be outdoor.
- One 220kV underground export cable of approx. 2.5km between the new ONSS and the existing TSO Grid SS
- One new 220kV bay in the existing TSO Grid SS including kWh metering. This work will be carried out by the TSO.

7.3 Option 3: 6MW WTGs – 66kV cables to shore

The Option 3 concept is based on the same overall concept as Option 1, with the change that the WTGs are the larger 6MW, and the array cable system has a operational voltage level of 66kV.

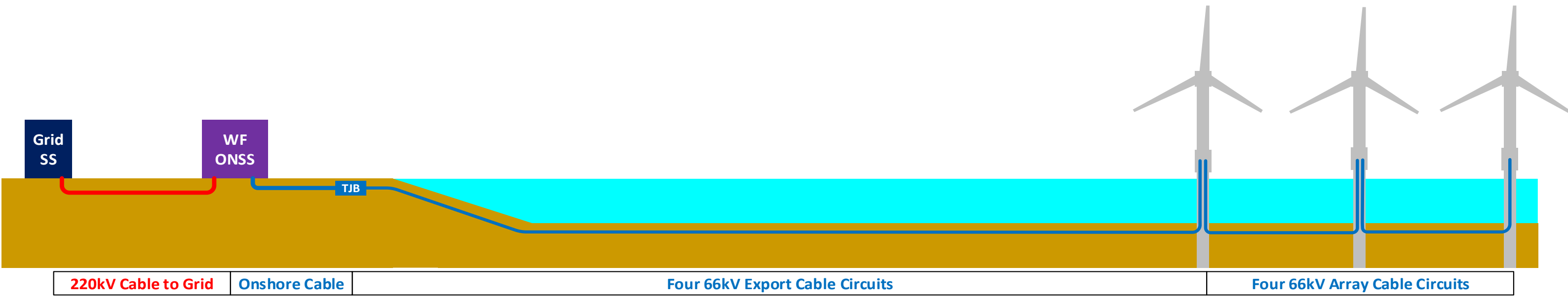


Figure 68 Power System Components - High Level Option 3

The concept offers a solution with an ONSS close to the landfall, but with no OSS. A number of 66kV submarine export cables from each radial/string are connected via cable joints at landfall, and 66kV buried land cables, to the new ONSS, and from here via a 220kV land cable to the existing TSO Grid SS.

The analysis in Appendix C indicates that the most optimal technical solution with 33 pcs. 6MW WTG's in 3 rows, and in 4 strings with 4 pcs. 66kV export cables to the ONSS. This even number of 66kV export cables also allows more even distribution of loads in the cables, and an equal load on the two 66/220kV ONSS transformers.

This concept will consist of:

- 33 pcs. 6MW 66kV WTG's in four array cable strings
- Each of the four strings consist of 7- 8 pcs. 66kV array cables each positioned with ≈1000m distance, i.e. a total of approx. 28 pcs. array cables with a total length of approx. 28km.
- 4 pcs. 66kV submarine export cables of either approx. 25-, 29- or 31km, with a total length of approx. 110km.
- A transition joint bay (TJB) at landfall with four 66kV cable joints, including provisions for fibre optic cables.
- Four parallel 66kV underground export cables each length approx. 0,5km, with a total length of approx. 4km.
- One new ONSS consisting of 66- and 220kV switchgear, two 66/220kV power transformers, reactors, STATCOM, harmonic filters and aux. systems. The ONSS will also include the windfarm SCADA system, necessary buildings, structures, roads etc. The 220kV switchgear will be outdoor, and the 66kV switchgear will be indoor.
- One 220kV underground export cable of approx. 2,5km between new ONSS and existing TSO Grid SS
- One new 220kV bay in existing TSO Grid SS including kWh metering. This work will be carried out by the TSO.

A proposed layout of the new 66/220kV ONSS are shown in Appendix C.

8 Indicative comparison

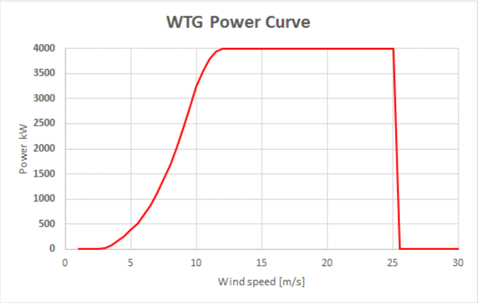
8.1 Capitalisation of energy losses

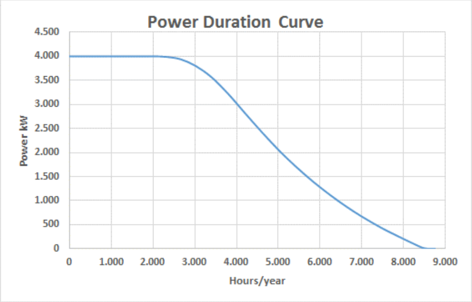
The energy losses will reduce the sale of annual energy from the entire wind farm thus having a negative impact on the revenue over its operational lifetime.

The cable system power losses are significant and varies between the different options investigated and must be considered together with the investment cost for the power infrastructure systems.

The cable conductor power losses are proportional with the quadrant of the load current. The relationship between the yearly power duration curve and the yearly energy losses can be estimated from a normalised power duration curve that is estimated as per below:

An approximate WTG power curve for a 4MW[5] unit is used with the assumed wind distribution – (Weibull parameters A= 10.48 // k=2.45 // Mean wind speed=9.3 m/s) to calculate the power duration curve over a year (8760h).





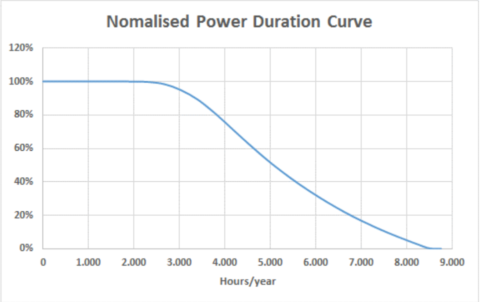


Figure 69 – Sample WTG Power, Power Duration and Normalised Power Duration Curves.

[5] 4MW unit was selected as a representative size for the 3MW and 6MW units considered for this advisory design. The normalised power duration curve calculated will not differ significantly if the WTG size is changed.

1kW power loss (at max. production) equals 3,387 kWh/year (integrating quadrant of the normalised power duration curve over the full year).

With an assumed energy sales price 0.06 EUR/kWh the yearly energy loss cost equals 3,387kWh/year x 0.06 EUR/kWh → 205 EUR/year.

An assumed discount rate: 8% p.a. and operational lifetime of 25 years give a capitalisation factor 10.7***.***

Consequently, the capitalised energy loss cost for 1kW equals
10.7x205EUR/y = 2.190Eur/25y

The capitalised energy losses can then easily be calculated as
P_{max_loss} x 2.190EUR

The above is not an accurate calculation, but is considered having sufficient accuracy to compare the power losses cost impact and is used in the following overall cost comparison of the options.

Table 16 summaries the power losses at maximum production and the resulting power delivered by the OWF to the PoC at the Grid SS. The power losses in the electrical distribution system is estimated to vary within the range of 3.9-11.6MW (2.0-5.9%).

The power delivered at the PoC varies in between 186-94MW.

Capitalised energy losses range in between 8.6-25.4 [EURur x 10^6]

	Option 1			Option 2 "OSS"		Option 3				Option 4 "OSS"
	Base Case	Alt. 1	Alt. 2	Base Case	Alt. 1	Base Case	Alt. 1	Alt. 2	Alt. 3	Base Case
	66x3MW 6x33kV Ex.Cab 6x Array Cab	66x3MW 5x33kV Ex.Cab 5x Array Cab	66x3MW 4x33kV Ex.Cab 4x Array Cab	66x3MW 230kV Ex.Cab 6x Array Cab	66x3MW 230kV Ex.Cab 4x Array Cab	33x6MW 4x66kV Ex.Cab 4x Array Cab	33x6MW 3x66kV Ex.Cab 3x Array Cab	33x6MW 3x66kV Ex.Cab 3x Array Cab	33x6MW 2x66kV Ex.Cab. 2x Array Cab	33x6MW 230kV Ex.Cab 4x Array Cab
	3MW-6xA	**3MW-5xA**	**3MW-4xA**	**3MW-OSS-6xA**	**3MW-OSS-5xA**	**6MW-4xA**	**6MW-3xA**	**6MW-3xA -ST**	**6MW-2xA**	**6MW-OSS-4xA**
Installed Power [MW]	198,0	198,0	198,0	198,0	198,0	198,0	198,0	198,0	198,0	198,0
Power Losses [MW]	11,6 5,9%	9,8 5,0%	10,7 5,4%	5,2 2,6%	4,8 2,4%	8,4 4,2%	7,6 3,8%	8,7 4,4%	6,2 3,1%	3,9 2,0%
Power at PoC [MW]	**186,4**	**188,2**	**187,3**	**192,8**	**193,2**	**189,6**	**190,4**	**189,3**	**191,8**	**194,1**
Energy Loss Capitalisation	25,4	21,5	23,4	11,4	10,5	18,4	16,6	19,0	13,6	8,6

Table 16 Power loss comparison

8.2 CAPEX & energy losses

Indicative investment costs based on European practice are calculated solely for comparison purposes for each of the options and optimisation alternatives addressed in this advisory design study. The cost estimates include supply and installation of components as per below (incl. 5% allocated to design, project management and supervision etc.)

- WTG components.
  - WTG Switchgear, WTG Power Transformer.
  - T-connector.
  - Cable protection system.

  - Hang-offs.
  - FOC splice and earthing boxes.

- MV cables, offshore.
  - Supply, transport, laying, burial, post-lay survey pulling operations to WTGs and on OSS.

- MV cables, onshore.
  - Cable trench excavation, backfilling, reinstatement, supply and installation of cable and cable joint.

- HV cable, offshore.
  - Supply, transport, laying, burial, post lay survey.

- HV cable onshore.
  - Cable trench excavation, backfilling, reinstatement, supply and installation of cable and cable joints.

- Offshore Substation.
  - Fabrication, transport and installation of topside and jacket structure, HV/MV/LV power systems, SCADA, utility/auxiliary systems/mechanical systems.

- Onshore Substation(s).
  - HV/MV transformers, reactors, HV/MV switchgear, SCADA, LV & UPS power systems, substation building, civil work and access roads.

Not included is geotechnical surveys, ROW/compensation cost/land lease agreements, WTGs, foundations, offshore crossing of other services, harmonic filter systems, STATCOM systems etc. Consequently, the cost indication below cannot be interpreted as all-inclusive budget cost estimates for the power system infrastructure.

	Option 1			Option 2 "OSS"		Option 3				Option 4 "OSS"
	Base Case	Alt. 1	Alt. 2	Base Case	Alt. 1	Base Case	Alt. 1	Alt. 2	Alt. 3	Base Case
	66x3MW 6x33kV Ex.Cab 6x Array Cab	66x3MW 5x33kV Ex.Cab 5x Array Cab	66x3MW 4x33kV Ex.Cab 4x Array Cab	66x3MW 230kV Ex.Cab 6x Array Cab	66x3MW 230kV Ex.Cab 4x Array Cab	33x6MW 4x66kV Ex.Cab 4x Array Cab	33x6MW 3x66kV Ex.Cab 3x Array Cab	33x6MW 3x66kV Ex.Cab 3x Array Cab	33x6MW 2x66kV Ex.Cab. 2x Array Cab	33x6MW 230kV Ex.Cab 4x Array Cab
	3MW-6xA	3MW-5xA	3MW-4xA	3MW-OSS-6xA	3MW-OSS-4xA	6MW-4xA	6MW-3xA	6MW-3xA -ST	6MW-2xA	6MW-OSS-4xA
WTG Components	11,7	11,7	11,7	11,7	11,7	10,8	10,8	10,8	10,8	10,8
MV Cables, Offshore	132,4	124,4	117,8	38,6	38,4	90,0	78,2	69,2	62,1	25,8
MV Cables, Onshore	0,9	0,8	0,8	0,0	0,0	0,5	0,4	0,3	0,4	0,0
HV Cable, Offshore	0,0	0,0	0,0	29,7	29,7	0,0	0,0	0,0	0,0	29,7
HV cable Onshore	1,1	1,1	1,1	1,6	1,6	2,9	2,9	2,9	2,9	2,3
Offshore Substation *)	0,0	0,0	0,0	61,6	61,4	0,0	0,0	0,0	0,0	62,1
Onshore Substation	7,1	7,0	7,0	2,5	2,5	7,8	7,7	6,8	7,1	2,5
Energy Loss Capitalisation	25,4	21,5	23,4	11,4	10,5	18,4	16,6	19,0	13,6	8,6
Total [Eur x10^6]	**179**	**167**	**162**	**157**	**156**	**131**	**117**	**109**	**97**	**142**
							"Not Straight"	"Straight Radial"		

*) Incl. all Electrical & Mechanical Plant

Table 17 CAPEX & Capitalised Energy Loss Comparison

The cost estimate summerised into CAPEX and capatilised energy losses is ilustrated in Figure 70.

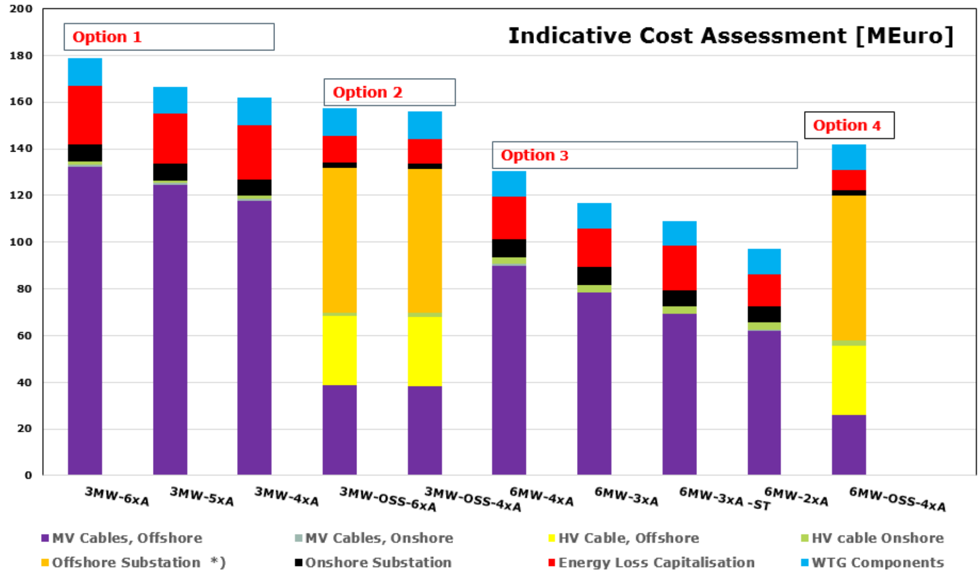


Figure 70   CAPEX & Capitalised Energy Loss Comparison – Break down

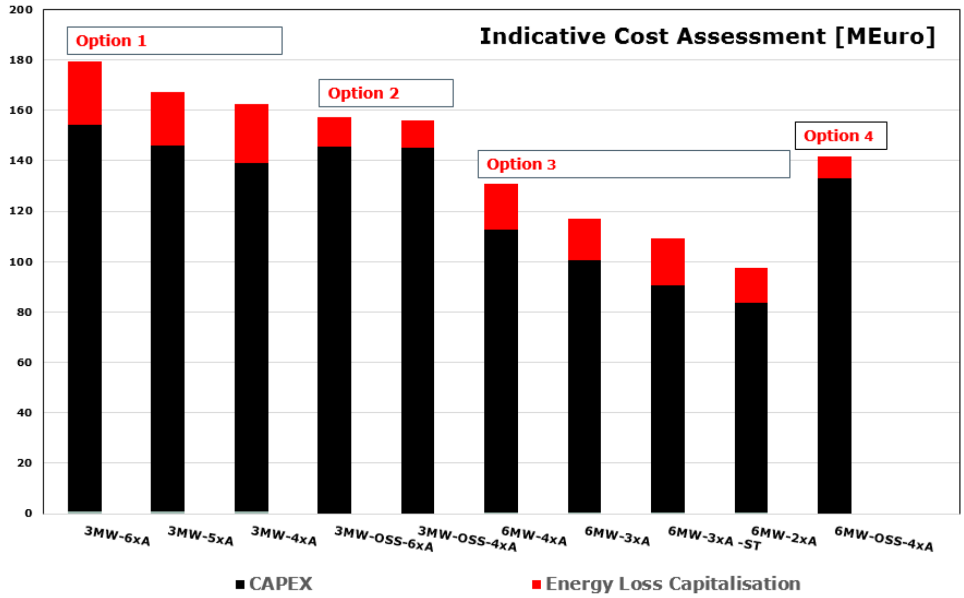


Figure 71   CAPEX & Capitalised Energy Loss Comparison - Aggregated

It is noticed that:

- 3MW WTGs.
  The capitalised energy losses are approx. two times larger if 33kV export cables are designed compared with one 220kV export cable circuit.

  The CAPEX for an optimised 33kV export cable solution (with four cables) is lower (≈95%) than the 220kV export cable option.

CAPEX + capatilised energy losses is lowest for the 220kV export cable option in all senarios analysed.

- 6MW WTGs.
  The capitalised energy losses are approx. two times larger if 66kV export cables are designed compared with one 220kV export cable circuit.

  The CAPEX for an optimised all 66V export cable options is lower than the 220kV export cable option.

  CAPEX + capatilised energy losses is lowest for the all 66kV export cable options in all senarios analysed compared with the 220kV export cable option.

The most significant findings are listed below:

- **3MW WTG Units**
  33kV operational voltage level for the WTGs is assumed.

  - 33kV export cables
    Decreasing the number of export cables using larger conductor sizes will decrease CAPEX (153 → 138 Eur x 10^6).

  - OSS with one 220kV export cable
    No significant cost saving is achived by reducing the number of array radials.

  - OSS vs. 33kV export cable
    The option with four 33kV export cable has same cost level as the option with OSS and one 220kV export cable. *(This is naturally very sensitive to the OSS cost estimate).*

- **6MW WTG Units**

  - 66kV Export cables
    Decreasing the number of export cables using larger conductor sizes will decrease CAPEX (112 → 82 Eur x 10^6).

  - OSS with one 220kV export cable
    No significant cost saving is achived by reducing the number of array radials.

- **33kV vs 66kV**
  The investment cost to MV cable system is decreased significantly (to ≈60%) when the operational voltage is raised from 33kV to 66kV.

8.3 Reliability

The options with 33kV or 66kV export cables from the shore to the first WTGs in the respective radial are in general considered to offer higher reliability than the options with OSS and one single 220kV export cable system.

The single 220kV cable circuit is a critical bottleneck for the entire OWF. It shall also be mentioned that replacement of (if ever) faulty 220kV components at the OSS will be more time critical than onshore. A long "+1 month" and weather dependent replacement operation can be expected in addition to the manufacturing of the component if purchased by the developer to his spare storage). Consequently, redundancy at the 220kV and 66/33kV busbars and for the LV main switchboards via the station auxiliary transformers is recommended.

Emergency generator will be required at the OSS for durations with the 220kV export cable disconnected. No emergency generator is required with 33kV or 66kV export cables since back-up supply from the grid can be designed via the regional distribution system.

8.4 General recommendations

Some very general recommendations can be given for a 200MW OWF located around 25km from the shoreline.

- A design (Option 2) utilising an OSS & one 220kV export cable is recommended as the most viable option if 3MW WTG units with 33kV operational voltage level are selected.
  (The CAPEX & capitalized energy losses are lower compared with the Option 1 solution comprising 4 large 33kV export cables to the WF ONSS. The large 33kV cable size might approach the limit of possible technical sound solutions – and will heavily depend on the landfall design in respect to HDD).

- A design (Option 3) with four 66kV export cable systems is recommended as the most viable option if 6MW WTG units with 66kV operational voltage level are selected.
  (The CAPEX & capitalized energy are lowest for all options analysed. Solutions exists already on the marked – the option with only two 66kV export cable might approach the limit of a possible sound technical solution).

It shall be mentioned that:

- The above recommendations do not apply for OWF with larger installed capacity or if the distance from shore is increased.

- The site layout also is an important factor (since the three rows and orientation assumed for this advisory design imposes larger cable sizes). A size layout with 4-5 rows could result in smaller 33 & 66kV export cables and perhaps even make the design with 33/220kV OSS less attractive compared with 4-6 33-66kV export cables.

- More accurate cost estimates on the OSS could trip the CAPEX for option 1 & 2 thus making option 1 most viable solution.

- An OSS with only one 220/66(34) kV power transformer can impose significant cost savings on HV/MV components and the OSS steel structure since a far less complex topside can be designed.

  The drawback will be that no redundancy exists at the OSS. Consequently, the OWF availability and the revenue will be smaller over the operational life time. Grid connection is lost during planned maintenance and if faults occur in the main transformers and other HV/MV components.

  Such decision can be taken when the business case is developed and CAPEX, OPEX and revenue cash flow for various concepts are investigated

9 Supplier & Contractor Survey

The OWF developer is recommended to develop a robust sourcing strategy in the premature stage of the project prior to his application and bid. The sourcing strategy should comprise:

- Geotechnical campaigns
- Power system study/Engineering
- Supply & installation of WTG
- Supply & installation of WTG foundations
- Supply of OSS
- Transport and installation of OSS
- Transport of WTG foundations and topsides
- Supply & installation of Sea cables. N.B. Two separate contracts are recommended: export and array cable systems, and possibly a further spilt into supply & installation
- SCADA & Communication System
- Operation & Maintenance Facilities

The developer is also required to set-up the offshore logistics in respect to Marine Coordination, operational harbour for storage/lout out of WTG foundations & offshore array cables, operational port for CTV transfer required during the construction and used by the OWF O&M organisation.

This section presents a survey on power system infrastructure components as the HV/MV sea cables and the OSS only.

All other project components related manufacture and installation of the HV & MV systems within the ONSS & OSS, onshore cable systems, SCADA and communication systems already is well known and understood by Indian EPCI contractors. Thus no survey have been implemented for these power system infrastructure components.

9.1 MV/HV Cable Suppliers

India today have several experienced suppliers of medium & high voltage cables for onshore applications. The manufacture plans are locally placed and operated either by Indian registered entities or forming part of an international cable manufacturing company having its basis in Europe, USA or Japan.

It is anticipated that local sourcing can be implemented for onshore cable up to 220kV both in respect to manufacturing, transport and installation. The major cable supplier also can take responsibility for EPCI thus the developer

No Indian cable supplier or installer for medium or high voltage sea cables suitable for an OWF have been identified.

It cannot be excluded that some experience with MV power armoured sea cables used for river crossings & supply to Islands exists and have been installed. However not in a scale or complexity required for the OWF.

The subsea cable system does not only consists of cable, joints and termination to switchgear. The engineering, manufacturing & installation of hang-offs, connector units, cable protection systems (bending restrictors) in an offshore context also from part of the scope and shall be developed.

It is anticipated that existing supplier producing MV onshore 3-core cables may have a sound basis to develop his production facilities for 3-core sea cable manufacturing if he enters close co-operation with an experienced manufacturer. He may already have adequate experience with the XLPE extrusion processes and quality management for single core cable and assembly of the single core cable to a three core cable suitable for onshore application.

The step up to a seacable manufacturing process however will require heavy investments in production lines/machinery for:

- Assembly of three single cores, profiles, fibre optical cable tube
- Production storage turntables for larger lengths/volume for 3-core assembly prior to armouring
- Steel armor process line
- Development and facilities for flexible power factory joints and FoC splice
- Storage turntable for armoured 3-core cable finished
- Testing facilities for the larger/longer cable lengths
- Load out facilities to CLV for long cables that cannot be transported on drum

- The cable contractor also shall consider his manufacturing location in respect to CLV loadout. Some suppliers have set-up the assembly & armouring next to harbour facilities and transport the 1-core cables from another established production facility

The cable supplier must establish a robust plan for his qualification tests of the offshore cables that today are standardised and having strict requirements specified by international organisations as IEC and CIGRE.

A very indicative time frame for upgrading onshore production facilities to an offshore set-up is in the range of 3 to 4 years for MV cables and 3 to 5 years for HV cables. This is naturally heavily depended on the Indian contractors experience, financial strength and ability to joint up with an already established offshore cable supplier on the international marked. Reference is made to Appendix D in respect to identified Indian and international MV/HV cable suppliers.

9.2 Offshore cable installation contractors

The market research for local suppliers, which was made in Q4 of 2017, showed that it wasn't possible for COWI to find an Indian supplier with experience in installation of sea cables.

No Indian contractors with offshore cable installation experience have been identified.

- Supply and installation, EPCI
  - NKT Cables
  - Prysmain Cables
  - Nexans Cables
  - LS Cables
  - Furukawa Electric Cables

- Installation only, EPCI
  (European based – teamed up with a cable manufacture)
  - Jan de Null
  - VBMS
  - Deep Ocean
  - Boskalis

9.3 Offshore platform contractors

The offshore wind industry in India is very new, and this reflects in the market research, which shows that there are no experienced local suppliers within manufacturing of topsides for offshore substations.

In the near future India and several other Asian countries are planning to establish various new offshore wind farms and therefore it is expected that the numbers of skilled/experienced suppliers will be growing fast.

Therefore, it will be obvious to transfer the know-how, which the Indian companies already have due to their strong traditions with production of steel constructions for the petrochemical sector and shipyards, to the production of offshore substations.

The offshore substation consists of a topside housing all HV/MV/LV power systems and a substructure either engineered as a jacket or monopile structure.

The topside requires far more complex engineering experience compared with the substructure since the M&E plant shall be interfaced within the deck/rooms.

The transport and installation of the topside & substructure can be organised by the OSS supplier if an EPCI scope is agreed.

The sourcing of the OSS fabrication and installation can be accommodated to an optimised mix of local (Indian) and foreign content.

- E.g. the steel construction of the substructure and the top-side can potentially be locally manged

- It is anticipated that a jacket support structure can be produced in a suitable Indian shipyard. This also could have logistic advances in respect to the transportation logistic/cost to the site

- The topside outfitting with M&E equipment will be an challenge for an unexperienced Indian contractor /shipyard and is not recommended without teaming up with an experienced engineering company and a contractor who have an proven record of EPC(I) deliveries

Consequently, it is assumed that it will be convenient to start a local production of the topsides for the substations or a joint venture with assistance from one of the foreign companies mentioned in the supplier survey listed in Appendix E.

The sourcing strategy for substructures and topside shall be implemented from the developers choice based on his abilities and experience. Some common adopted strategies used in Europe are indicated below:

A. Full EPCI – Topside & Substructure
   Contractor design, procure steel and M&E plant, fabricate, transport, install and commission the OSS

B. Full EPC – Topside & substructure
   Contractor design, procure steel and M&E plant, fabricate, and commission the OSS

   Developer organise transportation and installation of the OSS and hand back to the OSS Contractor at site for offshore test & commission

C. Partial EPC – Topside & Substructure
Contractor design, procure steel and M&E plant(Excl. eg. HV/MV components),fabricate, and commission the OSS

Developer organise concept design, provide HV/MV plant to the fabrication yard, organise transportation and installation of the OSS and hand back to the OSS Contractor at site for offshore test & commission of the LV systems. Hot test and commissioning against the power grid is implemented by the developers organisation.

This is an approach only recommended for an mature developer with in-house engineering capability – but could be a cost effective approach.

In all strategies the developer shall source the OWF SCADA & communication systems separately – since this will interface with the WF ONSS and the WTGs.

10 GETCO Power Study Report

FOWPI initiated a preliminary Power System Analysis (PSA) study issued by GETCO aiming at identifying possible GETCO substations appropriate for grid connection of the 200MW OWF.

Reference is given to Appendix F - GETCO Grid Study. Results are summarized commented in this section.

10.1 Summary of GETCO PSA

GETCO has identified three existing 220kV grid substations in the region illustrated in Figure 72, that can potentially be offered as possible grid connection points.

- 220 kV Otha (Mahuva)
- 220 kV Dhokadava
- 220 kV Timbdi

In addition GETCO's planned STU & CTU transmission nework up to 2020 time-frame indicates that a 400/220kV substation will be made available nearby Pipavav. The new substation will be connected to existing 400kV Amreli SS via a new double 400kV overhead line and consitude a significant reinforcement of the regional transmission network.

Other 220kV substations exist in the area but are not operated by GETCO. Consequently they cannot commit to these substations.

GETCO has selected and suggest Dhokadava SS as basis for a very preliminary basic power system study (load flow and short circuit performance) for the interconnection of the 200MW windfarm.

The PSA verifies that Dhokadava SS can receive the 200MW without causing overloading of connecting transmission lines in the region. A suitable number of contingency cases are analysed as well. The PSA does not exclude the two other 220kV substations as suitable grid interconnection points.

The PSA suggests a grid interconnection as shown in Figure 72.

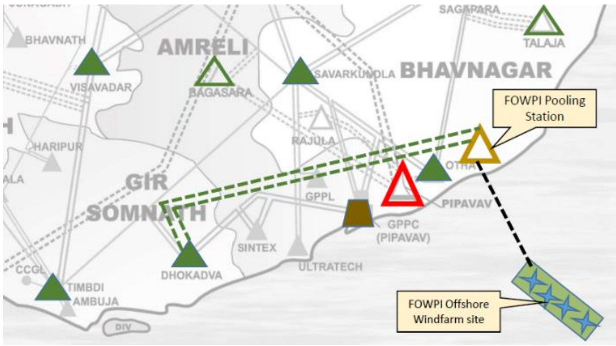


Figure 72 GETO PSA assumed offshore cable landing point & Grid SS. Overhead to 220 kV Dhokadava is illustrated with green dashes. Red triangle illustrated planned 400/220kV substation.

The PSA anticipates the OWF project construction with the following grid components onshore:

- 220kV onshore pooling station anticipated to be located nearby Jafrabad port.
- 220 kV, 1X25 MVAR switchable bus reactor / STATCOM at FOWPI on-shore wind pooling station
- A new ca. 50 km overhead line (2- circuit) to the Dhokadava SS
- 2 Nos. of 220 KV feeder bays at 220 KV Dhokadava (GETCO) substation

The PSA cannot be considered as a commitment from GETCO.

Any potential OWF developer shall commence a targeted application approach to determine and align a suitable design of the power system interconnection.

10.2 Comments to GETCO PSA

The PSA considers the 200MW OWF as a lump wind generator directly connected to an onshore wind pooling station. Consequently the impact from the onshore/offshore export cable circuits to the OWF and the array cables interconnecting the WTGs is not considered. These cables will contain large capacitances that will have a significant impact on the switchable shunt reactors rating suggested. GETCO's assumption *(Power factor 1.0 "No reactive power exchange at the POC")* can still be meet with properly engineered shunt reactors/SVC/STATCOM components at the onshore/offshore substations.

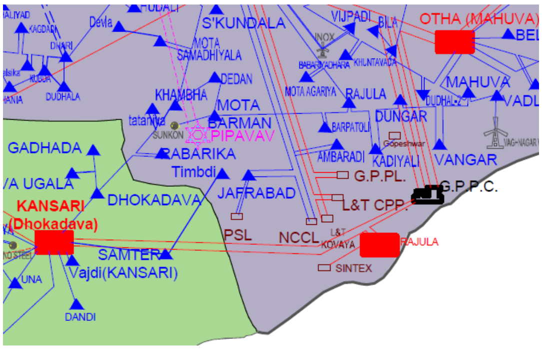


Figure 73 Regional 220kV GETCO Grid

The 220kV interconnection lines in between Dhokadva SS, Sintex SS, Ultratech SS, GPPC SS, GPPL SS, L&T CPP SS, Otha SS, Pipava SS seem not to be consistent in the power maps made available.

The PSA is implemented with grid as shown below.

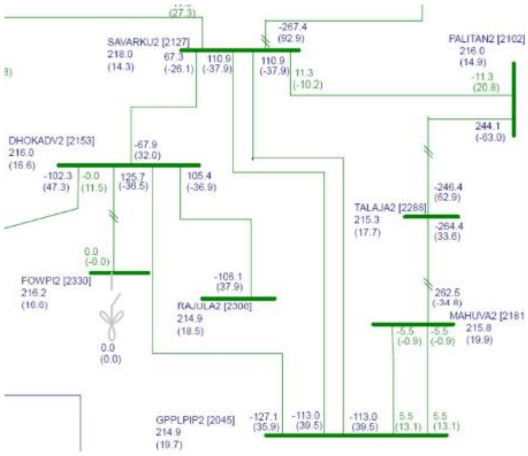


Figure 74 GETCO PSA – Assumed SLD

The power system model appears to be inconsistent with the two power maps provided. Good reasons for this inconsistency would most likely be revealed upon further clarification with GETCO are obtained and could involve a better and full understanding on the substation names and the base year assumed. (Exiting/planned substations and transmission lines are aligned with the base year).

The suggested Dhokadava SS is situated ca. 50km from the "nearest" landing point of the offshore cables. This imposes a significant increase of the OWF export cable (overhead line) required onshore from the preferred offshore cable landing point compared with the advisory design.

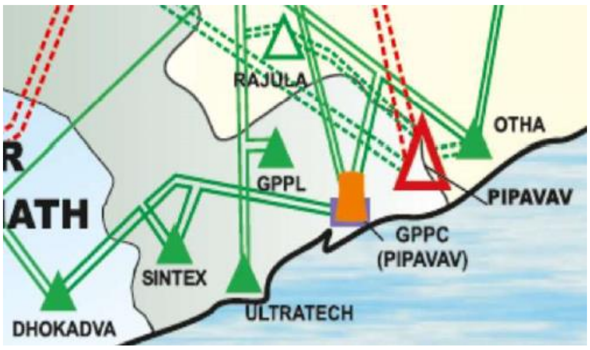


Figure 75 Regional Grid 15.11.2017

A double 220kV circuit overhead line is suggested. It shall be clarified if this is a request by GETCO or if a single circuit 220kV (suggested in the advisory design) can be accepted should the OWF developer be comfortable with such reliability offered for the OWF.

Existing 220kV substations in the region not operated by GETCO which might be suitable as connections point and could be investigated further for the 200MW OWF with the operators. The map below indicates these substations close by to the suggested landing point.

A. Utratrec Power Plant "GPPL" *)
B. GSPC Pipavav SS *)
C. Kovaya Cenment Plant *)
D. Sintex SS (Location not identified)

*) an outdoor switchyard exist – voltage level and ownership unknown

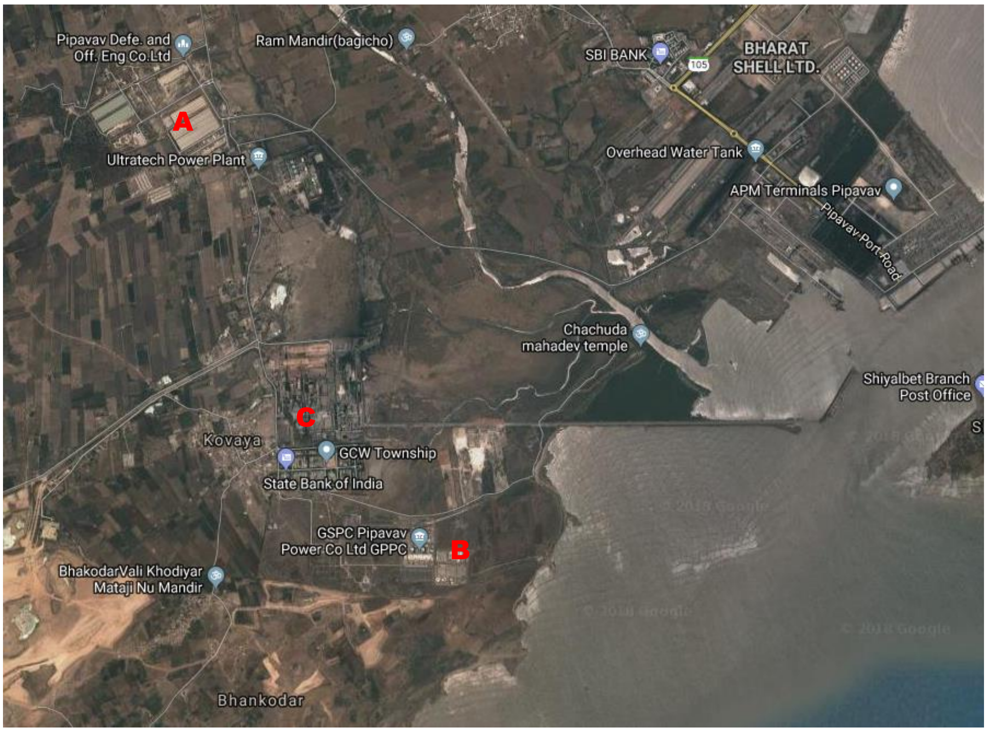


Figure 76 Potential GETCO & Private SS nearby preferred offshore cable landing point

The PSA states curtailment of OWF production may be required to avoid overload of the associated transmission network in off-peak load periods. This does not direct impact the design of the power system infrastructure, but must be considered by the developer when a power purchase agreement is negotiated.

10.3 Impact on Advisory Design

The GETCO PSA takes basis in an "OWF pooling station" and proposes a ≈50km 220kV double overhead line to the Dhokadva Grid SS. The advisory design does not recommend a 2-circuit 220kV cable/OHL from the shore to the Grid SS "PoC". A double circuit export cable/OHL will offer higher redundancy and availability – but also adds significant increase in the CAPEX that not is anticipated to be justified by the higher availability factor of the 200MW OWF.

The grid connection alternatives with 33kV or 66kV export cables suggested in the advisory design all consider a windfarm onshore substation close to the shore. Thus the offshore power system alternatives indicated are not directly impacted by the onshore power systems, unless the landing point is changed.

Some **preliminary and high level** reflections on the various grid connection possibilities for the FOWPI wind farm and the results of the PSA are given in the following and illustrated in the map sketch below.

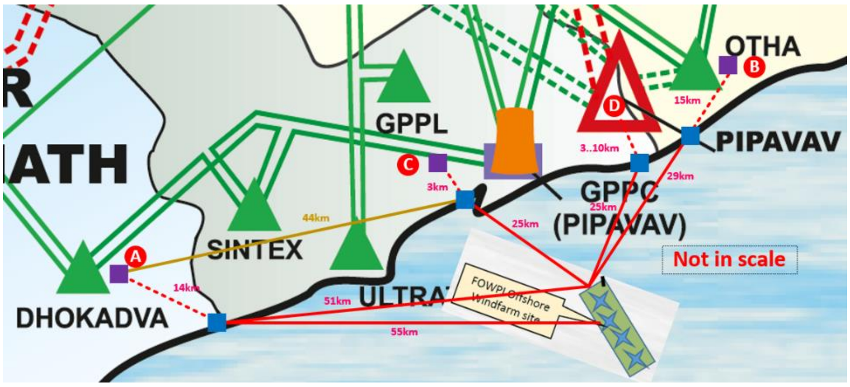


Figure 77 Optional grid connection approaches to 220kV network

Four different grid connection options are addressed in the following without any consultation with GETCO who naturally will have a final say on the grid connection to secure acceptable operation of the power grid.

A: Dhokadva SS

The ≈45km (direct line) distance from the suggested landing point to the grid SS will impose increased costs and complexity to the OWF project. Either a 230kV OHL or U/G cable circuit shall be constructed.

Viable design are available and possible to maintain grid code compliance in respect to the power factor/reactive power control at PoC. (By means of properly engineered design in respect to placement/sizing of shunt reactors, STACOM's etc.)

A total length (≈75km) export cable is possible and designed already for other OWF projects (>400MW). However a design focus point will be the voltage fluctuation at the WF ONSS (or OSS) 220kV busbar that shall be controlled and kept within acceptable limits. The 33kV (or 66 kV) busbar voltage criteria will not constitute a challenge since a suitable online tap-changer at the main 220/33 (66) kV transformers can maintain the voltage level. Preliminary concepts for the power infrastructure is indicated in the following figures.

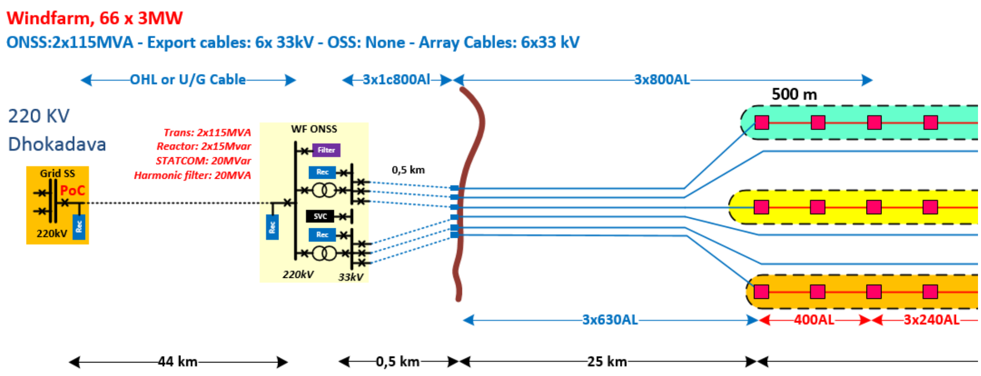


Figure 78 High level SLD – Six 33kV export cables to ONSS & 220kV OHL/UG-cable

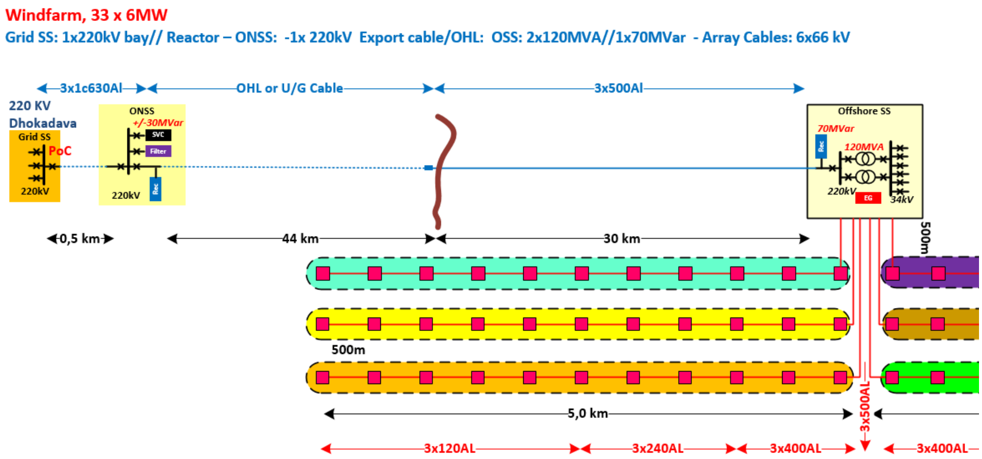


Figure 79 High level SLD – One 220kV export cable to ONSS

The need and rating of a 220kV shunt reactor at Dhokadava SS and OSS will be different if a 220kV export OHL or UG is designed since the total export cable circuit capacitance will change.

As an alternative the landing point of the offshore cables can be moved to shorten the ≈45km onshore 220kV OHL/UG-cable circuit. A preliminary line routing is indicated in ***Error! Reference source not found.***. Benefit could be less challenges in obtaining clearance on the onshore corridor in respect to environmental constrains and agreements with landowners. (15km is more attractive than 45km corridor length).

The drawback will be a significant larger CAPEX for the export cable component due to the expensive offshore section.

A very indicative cost assessment for the export cable alternatives is shown below.

	Offshore cable [km]	Onshore Cable [km]	OHL [km]	CAPEX
Advised Landfall	25	45	0	42 mio Euro
Advised Landfall	25		45	25 mio Euro
Alternative Landfall	55	15		54 mio Euro
Alternative Landfall	55		15	49 mio Euro

Table 18 Indicative cost assessment on onshore transmission circuit alternative

It is observed that the concept with a ca. 45 km OHL from the preferred landfall to the Dhokadva SS is the most cost attractive proposal. The alternative landfall (giving a shorter onshore route) is not cost attractive in any scenario.

Figure 80 Otha Export Cable routing

B: Otha SS

The Otha SS will be more attractive than Dhokada SS as connection substation since it offers a significant shorter route for the export cables. A very preliminary line route with 29km offshore cable and 15 km 220kV onshore cable/OHL is indicated beside. *(Compared with 24km and 3km anticipated in the advisory design and preferred landing point).*

The cost of offshore cable will increase proportional with the route length (≈+15%) unless larger cross sections for 66kV or 33kV export cables will be required to maintain acceptable voltage drop from the WF ONSS to the first WTG.

It is anticipated that this increase will demand larger cross sections for the 33kV export cable options. Thus the 33kV export cable options with only four or five radial are not considered viable since the cable cost will increase and unsuitable cable conductor sizes will be required.

The 66kV export cables are selected from a load current criteria rather than from a voltage drop criteria. Thus the conductor sizes are not anticipated to increase due to the cable length.

The 15km *(will be longer due to detailed routing, Right of Way etc.)* 220kV cable from WF ONSS to Otha SS also will give a higher CAPEX (≈+ 5.5 mio Eur). It is not anticipated that the conductor cross section need to be increased due to the longer length. These cost could be reduced considerably if an overhead transmission line is designed. A 220kV OHL was not suggested in the advisory design since a relatively short route length were considered and the U/G cables are maintenance free and not exposed to risk of damage as the OHLs. Further the challenges for a private operator to obtain environmental approval and consent from local authorities and land-owners could impose an unacceptable implementation time to secure the grid connection of the OWF timely.

The benefit with a 220kV OHL compared with the 220kV U/G cable could be reduced line investment costs and less requirements on the 220kV shunt reactors at the WF ONSS that will be more cost attractive.

C: New SS connected to existing 220kV overhead line

The 200MW OWF does not necessary need to be connected to an existing 220kV substation. If found acceptable by GETCO the PoC can be established at a new 220kV substation that connects to an existing 220kV overhead line. This option have not been considered in the preliminary PSA presented by GETCO or in the advisory design indicated.

If no available 220kV substations (GETCO or private) are available nearby the preferred landing point (shortest offshore cable) such new substation could be a feasible approach.

The diagrams below illustrate an eventual grid interconnection approach assuming that durable 220kV overhead lines exist inland close to the preferred offshore cable landing point. The line routing between Dhokadva SS, Sintex SS, Utractec SS, GPPL SS and GPPC SS are not identified in sufficient detail to suggest a preferred location of such new substation. Capacity of existing OHL conductors and location of suitable angle towers for the in feed to the ONSS are also important factors to be addressed.

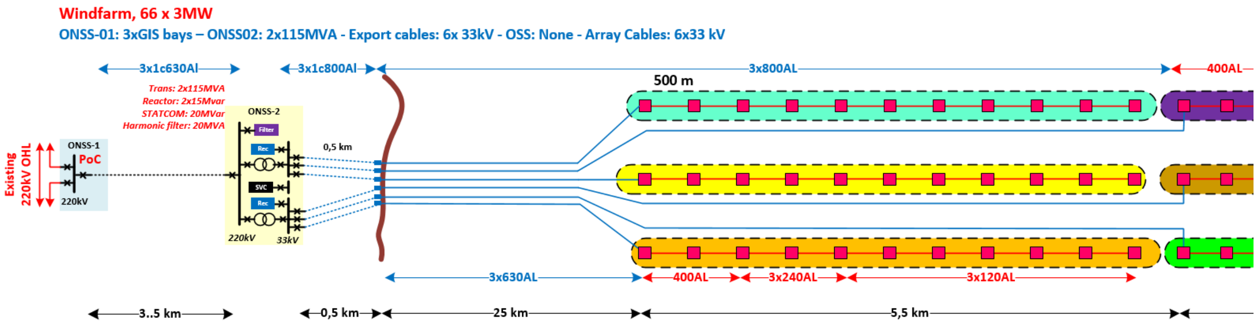
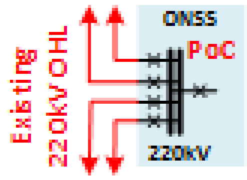


Figure 81 High level SLD – Six 33kV export cables to 220kV overhead line



If required by GETCO to achieve required reliability of the grid the ONSS could be connected by a 220kV GIS plant equipped with a double busbar as indicated beside. The GIS will require far less footprint than a traditional outdoor switchyard build with air insulated 220kV apparatus and busbars. The GIS can be designed with porcelain terminations allowing a direct connection from a 220 kV overhead line via a suitable gantry at the substation. A concept design showing the substation arrangement and footprint can be elaborated and suggested rapidly by any reputable 220kV GIS provider.

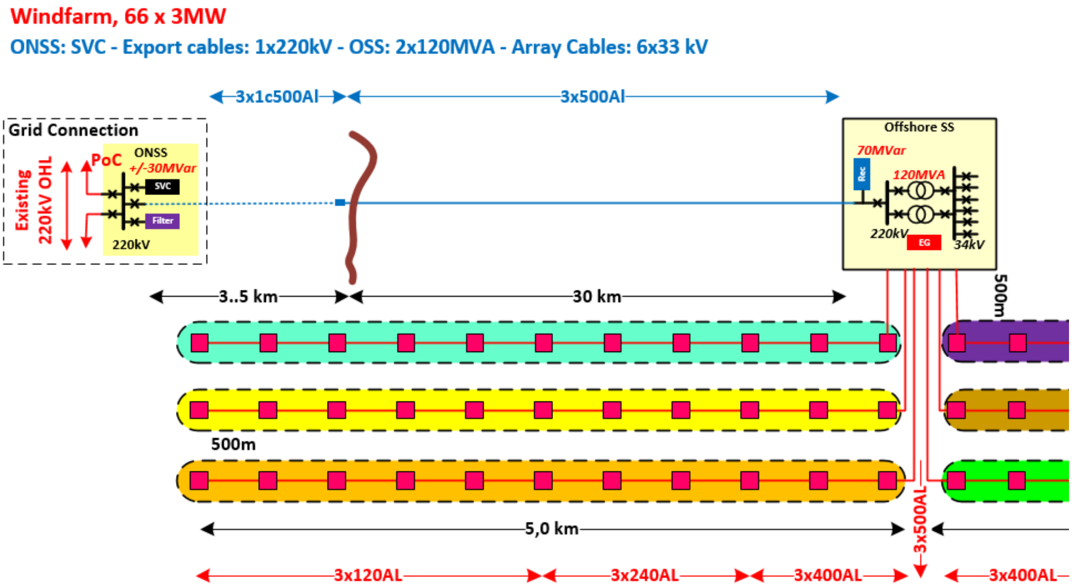


Figure 82 High level SLD – One 220kV export cable to 220kV overhead line

It is further observed that the double 220kV line Dhokavada-Sintex-GPPC already exists and apparently crosses another 220kV double line Ultractech-GPPL. (**Error! Reference source not found.**). If such crossing exists the location could be a very appropriate spot to construct a new substation as a strong hold point for the region. Such approach however could be more challenging to implement since the responsibilities on cost, design, operation between GETCO and the OWF developer will require more extensive agreements.

D: New 400/220kV SS

A 400/220kV substation, illustrated in Figure 77, is indicated with a location more favourable than the Otha SS. It is understood that this particular substation is planned in the future to receive a large bulk generation from wind power plants scheduled within the next decade.

If this substation is ready in a timeline acceptable for the 220kV OWF project program this connection point could be the preferred option for all parties. It is understood that the planning of this substation is in a premature stage and need further development by GETCO. The 400 kV OHLs required surely could be a bottleneck in respect to construction timeline alignment with the 200MW OWF. Perhaps a fast track construction focusing on the 220kV switchgear only could make possible a connection of the 200MW OWF if the regional network can consume the power without hampering a secure operation of the grid.

All in all, GETCO and the potential 200MW OWF developers shall address this when the OWF project development is in a more advanced phase and more committed timelines can be agreed.

E: 220 kV Timbdi SS

The substation is not considered viable as a connection point for the 200MW OWF location being investigated. The export cable distance is longer than the two other substations suggested. The Timbdi SS might be a feasible connection point if the 200MW OWF is situated further south along the cost line.

10.4 Recommendation

GETCO's PSA confirms that 200MW wind power generation can be connected to the regional grid either at the three identified GETCO operated 220kV substations or other 220kV substations operated by other parties.

It is understood that the 220kV transmission grid in the region even in a short timeline until the future 400/220kV substation is taken into operation can receive 200MW wind farm generated power without compromising the acceptable conditions for the grid set out by the GETCO.

It is also anticipated that the region can receive more wind power (200MW…400MW) in a short timeframe without substantial reinforcement of the 220kV grid. *(To be confirmed and verified by GETCO upon development of such offshore windfarm projects shall be initiated).*

A larger implementation scheme for offshore windfarm(s) 400MW …..2.000MW in the region will require reinforcement of the transmission grid. GETCO already has initiated studies for a more robust 400kV transmission grid and a 400/220kV substation nearby Pipavav port is to receive the wind farm power. The timeline for this reinforcement of the transmission grid is unknown. An overall planning shall be implemented by GETCO to identify when such substation can be made available for OWF developers.

The GETCO PSA did not address or identify any technical constrains that could indicate a future 200MW OWF cannot fulfil the prevailing grid code.

Based on above it is recommended the preferred landfall location is maintained by future OWF developers who as early as possible is advised to take direct contact to GETCO and operators of the existing 220kV substations to identify and determine suitable grid connection points as close as possible. The Dhokadava SS is not considered most attractive grid connection point for the

200MW windfarm due to higher CAPEX, larger losses and potential EIA/landowner constrains in relation to the construction of the onshore 220kV transmission line/cable.

This process must be in a close dialog with GETCO who shall give consent to the PoC location and be a vital stakeholder when the OWF developer shall negotiate and enter agreement on the PPA.

The OWF developer is also recommended to commence a dialog with GETCO and local authorities to establish the timeline and process for permitting, obtaining of RoW, and construction of the cost attractive 220kV overhead line. The OWF developer is also advised to seek local consultancy on the EIA studies and when private landowners shall be approached to negotiate compensation arrangement for either the UG-cable or transmission overhead lines.

Appendix A Option 1. 3 MW WTG with 6x33kV Export Cables

High level power system topology

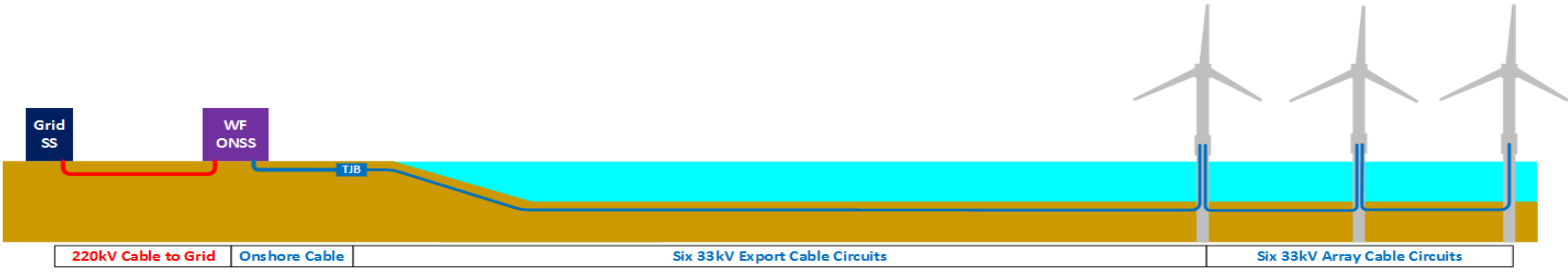


Figure 83 Power System Components - High Level Option 1

This concept offers a solution with the collection substation WF ONSS located onshore as close to the shore as possible. Thus an expensive offshore transformer platform can be avoided. A suitable number of 33kV cable radials will connect to the WF ONSS where the distribution voltage is stepped up to HV (220kV) suitable for direct transmission to the grid substation, Grid SS. Table 19 shows a simplified selection table of possible number of 33kV export cables only restricted by the limitation given by a 33kV cable circuit breaker rating (1250A) offered from the GIS suppliers. The radial currents indicated in table are ≈5% larger than the actual magnitude, since the power losses and the increased voltage in the cable radial not are considered. This is considered in the load-flow calculations implemented and reported in later sections of this advisory design report and supports the conductor selection.

The table illustrates that four to six export cable radials could be implemented.

Wind Turbine Generator Rating					3,0 MW		33 kV		Cosphi	0,97	54,1 Amp	
Layout	6 Radials			5 Radials			4 Radials			3 Radials		
Radial	WTG	MW	A	WTG	MW	A	WTG	MW	A	WTG	MW	A
1	11	33,0	595	14	42,0	758	17	51,0	920	22	66,0	1.190
2	11	33,0	595	14	42,0	758	17	51,0	920	22	66,0	1.190
3	11	33,0	595	14	42,0	758	16	48,0	866	22	66,0	1.190
4	11	33,0	595	12	36,0	649	16	48,0	866			
5	11	33,0	595	12	36,0	649						
6	11	33,0	595		0,0	0						
Sum	**66**	**198**	**3.571**	**66**	**198**	**3.571**	**66**	**198**	**3.571**	**66**	**198**	**3.571**

Table 19 Preliminary selection table on array radial numbers

The alternative with only three export cable radials is not assessed to be sustainable since it will not leave much safety margin against the circuit breaker 1250A rating and also requires very large cable sizes that could be produced but which are not found appropriate due to cost and cable handling parameters that may be impossible/not practical achievable in the WTG's.

The base case power system topology selected for the advisory design is the layout with six export cable radials. The two other alternatives with five and four export cables are also analysed in respect to load-flow studies to select suitable conductor sizes (based on a voltage criteria and short circuit capability) and to compute the investment cost and capitalised energy losses in order to make a CAPEX comparison between the alternatives. An even number of export cables could also be preferred since it allows a 50/50 distribution of the power between the two 220/33kV power transformers at the onshore substation. *(However, this should not be the argument for determining the overall topology, since these units are engineered/manufactured to project requirements and no spare units will be procured anyhow).*

The high level system topology with six export cables is illustrated Figure 84 where the main substation components and cable conductor sizes are indicated.

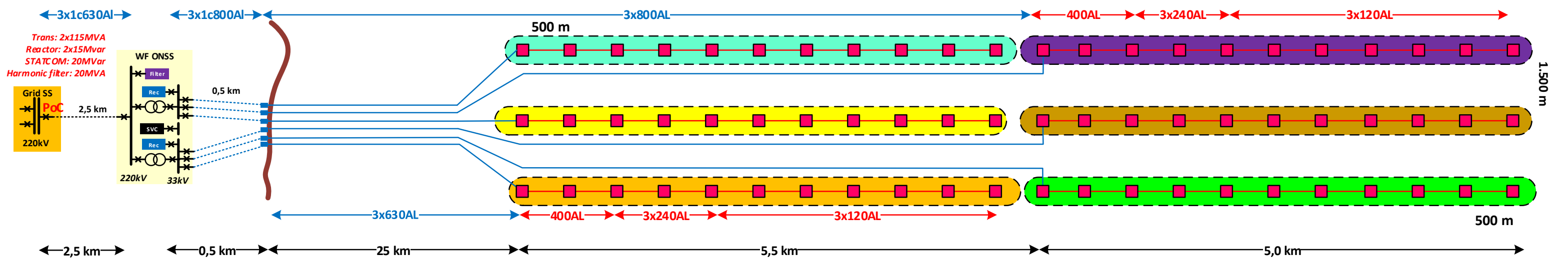


Figure 84 Power System Infrastructure Topology – Option 1 – Base Case

The WTGs are grouped into six strings each interconnected to the onshore substation via 25km and 31km offshore export cable circuits respectively.

The onshore power system consists of:

- TJB site, comprising six parallel joint bays separated with approx. 5 m.
- 500m cable corridor (approx.20m wide) allowing six parallel 33kV cable systems.
- Onshore substation WF ONSS comprising main components such as 33/220kV power transformers, 33kV and 220 kV switchgear, shunt reactors, STATCOM, harmonic filters, control building and other civil work.
- 2.5 km underground cable circuit interconnecting the WF ONSS with the Grid SS.
- 220kV line bay with kWh metering at the grid SS (PoC) all designed and constructed by the TSO.

The anticipated outline onshore (depends on the grid SS location) is indicated in Figure 85 .

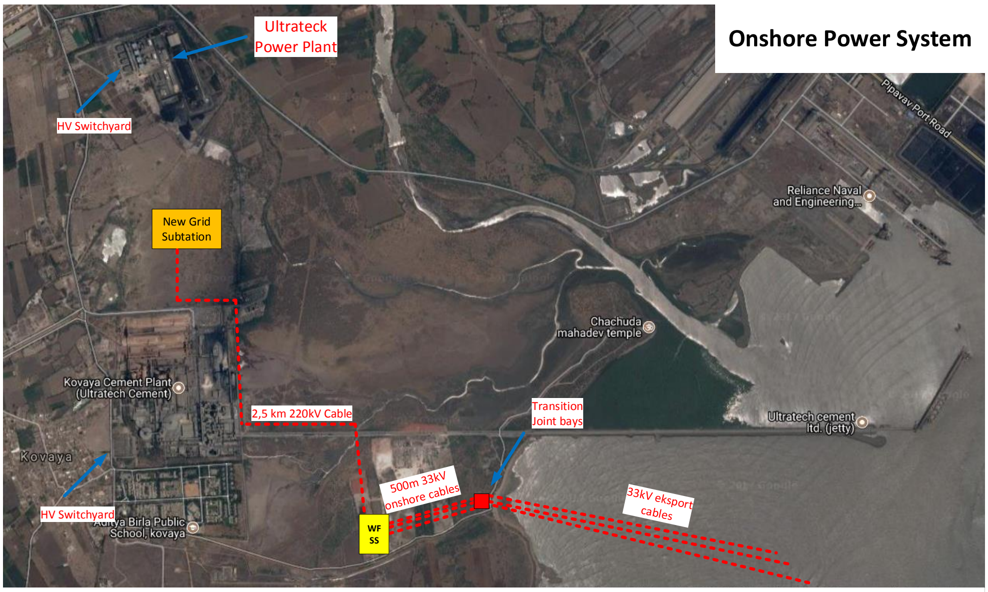


Figure 85 Option 1 – Assumed Onshore Cable Route

Rating of equipment

The wind farm power system comprises WTGs and switchgear, 33kV cable systems, a 33/220kV onshore substation, 33kV export cables, and the extension of the 220kV grid onshore substation. The SLD's below give a more detailed description of the configuration of the 0.4/33/220kV components.

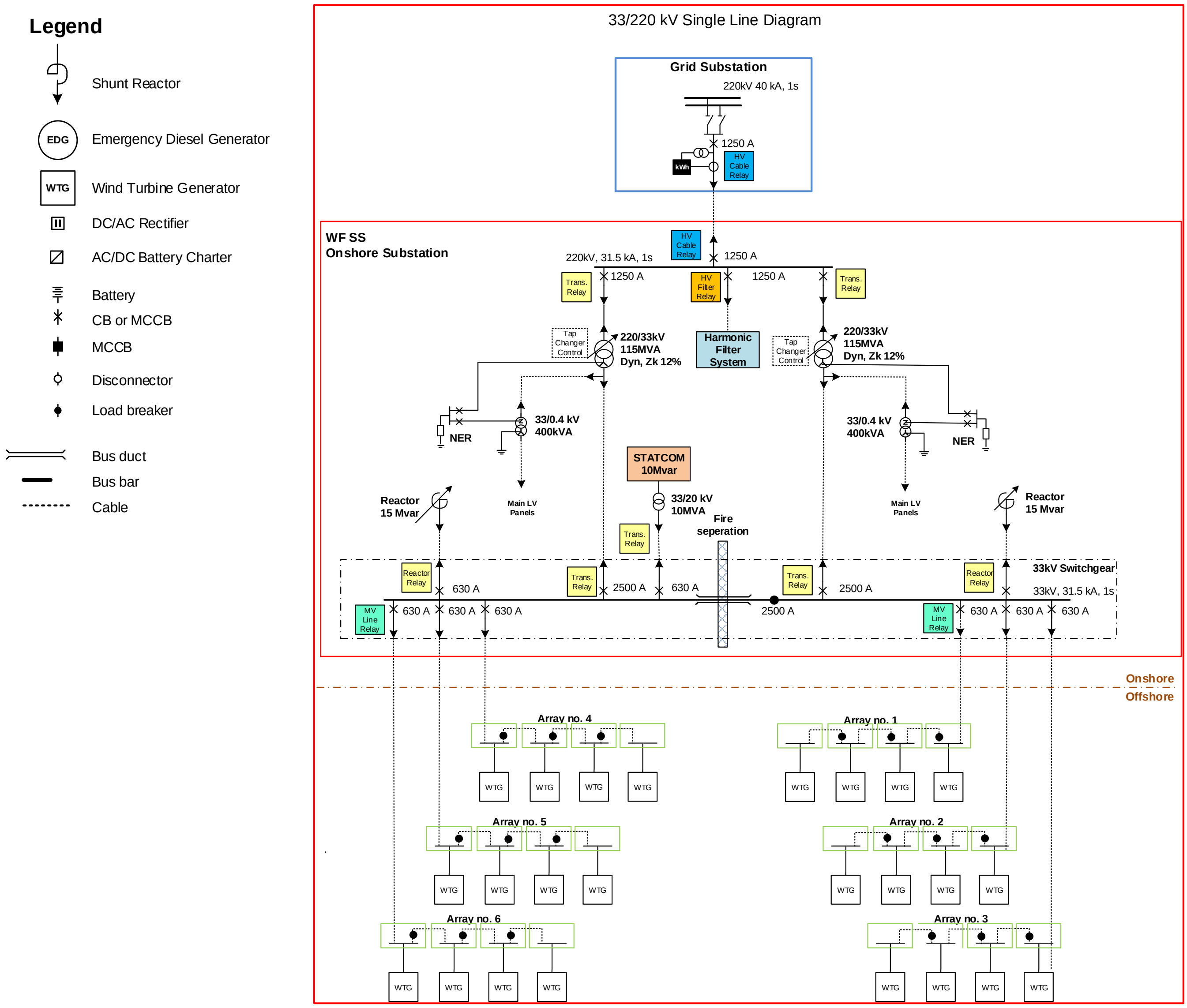
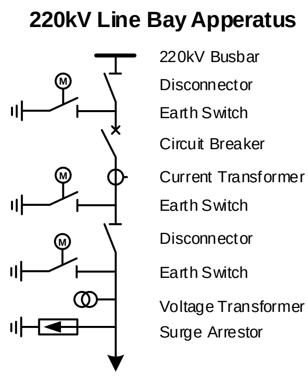


Figure 86 Option 1 – Simplified Single line diagram

The 220kV switching apparatus, instrument transformers and busbar are suggested as an outdoor switchyard designed in conformity with prevailing standards. The 220kV line bays are assumed to consist of components as indicated beside. (An indoor 220kV GIS can also be considered).



The two shunt reactors are sized to balance out the capacitance in the 33kV cable system. The rating of the STATCOM and harmonic filter systems are indicative but scaled from other OWF projects implemented in UK on the assumption that the IEGC does not deviate significant from UK.

The 33kV switch gear is recommended indoor and sectionalised with a bus-duct between two fire separated rooms.

The STATCOM can also be connected on a third winding on the two HV/MV power transformers. This option could offer saving of a 33kV switchgear but will require a more sophisticated relay protection arrangement.

The switchgear shall include protection relays to ensure fast, safe and efficient clearing at any type of LV, MV and HV fault, with back-up to ensure function at single item failure. Self-monitoring protective relays and with SCADA alarms raised at internal faults and loss of control voltage are suggested.

Suggested functions for the protection relays shown on the single line diagrams are illustrated in Figure 87.

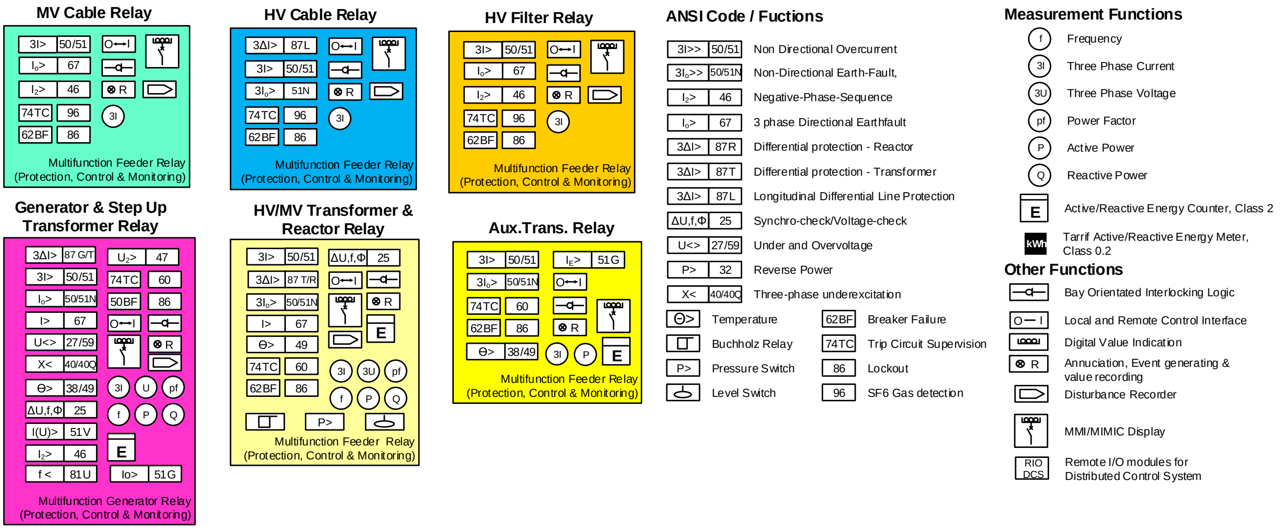


Figure 87 ANSI Code for suggested protection relay systems

Local control at the switchgear should be made possible by the mimic display integrated in the multifunctional replay placed either in separate relay panels or on the front/dedicated compartment forming part of the switchgear. Any tripping of a circuit breaker by a protective relay shall result in a trip-lockout condition in which it shall not be possible to reclose the breaker, locally or remotely, until a reset function specific to the breaker has been executed.

A redundant power supply path is suggested for the operation of the ONSS. The second station auxiliary transformer could be cancelled if reliable power from the grid company can be agreed via the 10-20kV power distribution system operated by the regional power utility in the area.

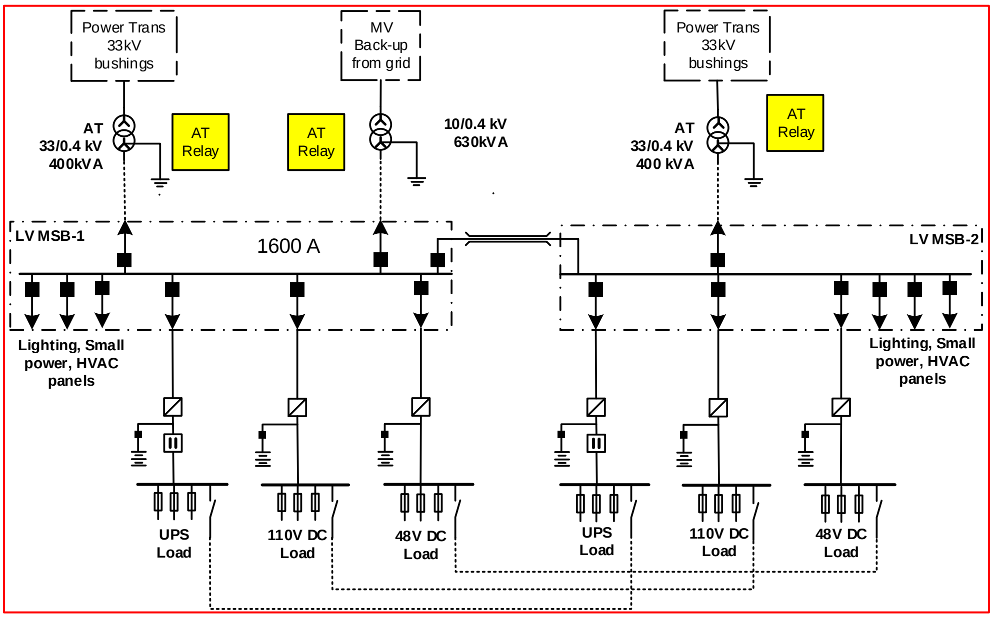


Figure 88 ONSS LV System Single Line Diagram Suggestion

Interlocking between main circuit breakers feeding the sub distribution boards shall be considered. Critical loads can be connected with two cables to both sub-distribution boards via different fire separated cable ways thus achieving a high availability and almost a 100% redundancy.

The station auxiliary transformers are rated to the substations own power consumption only.

Operational philosophy

Emergency power demand

The WTGs will have its own power consumption when not producing to the grid, since control systems, yaw operation of the nacelle and general preparedness of the machinery shall be maintained to commence production when the wind picks up again. The internal power consumption could come from hydraulic motors, yaw motors, water heating, water pumps, oil heating, oil pumps, control system and transformer losses. The no-load transformer losses will permanently be around 5-8kW for each WTG. Approx. 3kW for control systems bring the permanently load demand to approx. ≈10kW. The maximum load demand (with no diversity factor) could reach 70-80kW with all utilities in operation. A very simplified and indicative assessment of the aggregated load demand for the offshore wind park is presented in Table 20 for the 66 WTGs 3MW units layout.

	Minumum 1)	Maximum 2)	Total	
Load demand	10	70	80	kW/WTG
Load demand	660	4.620	5.280	kW/Park
	695	4.863	5.558	KVA/Park
Diversity factor, WTG	100%	50%	50%	KVA
Diversity factor, Park	100%		75%	KVA
Load demand, Park	695		2.084	KVA
SAT Rating	**347**		**1.042**	**KVA/SAT**

1) Trans no-load & conrol
2) All utilities agregated

Table 20 WTG power consumption estimate table

Approximately 2MVA will be required with all WTGs connected to the grid. This load demand can easily be delivered by the grid via the 33kV cable system and does not constitute operational issues in normal operational conditions with no-faults or components out for maintenance.

Long-time power failure could cause issues for the WTGs thus power supply options should be considered for such scenarios.

The WTGs will need a minimum of power and could have issues if power cuts are more than 1-3 days. The supply to control system and condensation heating elements in switchboards can be maintained by the WTG battery system. Yaw operations and other loads necessary during a long timeslot cannot be powered from the battery, thus a more robust power supply shall be arranged. This can be organised either from a central source (emergency generator or grid supply) "if redundant supply path exist" or by emergency gen-sets mobilised at the WTGs.

WTG's rated >6MW can be designed with a small gen-set and maintained with same intervals as the other equipment as the WTG. This is seldom preferred solution for 3MW WTGs.

Power system reliability

It is anticipated that the grid SS offers a solid and reliable connection point on a double 220kV busbar having redundant line connections (minimum 2) to the regional grid. If the grid substation serves other OWF's it may be built with 500/220kV power transformers and connect to the 500kV grid.

Table 21 indicates an initial mapping of the operational modes assumed for the wind farm with base case power system topology.

Operational Senario	Grid SS	Windfarm Substation												Array Cable System / WTG's			
	220kV SVG & cable	220kV Busbar	220kV Line Bay	230/33kV PT01	33kV busbar 1	33kV cable feeder	SAT 1	33 kV bus coubler	230/33kV PT02	33kV busbar 2	33kV cable feeder	SAT 2	LV back up from grid	33kV cable radial BB1	WTG on BB1 radials	33kV cable radial BB2	WTG on BB2 radials
Normal Operation								Open					NA				
Fault Scenarios with full or partial operation of the WTGs																	
Fault 01: 220kV Cable	F or M							Open							WTG supply only		WTG supply only
Fault 02: 220/33kV –PT01				F or M									NA		<25% prod		
Fault 03: 33 kV Busbar 01					F or M			Open							All Radial lost		
Fault 04: 33 kV Exp. Cable						F or M									Radial lost		
Fault 05: 33kV array cable															Upstream WTG's ok		

(red)	Component faulty/have maintenance ongoing or switch/circuit breaker open
(blue)	Component disconnected
(green)	Component allows 100% operation
(yellow)	Component only allows partial operation, WTG's powered from grid/emergeny generator or or via loop if designed
(purple)	No production to grid. Only power supply to WTG's

Table 21 Option 1 – Power System Operational Mode – Normal & Faulty Operation

The availability of the shunt reactors, harmonic filters and STATCOM will also impact the OWF operation, since a disconnection of one system could impose limitation to the number of WTGs allowed connected to accommodate the grid code.

The fault scenarios in respect to consequences and mitigation are briefly discussed below, Table 22:

Failure	Consequence / *Mitigation* *)
Fault 01: 220kV cable or switchgear is disconnected.	Grid blackout A complete grid black out is only anticipated to lasting max. 1-2 days. *The WTGs can go in "cold mode" power supplied by its battery reserve.* 220kV system damage A 220kV cable fault or a server damage on the 220kV busbar/switchyard in Grid SS or WF ONSS will shut-down the OWF until repair is completed. Onshore cable repair can be implemented within 1-3 weeks depended on mobilisation of skilled jointers. Replacement and repair of 220kV outdoor components can also be implemented within 1-2 weeks (assuming spares are available and preparedness via O&M organisation is established). *Emergency power supply to the WTGs can be provided by the power grid via the station auxiliary transformers feeding into the 33kV system at the WF ONSS.*
Fault 02: 220/33kV power transformer connected to 33kV switchgear busbar 01 is disconnected.	Only one 220/33kV power transformer and *station auxiliary transformer* will be available. A fatal damage of the power transformer will require a replacement. Lead time and installation will be 6-9 months. *The other power transformer will serve the full windfarm via the two 33kV switchgear busbar sections being connected by the bus coupler.* *All WTGs can be powered for own consumption and can produce up to the limit of the power transformer.* *Curtailment shall be made when the total production exceed the current capacity of the power transformer*.
Fault 03: 33kV busbar section 01 disconnected	A 33kV busbar failure could be fatal and take out the full section and require full replacement of the GIS. All WTGs connected to the busbar section cannot be supplied with power from the grid. Lead-time and installation could be 4-6 months. *Option A: Three emergency gen-sets on a rental basis can be utilised at the first WTG in the string and feed the other WTGs downstream.*

	(Refilling of fuel offshore will be a large cost). *Option B: The WTGs can be powered by the AT01 (grid connected) and the three export cables connected via temporary set up with 33kV cables and eventual 33kV switchgear.*
Fault 04: 33kV export cable disconnected	A 33kV export cable failure onshore would most likely be provoked by an excavation damage caused by a 3rd party. The full radial will be lost and WTGs cannot be powered from grid until the fault is cleared out. The repair can be implemented within a week. (The wind farm project is advised to keep suitable number of cable joints and cable on spare). *The WTGs can be powered by an emergency gen-set on a rental basis which can be utilised at the first WTG in the string and feed the other WTGs downstream.* A 33 kV export cable failure offshore will have the same consequences, but the repair time will be 1-3 months depending on vessel availability. 33kV feeder failure. If the damage is restricted to the MV compartment only one export/array cable connected will be disconnected. The other strings with WTGs can continue production. *Replacement/retrofitting of a damaged 33kV cubicle can be implemented within one month with available spare parts. The extent of damage naturally effect the repair time. Internal faults in complete GIS will most likely be restricted to the faulty compartment and will not affect other compartments.*
Fault 05: 33kV array cable partial disconnected	The WTGs downstream after the disconnected cable will not be able to produce or receive power from the grid. *Option A: The effected WTG can be powered from an emergency gen-sets on a rental basis which can be utilised at the first WTG and feed the other WTGs downstream.* *Option B:* *The OWF is designed with 33kV loops between the last WTGs in the radial that will allow some power production and grid supply. This option is normally deselected due to the high investment cost compared with the rental cost to the emergency generators.*

Table 22 Option 1 Assessment on risk/mitigation in respect to power system faults

Emergency generator options for full radials will require an assessment to what extent a shunt reactor will be required to compensate for the capacitive power in the 33kV cable systems.

The bottleneck for the OWF power supply will be the onshore 220kV cable system from the Grid SS and the 220kV switchgear at the WF ONSS. The grid availability can be improved if two 220kV cable circuits are installed either both connected to the same Grid SS or having the ONSS looped in between two separate Grid SS.

The last alternative could define the 220kV cable system as part of the TSO grid and add complications in relation to the load capacity required and the kWh metering concept.

It also shall be mentioned that a 220kV overhead line most likely will have shorter repair time and less construction cost. This option however, is deselected since 'right of way' and approval process for overhead lines (OHLs) are time consuming and complex and could cause delay for the developer's construction of the OWF. Further, OHLs require yearly maintenance and are exposed to damage from natural causes and act of man.

The topology with six 33kV radials gives a good reliability since a damage on one of the export sea-cables only will reduce the park production by 1/6.

The 220kV and 33kV switchgear could be designed as double busbars to improve grid availability during maintenance and faults. A more detailed assessment including the marginal cost compared with the lost revenue caused by fault probability and planned maintenance could give a basis for such decision.

Preliminary power grid study

For the purpose of this report, only simplified and preliminary power system studies involving load-flow and short circuit calculations have been carried out. The studies aim at selection of cable conductor sizes, and transformer/shunt reactor ratings.

The long (25km and 30km) export cables will contribute with a significant increase in the voltage at full production.

The maximum voltage of cable and apparatus will be 36kV, thus the busbars at the ONSS shall be maintained at 33kV at all operational scenarios. The power transformers then must be designed with automatic voltage regulation facilities thus online tap changers 10x +/-1.0% is suggested to account for voltage fluctuation in the power grid (+/- 10%) and the impact from the wind farm at high or no-production scenarios.

Two 115MVA 220/33kV power transformers each rated for half OWF production is advised and will give approx. 15-25% spare capacity should one of the transformers be faulty or out for maintenance. The OWF will deliver around 2x 95MVA to the ONSS 33kV busbar.

Thus approx. 10MVA production is allowed via the 33kV bus-coupler in the ONSS should one of the power transformers be disconnected. This will bring the energised transformer in a full load operation 115MVA. (Even more than +10MVA can be allowed in short duration since the overload capacity of the transformers is large and the condition (oil and winding temperature) can be monitored on-line and give accurate data to the system operators in the control room.

Two 33kV shunt reactors each 15MVar is suggested to compensate for the capacitance in the 33 kV cables at no production. The shunt reactor can be either fixed or with regulation facilities. This cannot be firmly established before a full power system study with selected WTGs and a clear understanding of the prevailing grid code is completed. The rating of the shunt reactor will also be closely linked with the sizing of the STATCOM/SVC and the harmonic filters.

The 220kV and 33kV apparatus at the ONSS is rated to 31.5kA 1s. The WTGs can do with 20kA, 1s since the large export cables will damp the grid contribution and the WTGs only feed in around 1.25-1.5x load current during a 3ph short circuit fault.

The conductor sizes "120 mm^2 Al [11.3kA], 240mm2 AL [22.7kA]" are far down-stream from the ONSS 33kV busbar and will not be challenged by high circuit currents from the grid.

The export cables "3x400mm^2 Cu [57kA], 3x630mm^2 Cu [90kA], 3x1c x 630mm^2 AL [60kA] will accommodate the max. 31.5 kA from the ONSS.

The power losses from WTGs to grid SS (PoC) at full production is computed and summarised in Table 23:

Cable	**Length**	**Power Loss**
Array Cables		
3x120 mm^2 XLPE-AL	19.8 km	699 kW
3x240 mm^2 XLPE-AL	6.6 km	433 kW
3x400 mm^2 XLPE-AL	6.6km	444 kW
Export Cable System		
3x630 mm^2 XLPE-AL	75.0 km	4.416 kW
3x800 mm^2 XLPE-AL	93.0 km	4.510 kW
3x1c 800mm2 XLPE-AL	3.0 km	144 kW
33/220 kV Power Transformers	---	834 kW
220kV Export cable to grid SS	2.5 km	107 kW
Total	**207km**	**11.6 MW**

Table 23 Option 1 – Base case – Cable lengths & power losses

It is observed that the 33kV export cables accounts for more than 80% of the total losses and also impose a significant reduction of the OWF power delivered to the PoC.

This could be an argument for the developer to install one or two additional WTGs. The cost will be marginal but will ensure that full 200MW power can be delivered to the PoC. These additional WTGs also can contribute with production when other WTGs are out for planned maintenance.

Cable system

Offshore cable

The permissible loading for relevant 36kV XLPE cable sizes are listed below for 2m burial depth, soil resistivity 0.7Km/W and soil temperature 25ºC. In general, Al conductor cables should be preferred as the most cost efficient option, thus only Cu cable for load currents not possible with Al conductors are listed. *(Rating tables provided by supplier Nexans).*

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
Nexans Three Core Sea XLPE-AL Cable "36kV" 2m/0,7Km/W, 25oC																	
S36XLPE3x120Al	297	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	304
S36XLPE3x150Al	331	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	339
S36XLPE3x185Al	375	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	384
S36XLPE3x240Al	432	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	442
S36XLPE3x300Al	484	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	495
S36XLPE3x400Al	548	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	561
S36XLPE3x500Al	614	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	628
S36XLPE3x630Al	684	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	700
S36XLPE3x800Al	751	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	768
Nexans Three Core Sea XLPE-Cu Cable "36kV" 2m/0,7Km/W, 25oC																	
S36XLPE3x500Cu	748	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	765
S36XLPE3x630Cu	817	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	836
S36XLPE3x800Cu	875	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	895
S36XLPE3x1000Cu	925	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	946
S36XLPE3x1200Cu	960	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	982

Table 24 Option 1 – Sea cable selection table

The current figures are incorporated in the load-flow model, and consequently fast determination can be done for any array cable topology investigated.

Offshore array cables

The internal cable circuits within the windfarm is organised in 6 strings. The prime criteria for the cable route design is aiming at a routing with as few km cables as possible, even if it may provoke larger conductors upstream against the shore. The park layout in three rows with the export cables approaching from west invites to organising the six strings as indicated in Figure 89:

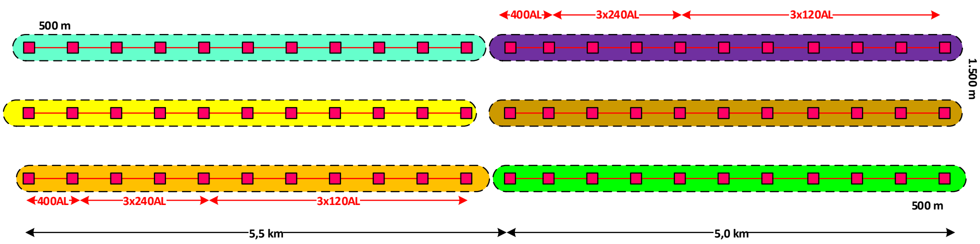


Figure 89 Option 1 – Alternative 1 – Array cable cross sections

Three different conductor sizes are recommended to achieve a feasible mix of production planning (expensive to start up short lengths). The conductor sizes along the strings are further selected from a load capacity and voltage drop criteria.

Type	**Length *)**
3x400mm^2 Al	3.3 km
3x240mm^2 Al	9.9 km
3x120mm^2 Al	19.8 km

Table 25 Option 1 – Alternative 1 – Cable lengths

*) The cable length between the WTGs assumes 50m cable each WTGs and also ca. 1% contingency for the route planning and seabed couture.
It is advised to install the array cables from individual cable drums transported to a rented quayside at the nearest port (Pipavav) and loaded to the cable installation vessel for a surface laid operation. The benefit will be a cost effective transportation of the cables since sea transport on a CLV with turntable mobilised could be more expensive and allow for the cost to the cable drums).

The optimal logistic planning separate drum vs. array cables delivered in long continuous length (cut during offshore installation) cannot be determined before proposals are given both from suppliers and installation contractors. The transit from the factory to the site shall be carefully assessed since it will have a direct impact on the cost and duration of the cable installation work.

It is advised to do a post lay burial operation with a suitable jetting/cutting tool and also organise a 3rd party survey for the DoB verification of the cable installer's As-built data.

Offshore export cables

The conductor size of the six export cables are determined purely from a voltage drop criteria.

Three strings ≈25 km each 3x400mm^2 Cu
Three strings ≈31 km each 3x630mm^2 Cu
No offshore cable joints should be planned – 2 or 3 flexible joints should be anticipated in each product delivered from the factory

CLVs today can be mobilised with large turntables and load 3x25km cables in a first loading/transit/laying operation campaign. (Possible also 3x31km in a 2nd campaign). This will give substantial cost savings since CLV time spent on transit and planning/mobilisation for separate loading operations can be saved.

It is anticipated that the number of boulders and crossing of other services are limited in number, thus it is suggested to plan the export cable installation on a simultaneous laying/burial operation – with a plough tool as the most suitable tool.

The distance between the export cable circuits shall be determined with sufficient space for an offshore repair joint installation and the following over-boarding in case a repair joint would be required during the operational lifetime. Over-boarding of an assembled offshore joint typically will be laid in an omega (over-length deviating from the straight cable alignment route) at the seabed and should allow two times water depth space for handling of cable ends and joint. Thus a separation in the range of 50-75m should be planned for and will require a total export cable corridor approx. 500m.

Landfall

It is advised that the offshore cable installation for each circuit commences with the landfall pull-in operation. The TJB shall be prepared to receive the offshore cables pulled in from the CLV approximately 300-500m from the high water level mark at the beach. The CLV distance will be determined by the seabed contour and the water depth required by the CLV. The cable pull-in should be planned as a straight line as far as possible taking the water current into consideration.

Figure 89 indicates a possible outline of the cable routing and burial options for the landfall.

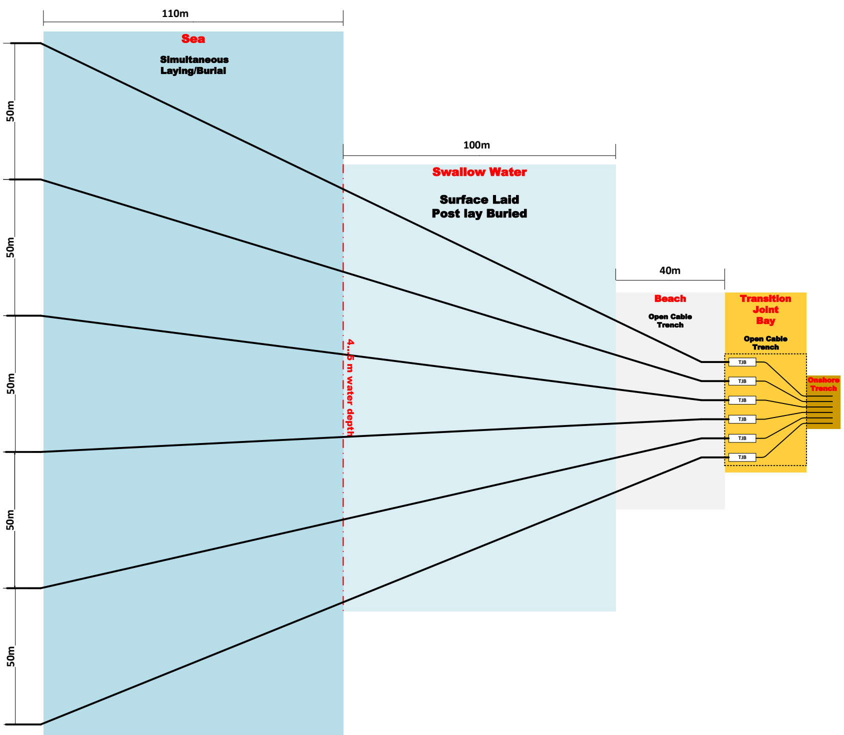


Figure 90   Option 1- Base Case – Indicative landfall routing & TJB

Transition joint bay

The wind farm developer shall identify a suitable location for the six transition joints that constitute the interface between the offshore and onshore cable systems.

The transition joint bay worksite could be active in up to one year prior to offshore work since the onshore cables often will/shall be ready before the offshore cable campaign commence. It is of paramount importance that adequate agreements with landowners are in place prior to signing the contracts with cable supply and installation contractors, in order to secure access to sufficient land.

The footprint of the TJB will be around 30m x 50m and will also involve construction of access roads necessary for the civil work and the mobilisation of the heavy cable winch. The worksite should be fenced and have 24/7 security guards in particular since eventual vandalism of the sea-cable after its installation could have severe consequences on the energisation program.

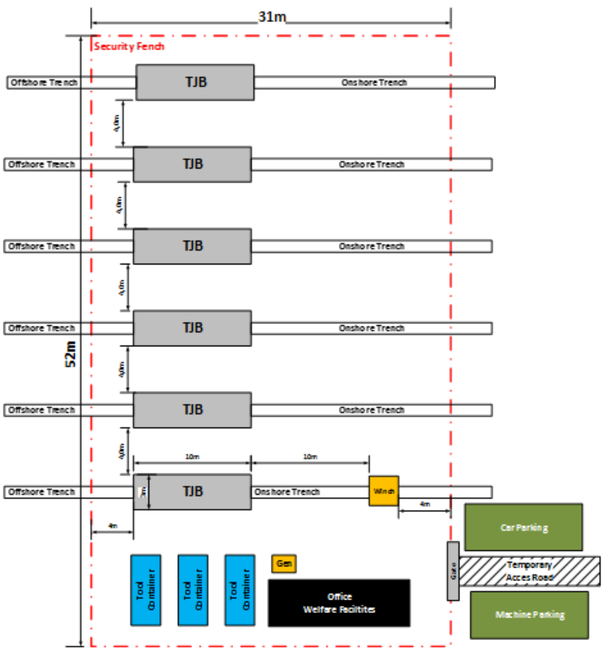


Figure 91 Option 1 – Base Case TJB Compound arrangement

The TJB will require careful planning by the developer in respect to program and interface management since various contractors will be active on a work scope as listed below:

- Mobilisation of site and access road civil work.

- Civil work onshore cable trench and joint.
- Cable pulling – onshore cable sections.
- Backfilling and reinstatement of onshore cable trench.
- Mobilisation of offshore cable winch.
- Opening of cable trench towards the beach.
- Offshore cable pulling.
- Assembly of cable armour clamp.
- Transition cable joint assembly.
- Backfill and reinstatement of cable joint bay.
- Demobilisation of site and removal of access road.

The above work will be implemented by around 2-5 different contractors. The risk for delay, unintended cable damage or improper quality will require the Employers full focus unless the project is implemented under a full EPCI contract, in which case the risk will lie with the EPCI contractor.

Onshore cable system

The maximum load current is calculated to approx. 575A for each export cable at full OWF production. The conductor sizing of the six 33kV onshore cable systems are designed for 3m separation account for the mutual heating between the circuits. A total corridor approx. 20m wide would be required.

An indicative selection table for 36kV single core XLPE-AL cables with the installation conditions assumed is shown in Table 26.
(F/T: Flat/Trefoil installation, CB: Cross-bonded or single earthed screens)

Current Capacity of Cables

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
36kV Single Core XLPE-AL Cable																	
"36kV" 1m/1,0 Km/W in selected sand --> 1,5 Km/W to consider soil outside // System distance 3m																	
36XLPE1x500Al-F-CB	660	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**527**
36XLPE1x630Al-F-CB	755	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**603**
36XLPE1x800Al-F-CB	855	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**683**
36XLPE1x1000Al-F-CB	960	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**767**
36XLPE1x1200Al-F-CB	1.040	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**831**
36XLPE1x1400Al-F-CB	1.115	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**891**
36XLPE1x500Al-T-CB	620	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**495**
36XLPE1x630Al-T-CB	710	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**567**
36XLPE1x800Al-T-CB	805	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**643**
36XLPE1x1000Al-T-CB	895	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**715**

Table 26 Option 1 – Base case – Cable Selection Table, Standard Trench

A single point bonded screen arrangement with parallel Cu wires *(can be shared between the circuits)* is advised with the 3x1c 800mm^2 XLPE-Al cable cores laid in a three foil formation. No road crossings requiring ducts are anticipated along the 500m cable corridor.

The standard installation (three core cable direct in controlled sand-fill) will make a loading ≈645A possible. The Contractor may choose to install the cables in pre-laid duct in close trefoil that will allow ≈580A, just at the limit of the max 575A required. In order to introduce a design safety margin and also consider larger burial depth e.g. 1.5m, a flat formation of the ducts separated 0.25m would increase the permissible loading significant as per below sketches and selection table.

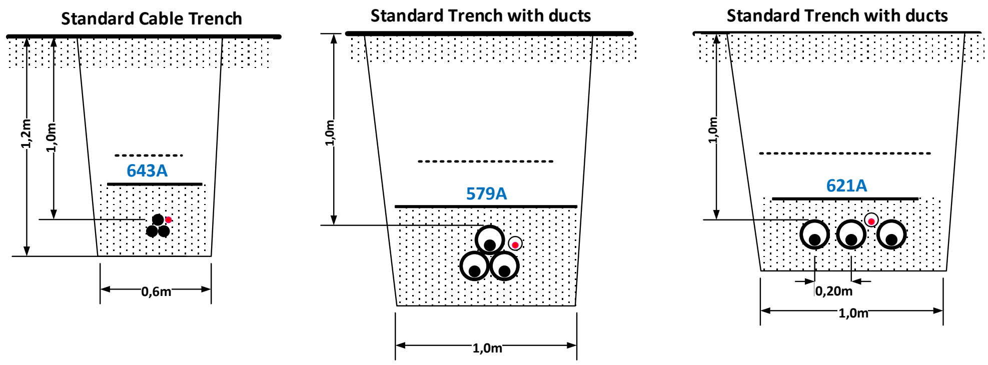


Figure 92 Option 1 – Base Case – Standard Onshore Cable Trenches Suggested

Current Capacity of Cables																	
Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
36XLPE1x800Al-T-CB	805	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	6	0,93	1,10	**0,80**	**643**
36XLPE1x800Al-T-CB	805	30	0,93	1,00	1,00	1,50	0,84	Y	0,90	De	1,00	3000	6	0,93	1,10	**0,72**	**579**
36XLPE1x800Al-F-CB	855	30	0,93	1,00	1,00	1,50	0,84	Y	0,90	200	1,01	3000	6	0,93	1,10	**0,73**	**621**
36XLPE1x800Al-T-CB	805	35	0,89	1,50	0,95	1,50	0,84	Y	0,90	De	1,00	3000	6	0,93	1,10	**0,65**	**526**
36XLPE1x800Al-F-CB	855	35	0,89	1,50	0,95	1,50	0,84	Y	0,90	250	1,03	3000	6	0,93	1,10	**0,67**	**576**
36XLPE1x800Al-F-CB	855	35	0,89	3,00	0,86	1,50	0,84	Y	0,90	500	1,13	3000	6	0,93	1,10	**0,67**	**572**

Table 27 Option 1 – Base Case – Cable Selection Table, Road Crossings

Should road crossings with ducts and larger burial depth occur then the 800mm^2 Al conductor will have insufficient capacity unless a spacing of the single cores is made in-between the cable ducts. When designing the cable crossing of asphalt roads also an increased soil temperature from the solar radiation on the surface should be considered. (A simple approach suggested is adding 5^{o}C to the native soil temperature). For small roads an excavation and pre-lay of the cable ducts usually can be agreed with the road authorities. This also could allow an agreed design with cable/ducts embedded in concrete that can secure proper thermal resistivity and mechanical protection of the cables. Depending on the burial depth it will be necessary to place the cables in a flat formation separated approx. 0.25m.

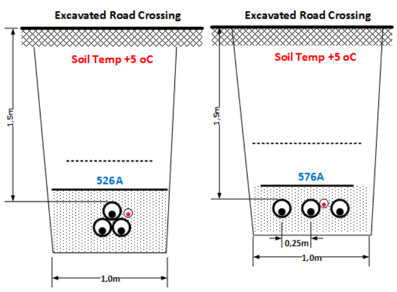


Figure 93 Option 1 – Base Case
Cable Trenches Road Crossings

Pre-excavation of larger roads is seldom accepted by the road authorities. Then a horizontal directional drilling operation with three separate ducts must be implemented. The ducts will often approach a depth of around 3-4m thus imposing a significant derating of the cable load capacity. The HDD operation will not allow mitigation/design to improve the soil thermal resistivity. This, however, is counteracted by the large depth which approaches the underground water level (since the installation is nearby the cost line). The only mitigation possible to improve the cable load capacity is increasing the distance between the ducts and inject bentonite/grout with low thermal resistivity after the cables are pulled. If this is insufficient – a larger cable conductor must be used to the particular section.

Table 27 addresses a road crossing with ducts and indicates three ducts buried/drilled at 3m and separated 0.5m will have 572A capacity compared with the 498A for the single core cables laid in close trefoil. (575A is the requirement). In-situ and laboratory thermal resistivity measurements on samples is a must for the design and selection of the crossing layout.

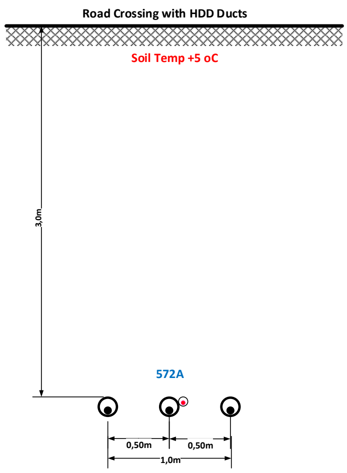


Figure 94 Road Crossing with HDD

The combinations of cable sizes and installation conditions are numerous, and hence a firm selection of the cable conductors shall not be done before a detailed design is implemented for the consented cable corridor with the soil characteristics known.

The cable systems in the suggested corridor is placed on a greenfield site that does not collide with outer underground services (exiting cables/pipe lines). Thus it is anticipated that a sequential opening/cable pulling/backfilling installation approach can be implemented in an open excavated trench. If not, then a duct system could be considered to ease the civil work, but this could provoke an increase to 1000mm^2 Al conductor size as discussed above.

It should be mentioned that should a 20m corridor not be possible – then a cable concrete culvert with the cable circuits laid in air on cable ladders be considered. This option could be sustainable and cost attractive for short lengths but also introduce several design challenges in respect to securing the cables against vandalism or unintended damage caused by collapse of the top cover. It shall be mentioned that natural ventilation of the air to the surroundings also must be considered to avoid overheating of the cables.

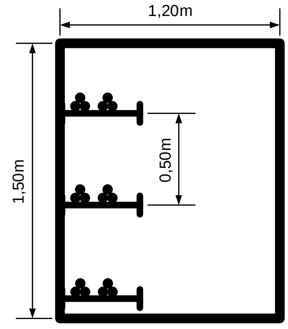


Figure 95 MV cables installed in concrete culvert

Wind farm substation

The 33/220kV wind farm substation onshore (ONSS) should be located as close as possible to the shore to reduce the amount of the six 33kV export cable circuits.

The substation is intended to provide standard facilities for automatic operation of the plant, security, and comfort facilities for maintenance staff. It is suggested to design a prefabricated substation building with all necessary installations, including:

- LV power system
- Internal lighting
- AC and heating/cooling
- Sanitary installations
- Fire detection
- Lightning protection
- Access control, extruder alarm and security installations.

The WF ONSS will comprise:

- Substation facilities
  - Fence, access roads.
  - Gate and safety control.
  - Internal roads & parking area.

- Space for O&M spare parts for the wind farm and power systems.

- Two 115 MVA 220/33kV main transformers.

- 220 kV outdoor switch yard consisting of a:
  - Single busbar
  - Two transformer bays
  - One cable line bay

  - 220 kV harmonic filter system on separated line bay
  - Support structures, insulators, bar wires, connectors/clamps etc.
  - Earthing and lightning protection system.

- 33kV outdoor equipment
  - Two 33/.4kV station auxiliary transformers.
  - Neutral earthing resistor.
  - STATCOM plant connected to 33kV busbar.

- Prefabricated substation building with all necessary installations, including:

  - 33kV switchgear with protective relays.
  - SCADA, protection relays panels.
  - LV main switchboards and distribution systems.
  - UPS and DC power systems.
  - Internal lighting.
  - Escape lighting.
  - Air conditioning and heating.
  - Sanitary installations.
  - Fire detection.
  - Lightning protection.
  - Access control and security installations.

- Cable systems for:
  - 33kV cable systems.
  - LV, UPS & DC systems.
  - Small power, lighting, and communication.

The sketch in Figure 96 shows a possible layout of the substation. The sketch is only intended to give a first indication of the footprint required. A more exact layout shall be developed and presented to the TSO and other relevant authorities. The design shall be based on Indian practice and will not have substantial different requirements to layout compared with other Indian HV substations. Consequently, only very high level indicative arrangement drawings and single line diagrams are presented in this advisory design report.

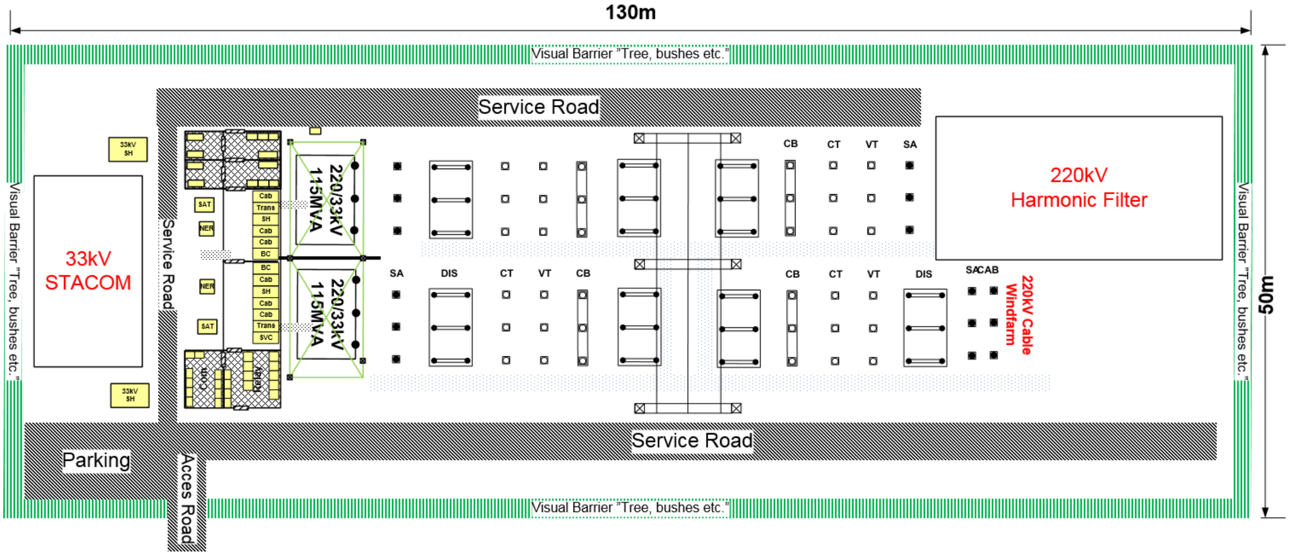


Figure 96 Option 1 – Base case – ONSS indicative arrangement.

HV interconnector to Grid SS

The HV interconnector between the ONSS and the Grid SS is anticipated to be designed, installed and operated by the wind farm developer.

The load capacity requirement will be ≈495 A.

A 220kV underground cable circuit is advised assuming that only 2-4km distance exist between the WF ONSS and the Grid SS. A very preliminary cable corridor is shown in the figure. An overhead line could be a cost attractive alternative offering lower CAPEX but will require yearly maintenance compared with the underground cable systems being maintenance free. The OHL also will have a larger exposure to vandalism, and damage due to environmental impact (corrosion, pollution on insulators, lightning risk etc.) The cable corridor suggested passes uncultivated fields but also crosses a large road and water canal that cannot be excavated in an open trench.

Figure 97 Option 1 – Base Case – 220kV cable route suggested

It is recommended to design a pre-laid duct system as a standard for the cable circuit. The drawbacks will be increased cost to ducts and requirement of a cable with a larger conductor. (Most possible one increased standard size). Benefits could be increased mechanical protection of the cables during installation and operation and a separation between the civil work related to the cable trench and the cable pulling operation. This will give a better interface between two potential contractors and can have program benefits as well. (In particular if environmental restrictions apply for the trench work

A single 220kV underground cable circuit 3x1c x 630mm² XLPE Al (cross bonded screens) laid in ducts as indicated in Table 28 is suggested.

Current Capacity of Cables

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
230 kV XLPE-AL Land Cables in ducts with selected sand 1.0 Km/W ---> 1.5 Km/W to account for soil																	
245XLPE1x500Al-T-CB	620	30	0,93	1,50	0,95	1,50	0,84		1,00	De	1,00		1	1,00	1,10	**0,82**	**506**
245XLPE1x630Al-T-CB	710	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**522**
245XLPE1x630Al-F-CB	740	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**544**
245XLPE1x800Al-T-CB	805	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**591**
245XLPE1x1000Al-T-CB	900	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**661**
245XLPE1x1200Al-T-CB	970	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**713**
245XLPE1x630Al-T-B	670	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**492**
245XLPE1x800Al-T-B	745	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**547**
245XLPE1x1000Al-T-B	820	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**602**

Table 28 Option 1 – Base case – 220kV onshore cable selection table.

The cable system can also be designed with ducts placed in close trefoil if an 800mm² Al conductor is selected. (This is an optimisation to be carried out by the cable contractor having the detailed and updated insight to cost of the cable and civil work components).

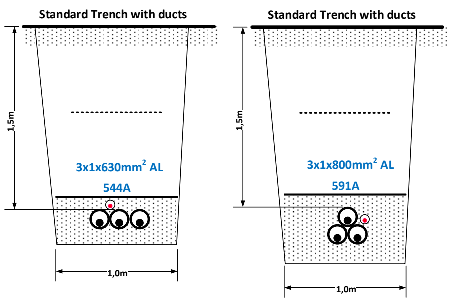


Figure 98 220kV Onshore Cable Trenches Typical Arrangement

The cross bonding will require that the assumed 2.5km cable is jointed in three approximately equal lengths to achieve optimal reduction of the circulating screen currents.

The crossing of the large road and water canal is suggested with no-dig technology offered by the HDD. The 495A load capacity can be maintained by increasing the separation between the cable cores as indicated in the table and sketch below, Table 29 and Figure 99.

Current Capacity of Cables														
Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	Qty.	faktor	A
245XLPE1x630Al-F-CB	740	35	0,89	1,50	0,95	1,50	0,84	Y	0,90	De	1,00	1,10	**0,70**	**520**
245XLPE1x630Al-F-CB	740	35	0,89	3,00	0,86	1,50	0,84	Y	0,90	400	1,11	1,10	**0,71**	**523**
245XLPE1x630Al-F-CB	740	35	0,89	4,00	0,83	1,50	0,84	Y	0,90	500	1,13	1,10	**0,69**	**514**

Table 29 220kV onshore cable – selection table – crossings

The accuracy of the HDD operation will depend on the soil characteristic and the equipment used and may force a minimum 0.5m distance. The successful HDD operation will depend on a geo-technical survey implemented at the crossing point to establish a sound basis for the profile and selection of tools. A road crossing with excavated trench and pre-laid ducts placed horizontal and close to 1.5m depth will also secure the load capacity of the 3x1c x630mm^2 Al cable circuit.

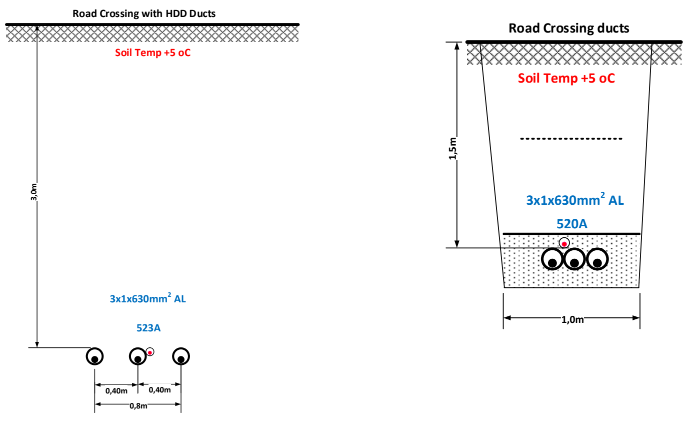


Figure 99 220kV cable – onshore HDD and road crossing arrangment

Grid SS connection

The extension (or newly built) Getco's 220kV grid substation with an outdoor 220kV line bay ready to receive the power from the OWF is anticipated to be planned, designed, build, commissioned by the transmission operator. The work scope and interfaces shall be detailed in a power purchase agreement that should be completed early in the project planning and also be coordinated with the power system grid studies.

The Grid SS will be the point of connection to Getco's 220kV grid and shall consider the following interfaces:

Component	Wind farm	Getco
220 kV cable	220kV cable, cable termination incl. Structure.	220kV surge arrestor on support structure. 220kV cable bay with circuit breakers, disconnectors, earth

		switches, instrument transformers
Fibre Optical Communication	Fibre optical cable from line bay to control room	Optical distribution frame, internal FOC to relay panels
220kV relay protection	Delivery of line differential protection relay panel. Functionalities and protocol to WF ONSS relays shall be coordinated	Built-in and commissioning of cable protection relay systems.
Tariff meter	No input	Energy measurements and tariff equipment/panels as per PPA
SCADA	The interrelation between the OWF and TSO SCADA shall be detailed in respect to exchange of data (operational performance, position of switching devices, energy measurements, production forecasts, etc.) The authorisation to implement switching operations of the 220kV breakers at the Grid SS and the ONSS also shall be defined.	

Table 30 High level interface matrix – TSO vs. OWF developer

The substation arrangement will be defined by Getco's internal standards and guidelines and will not be addressed further in this report.

Optimisation Potential

The number of 33kV radials (six) can be reduced if larger cable conductors are selected. The main objective of this would be reducing the CAPEX. The cost savings would mainly be driven by the fewer export cables and a shorter total installation campaign. Possible routing and sizing of the array cables for five and four array cable strings respectively are illustrated below.

Five 33kV Strings

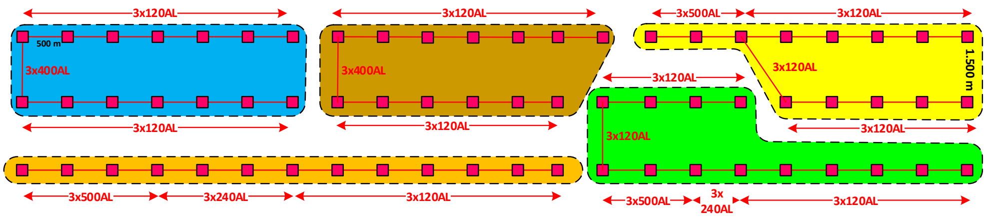


Figure 100 Option 1 – Alternative 1 – Array cable routing and cross section

Four 33kV Strings

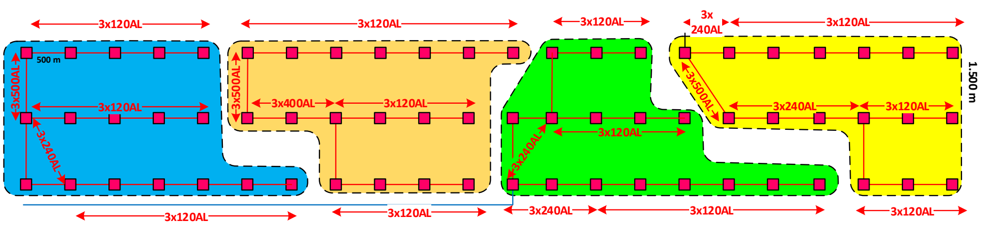


Figure 101 Option 1 – Alternative 2 – Array cable routing and cross section

The aggregated cable length and indicative supply/installation cost summarised are tabled below, Table 31:

Cable Size	Six Radials	Five Radials	Four Radials
	km	km	km
MV Sea Cables	**202.0**	**177.6**	**157.2**
33_3x630cu	0.0	50.0	0.0
33_3x800cu	0.0	92.0	55.5
33_3x1000cu	0.0	0.0	60.0
33_3x120Al	19.8	26.9	27.8
33_3x240Al	6.6	2.2	8.1
33_3x400Al	6.6	2.7	1.1
33_3x500Al	0.0	3.9	4.7
33_3x630Al	75.0	0.0	0.0
33_3x800Al	93.0	50.0	0.0
MV Cable Systems, Onshore	**3.0**	**2.5**	**2.0**
33kV 3x1x800Al	3.0	0.0	0.0
33kV 3x1x1200Al	0.0	2.5	0.0
33kV 3x1x800Cu	0.0	0.0	2.0
HV Cable Systems	**2.5**	**2.5**	**2.5**
Onshore: 3x1c630Al	2.5	2.5	2.5

Supply & Installation Cost [Euro x10^6]			
MV Cable offshore			
Cable & Equipment supply	19.2	23.1	25.6
Installation	106.7	95.4	86.6
MV Cable onshore			
Cable & Equipment supply	0.4	0.4	0.4
Installation	0.5	0.4	0.3
HV Cable offshore			
Cable & Equipment supply	0.0	0.0	0.0
Installation	0.0	0.0	0.0
HV Cable onshore			
Cable & Equipment supply	0.8	0.8	0.8
Installation	0.2	0.2	0.2
Total	**127.8**	**120.4**	**114.0**
Power loss at max. load [kW]	**11,585**	**9,002**	**9,914**

Table 31 Option 1 – Cable length, power losses & CAPEX comparison

The four string option with 3x800Cu and 3x1000Cu cables is not considered a suitable design if duct systems at the landfall are used below 2 m burial depth. (The increased burial depth will cause additional heating and demand even larger conductors). 3x1000 mm Cu cable may also be difficult to install in the WTG due to the large minimum bending radius.

The installation cost in addition to laying/burial operations also comprises supply/installation at the WTGs in relation to:

- Termination of cables to connector units.
- Connector units.
- Cable Protection Systems.
- Hang-offs.

- Fibre optical splice boxes.

The options in addition to the lower CAPEX also will have programme benefits since a faster offshore installation campaign for the export cables can be planned for:

- The area required at the landfall will be smaller.
- The width of the requested cable corridor onshore from TJB to the ONSS will be narrower.

Drawbacks could be:

- Reliability/availability factor will be reduced.
- The large cross-sections may not be standard from the suppliers and will require additional qualification/type test of cables and accessories.
- The switchgear will be utilised closer to its limit.
- The large cable size above 630 mm² may introduce installation issues in the WTG.

A more comprehensive cost assessment also addressing the substation cost and capitalised energy losses for a number of options are presented and discussed in Section 8.

Appendix B Option 2. 3MW WTG with 220kV Export Cable

High level power system topology

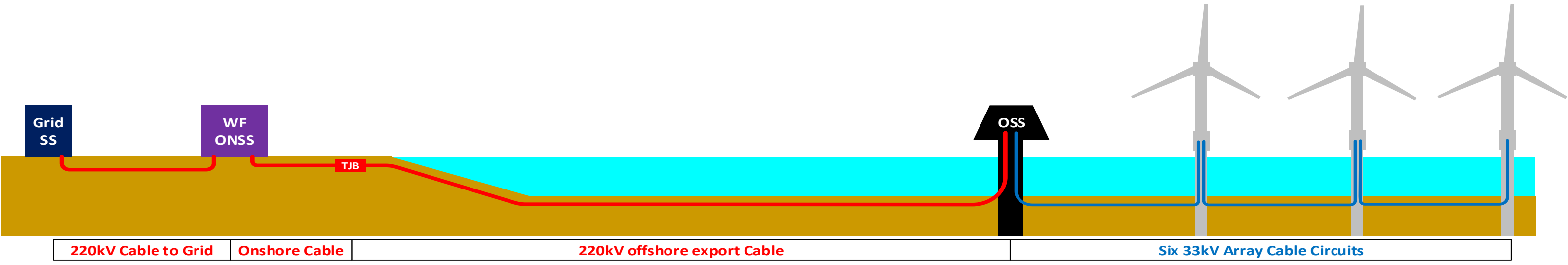


Figure 102 Power System Components - High Level Option 2

This concept offers a solution with the collection substation located offshore where the distribution voltage is stepped up to high voltage suitable for direct transmission to the onshore grid substation via the WF ONSS. The concept implies that the large number of long 33kV export cables can be avoided. Only one 220kV submarine cable to the WF ONSS is advised. (A second 220kV export cable will offer redundant power supply and higher availability factor for the OWF. However, the increased CAPEX can't be justified by improved operation of the OSS "energy sales" during maintenance or disconnection of the single cable caused by cable repair should a cable failure occur). The array cables can be operated at a higher operational level 34kV [6] voltage level since the voltage drop in the system does not include the long MV cables to shore thus the voltage level criteria becomes less restrictive and smaller conductor sizes may be possible for some sections.

Table 32 shows a simplified selection table of possible number of 34kV array cables only restricted by the limitation given by the 34kV cable circuit breaker rating (1250A) offered from the GIS suppliers. The radial current will be slightly smaller since the power losses and the increased voltage in the cable radial is not considered. This is considered in the load-flow calculations implemented and reported in later sections of this advisory design report.

Wind Turbine Generator Rating					**3,0 MW**		**34 kV**		**Cosphi**	**0,97**	**52,5 Amp**	
Layout	6 Radials			5 Radials			4 Radials			3 Radials		
Radial	WTG	MW	A	WTG	MW	A	WTG	MW	A	WTG	MW	A
1	11	33,0	578	14	42,0	735	17	51,0	893	22	66,0	1.155
2	11	33,0	578	14	42,0	735	17	51,0	893	22	66,0	1.155
3	11	33,0	578	14	42,0	735	16	48,0	840	22	66,0	1.155
4	11	33,0	578	12	36,0	630	16	48,0	840			
5	11	33,0	578	12	36,0	630						
6	11	33,0	578									
Sum	**66**	**198**	**3.466**	**66**	**198**	**3.466**	**66**	**198**	**3.466**	**66**	**198**	**3.466**

[6] 34kV operational voltage will allow 2kV increase from the OSS to the last WTG to stay below maximum 36kV permissible voltage.

Table 32 Option 2 – Preliminary Selection Table – Array Cable Radial Number

The table illustrates that three to six array cable radials could be implemented.

The alternative with only three export cables is not found sustainable since it will not leave much safety margin against the circuit breaker 1250A rating and also requires very large cable sizes that could be produced but are found inappropriate due to cost and handling parameters at the WTG's.

The base case topology selected for the advisory design is with six array cable circuits. The alternative with four array cable circuits is also analysed in load-flow studies to select suitable conductor sizes (based on a voltage criteria and short circuit capability) and compute the investment cost and capitalised energy losses to make a CAPEX comparison between the alternatives. An even number of export cables could also be preferred since it allows a 50/50 distribution of the power between the two 220/34kV power transformers at the OSS. *(However, this should not be the argument for determining the overall topology, since these units are engineered/manufactured to project requirements and no spare units will be procured anyhow).*

The high level power system topology with six array cables is illustrated in Figure 103 where the main substation components and cable conductor sizes are indicated.

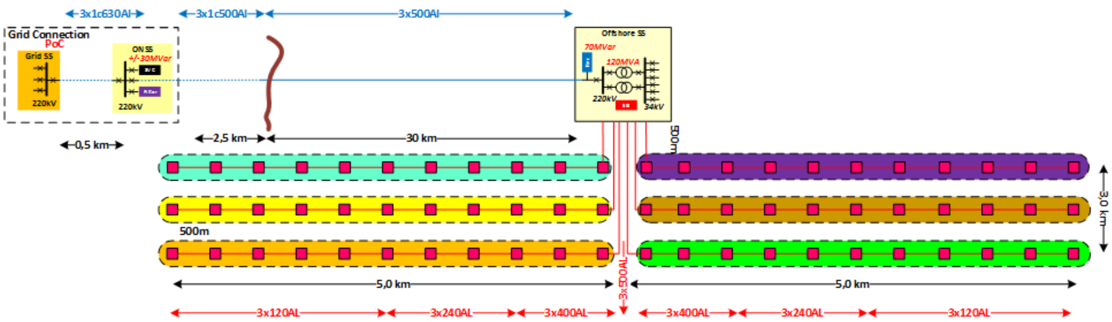


Figure 103 Option 2- Base Case – Power System Infrastructure Topology

The WTGs are grouped into six strings each interconnected to the OSS, and then to the WF ONSS via a 30km offshore 220kV export cable circuit and further to the Grid SS via 0,5km cable circuit.

The onshore power system consists of:

- TJB site, comprising one 220kV cable joint bay.
- 2.5 km cable corridor (2m wide) allowing one 220kV cable system to the WF ONSS.
- Onshore substation comprising main components as 220kV switchgear, STATCOM, harmonic filters, control building and other civil work, etc.

- 0.5 km underground cable circuit interconnecting WF SS with the Grid SS.
- 220kV linebay with kWh metering at the grid SS (PoC) all designed and constructed by the TSO.

The anticipated outline of onshore power infrastructure system (depends on the Grid SS location) as indicated in the map in Figure 104:

Figure 104 Option 2 – Onshore Cable Route & Substations Suggested

Rating of equipment

The wind farm power system comprises WTGs and switchgear, 33kV array cable systems, a 33/220kV offshore substation, 220kV export cable, 220kV substation adjacent to the extension of the 220kV grid onshore substation at the Indian TSO Getco. The SLD's below give a more detailed description of the configuration of the 0.4/34/220kV components.

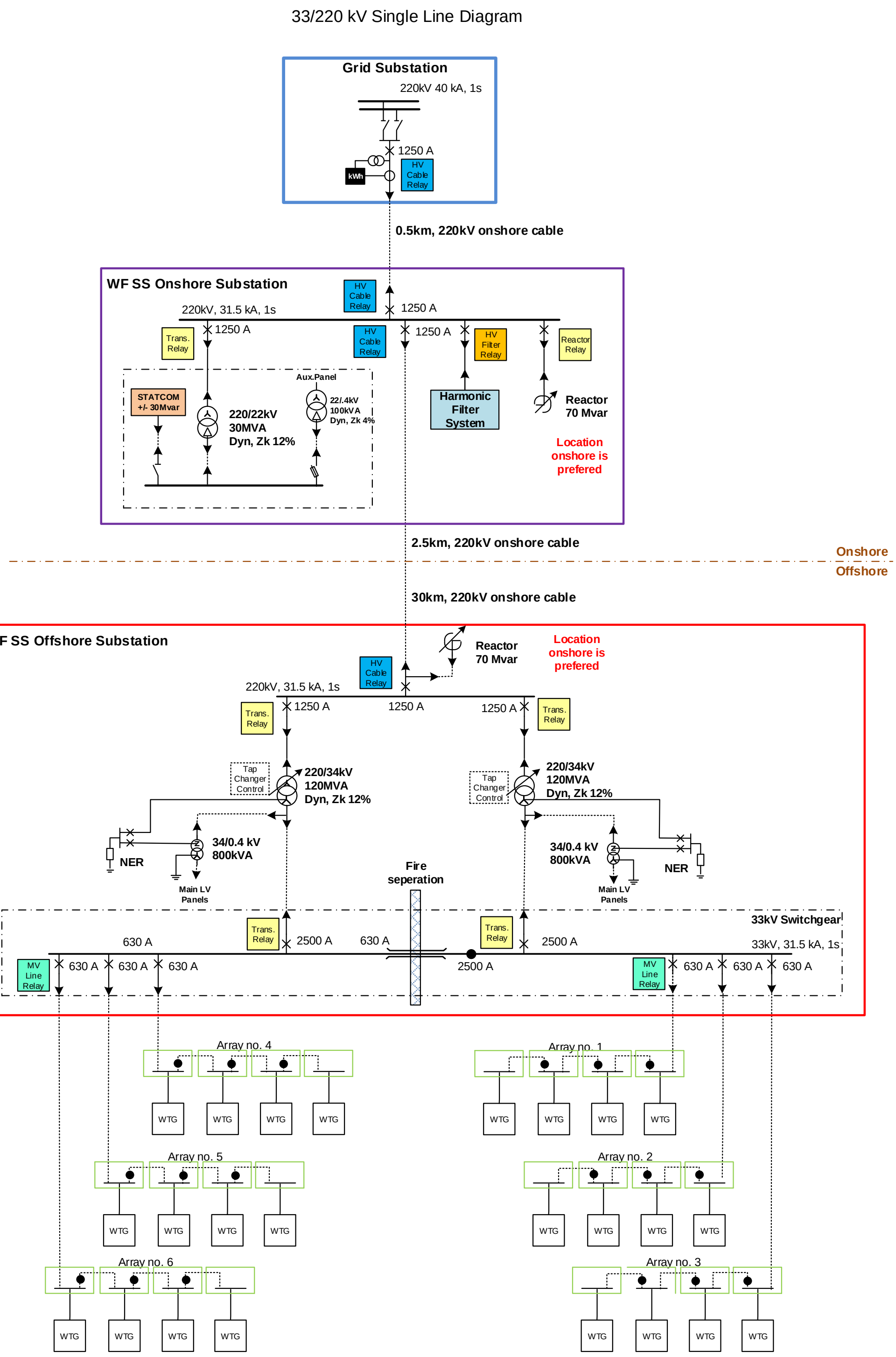


Figure 105 Option 2 – Base Case – Simplified High Level Single Line Diagram

The two shunt reactors indicated (≈70MVar in total) are sized to balance out the capacitance in the 220kV cable system at no WTG production. Given the short cable length it may be a solution to only install a shunt reactor at the WF ONSS. It shall also be noticed that the 220kV load current will depend on the location of the shunt reactor. (Higher currents if placed at WF ONSS). If placed at the OSS it is suggested to connect the shunt reactor directly to the 220kV feeder thus saving an expensive 220kV GIS feeder. A combined differential protection for the transformer/reactor will then be required.

The rating of the STATCOM and harmonic filter systems are indicative but scaled from other OWF projects implemented in UK on the assumption that the IEGC does not deviate significant from UK.

It is recommended that the 34kV switchgear is sectionalised with a bus-duct between two fire separated rooms.

The STATCOM is connected via a dedicated 220/22kV transformer[7]. The STATCOM system is often designed and supplied by the manufacturer as a separate and special part the onshore substation.

Reference is made to option 1 in respect to the relay protection systems that are based on same principles as the 33/220 kV onshore substation.

Operational philosophy

Emergency power demand

The WTGs will have its own power consumption as addressed in option 1.

The OSS also will require local power generation for lighting, HVAC and auxiliary systems (cranes, hoists, etc.) during periods when the 220kV export cable is disconnected (maintenance or fault). The emergency generator shall be tested from the fabrication yard and be ready for operation in the timespan from the OSS is installed and until to the commissioning and energisation of the ONSS has finished. During this period the emergency generator also shall power the cable pulling winch for the installation of the export cable and the six array cables. The generator rating will be determined when an OSS load demand table is established during the detailed design. The generator set will have a rating in the range of 400-800kVA for the OSS power consumption.

The gen-set can also be designed for power supply to WTGs in the scenario that a long outage of the 220kV export cable occur. This is however a design rarely selected since the power factor compensation related to the 34kV array cable capacitance will require investments in dedicated shunt reactor(s) and 34kV switchgear in the range of 3-4 MVar.

Power system reliability

Reference is made to option 1.

---

[7] The STATCOM can be connected at 15-36kV depended on size and manufactures preferred design.

The single 220kV offshore cable system constitutes a severe bottleneck and can have fatal impact the business case in the event of 3rd part damages or unprovoked failure. The duration of an offshore cable fault lasts 2-3 months depending on vessel availability/mobilisation/transit and weather conditions.

Consequently, larger OWF's > 400 MW most often are designed with two export cables.

Preliminary power grid study

In this advisory report, we have only included simplified and preliminary power system studies involving load-flow and short circuit calculations. The studies aim at selection of the cable conductor sizes and transformer/shunt reactor ratings.

The present option does not include long 33kV export cables, thus the voltage drop criteria is less important. The maximum voltage of cable and apparatus will be 36kV. The power transformers on the OSS must be designed with automatic voltage regulation facilities thus online tap changers 10x +/-1.25% is suggested to account for voltage fluctuation in the regional power grid (+/- 10%) and the impact from the wind farm at high or no-production scenarios.

Given the shorter MV radials (compared with option 1) the MV busbar voltage at the OSS can be maintained at a higher voltage 34kV at all operational scenarios. This will give less current and could make possible some of the array cables could be selected with a smaller conductor than compared with 33kV operational voltage level.

Two 120MVA 220/34kV power transformers each rated for half OWF production is advised and will give approx. 20% spare capacity should one of the transformers be faulty or out for maintenance. The OWF will deliver 2x 101MVA to the ONSS 34kV busbar.

Thus approx. 20MVA production is allowed via the 34kV bus-coupler in the OSS should one of the power transformers be disconnected. This will bring the energised transformer in a full load operation 120MVA. (Even more than +20MVA can be allowed in short duration since the overload capacity of the transformers are large and the condition (oil and winding temperature can be monitored on-line and give accurate data to the system operators in the control room).

One 220kV shunt reactor each 70MVar is suggested to compensate for the capacitance in the 220kV and 34kV cables at no production. The shunt reactor can be either fixed or with regulation facilities. This cannot be firmly established before a full power system study with selected WTGs and a clear understanding of the prevailing grid code is completed. The rating of the shunt reactor will also be closely linked with the sizing of the STATCOM/SVC and the harmonic filters required at the onshore substation.

The 220kV components at the OSS and ONSS are rated to 31.5kA 1s. The 3 phase short circuit current at the OSS 34kV busbars are calculated to 17kA when the power transformers are selected with 12% impedance voltage thus 34kV switchgear may be designed to 25kA.

The WTGs can do with 20kA, 1s since the first array cable will damp the grid contribution and the WTGs only feed in around 1.25-1.5x load current (≈51-54A) during a 3ph short circuit fault.

The conductor sizes “120 mm² Al [11.3kA], 240mm2 Al [22.7kA]” are far down steam from the OSS 34kV busbar and will not be challenged by high circuit currents from the grid.

The power losses from the WTGs to grid SS (PoC) at full production are computed and summarised in Table 33:

Cable	Length	Power Loss
Array Cables		
3x120 mm² XLPE-AL	16.5 km	452 kW
3x240 mm² XLPE-AL	9.9 km	611 kW
3x400 mm² XLPE-AL	6.6 km	475 kW
3x500 mm² XLPE-AL	12.3 km	942 kW
220kV Export Cable System		
3x500 mm² XLPE-AL	30.0 km	1.761 kW
33/220 kV Power Transformers	---	857 kW
220kV Export cable to grid SS	3.0 km	138 kW
Total	**78 km**	**5 MW**

Table 33 Option 2 – Base Case – Cable Length & Power Loss Summary

It is observed that the 220kV export cable accounts for less than 40% of the total power losses. Still the 220kV cable power losses constitutes a significant contribution to the total power losses that reduces the OWF power delivered to the PoC to 193MW.

The 5MW power system losses could be an argument for the developer to install one or two additional WTGs. The cost will be marginal but will ensure that full 200MW power can be delivered to the PoC. These additional WTGs also can contribute with production when other WTGs are out for planned maintenance.

Array cable circuits

The internal MV cable circuits within the wind farm is organised in 6 strings. The prime criteria for the cable route design is aiming at a routing with as few km cables as possible even if it may provoke larger conductors upstream against the shore. The park layout in three rows with the export cables approaching from west invites to organising the six strings as indicated below with the OSS placed north of the park in the middle of the 22 WTGs located in three rows.

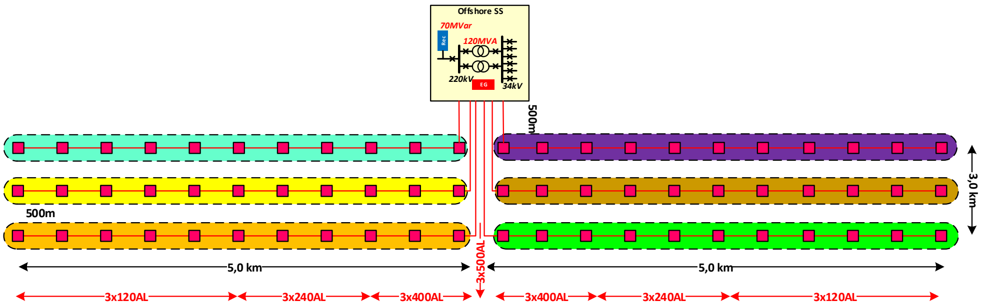


Figure 106 Option 2 – Base case – Array Cable Layout & Conductor Cross Sections

The conductor sizes along the strings are selected from a load capacity only. The suggested operational voltage 34kV at the OSS MV busbar and the relative short lengths of the radials do not cause risk of unaccepted voltages above maximum 36kV at the most remote WTG's.

Four different conductor sizes are identified:

Type	Length *)
3x120mm^2 Al	16.5 km
3x240mm^2 Al	9.9 km
3x400mm^2 Al	6.6 km
3x500mm^2 Al	12.3 km
Total	**45.3km**

Table 34 Option 2 – Base case – Cable Length Summary

***)** *The cable length between the WTGs assumes 50 m cable between each WTG and also approx. 1% contingency for the route planning and seabed couture.*

Replacing the 400mm2 conductors with 500mm2 may be cost optimal to achieve a feasible mix of production planning (expensive to start up short lengths).

The laying and burial operation suggested is surface laying followed by PLB operation as discussed in option 1.

Offshore substation

HV & MV System

The electrical system comprises the following:

› Two 120MVA, 34/220kV Power transformers.

- One 70MVar, Shunt reactor (connected direct to export cable feeder.
- One 220kV GIS – single busbar – three bays.
- Two 800kVA 34/0.4kV auxiliary transformers.
- Two neutral resistors for 34kV system.
- Two separate 34kV GIS located in fire separated rum and connected with a bus-duct.
- Protective relay systems either housed in the GIS front or in separate panels.
- 220kV cable systems interconnecting transformers/reactors with the GIS.
- One 220kV cable system from GIS to cable deck joint connecting to the offshore export cable *(joint assembled offshore after cable pull-in).*
- 34kV cable systems connecting the transformers with the GIS.
- Six 34kV cable systems from GIS to cable deck joint connecting to the offshore array cables *(joint assembled offshore after cable pull-in).*

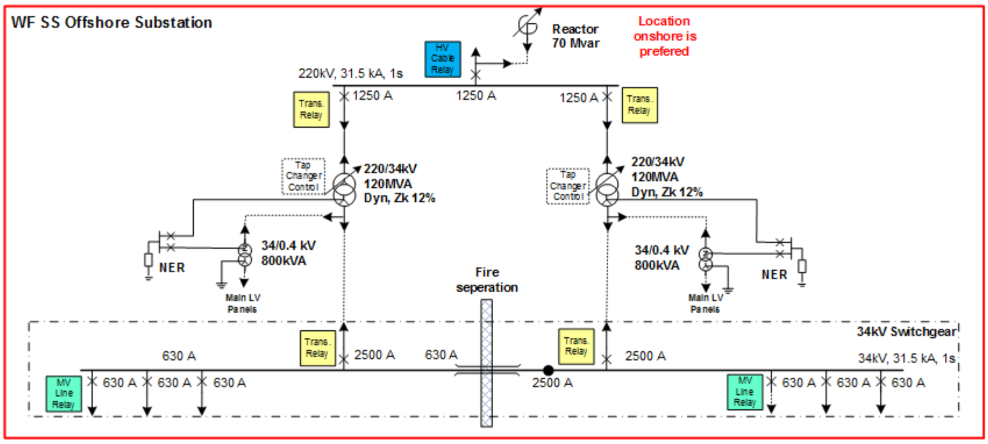


Figure 107 Option 2 – High Level Single Line Diagram - OSS

LV power system

The LV systems shall be designed for powering the substation when no grid power is delivered due to a disconnected 220kV cable. A redundant LV power supply path is suggested via two auxiliary transformers connected directly to the 34kV bushings on the main power transformers. Two fire separated LV main switchboards are advised with the emergency generator connected to one of them. An outline of the main single line diagram for the LV power systems is shown in Figure 108.

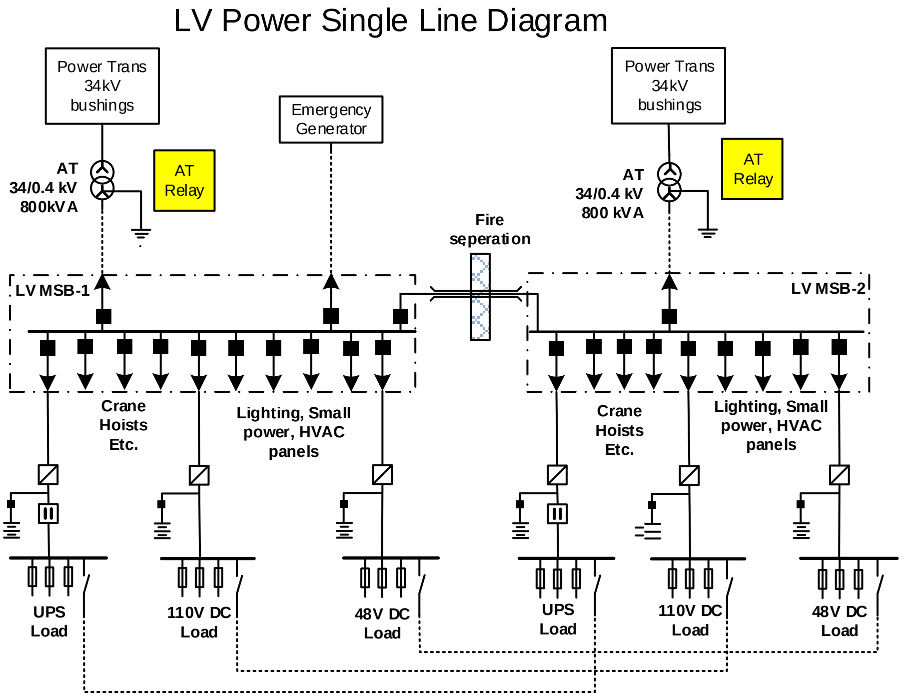


Figure 108 Option 2 – Suggested LV Single Line Diagram - OSS

The auxiliary transformers and the two UPS shall provide power to various components and utilities necessary for operating the OSS. The sizing of the auxiliary transformers shall be based on a total load demand table that includes diversity factors for the individual loads. The mapping of characteristics for the load shall identify the required duration (for DC-battery sizing) and reliability in respect to UPS and/or the redundancy power supply path.

Three possible levels of power reliability are illustrated in Figure 109 and shall be determined further during the detailed OSS design.

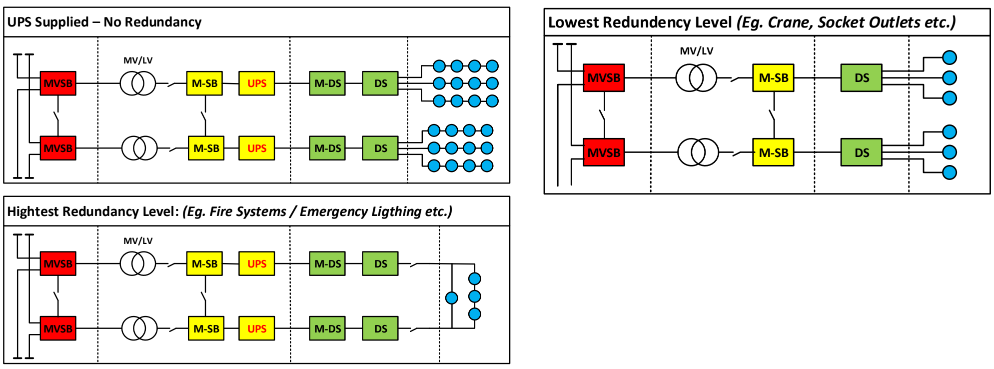


Figure 109 LV availability & redundancy - Typical Power Supply Options

The list below indicates the various load consumption items and is indicative only.

- Light and socket outlets.

- Control and remote operation of:
  - Power Transformers.
  - Shunt Reactor.
  - 33kV Switchgear

- Protective Relay Panels.
- SCADA Systems.
- Helideck.

- Mechanical Systems.
  - HVAC.
  - Cable Pulling Winch.
  - Sanitary waste water systems.
  - Cathodic protection systems.
  - Topdeck Crane installations.
  - Davit Crane Equipment.
  - HV Room Switchgear Crane.
  - MV Room Switchgear Crane.
  - Cable Deck Hoist.

- Utility Systems
  The OSS is usually designed with miscellaneous utility systems for announcement, communicating, remote monitoring, monitoring of parameters, marking of the topside module both for aircraft and ships and controlling of the topside module.

  - Public Announcement System.
    The PA system shall be able to communicate with other systems and as a minimum give alarm for the following:

    - Fire alarms.
    - Fire extinguishing.
    - Lights out: 'Lighting turns off in short time'.

  - CCTV system (for remote monitoring of selected vital parts on the topside module).

  - Radio Link.
  - Wireless network.
  - Telephone system.
  - VHF radio system.
  - Weather station.

  - Navigation/aviation system (e.g. installed two red low-intensity obstruction lights at the top of the antenna mast, and with an auxiliary control box placed inside the control room.

  - Vessel Traffic Management System (consisting of a radar system and an Automated Identification System (AIS).

  - Platform Structural Monitoring System.

- Fire & Safety Systems.
  - Fire alarm system.
  - Fire sprinkler System.
  - Fire Water Pump.
  - Foam Fire extinguishing system.
  - Inert gas fire-extinguishing system.
  - Transformer/reactor extinguishing system.
  - CO2 Fire extinguishing system.
  - Access control systems.
  - CCTV Monitoring Systems for HSE purpose.
  - Intruder Alarm System.

Offshore export cable

The load current for the 220kV export cable at full WTG production will depend on the operational voltage provided by the TSO at the grid SS PoC on the 220kV busbar. The extreme load currents with 70MVar connected at the OSS is tabled in Table 35:

Operational Voltage	Landfall	OSS
U_{opr_min} (90%): 198 kV	560 A	575A
U_{opr_nom} (100%):220 kV	510 A	515 A
U_{opr_max} (110%): 242 kV	470 A	470 A

Table 35 220kV Export Cable Load Current vs. operational voltage

The extremes are not considered relevant for longer time durations. The minimum voltage scenario also will be counteracted by the Grid SS busbar voltage increase generated by the wind farm at full production that is not considered in the simplified and preliminary load-flow analyses implemented for this advisory design.

I_{max} 540A is recommended as a robust base current for the conductor selection. A more accurate assessment can be done when a power system study taking into consideration the national/regional grid is done. The maximum load current will also depend on the TSO’s commitment in respect to voltage quality and duration that will form part of the power purchase agreement entered into between the wind farm developer and the TSO.

The conductor size of 220kV export cables are determined purely from a loading capacity criteria. The voltage drop at maximum load for the 30km will range in between 1.0-2.0% with the relevant conductor sizes.

The single 220kV export cable is a bottleneck in the power infrastructure system. The significant cost for HV submarine cable systems does not invite to installing a 2nd circuit to give redundancy. Thus the cable installation shall consider a sufficient burial depth offering protection against potential anchor damage. A burial depth of 1.5m is commonly adopted. The rating of the cable however should consider a larger depth to account for eventual seabed movement and sections where a larger burial depth could be required. Thus rating factors for the 220kV cable is advised to be 2.5m burial depth, soil thermal resistivity 0.7 Km/W at a 25°C soil temperature.

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
230 kV XLPE-AL Sea Cables																	
S230XLPE3x300Al	430	25	0,96	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,06	456
S230XLPE3x400Al	485	25	0,96	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,06	514
S230XLPE3x500Al	540	25	0,96	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,06	572
S230XLPE3x630Al	600	25	0,96	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,06	636
S230XLPE3x800Al	660	25	0,96	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,06	699
S230XLPE3x1000Al	720	25	0,96	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,06	763

Table 36 220kV sea cable – Selection table

A 3x500mm^2 XLPE-Al cable is suggested having 572A loading capacity when a 10% factor for load fluctuation is considered.
The sensitivity against changes in the design parameters is investigated in Table 37:

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
230 kV XLPE-AL Sea Cables																	
S230XLPE3x500Al	540	30	0,93	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,03	554
S230XLPE3x500Al	540	30	0,93	3,00	0,86	0,70	1,14		1,00		1,00			1,00	1,10	1,00	542
S230XLPE3x500Al	540	30	0,93	4,00	0,83	0,70	1,14		1,00		1,00			1,00	1,10	0,97	523
S230XLPE3x500Al	540	25	0,96	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,06	572
S230XLPE3x500Al	540	25	0,96	2,50	0,88	0,80	1,08		1,00		1,00			1,00	1,10	1,00	542
S230XLPE3x500Al	540	25	0,96	2,50	0,88	1,00	1,00		1,00		1,00			1,00	1,10	0,93	502
S230XLPE3x500Al	540	30	0,93	2,50	0,88	0,70	1,14		1,00		1,00			1,00	1,10	1,03	554
S230XLPE3x500Al	540	30	0,93	2,50	0,88	0,80	1,08		1,00		1,00			1,00	1,10	0,97	525
S230XLPE3x500Al	540	30	0,93	2,50	0,88	1,00	1,00		1,00		1,00			1,00	1,10	0,90	486
S230XLPE3x500Al	540	30	0,93	3,00	0,86	0,70	1,14		1,00		1,00			1,00	1,10	1,00	542
S230XLPE3x500Al	540	30	0,93	3,00	0,86	0,80	1,08		1,00		1,00			1,00	1,10	0,95	513
S230XLPE3x500Al	540	30	0,93	3,00	0,86	1,00	1,00		1,00		1,00			1,00	1,10	0,88	475

Table 37 220kV sea cable - Sensitivity Analyse on installation conditions

It is observed that:

- Soil temperature increase +5°C will de-rate 575A → 554A.
- Soil thermal resistivity increase 0.7 →0.8 will give a de-rating 575A → 542A.

The far most important factor is the soil thermal resistivity which will cause an unacceptable derating if values larger than 0.8 km/W occur. The table clearly illustrates why a suitable number of soil thermal resistivity must be taken into account in the front engineering phase prior to selection of conductor sizes.

No offshore cable joints should be planned – 3 or 4 flexible factory joints should be anticipated in each the products delivered from the factory

CLVs today easily can be mobilised with large turntables and load 30km 220kV cable in a single loading/transit/laying operation campaign*. (Could be even combined with eventual loading of long array cable sections should same cable supplier or nearby load out harbours be a logistic possible)*. This will give substantial cost savings since CLV time spent on transit and planning/mobilisation for separate loading operations can be saved.

It is anticipated that the number of boulders and crossing of other services are limited in number, thus it is suggested to plan the export cable installation on a simultaneous laying/burial operation – with a plough tool as the most suitable tool.

Landfall

It is advised that the offshore cable installation commences with the landfall pull-in operation. The TJB shall be prepared to receive the offshore cables pulled in from the CLV located approximately 300-500m from the high water level mark at the beach. The CLV distance will be determined by the seabed contour and the water depth required by the CLV. The cable pull-in should be planned as a straight line as far as possible taking the water current into consideration.

The illustration in Figure 110 indicates a possible outline of the cable routing and burial options for the landfall.

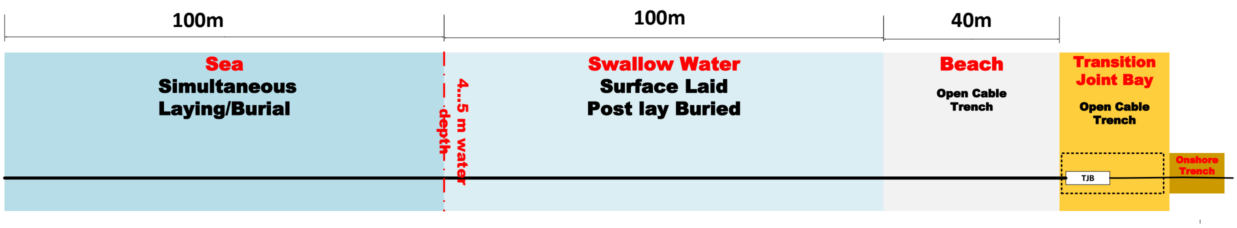


Figure 110 220kV Landfall – preliminary installation/burial methods suggested

It might be requested to apply additional protection of the 220kV cable at the beach and at the shallow water section. This could be designed as:

- Shallow Water Section.
  - Cable laying in a pre-excavated trench. Placing of stone/rock bags above the cable.
  - Surface laying of cable the seabed followed by post laid stone/rock bags above the cable.
  - Surface laying of cable at the seabed followed by post laid concrete mattresses.

- Beach
  - Cables laid in a pre-excavated trench and is post protected with semi pipes installed around the cables. (De-rating of the cable shall be considered).
  - Cables laid in a pre-excavated trench and is post lay protected with concrete mattresses.

Photos and illustration from UK supplier, Subsea Protection Systems Ltd

Transition Joint Bay

A possible outline of the 220kV transition joint bay work site is illustrated in Figure 111.

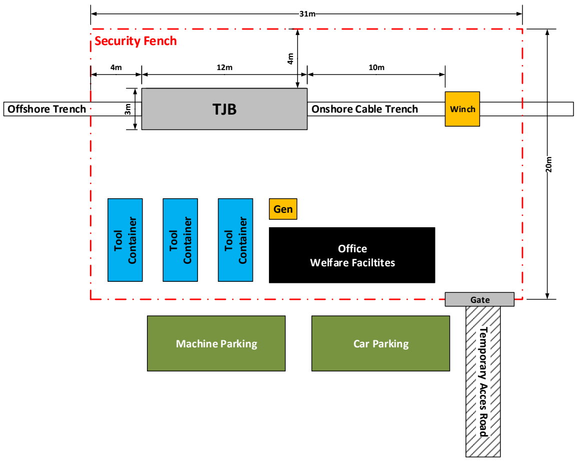


Figure 111 220kV TJB Compound arrangement

Further reference is made to option 1.

Onshore 220kV cable system to ONSS

The design load current is chosen to 540A as previously discussed.

A 220kV cable circuit installed in ≈2,5km pre-laid ducts is suggested with a route as

Figure 112 - Option 2 – 220kV onshore cable route

per the figure beside to the assumed location of the Grid SS.

The standard trench with three ducts placed in trefoil at 1.5 m burial depth will require 3x1c 800mm^2 Al with cross bonded screens when the conditions at eventual excavated road crossings and the HDD crossings are considered as illustrated in the selection table shown in Table 38.

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
230 kV XLPE-AL Land Cables in ducts with selected sand 1.0 Km/W ---> 1.5 Km/W to account for soil																	
245XLPE1x500Al-T-CB	620	30	0,93	1,50	0,95	1,50	0,84		1,00	De	1,00		1	1,00	1,10	**0,82**	**506**
245XLPE1x630Al-T-CB	710	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**522**
245XLPE1x630Al-F-CB	740	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**544**
245XLPE1x800Al-T-CB	805	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**591**
245XLPE1x1000Al-T-CB	900	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**661**
245XLPE1x1200Al-T-CB	970	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**713**
245XLPE1x630Al-T-CB	710	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**522**
245XLPE1x800Al-T-CB	805	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**591**
245XLPE1x1000Al-T-CB	900	30	0,93	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,73**	**661**
245XLPE1x800Al-F-CB	845	35	0,89	1,50	0,95	1,50	0,84	Y	0,90	De	1,00		1	1,00	1,10	**0,70**	**594**
245XLPE1x800Al-F-CB	845	35	0,89	3,00	0,86	1,50	0,84	Y	0,90	400	1,11		1	1,00	1,10	**0,71**	**597**
245XLPE1x800Al-F-CB	845	35	0,89	4,00	0,83	1,50	0,84	Y	0,90	500	1,13		1	1,00	1,10	**0,69**	**587**

Table 38 Option 2 – 220kV onshore cable selection table

Onshore Wind farm Substation

The purpose of the onshore substation is interfacing the 220kV offshore cable with the Grid SS and be equipped with apparatus that enable the wind farm to comply with the prevailing grid code.

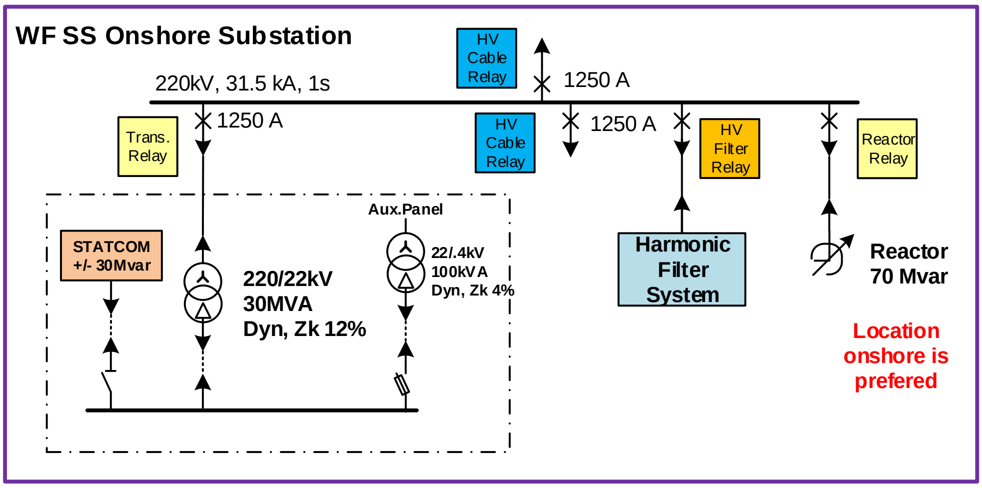


Figure 113 Option 2 – WF ONSS High Level Single Line Diagram

The ONSS will comprise:

- Substation facilities.
  - Fence, access roads.
  - Gate and safety control.
  - Internal roads & parking area.

- Space for O&M spare parts for the wind farm and power systems.

- 220kV outdoor switch yard consisting of a:

  - Single busbar.
  - Two cable line bays.
  - One cable line bay.
  - One line bay for 220kV Harmonic filter system.
  - One eventual line bay for a 70MVarshunt reactor if not installed at the OSS.
  - Support structures, insulators, bar wires, connectors/clamps etc.
  - Earthing & lightning protection system.

- Prefabricated substation building with all necessary installations, including:

  - SCADA, protection relays panels.
  - LV main switchboards and distribution systems.
  - UPS and DC power systems.
  - Internal lighting.

It is suggested to design a prefabricated substation building with all necessary installations, including:

- LV power system.
- Internal lighting.
- AC and Heating.
- Sanitary installations.
- Fire detection.
- Lightning protection.
- Access control, extruder alarm and security installations.

The sketch in Figure 114 shows a possible layout of the substation. The sketch is only intended to give a first indication of the footprint required. A more exact layout shall be developed and presented to the TSO and other relevant authorities by the developer during his conceptual design phase. The design shall be based on Indian practice and will not have substantial different requirements to layout or compared with other Indian HV substations. Consequently only very high level arrangement drawings and single line diagrams have been presented in this advisory design report.

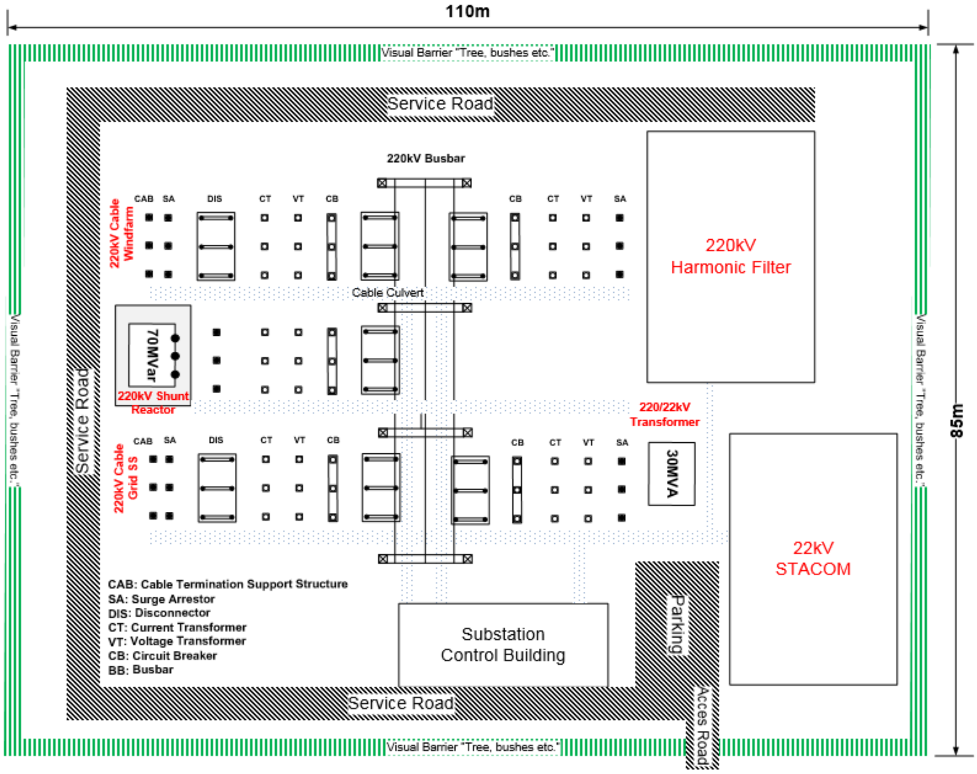


Figure 114 Option 2 – WF ONSS Indicative Arrangement

HV interconnector to Grid SS

Reference is made to option 1.

Grid SS Connection

Reference is made to option 1.

Optimisation potential

The number of 33kV radials (six) can be reduced to four if larger cable close to the OSS conductors are selected. The main objective is reducing the CAPEX. Possible routing and sizing of the array cables with four array cable strings are illustrated in Figure 115.

Four 33kV Strings

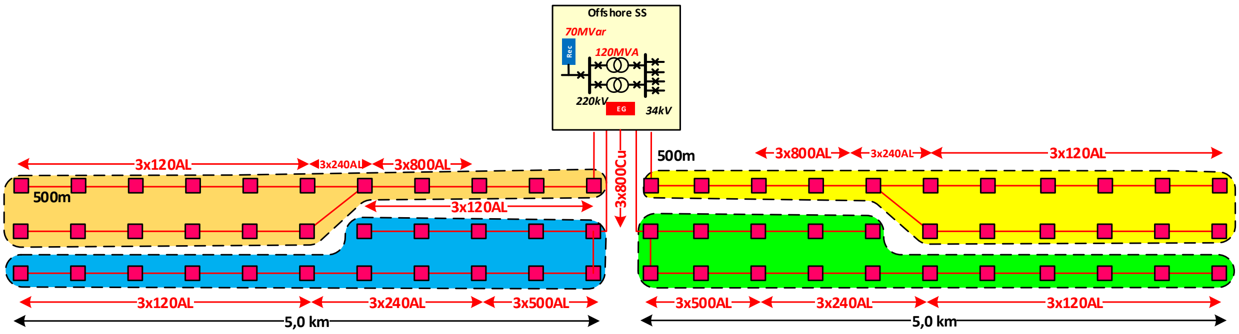


Figure 115 Option 2 – Alternative 1 – Array Cable Layout & Conductor Size

The aggregated cable length and indicative supply/installation cost summarised are tabled below:

Cable Size	Six Radials	Four Radials
	km	km
MV Sea Cables	**45.3**	**43.7**
3x120Al	16.5	20.9
3x240Al	9.9	7.5
3x400Al	6.6	--
3x500Al	12.3	5.3
3x800Al	--	2.2
3x800Cu	--	7.8
HV Cable Systems	**33.0**	**33.0**
Offshore: 3x500Al	30.0	30.0
Onshore: 3x1c630Al	3.0	3.0
Supply & Installation Cost [Euro x10^6]		
MV Cable offshore		
Cable & Equipment supply	3.0	3.6
Installation	33.7	33.0
MV Cable onshore		
Cable & Equipment supply	0	0
Installation	0	0
HV Cable offshore		
Cable & Equipment supply	12.8	12.8
Installation	15.5	15.5
HV Cable onshore		
Cable & Equipment supply	1.2	1.2
Installation	0.3	0,3
Total	**66.6**	**66.4**
Power loss at max. load [kW]	**5,212**	**4,793**

Table 39 Option 2 – Cable Length, CAPEX & Power Loss Summary

The four string option with 3x800Cu and 3x800Al cables is not considered a suitable alternative since total length and cost of cables are almost equal, thus the selection of a design with larger conductors and more cable sizes are not considered viable. The cost saving would be slightly larger since a saving from the two less 34kV GIS feeders is not considered in the above simple cost estimate.

Appendix C Option 3. 6MW WTG with 4x66kV Export cables

High level power system topology

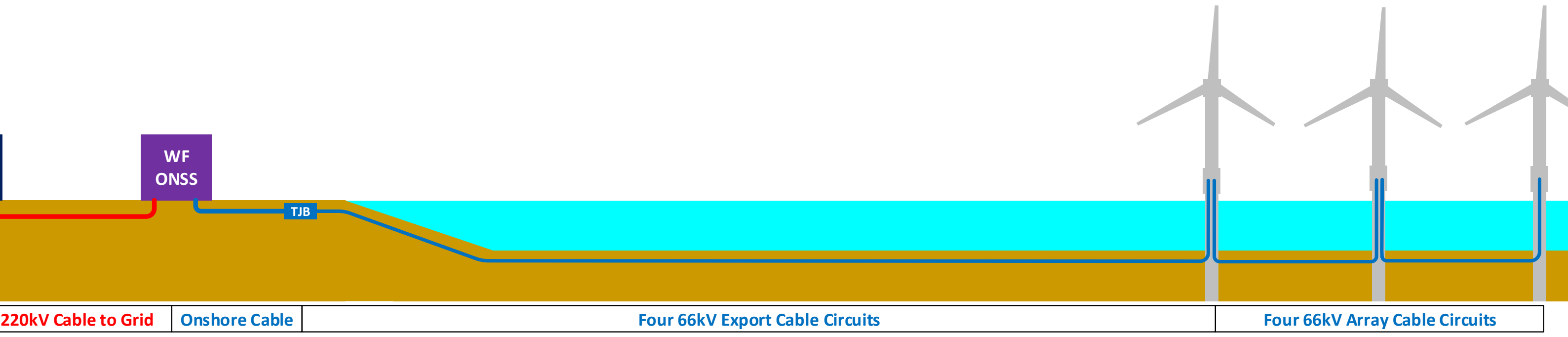


Figure 116 Power System Components - High Level Option 3

The concept is based on the same overall concept as option 1 now just with the change that the WTGs are larger, and the array cable systems is operated at 66kV voltage level.

Table 40 shows a simplified selection table of possible number of 66kV export cables only restricted by the limitation given by the 66kV cable circuit breaker rating (1250A) offered from the GIS suppliers.

Wind Turbine Generator Rating					6,0 MW		66 kV		Cosphi	0,97	54,1 Amp	
Layout	5 Radials			4 Radials			3 Radials			2 Radials		
Radial	WTG	MW	A	WTG	MW	A	WTG	MW	A	WTG	MW	A
1	7	42,0	379	9	54,0	487	11	66,0	595	17	102,0	920
2	7	42,0	379	8	48,0	433	11	66,0	595	16	96,0	866
3	7	42,0	379	8	48,0	433	11	66,0	595			
4	6	36,0	325	8	48,0	433						
5	6	36,0	325		0,0	0						
Sum	33	198	1.786	33	198	1.786	33	198	1.786	33	198	1.786

Table 40 Option 3 – Preliminary Selectin Table – Array Cable Radials Number

The table illustrates that three to five export cable radials could be implemented.

The alternative with five radials is not considered feasible due to a higher CAPEX compared with the four radial alternative since the cost for the export cable to shore is a significant cost driver.

The alternative with only two export cables is not found suitable since it will not leave much safety margin against the circuit breaker 1250A rating and also requires very large cable sizes that could be produced but are found not appropriate due to cost and handling parameters.

The base case topology selected for the advisory design is with four export cables. The other alternatives with three export cables are also analysed in respect to load-flow studies to select suitable conductor sizes (based on a voltage criteria and short circuit capability) and compute the investment cost and capitalised energy losses to make a CAPEX comparison between the alternatives. An even number of export cables could also be preferred since it allows a 50/50 distribution of the power between the two 220/33kV power transformers at the WF ONSS. *(However, this should not be the argument for determining the overall topology, since these units are engineered/manufactured to project requirements and no spare units will be procured anyhow).*

The high level system topology with four export cables is illustrated in Figure 117 where the main substation components and cable conductor sizes are indicated.

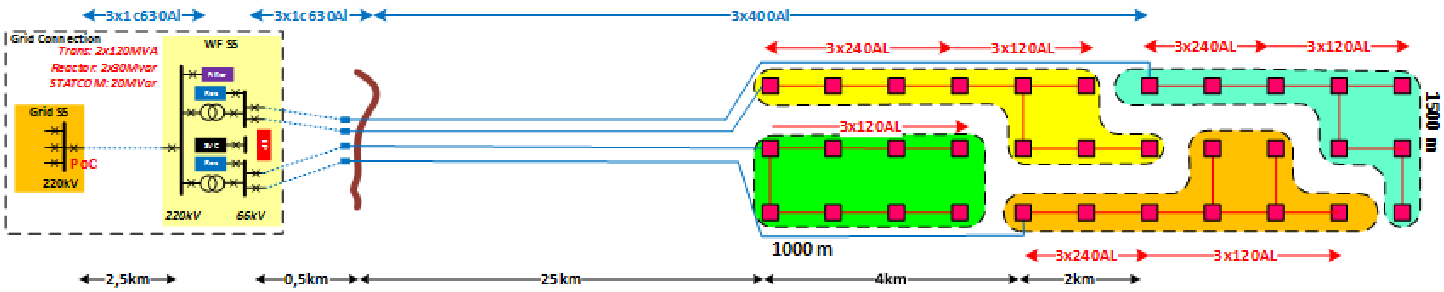


Figure 117 Option 3 – Base Case - Power System Infrastructure Topology

The WTGs are grouped into four stings each interconnected to the onshore substation via 25km, 29km or 31km offshore export cable circuits.

The onshore power system consists of:

- TJB site, comprising four parallel joint bays separated approx. 4 m.
- 500m cable corridor (approx. 6m wide) allowing four parallel 66kV cable systems.
- Onshore substation comprising main components as 66/220kV power transformers, 66kV and 220kV switchgear, shunt reactors, STATCOM, harmonic filters, control building and other civil work, etc.
- 2.5 km underground cable circuit interconnecting ONSS with the grid SS
- 220kV line-bay with kWh metering at the grid SS (PoC) all designed/constructed by the TSO.

The anticipated outline onshore (depends on the Grid SS location) is indicated on the map in Figure 118.

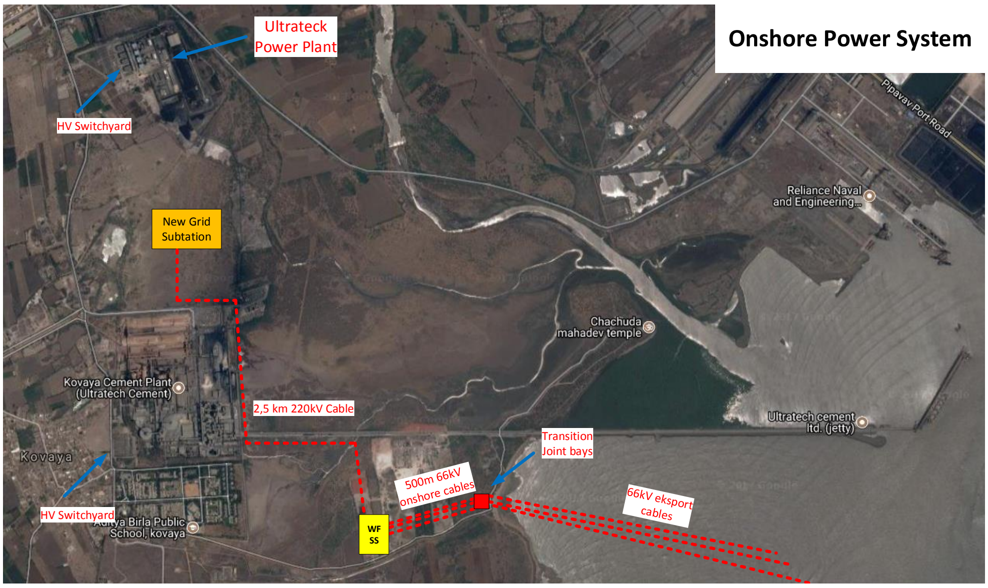


Figure 118 Option 3 – Onshore Cable Route & suggested substations

Rating of equipment

The wind farm power system comprises WTGs and switchgear, 66kV cable systems, a 66/220kV onshore substation, 220kV cable circuit interconnecting the grid SS, and the extension of the 220kV grid SS at the Indian TSO Getco. The SLDs in Figure 119 gives a more detailed description of the configuration of the 0.4/66/220kV components.

The topology is similar to the 33/220kV substation described in option 2 but with 66kV GIS suggested and a different rating for shunt reactors, STATCOM and harmonic system. All other components and systems will be almost identical.

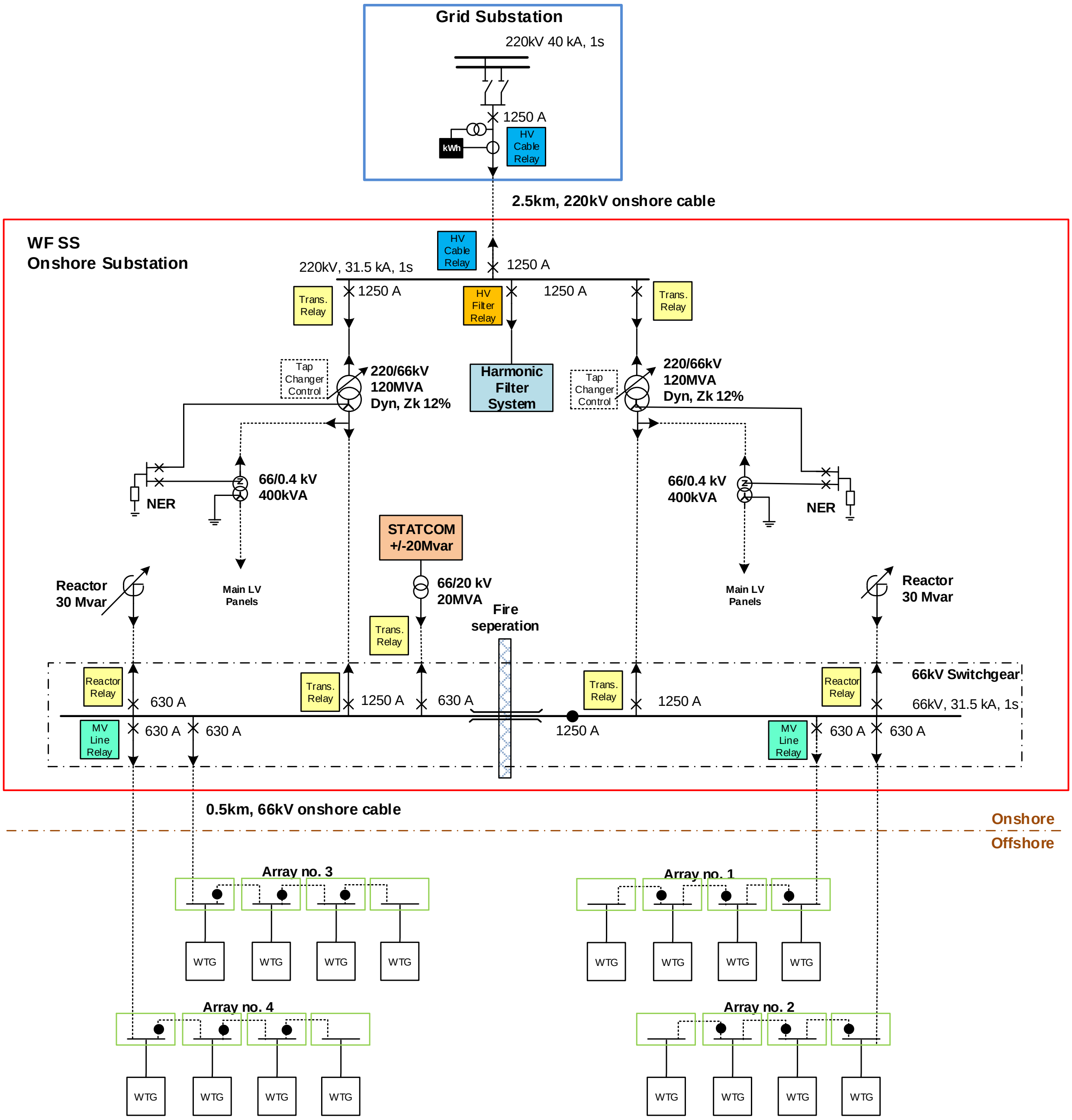


Figure 119 Option 3 – High Level Single Line Diagram

Operational philosophy

Reference is made to option 1 given the power system topology does not change when the voltage level of the export cables is increased from 33kV to 66kV.

Preliminary power grid study

Only simplified and preliminary power system studies involving load-flow and short circuit calculations have been implemented. The studies aim at selection of the cable conductor sizes, transformer/shunt reactor ratings.

The long (25-32km) export cables will contribute with a significant increase in the voltage at full production. The voltage impact in the radial will be significant less than the 33kV alternative, consequently, more power generation can be designed for each radial. The cable sizing of the export cables will not solely be based on the voltage drop, thus significant smaller conductor sizes can be used.

The maximum voltage of cable and apparatus will be 72.5V, thus the busbars at the WF ONSS shall be maintained at 66-69kV at all operational scenarios. The load flow calculation results with optimised cable conductor sizes are shown in Appendix C for the max production scenario. 66kV is maintained at the WF ONSS 66kV busbar by the online tap changers on the power transformer. The maximum voltage in the last WTG downstream is then calculated to approx. 69.7kV (106pu) at cosΦ=0.97 when 220kV is delivered at the Grid SS.

The power transformers must then be designed with automatic voltage regulation facilities thus online tap changers 10x +/-1.25% is suggested to account for voltage fluctuation in the power grid (+/- 10%) and the impact from the wind farm at high or no-production scenarios.

Two 120MVA 220/66kV power transformers each rated for half of the OWF production is advised and will give around 15-25% spare capacity should one of the transformers be faulty or out for maintenance. The OWF will deliver approx. 95MVA +100MVA to the WF ONSS 66kV busbar.

Thus ≈20MVA production is allowed via the 66kV bus-coupler in the ONSS should one of the power transformers be disconnected. This will bring the energised transformer in a full load operation 120MVA. Even more than +20MVA can be allowed in short duration since the overload capacity of the transformers are large and the condition (oil and winding temperature) can be monitored on-line and give accurate data to the system operators in the control room.

Two 66kV shunt reactors each 30MVar is suggested to compensate for the capacitance in the 66kV cables at no production. The shunt reactor can be either fixed or with regulation facilities. This cannot be firmly established before a full power system study with selected WTGs and a clear understanding of the prevailing grid code is completed. The rating of the shunt reactor will also be closely linked with the sizing of the STATCOM/SVC and the harmonic filters that will contribute with power compensation adjustment at low production.

The 220kV and 66kV apparatus at the WF ONSS is rated to 31.5kA 1s. The WTGs can do with 20kA, 1s since the large export cable will dampen the grid contribution and the WTGs only feed in around 1.25-1.5x load current during a 3ph short circuit fault.

The conductor sizes "120 mm² Al [11.3kA], 240mm2 AL [22.7kA]" are far down-stream from the ONSS 66kV busbar and will not be challenged by high circuit currents from the grid.

The export cables "3x400mm² AL [38kA] and 3x1c x 630mm² Al [60kA] will accommodate the max. 31.5 kA from the ONSS.

The power losses from the WTGs to grid SS (PoC) at full production is computed and summarised in Table 41:

Cable	Length	Power Loss
Array Cables		
3x120 mm² XLPE-AL	24,9 km	520 kW
3x240 mm² XLPE-AL	8,4 km	423 kW
Export Cable System		
3x400 mm² XLPE-AL	111,5 km	6.568 kW
3x1c 630mm2 XLPE-AL	2,0 km	75 kW
66/220 kV Power Transformers	---	800 kW
220kV Export cable to grid SS	2,5 km	111 kW
Total	**149km**	**8,4 MW**

Table 41 Option 3 – Base Case – Cable Length & Power Loss Summary

It is observed that the four 66kV export cables accounts for more than 75% of the total losses and also impose a significant reduction of the OWF power delivered to the PoC.

Cable system

Offshore array cables

The internal cable circuits within the wind farm is organised in 4 strings aiming at having equal number of WTGs in each. The prime criteria for the cable route design is aiming at a routing with as few km cables as possible even if it may provoke larger conductors upstream against the shore. The park layout in three rows with the export cables approaching from west invites to organising the six strings as indicated in Figure 120:

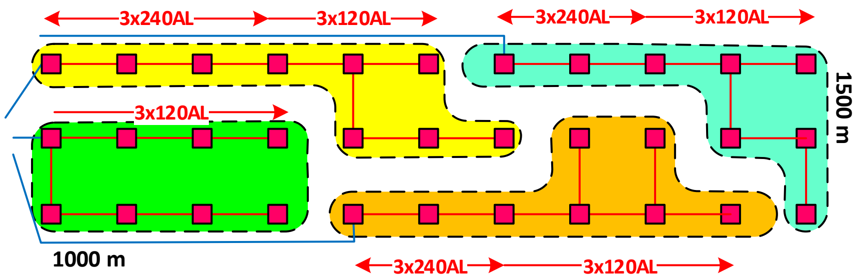


Figure 120 Option 3 – Base Case – Array Cable Routing & Cable Size

Only two different conductor sizes are recommended to achieve a feasible mix of production planning (expensive to start up short lengths). The conductor sizes along the strings are further selected from a load capacity since the voltage drop criteria is not significant with the length and load for 66kV voltage level.

Type	**Qty**	**Length *)**
3x240mm² Al	8	8,4 km
3x120mm² Al	21	24,9 km

Table 42 Option 3 – Base case – Array cable number & length summary

*) The cable length between the WTGs assumes 50 m cable between each WTG and also around 1% contingency for the route planning and seabed couture.

It is advised to install the array cable from individual cable drums transported to a rented quayside at the nearest port (Pipavav) and loaded to the cable installation vessel for a surface laid operation. The benefit will be a cost effective transportation of the cables since sea transport on a CLV with turntable mobilised could be more expensive and allow for the cost to the cable drums.

The optimal logistic planning separate drum vs. array cables delivered in long continuous length (cut during offshore installation) cannot be determined before proposals are given both from suppliers and installation contractors. The transit from the factory to the site shall be carefully assessed since it will have a direct impact on the cost and duration of the cable installation work.

It is advised to do a post lay burial operation with a suitable jetting/cutting tool and also organise a 3rd party survey for the DoB verification of the cable installers As-built data.

Offshore export cables

The conductor size of the four export cables are determined purely from a load capacity criteria since the voltage drop is not of major significance for the distance and load at 66kV voltage level.

Four strings ≈25km, 29km or 31km each 3x400mm^2 Al selected from Table 43 to meet the maximum load current 505A in the radial with 9 WTGs.

Current Capacity of Cables																	
Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
Nexans Three Core Sea XLPE-AL Cable "72kV" 2m/0,7Km/W, 25oC																	
S72XLPE3x95Al	260	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	266
S72XLPE3x120Al	295	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	302
S72XLPE3x150Al	329	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	337
S72XLPE3x185Al	372	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	381
S72XLPE3x240Al	429	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	439
S72XLPE3x300Al	480	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	491
S72XLPE3x400Al	542	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	554
S72XLPE3x500Al	607	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	621
S72XLPE3x630Al	675	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	691
S72XLPE3x800Al	739	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	756
Nexans Three Core Sea XLPE-Cu Cable "72kV" 2m/0,7Km/W, 25oC																	
S72XLPE3x630Cu	802	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	820
S72XLPE3x800Cu	857	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	877
S72XLPE3x1000Cu	900	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	921
S72XLPE3x1200Cu	940	25	0,93		1,00		1,00		1,00		1,00			1,00	1,10	1,02	962

Table 43 Option 3 – Array cable selection table

No offshore cable joints should be planned – 2 or 3 flexible joints should be anticipated in each the products delivered from the factory

CLV's today can be mobilised with large turntables and load two export cables in two loading/transit/laying operation campaign. It may even be possible to load all four cables (110km) in one campaign if a large CLV is available. This will give substantial cost savings since CLV time spent on transit and planning/mobilisation for separate loading operations can be saved.

As for the 33kV export cables it is suggested to plan the export cable installation on a simultaneous laying/burial operation – with a plough tool as the most suitable tool.

The distance between the export cable circuits shall be determined with sufficient space for an offshore repair joint installation and the following over-boarding should a repair joint be required during the operational lifetime. Over-boarding of an assembled offshore joint typically will be laid in an omega at the seabed and should allow two times water depth space for handling of cable ends and joint. Thus a separation in the range of 50-75m should be planned for and will require a total export cable corridor of around 250m.

Landfall

It is advised that the offshore cable installation for each circuit commences with the landfall pull-in operation. The TJB shall be prepared to receive the offshore cables pulled in from the CLV approximately 300-500m from the high water level mark at the beach. The CLV distance will be determined by the seabed contour and the water depth required by the CLV. The cable pull-in should be planned as a straight line as far as possible taking the water current into consideration.

The illustration in Figure 121 indicates a possible outline of the cable routing and burial options for the landfall.

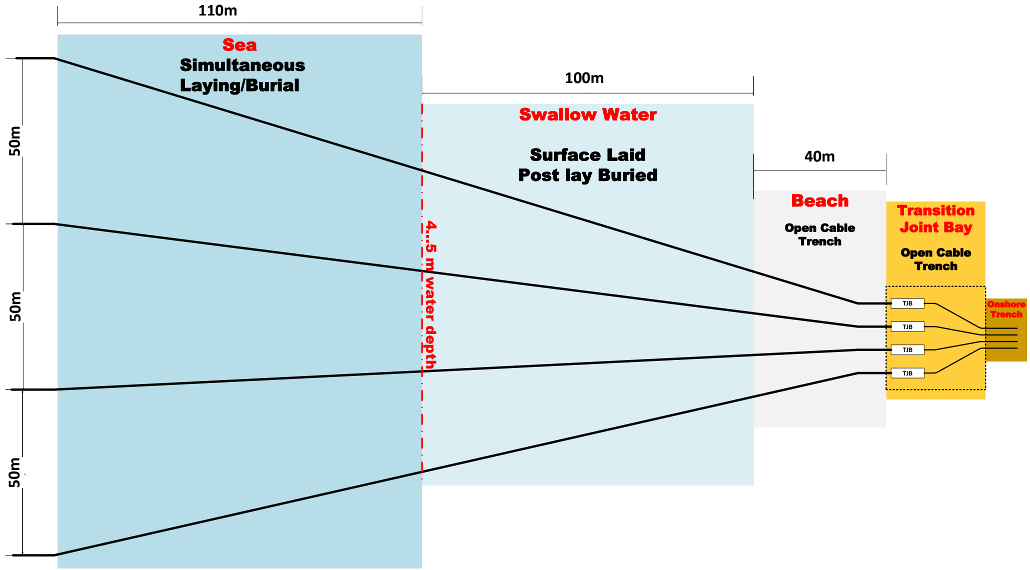


Figure 121 Option 3 – Landfall – Preliminary installation & burial methods suggested

Transition joint bay arrangement

The transition joint bay for a 66kV cable system compared with a 33kV system does not differ significantly in the space required for the jointing container or tent.

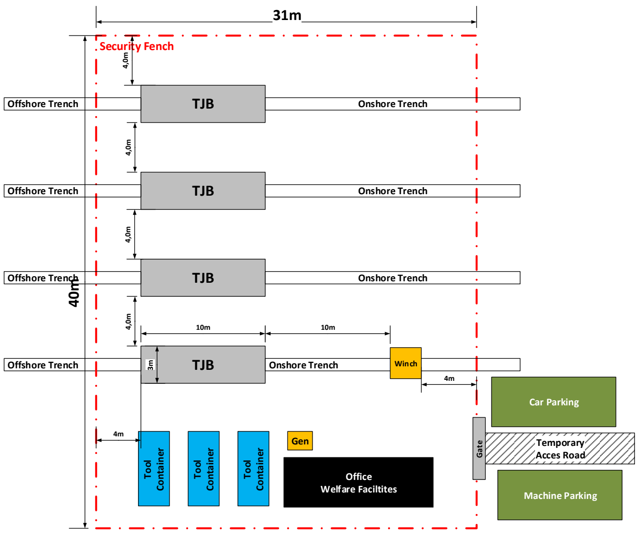


Figure 122 Option 3 – TJB arrangement

The footprint will be around 30m x 40m and will also involve construction of access roads necessary for the civil work and the mobilisation of the heavy cable winch. The worksite should be fenced of and have 24/7 security guards in particular since eventual vandalism of the sea-cable after its installation could be fatal and involve severe program delay and cost increase.

Onshore cable system, 66kV

The maximum load current is calculated to approx. 505A for each export cable at full OWF production. The conductor sizing of the four 66kV onshore cable systems are designed for 3m separation, and accounts for the mutual heating between the circuits. A total corridor 15m wide would be required.

An indicative selection table for 72kV single core XLPE-Al cables with the installation conditions assumed is shown in Table 44.
(F/T: Flat/Trefoil installation, CB: Cross-bonded or single earthed screens)

Current Capacity of Cables

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
72.5kV Single Core XLPE-AL Cable																	
"72.5kV" 1m/1,0 Km/W in selected sand --> 1,5 Km/W to consider soil outside // System distance 3m																	
72XLPE1x400Al-T-CB	545	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	4	0,94	1,10	0,80	438
72XLPE1x500Al-T-CB	620	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	4	0,94	1,10	0,80	498
72XLPE1x630Al-T-CB	710	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	4	0,94	1,10	0,80	570
72XLPE1x630Al-T-CB	710	30	0,93	1,00	1,00	1,50	0,84	Y	0,90	De	1,00	3000	4	0,94	1,10	0,72	513
72XLPE1x800Al-T-CB	805	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	4	0,94	1,10	0,80	647
72XLPE1x1000Al-T-CB	895	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	4	0,94	1,10	0,80	719
72XLPE1x1200Al-T-CB	965	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	4	0,94	1,10	0,80	775

Table 44 Option 3 –66kV Onshore Cables – Selection Table

A single point bonded screen arrangement with parallel Cu wires *(can be shared between the circuits)* is advised with the 3x1c 630mm^2 XLPE-Al cable cores laid in a three foil formation for the standard cable trench. No road crossings requiring ducts are anticipated along the 500m cable corridor.

The standard installation (three core cable direct in controlled sand-fill) will make possible a loading ≈570A. The contractor may choose to install the cables in pre-laid duct in close trefoil that will allow ≈513A, just at the limit of the max 505A required. In order to introduce a design safety margin and also consider larger burial depth e.g. 1.5m, a flat formation of the ducts separated with 0.25m would increase the permissible loading significant as per below sketches and selection table.

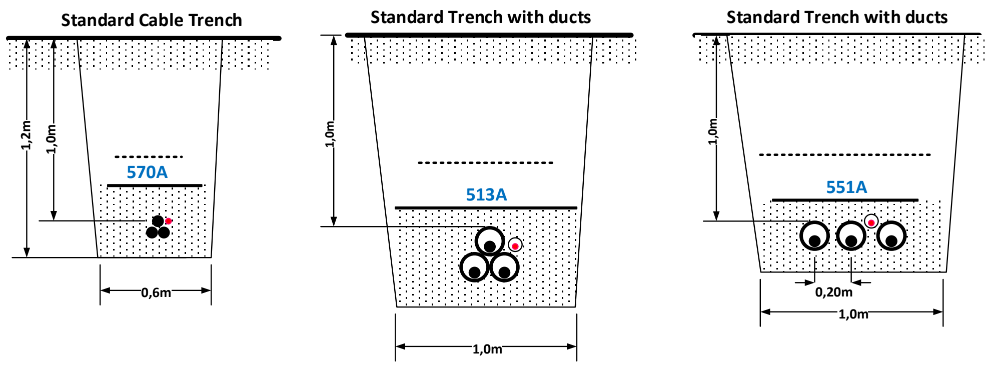


Figure 123 Option 3 – Typical 66kV Onshore Standard Cable Trenches

Should road crossings with ducts and larger burial depth occur then the 630mm^2 Al conductor will have insufficient capacity unless a spacing of the single cores is made in between the cable ducts. When designing the cable crossing of asphalt roads also an increased soil temperature from the solar radiation on the surface should be considered. (A simple approach suggested is adding 5^{o}C to the native soil temperature). For small roads an excavation and pre-lay of the cable ducts usually can be agreed with the road authorities. This also could allow an agreed design with cable/ducts embedded in concrete that can secure proper thermal resistivity and mechanical protection of the cables. Depending on the burial depth it will be necessary to place the cables in a flat formation separated by around 0.25m.

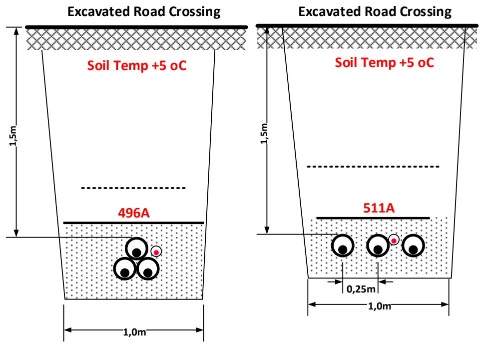


Figure 124 Option 3 – 66kV Cable Road Crossing Arrangement

Pre-excavation of larger roads is seldom accepted by the road authorities. Then a horizontal directional drilling operation with three separate ducts must be implemented. The ducts will approach 3-4m depth thus imposing a significant derating of the cable load capacity. The HDD operation will not allow mitigation/design to improve the soil thermal resistivity. This however is counteracted by the large depth approaching the underground water level (since the installation is nearby the cost line). The only mitigation possible to improve the cable load capacity is increasing the distance between the ducts and inject bentonite/grout with low thermal resistivity after the cables are pulled. If this is insufficient – a larger cable conductor must be used to the particular section.

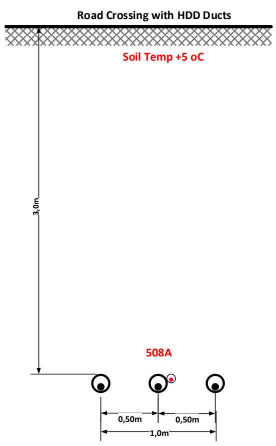


Figure 125 Option 3 – 66kV Onshore HDD arrangement

The selected table below addresses a road crossing with ducts and indicates three ducts buried/drilled at 3m and separated by 0.5m will have 508A capacity. *(505A is the requirement- but only for the heaviest loaded cable, consequently the mutual heating will be less and offer a safety margin).*

Current Capacity of Cables

Cable Type	In	Soil Temperature		Burial Dept.		Soil Th.Res		Pipe		Phase Separation		Parallel run in soil			Cylc. Factor	Res. Derate	Iz
sqmm	A	oC	faktor	m	faktor		faktor	Y/N	faktor	mm	faktor	mm	Qty	faktor	Qty.	faktor	A
72.5kV Single Core XLPE-AL Cable																	
"72.5kV" 1m/1,0 Km/W in selected sand --> 1,5 Km/W to consider soil outside // System distance 3m																	
72XLPE1x630Al-F-CB	755	30	0,93	1,00	1,00	1,50	0,84		1,00	De	1,00	3000	4	0,94	1,10	**0,80**	**607**
72XLPE1x630Al-F-CB	755	30	0,93	1,00	1,00	1,50	0,84	Y	0,90	De	1,00	3000	4	0,94	1,10	**0,72**	**546**
72XLPE1x630Al-F-CB	755	30	0,93	1,00	1,00	1,50	0,84	Y	0,90	200	1,01	3000	4	0,94	1,10	**0,73**	**551**
72XLPE1x630Al-F-CB	755	35	0,89	1,50	0,95	1,50	0,84	Y	0,90	De	1,00	3000	4	0,94	1,10	**0,66**	**496**
72XLPE1x630Al-F-CB	755	35	0,89	1,50	0,95	1,50	0,84	Y	0,90	250	1,03	3000	4	0,94	1,10	**0,68**	**511**
72XLPE1x630Al-F-CB	755	35	0,89	3,00	0,86	1,50	0,84	Y	0,90	500	1,13	3000	4	0,94	1,10	**0,67**	**508**

Table 45 Option 3 – 66kV onshore cable – Sensitivity analyse – Installation Conditions

In-situ and laboratory thermal resistivity measurements on samples is a must for the design and selection of the crossing layout.

The combinations of cable sizes and installation conditions are numerous thus a firm selection of the cable conductors shall not be done before a detailed design is implemented for the consented cable corridor with the soil characteristics known.

As for the six onshore 33kV onshore cable circuits a concrete culvert could also be considered for the 66kV cable circuits.

Wind farm substation

The outline and arrangement of the onshore substaion can be similar to option 2 having six 33kV export cables. The HV/MV components will have similar dimensions, allthoug the 66kV GIS will be larger than the 33kV GIS.

Reference is made to option 2.

HV interconnector to Grid SS

Reference is made to option 2.

Grid SS Connection

Reference is made to option 2.

Optimisation potential

The number of 66kV radials (four) can be reduced if larger cable conductors are selected. The main objective is reducing the CAPEX mainly driven by the fewer export cables and a shorter total installation campaign. Possible routing and sizing of the array cables for three and two array cable strings are illustrated below.

Three 66kV Strings – Straight radials

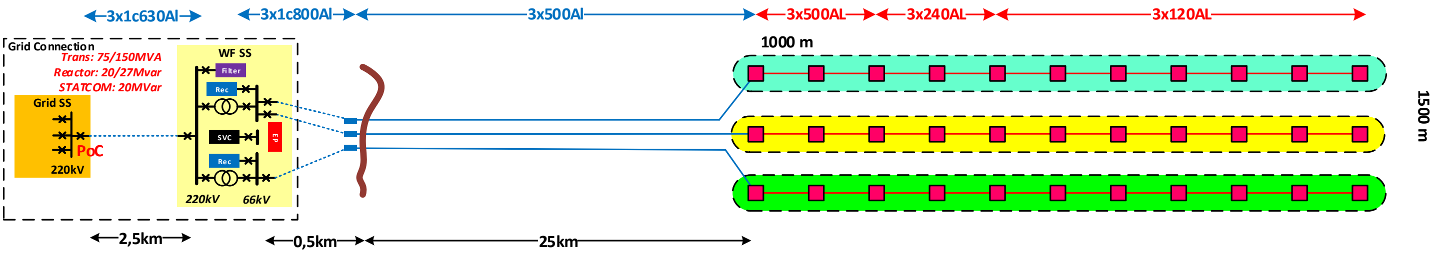


Figure 126 Option 3 – Alternative 1 – Topology & Cable Size

The 66/220kV power transformers must be rated different 75MVA and 150MVA to account for the three radials with equal number of WTGs.

Three 66kV Strings balanced production to 66kV busbar

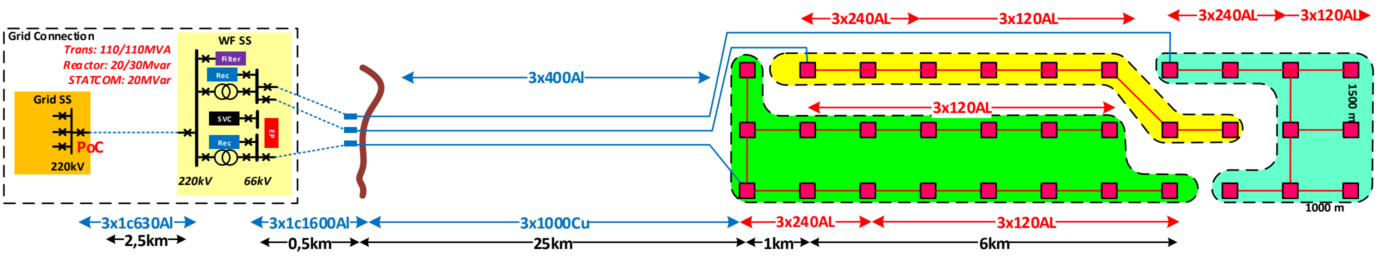


Figure 127 Option 3 – Alternative 2 – Topology & Cable Size

The 66/220kV power transformers are equally sized, but the export cables have different cross-sections.

Two 66kV Strings

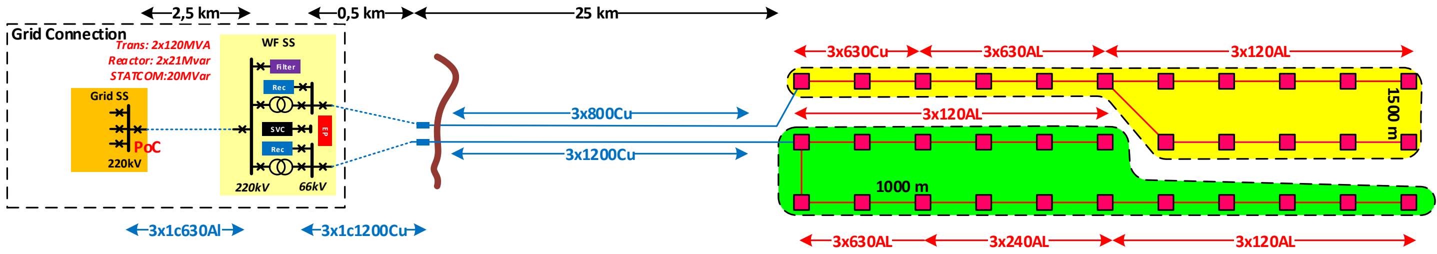


Figure 128 Option 3 – Alternative 3 – Topology & Cable Size

The aggregate cable length and indicative supply/installation cost summarised is tabled below, Table 46:

Cable Size	**Four Radials**	**Three Radials**	**Three Radials *)**	**Two Radials**
	km	**km**	**km**	**Km**
MV Sea Cables	**144.8**	**118.4**	**108.1**	**83.9**
66kV3x630cu	0.0	0.0	0.0	3.2
66kV3x800cu	0.0	0.0	0.0	25.0
66kV 3x1000cu	0.0	25.0	0.0	0.0
66kV 3x1200cu	0.0	0.0	0.0	25.0
66kV 3x120Al	24.9	26.5	17.4	21.8
66kV 3x240Al	8.4	8.9	9.5	3.2
66kV 3x400Al	111.5	58.0	0.0	0.0
66kV 3x500Al	0.0	0.0	81.3	0.0
66kV 3x630Al	0.0	0.0	0.0	5.8
MV Cable, Onshore	**2.0**	**1.5**	**1.5**	**1.0**
33kV 3x1x800Al	0.0	0.0	1.5	0.0
66kV 3x1x630Al	2.0	1.0	0.0	0.0
66kV 3x1x1600Al	0.0	0.5	0.0	0.0
66kV 3x1x1200Cu	0.0	0.0	0.0	1.0
HV Cable Systems	**2.5**	**2.5**	**2.5**	**2.5**
Onshore: 3x1c630Al	2.5	2.5	2.5	2.5
Power Losses [MW]	**8.4**	**7.6**	**8.7**	**6.2**
Supply & Installation Cost [Euro x10^6]				
MV Cable offshore				
Cable & Equipment supply	14.4	15.6	12.0	16.5
Installation	71.3	58.9	54.0	42.6
MV Cable onshore				
Cable & Equipment supply	0.3	0.3	0.2	0.3
Installation	0.1	0.1	0.1	0.1
HV Cable offshore				
Cable & Equipment supply	0.0	0.0	0.0	0.0
Installation	0.0	0.0	0.0	0.0
HV Cable onshore				
Cable & Equipment supply	1.7	1.7	1.7	1.7
Installation	0.5	0.5	0.5	0.5
Total	**88.3**	**77.0**	**68.3**	**61.6**

**) Straight radials*

Table 46 Option 3 – Cable length, CAPEX & power loss summary

The two string option with 3x800Cu and 3x1200Cu cables is not considered a suitable design if duct systems at the landfall are used below 2m burial depth. (The increased burial depth will cause additional heating and demand even larger conductors). 72.5kV / 1250A rated switchgear will be required and could be a challenge.

The installation cost in addition to laying/burial operations also comprises supply/installation at the WTGs in relation to:

- Termination of cables to connector units.
- Connector units.
- Cable Protection Systems.
- Hang-offs.
- Fibre optical splice boxes.

The options in addition to the lower CAPEX also will have programme benefits since:

- A faster offshore installation campaign for the export cables can be planned for.
- Area required at the landfall will be smaller.
- Width of the requested cable corridor onshore from TJB to the ONSS will be narrower.

Drawbacks could be:

- Reliability/availability factor will be reduced with fewer export cables.
- The large cross-sections may not be standard from the suppliers and will require additional qualification/type test of cables and accessories.
- The switchgear will be utilised closer to its limit.

A more comprehensive cost assessment also addressing the substation cost and capitalised energy losses for a number of options are presented and discussed in Section 8.

Appendix D Survey - Cable Suppliers

Company name	**Product Ranges**								**Homepage**
	Land cables				**Sea cables**				
	HV		**MV**		**HV**		**MV**		
	Max. Voltage		**Max. Voltage**		**Max. Voltage**		**Max. Voltage**		
Indian suppliers									
KEI	Up to 220kV	**Yes**	Not known	**Yes**		**No**		**No**	http://www.kei-ind.com
Gloster	Up to 220kV	**Yes**	Up to 33kV	**Yes**		**No**		**No**	http://www.glostercable.com
Polycab Wires Pvt. Ltd	66kV to 220kV	**Yes**	3.3 – 33kV	**Yes**		**No**		**No**	www.polycab.com
Sterlite Technologies Ltd		**No**		**No**		**No**		**No**	https://www.sterlitetech.com
Finolex Cables Ltd		**No**		**No**		**No**		**No**	http://finolex.com
Havells India Ltd		**No**		**No**		**No**		**No**	http://www.havells.com
RR Kabel		**No**		**No**		**No**		**No**	http://www.rrkabel.com
Diamond Power Infrastructure Ltd	Up to 550kV	**Yes**	1, 22, 33 and 66	**Yes**		**No**		**No**	http://dicabs.com
Gupta Power Infrastructure Ltd		**No**	Up to 66kV	**Yes**		**No**		**No**	https://www.guptapower.com
Shilpi Cable Technologies Ltd		**No**		**No**		**No**		**No**	http://www.shilpicables.com
RPG Cables (	66kV to 220kV	**Yes**	3.3 – 33kV	**Yes**		**No**		**No**	http://www.rpgcables.com
Universal Cables Ltd.	66kV to 220kV	**Yes**	3.3 – 33kV	**Yes**		**?**		**?**	http://www.unistar.co.in
Apar Industries Ltd. (Unit: Uniflex Cables)		**No**	Up to 66kV	**Yes**		**No**		**No**	http://www.apar.com
Anchor by Panasonic		**No**		**No**		**No**		**No**	http://anchor-world.com
V-Guard Industries Ltd		**No**		**No**		**No**		**No**	http://www.vguard.in
AKSH Optifibre Ltd.		**No**		**No**		**No**		**No**	http://www.akshoptifibre.com
Lapp India Pvt. Ltd.		**No**		**No**		**No**		**No**	https://products.lappgroup.com
LEONI Cable Solutions (India) Pvt. Ltd.		**No**		**No**		**No**		**No**	https://www.leoni-automotive-cables.com
Foreign suppliers									
NKT Cables	Up to 550kV	**Yes**	Up to 72.5kV	**Yes**	Up to 550kV	**Yes**	Up to 33kV	**Yes**	http://www.nkt.com/index.html
Nexans	Up to 500kV	**Yes**	Up to 72.5kV	**Yes**	Up to 525kV	**Yes**	Up to 33kV	**Yes**	http://www.nexans.co.uk
ZTT Group	---	?	---	?	110kV	**Yes**	---	**?**	http://www.zttcable.com
Prysmian Group	Up to 420kV	**Yes**	Up to 33kV	**Yes**	Up to 220kV	**Yes**	Up to 66 kV	**Yes**	https://www.prysmiangroup.com
JDR Cables		**No**		**No**		**No**	33, 66 kV	**Yes**	http://www.jdrcables.com
LS Cable & Systems	Up to 220kV	**No**	Up to 72.5kV	**Yes**	Up to 220kV	**Yes**	33, 66 kV	**Yes**	http://www.lscns.com/en/main.asp
Furukawa Electric	Up to 550kV	**No**	Up to 72.5kV	**Yes**	Up to 220kV		66kV	**Yes**	http://www.furukawa.co.jp/en/product/energy/power_cable/index.html
Orient Cable	Up to 220kV	**No**	Up to 72.5kV	**Yes**	Up to 550kV (Single core)		33kV	**Yes**	http://www.orientcable.com/en/

Appendix E Survey – OSS Suppliers

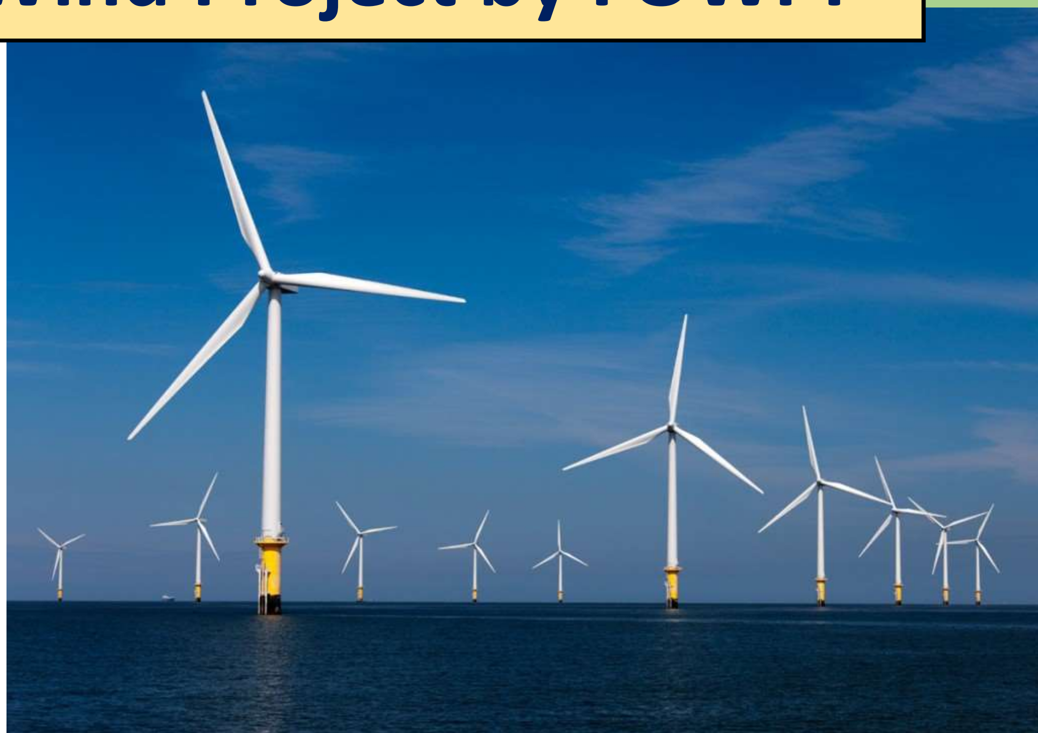
Offshore Substations(only manufaturers of topsides)														
						References								
Company name	Projects terminated												Remarks	Homepage
	Newest			First		Production in MW		0>=200 MW	400<=200 MW	>400 MW	Situated			
	Name	MW/kV	Year	Name	Year	Highest	Lowest							
Bladt Industries	Bligh Bank	165/132	2016	Nysted	2002	400	100	**8**	**7**	**0**	**Europe**		Further projects can occur	https://www.bladt.dk
Engie Fabricon	Burbo Bank ext.	258/220	2017	Amrumbank West	2016	302	258	**0**	**2**	**1**	**Europe**		Further projects can occur	http://www.cofelyfabricom-gdfsue
Hollandia Offshore	Kriegers Flack	200/215	2017	Dantysk	2013	288	108	**2**	**2**	**0**	**Europe**		Further projects can occur	http://www.hollandiaoffshore.nl
Western Shipyard	Bard Offshore 1	400/155	2013	N.A	N.A	N.A	N.A	**0**	**1**	**0**	**Europe**		Further projects can occur	http://www.wsy.lt/
Keppel Verolme BV	Global Tech 1	400/155	2015	N.A	N.A	N.A	N.A	**0**	**1**	**0**	**Europe**		Further projects can occur	http://www.damenshiprepair.com
Stahlbau Nord	Nordergründe	110/155	2017	N.A	N.A	N.A	N.A	**1**	**0**	**0**	**Europe**		Further projects can occur	http://www.sbn-bhv.de
Lemants	Gode Wind 1 og 2	582/155	2018	Merkur	2017	582	396	**0**	**1**	**3**	**Europe**		Further projects can occur	http://www.iemants.com
Mostostal	Alpha Ventus	60/110	2015	N.A	N.A	N.A	N.A	**1**	**0**	**0**	**Europe**		Further projects can occur	http://www.mostostal.com.pl
BVT Bremen	Meerwind Süd/Öst	295/155	2015	N.A	N.A	N.A	N.A	**0**	**1**	**0**	**Europe**		Further projects can occur	http://www.bvt-bremen.de
STX France	Arkona	385/220	2018	Westermost Rough	2015	385	210	**0**	**3**	**0**	**Europe**		Further projects can occur	http://stxfrance.fr/en
HSM Offshore BV	Borkum Riffgrund 2	450/155	2018	Horns Rev A	2002	450	160	**1**	**3**	**1**	**Europe**		Further projects can occur	https://www.hsmoffshore.com

Offshore Substations (Topside)											
Company name	Projects terminated *)					References *)					Homepage
	Newest			First		Production in MW		0>= 200MW	200 -400 MW	> 400 MW	
	Name	MW/kV	Year	Name	Year	Highest	Lowest				
Bladt Industries	Bligh Bank	165/132	2016	Nysted	2002	400	100	8	7	0	https://www.bladt.dk
Engie Fabricon	Burbo Bank ext.	258/220	2017	Amrumbank West	2016	302	258	0	2	1	http://www.cofelyfabricom-gdfsuez.com
Hollandia Offshore	Kriegers Flack	200/215	2017	Dantysk	2013	288	108	2	2	0	http://www.hollandiaoffshore.nl
Western Shipyard	Bard Offshore 1	400/155	2013	N.A	N.A	N.A	N.A	0	1	0	http://www.wsy.lt/
Keppel Verolme BV	Global Tech 1	400/155	2015	N.A	N.A	N.A	N.A	0	1	0	http://www.damenshiprepair.com
Stahlbau Nord	Nordergründe	110/155	2017	N.A	N.A	N.A	N.A	1	0	0	http://www.sbn-bhv.de
Smulders	Merkur	2017	2018	Belwind Offshore Wind Farm	2010	582	396	3	7	3	http://www.smulders.com/en
Mostostal	Alpha Ventus	60/110	2015	N.A	N.A	N.A	N.A	1	0	0	http://www.mostostal.com.pl
BVT Bremen	Meerwind Süd/Öst	295/155	2015	N.A	N.A	N.A	N.A	0	1	0	http://www.bvt-bremen.de
STX France	Arkona	385/220	2018	Westermost Rough	2015	385	210	0	3	0	http://stxfrance.fr/en
HSM Offshore BV	Borkum Riffgrund 2	450/155	2018	Horns Rev A	2002	450	160	1	3	1	https://www.hsmoffshore.com

*) *Further projects can occur*

Appendix F GETCO Grid Study

Study Report for evacuation of 200 MW of Wind Power through Offshore Wind Project by FOWPI



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1. Overview

India, through the last two decades has witnessed substantial growth in wind energy capacity addition. The growth momentum has spread across major wind rich states such as Tamil Nadu, Gujarat, Rajasthan and Karnataka. Today, in terms of wind power installed capacity, India is globally placed at 4^{th} position. The present wind power installed capacity in the country is around 28.28 GW.

The Ministry of New and Renewable Energy (MNRE) is playing an active role in promoting the adoption of renewable energy resources by offering various incentives, introducing new policies, implementation of new projects and schemes.

Under the set target of installed capacity of 175 GW renewable power by end of 2022, tentative target for the state of Gujarat is 17.13 GW.

- 8020 MW of Solar power
- 8800 MW of Wind power
- 25 MW Small Hydro Project (SHP)
- 288 MW Biomass project

Gujarat has a cumulative renewable energy installed capacity of 7067 MW as on 1^{st} March 2017. Out of the total installed RE capacity, 5525 MW is contributed by wind energy and that accounts for 78% of total renewable energy generation capacity.

A 7,600 Km Coastline offers India a huge offshore potential and with Government of India approving a National Offshore Wind Energy Policy in 2015, India's wind energy capacity is bound to see a significant rise.

About GETCO

Gujarat Energy Transmission Corporation Ltd (GETCO) was formed in 1999 and was registered under the Companies Act, 1956 as a part of the power sector reforms process in the state. The Company was promoted by erstwhile Gujarat Electricity Board (GEB) as its wholly owned subsidiary in the context of liberalization and as a part of efforts towards restructuring of the Power Sector. The company commenced commercial operation with effect from 1st April 2005.

Organizational development and institutional strengthening are the other areas into which the management of GETCO is looking into to transform GETCO into a commercially viable vibrant organization. Apart from internal reforms – institutional strengthening and organizational development – GETCO is also gearing up to meet the regulatory challenges, both in terms of operational efficiency and commercial & financial implications of the same.

Further, GETCO was notified as State Transmission Utility (STU) by Government of Gujarat vide Notification No.GHU-04-31-GEB-1104-2946-K Dated 29th May 2004 with the purpose of improving efficiency in the state's electricity transmission activities.

GETCO started functioning as an independent company from 1st April 2005. The bulk power generated at various generating stations in the state and the share of power generated by Central Sector Stations is transmitted to Distribution Companies at various interface points in the State through an extensive network of 400 KV, 220 KV, 132 KV and 66 KV transmission lines and substations. GETCO carries energy to all the six distribution companies in the state, including AEC and SEC, which in turn supply power to more than 1.20 Crores consumers across the state.

About FOWPI

First Offshore Wind Project of India (FOWPI) is a project funded by European Union (EU) and it aims to support Ministry of New and Renewable Energy (MNRE) and National Institute of India (NIWE) in strengthening the country's offshore wind energy sector and provide technical assistance in preliminary implementation of first off-shore wind farm project of India, on a sea bed area of 70 sq. km. with a tentative capacity sizing of 200MW near the Gulf of Khambat, approximately 25km off the shore of Gujarat.

FOWPI project is led by COWI A/S Denmark with local key-support by WindForce Management Services Ltd and COWI India Ltd involve in the project implementation. The project is well supported by European Union (EU), Ministry of New and Renewable Energy- India (MNRE) and National Institute of Wind Energy- India (NIWE).

FOWPI (First Offshore Wind Farm Project of India) will promote the use of sustainable energy in India through:

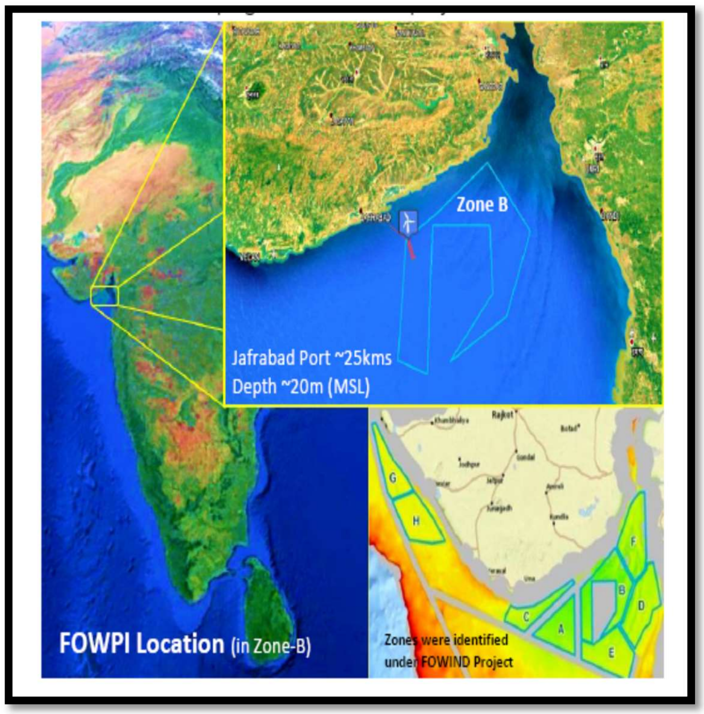
- Building of Indian Knowledge Bank with data on Indian and European stakeholders and capturing European experience in offshore wind
- Preliminary Design and Technical Specifications for a 200 MW offshore wind farm off the coast of Gujarat, including:

    - Geophysical site survey providing bathymetric map and soil information, and geotechnical desktop study
    - Metocean Assessment
    - Wind Turbine technology guidance
    - Preliminary foundation design, including appurtenances
    - Preliminary electrical design, including array cable layout, substation and grid connection
    - Preliminary wind farm layout and annual energy production estimation
    - Environmental Scoping
    - Coastal & Onshore study, including guidance on construction and O&M harbour

- Development of a Financial Investment Model for the first offshore wind farm in India
- Procedures for Permit Management, Certification and Health and Safety based on EU experience and best practice
- Enhance the capacity of National Institute of Wind Energy (NIWE) to act as the nodal agency for the offshore wind sector in India. Also assist in capacity building of the MNRE for offshore wind
- Secretariat Services including support for stakeholders with technical input and logistical support

2. Project Highlights

First Offshore Wind Project of India (FOWPI) is planned to achieve 200MW sized offshore wind farm near the coast of Gujarat, approx. 25km from Jafarabad.

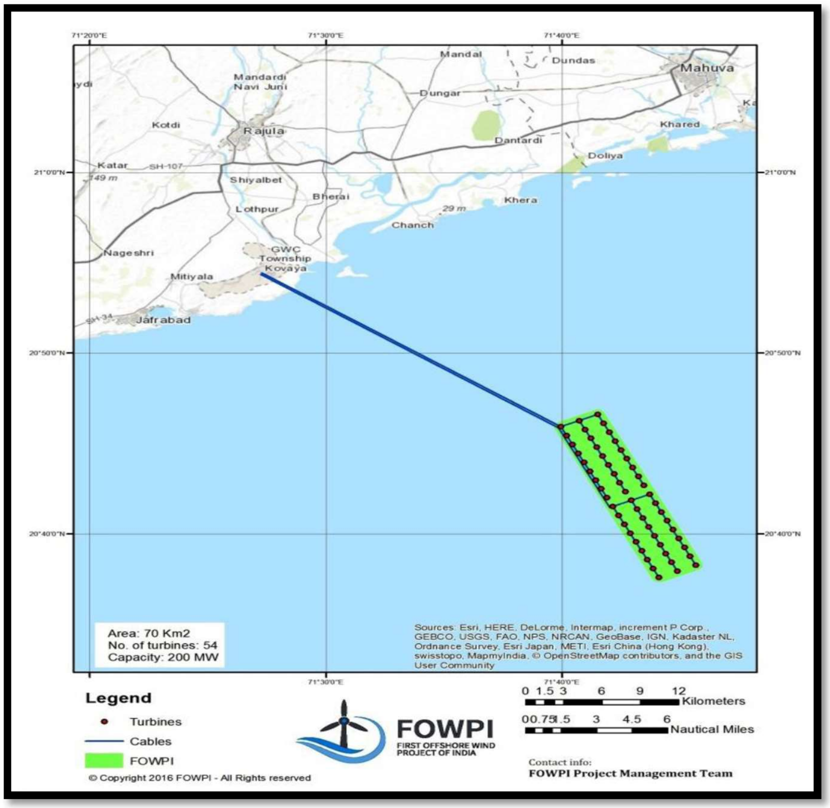


The project is expected to be operational by 2022. The total area occupied by the Project site is approximately 70 km2 with an average water depth of about 20m.

The wind turbine generators will likely be organized in three rows with a distance of about 1500m between each row. The spacing between wind turbines is expected to be in range between 500m to 1000 m

The preliminary design basis for the project is expected to consider a range of turbines from 3MW to 8MW capacities. This range would lead to an indicative number between 67 and 25 wind turbines.

Tentative Site Layout



-Source: FOWPI

3. Methodology adopted for the studies

The Load Flow Studies and Short Circuit studies are carried out to check the feasibility and to access the transmission infrastructure required for evacuating 200 MW offshore wind farm generation in the GETCO grid during average load conditions for 2020 timeframe.

System studies are carried considering 200 MW injection from an on-shore pooling station near the proposed site, to be established by offshore wind developer. Evacuation of power from offshore WTGs to on-shore pooling station is to be arranged by wind farm developer.

The load flow studies for evacuation of the total wind farm generation of 200 MW with 80% injection (i.e. 160 MW, based on available data) for 2020 timeframe have been considered along with following assumptions-

- Planned STU & CTU transmission network up to 2020 time-frame (including 400 KV D/C Amreli – Kasor line, 400 KV Kalavad & 400 KV Pipavav substation with associated elements, LILO of 220 KV S/C Jetpur – Sardargadh line at 220 KV Shapur S/S, LILO of 220 KV D/C Visavadar – Dhokadava line at 400 KV Keshod, 220 KV Bagasara and 220 KV Talaja with associated elements etc. surrounding Dhokadava area).
- Anticipated conventional generation capacity addition for 2020 time-frame.
- Anticipated RE capacity addition of around 2000 MW wind power projects (in-principle approval given by GETCO).
- Maximum 70% RE injection is considered along with 70% ex-bus capacity for conventional power projects located in Saurashtra area (near to technical minimum capacity).
- Average peak load is considered for Gujarat system for 2020 condition i.e. Total Gujarat load is around 15000 MW.
- It is assumed that the generated power from proposed 200 MW offshore wind project will be consumed within Gujarat only.

- These studies are carried out for transmission of power from on-shore pooling station to be established by offshore wind developer.
- Transmission of power generated from off-shore WTGs up to on-shore pooling station shall be studied and planned by FOWIND / offshore wind developer.

The short circuit study for determining the maximum three phase symmetrical fault level for 2020 timeframe is carried out.

4. Proposed Connectivity Scheme

Following generating plants are located in the vicinity of Jafrabad port-

- GPPC, Pipavav CCPP – 2 x 351 MW
- BECL, Bhavnagar TPS – 2 x 250 MW
- RE Capacity – 1500 MW (already granted)

Further, proposed FOWIND project with a capacity of 500 MW is granted connectivity from 400 KV Pipavav (timeframe – 2020). Also around 1000 MW generation capacity is already granted connectivity at 66 KV / 220 KV network in Saurashtra area.

Nearest GETCO EHV substations to the proposed FOWPI site are 400 KV Pipavav, 220 KV Otha & 220 KV Dhokadava. Considering prior approved connectivity from 400 KV Pipavav and 220 KV Otha, it is proposed that 200 MW offshore wind project by FOWPI be connected at 220 KV level at 220 KV Dhokadava substation.

Detailed connectivity scheme to be established by offshore wind developer is as under:

- 220 KV FOWPI on-shore pooling station near Jafrabad port,
- 220 KV D/C FOWPI on-shore pooling station – Dhokadava (proposed GETCO substation) line (approx. 50 RKM),
- 220 KV, 1X25 MVAR switchable bus reactor / STATCOM at FOWPI on-shore wind pooling station
- 2 Nos. of 220 KV feeder bays at 220 KV Dhokadava (GETCO) substation

5. Power System Studies

The maximum and minimum reactive power limits of the wind farm generators are considered as ‘0 (zero)’ MVAr so that the wind farm generators will neither draw nor inject any reactive power from or to the grid.

To access the transmission requirement for grid integration of 200 MW offshore wind project of FOWPI, a lump wind generator with 200 MW capacity is considered at on-shore pooling station to be established by offshore wind developer. Transmission of power generated from off-shore WTGs up to on-shore pooling station shall be planned by FOWPI / offshore wind developer.

[A] Load Flow Studies:

Results on the Single Line Diagram (SLD) shall be read as:

- The voltage magnitude of bus is represented by V (δ), where V is the bus voltage in KV and (δ) is voltage angle in degree.
- The power flow in any element is represented by P (Q) format, where P is the real power and (Q) is the reactive power.
- Power flow P or (Q) away from the bus is shown negative.
- Power flow P or (Q) towards the bus is shown positive.

The different case studies and their analysis are furnished below:

1. Base-case:

This is the base case for feasibility of evacuating 200 MW offshore wind power generation at 220 KV Dhokadava substation (GETCO) through 220 KV D/C AL-59 line. The line flows are quite normal and within limits. The power flows are shown on the SLD marked as Exhibit- (1A- Before integration) & (1B- After integration). Power flow on associated 220 KV lines and ICTs for before and after integration of 200 MW offshore wind power is tabulated hereunder:

Sr No.	Name of the line	Before integration of wind power	After integration of 200 MW wind power
1	400 KV S/C Jetpur - Amreli	399	398
2	400 KV S/C Amreli - Chorania	400	412
3	400 KV D/C Amreli - Fedra	2 X 538	2 X 551
4	220 KV S/C Dhokadava - Rajula	(-105)	(-76)
5	220 KV S/C Dhokadava - Savarkundla	67	115
6	220 KV S/C Dhokadava - Timbdi	102	153
7	220 KV S/C Dhokadava - GPPLPip	(-125)	(-93)
8	220 KV D/C Amreli - Savarkundla	2 X (-132)	2 X (-162)
9	220 KV D/C Amreli - Visavadar	2 X (-73)	2 X (-75)
10	220 KV D/C Dhokadava – FOWPI line	0	2 X (-80)

2. Contingency Case-1

In the Base Case, outage of 220 KV S/C Dhokadava – Timbdi line is considered. The line flows are quite normal and within limits. The power flows are shown on the SLD marked as Exhibit-2.

Sr No.	Name of the line	After integration of 200 MW wind power
1	400 KV S/C Jetpur - Amreli	380
2	400 KV S/C Amreli - Chorania	413
3	400 KV D/C Amreli - Fedra	2 X 552
4	220 KV S/C Dhokadava - Rajula	(-35)
5	220 KV S/C Dhokadava - Savarkundla	183
6	220 KV S/C Dhokadava - Timbdi	0
7	220 KV S/C Dhokadava - GPPLPip	(-48)
8	220 KV D/C Amreli - Savarkundla	2 X (-204)
9	220 KV D/C Amreli - Visavadar	2 X (-58)
10	220 KV D/C Dhokadava – FOWPI line	2 X (-80)

3. Contingency Case-2

In the Base Case, outage of 220 KV S/C Dhokadava – Savarkundla line is considered. The line flows are quite normal and within limits. The power flows are shown on the SLD marked as Exhibit-3.

Sr No.	Name of the line	After integration of 200 MW wind power
1	400 KV S/C Jetpur - Amreli	403
2	400 KV S/C Amreli - Chorania	411
3	400 KV D/C Amreli - Fedra	2 X 550
4	220 KV S/C Dhokadava - Rajula	(-39)
5	220 KV S/C Dhokadava - Savarkundla	0
6	220 KV S/C Dhokadava - Timbdi	191
7	220 KV S/C Dhokadava - GPPLPip	(-52)
8	220 KV D/C Amreli - Savarkundla	2 X (-146)
9	220 KV D/C Amreli - Visavadar	2 X (-80)
10	220 KV D/C Dhokadava – FOWPI line	2 X (-80)

4. Contingency Case-4

In the Base Case, outage of one circuit of 220 KV D/C Amreli – Savarkundla line is considered. The line flows are quite normal and within limits except for the other circuit of 220 KV D/C Amreli – Savarkundla line, which is loaded above its thermal capacity. The power flows are shown on the SLD marked as Exhibit-4.

Sr No.	Name of the line	After integration of 200 MW wind power
1	400 KV S/C Jetpur - Amreli	406
2	400 KV S/C Amreli - Chorania	408
3	400 KV D/C Amreli - Fedra	2 X 546
4	220 KV S/C Dhokadava - Rajula	(-79)
5	220 KV S/C Dhokadava - Savarkundla	102
6	220 KV S/C Dhokadava - Timbdi	173
7	220 KV S/C Dhokadava - GPPLPip	(-97)
8	220 KV S/C Amreli - Savarkundla	(-238)
9	220 KV D/C Amreli - Visavadar	2 X (-87)
10	220 KV D/C Dhokadava – FOWPI line	2 X (-80)

5. Contingency Case-5

In the Base Case, outage of 220 KV S/C Amreli - Visavadar line is considered. The line flows are quite normal and within limits. The power flows are shown on the SLD marked as Exhibit-5.

Sr No.	Name of the line	After integration of 200 MW wind power
1	400 KV S/C Jetpur - Amreli	407
2	400 KV S/C Amreli - Chorania	410
3	400 KV D/C Amreli - Fedra	2 X 549
4	220 KV S/C Dhokadava - Rajula	(-74)
5	220 KV S/C Dhokadava - Savarkundla	118
6	220 KV S/C Dhokadava - Timbdi	148
7	220 KV S/C Dhokadava - GPPLPip	(-92)
8	220 KV D/C Amreli - Savarkundla	2 X (-168)
9	220 KV S/C Amreli - Visavadar	(-100)
10	220 KV D/C Dhokadava – FOWPI line	2 X (-80)

6. Contingency Case-6

In the Base Case, outage of one circuit of 220 KV D/C Dhokadava – FOWPI (evacuation line) is considered. The line flows are quite normal and within limits. The power flows are shown on the SLD marked as Exhibit-6.

Sr No.	Name of the line	After integration of 200 MW wind power
1	400 KV S/C Jetpur - Amreli	398
2	400 KV S/C Amreli - Chorania	412
3	400 KV D/C Amreli - Fedra	1102
4	220 KV S/C Dhokadava - Rajula	(-76)
5	220 KV S/C Dhokadava - Savarkundla	115
6	220 KV S/C Dhokadava - Timbdi	152
7	220 KV S/C Dhokadava - GPPLPip	(-93)
8	220 KV D/C Amreli - Savarkundla	2 X (-162)
9	220 KV D/C Amreli - Visavadar	2 X (-75)
10	220 KV S/C Dhokadava – FOWPI line	2 X (-80)

[B] Short circuit studies

The short circuit study for determining the maximum three phase symmetrical fault level for 2020 timeframe is carried out. The fault levels of important and connected substations are furnished below:

Sr. No.	Name of substation	Fault Level	
1	220 KV Dhokadava (GETCO)	4464	11.71
2	220 KV FOWPI (on-shore pooling station)	2309	6.06
3	400 KV Amreli	15436	22.28
4	400 KV Jetpur	11983	17.27
5	400 KV Pipavav	6899	9.95
6	220 KV Savarkundla	7082	18.58
7	220 KV Timbdi	3805	9.98
8	220 KV Visavadar	6229	16.34
9	220 KV Rajula	4059	10.65

The above results reveal that the fault level of associated substations is within the limits.

6. Synopsis

From the analysis of the Base Case, the Contingency Case studies and the Short Circuit Studies, the observations noted are as below:

1. 200 MW power generated from offshore WTGs can be safely evacuated at 220 KV Dhokadava (GETCO) substation under average load conditions with the following transmission system to be established by offshore wind developer:

    1) 220 KV FOWPI Onshore Pooling station
    2) 220 KV D/C FOWPI Onshore Pooling substation – Dhokadava line (Approx. 50 RKM)
    3) Construction of 2 Nos. of 220 KV feeder bays at 220 KV Dhokadava (GETCO) substation.
    4) 220 KV, 1X25 MVAR switchable bus reactor/STATCOM at the 220 KV FOWPI Onshore pooling station.

2. The short circuit studies reveal that the fault level of associated substations are within the limits.

3. It is assumed that the generated power from proposed 200 MW offshore wind project will be consumed within Gujarat only.

4. As drawl points are not known today, network adequacy at drawl points within GETCO network, will be accessed through separate studies after availability of drawl points by FOWPI/ offshore wind developer.

5. These studies are carried out for transmission of power from on-shore pooling station to be established by offshore wind developer.

6. Transmission of power generated from off-shore WTGs up to on-shore pooling station shall be studied and planned by FOWPI.

7. FOWPI has to ensure that reactive power requirement of WTGs, on-shore pooling station as well as subsea power cable (for transmission from off-shore platforms to on-shore pooling station) shall be compensated locally and shall not impact the grid.

8. Also, FOWPI have to submit a detailed report to comply with various technical requirements for grid connection of Renewable Energy sources, as per The Central Electricity Authority (Technical Standards for Connectivity to the Grid) Amendment Regulations, 2013 and Grid Code.

9. Whenever any contingency of the evacuation line and / or the associated transmission network occurs, wind generation have to be restricted or stopped to avoid overloading of any element of the associated transmission network.

10. Especially in off-peak load condition, if the overall system load crashes substantially, the wind farm generation has to be reduced to such a level that any element of the associated transmission network shall not get overloaded.

11. This study is purely an indicative study considering all the generation capacity addition and the transmission network corresponding to the timeframe of 2020 and hence, this shall not be considered as a connectivity approval. This study report does not warrant any permission to the said project. Also, due care shall be taken that this report is not to be used for any commercial and / or legal purposes.

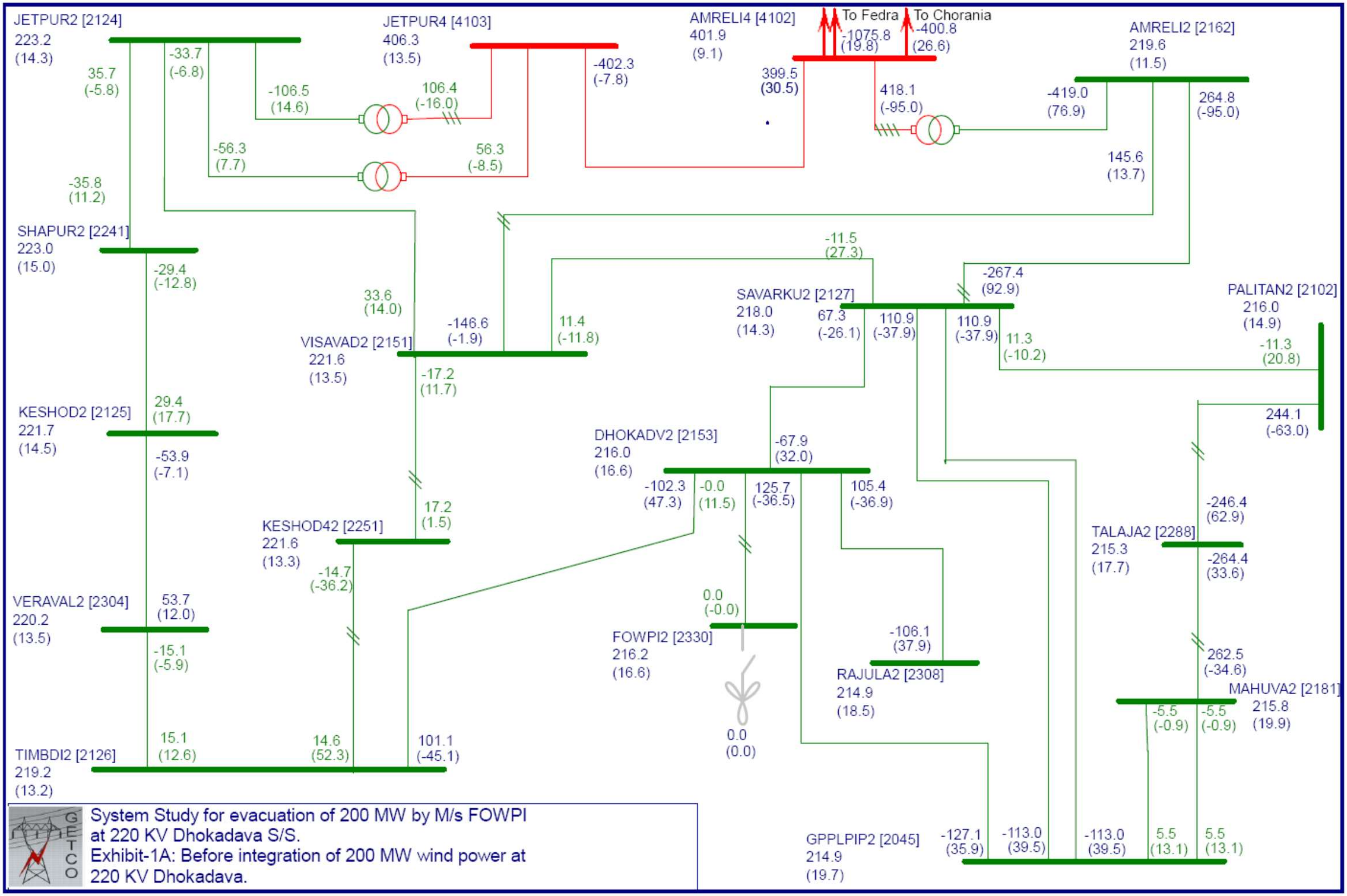
ANNEXURE – 1

Bus Voltage	Bus Description	Bus Name Considered	Remark
220 KV	220 KV Bus at onshore pooling substation	FOWPI2	FOWPI
400 KV	Jetpur substation	JETPUR4	GETCO
400 KV	Amreli substation	AMRELI4	GETCO
400 KV	Fedra substation	FEDRA4	GETCO
400 KV	Chorania substation	CHORANI4	GETCO
220 KV	Jetpur (220 KV Bus of 400 KV Jetpur)	JETPUR2	GETCO
220 KV	Shapur substation	SHAPUR2	GETCO
220 KV	Keshod substation	KESHOD2	GETCO
220 KV	Veraval substation (Proposed)	VERAVAL2	GETCO
220 KV	Timbdi substation	TIMBDI2	GETCO
220 KV	Visavadar substation	VISAVAD2	GETCO
220 KV	Keshod (220 KV Bus of 400 KV Keshod) (Proposed)	KESHOD42	GETCO
220 KV	Savarkundla substation	SAVARKU2	GETCO
220 KV	Dhokadava substation	DHOKADV2	GETCO
220 KV	Rajula substation (Proposed)	RAJULA2	GETCO
220 KV	GPPL Pipavav plant (220 KV Bus)	GPPLPIP2	GPPL
220 KV	Sagapara substation	PALITANA2	GETCO
220 KV	Talaja substation (Proposed)	TALAJA2	GETCO
220 KV	Otha substation	MAHUVA2	GETCO
220 KV	Amreli (220 KV Bus of 400 KV Amreli)	AMRELI2	GETCO

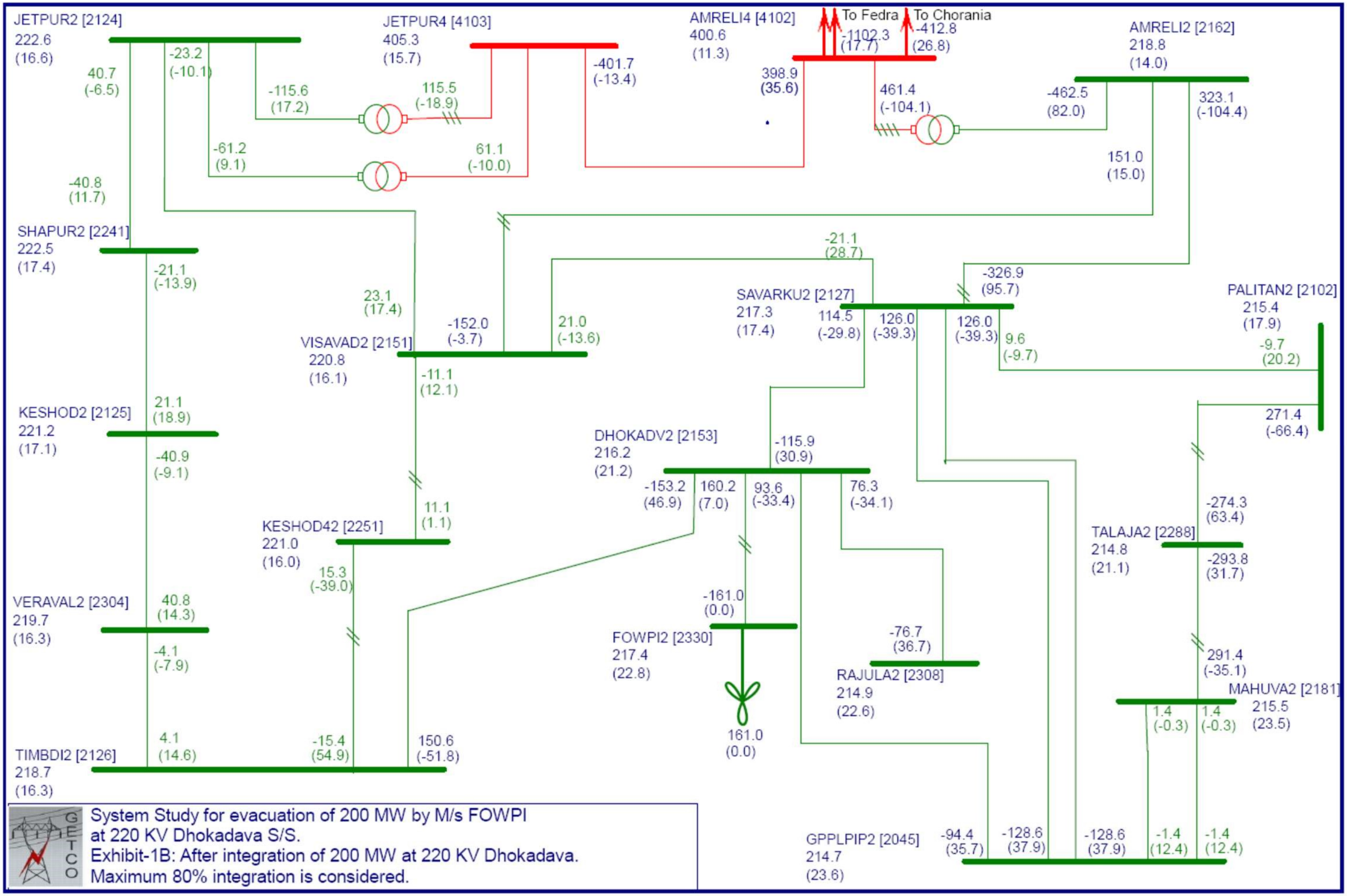
7. Study Results

Sr No.	Particular	Exhibit Name/No
1	Before integration of 200 MW wind power at 220 KV Dhokadava substation	1-A
2	After integration of 200 MW wind power at 220 KV Dhokadava substation	1-B
3	Integration of 200 MW wind power at Dhokadava with outage of 220 KV S/C Dhokadava- Timbdi line	2
4	Integration of 200 MW wind power at Dhokadava with outage of 220 KV S/C Dhokadava- Savarkundla line	3
5	Integration of 200 MW wind power at Dhokadava with one circuit of 220 KV D/C Amreli- Savarkundla line out of service	4
6	Integration of 200 MW wind power at Dhokadava with one circuit of 220 KV D/C Amreli- Visavadar line out of service	5
7	Integration of 200 MW wind power at Dhokadava with one circuit of 220 KV D/C Dhokadava – FOWPI (evacuation line) out of service	6

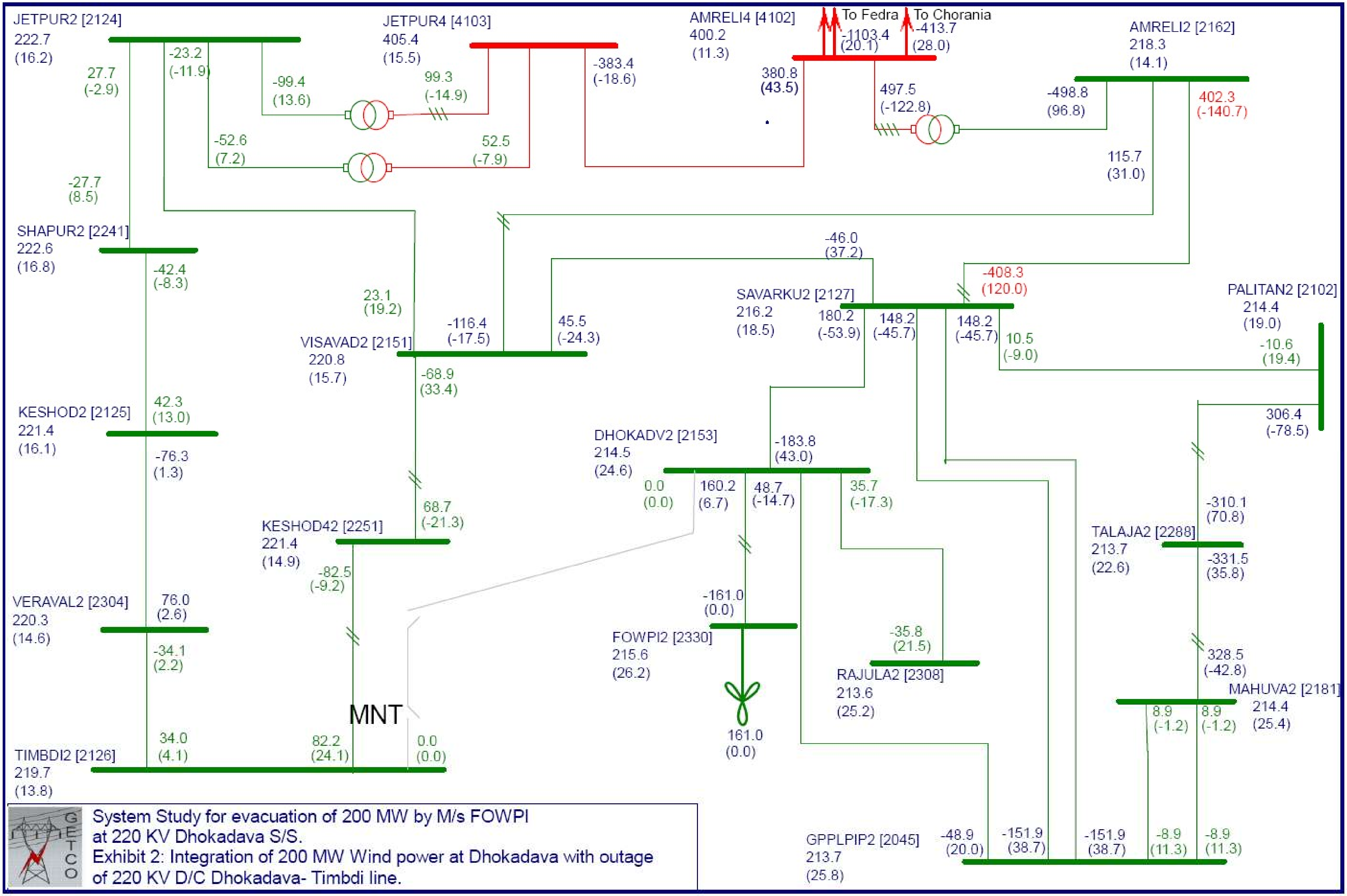
Power Map



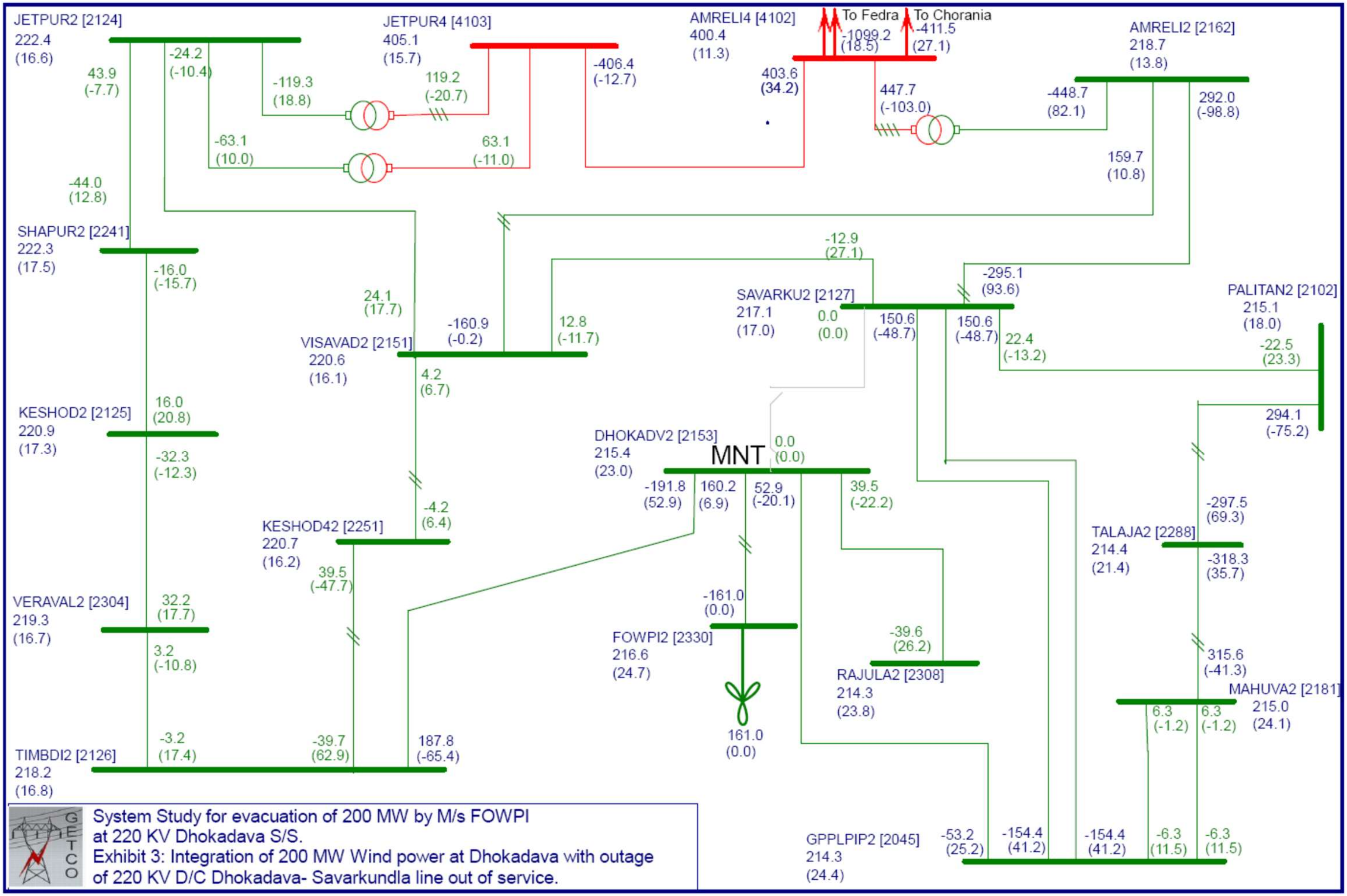
System Study for evacuation of 200 MW by M/s FOWPI at 220 KV Dhokadava S/S.
Exhibit-1A: Before integration of 200 MW wind power at 220 KV Dhokadava.



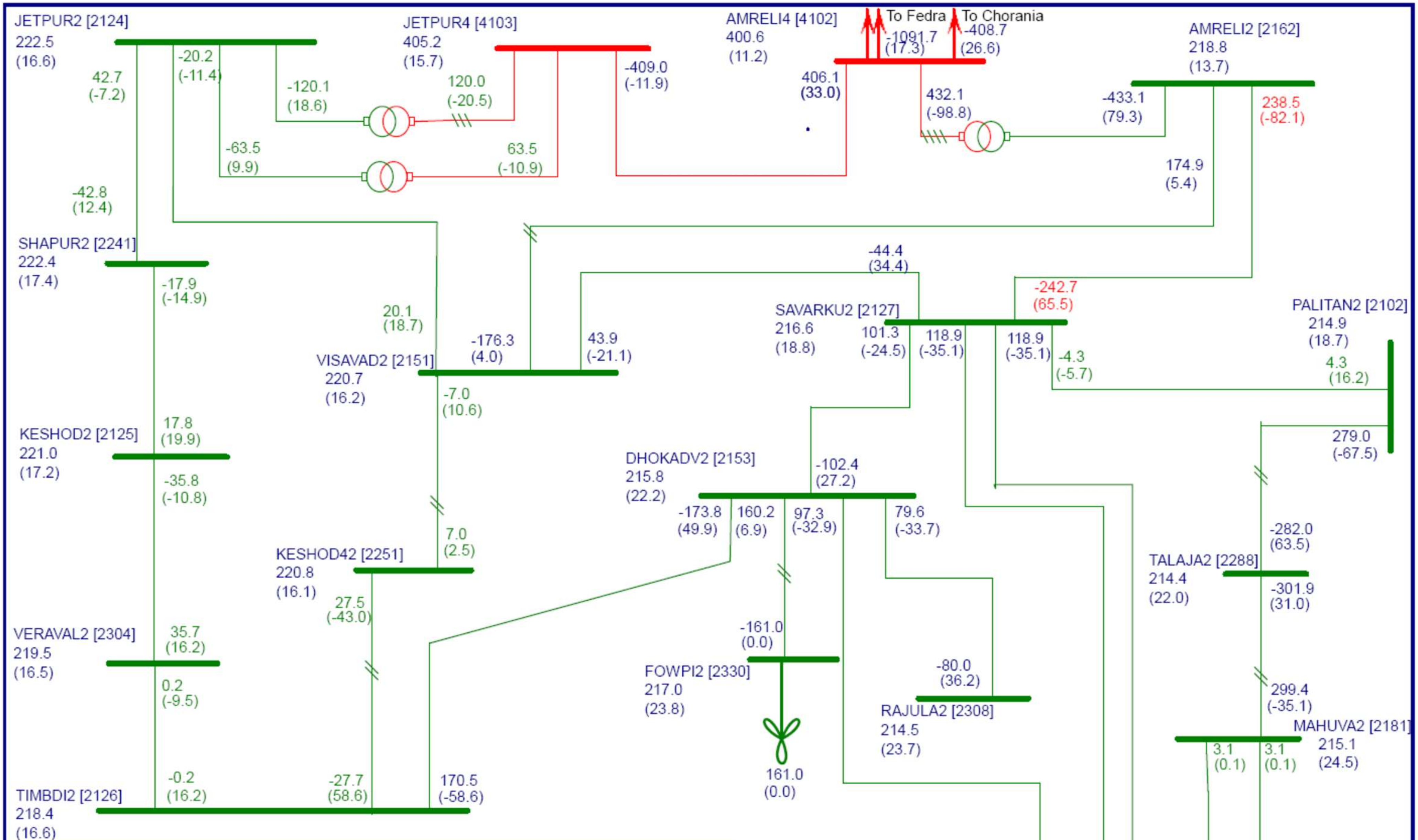
System Study for evacuation of 200 MW by M/s FOWPI
at 220 KV Dhokadava S/S.
Exhibit-1B: After integration of 200 MW at 220 KV Dhokadava.
Maximum 80% integration is considered.



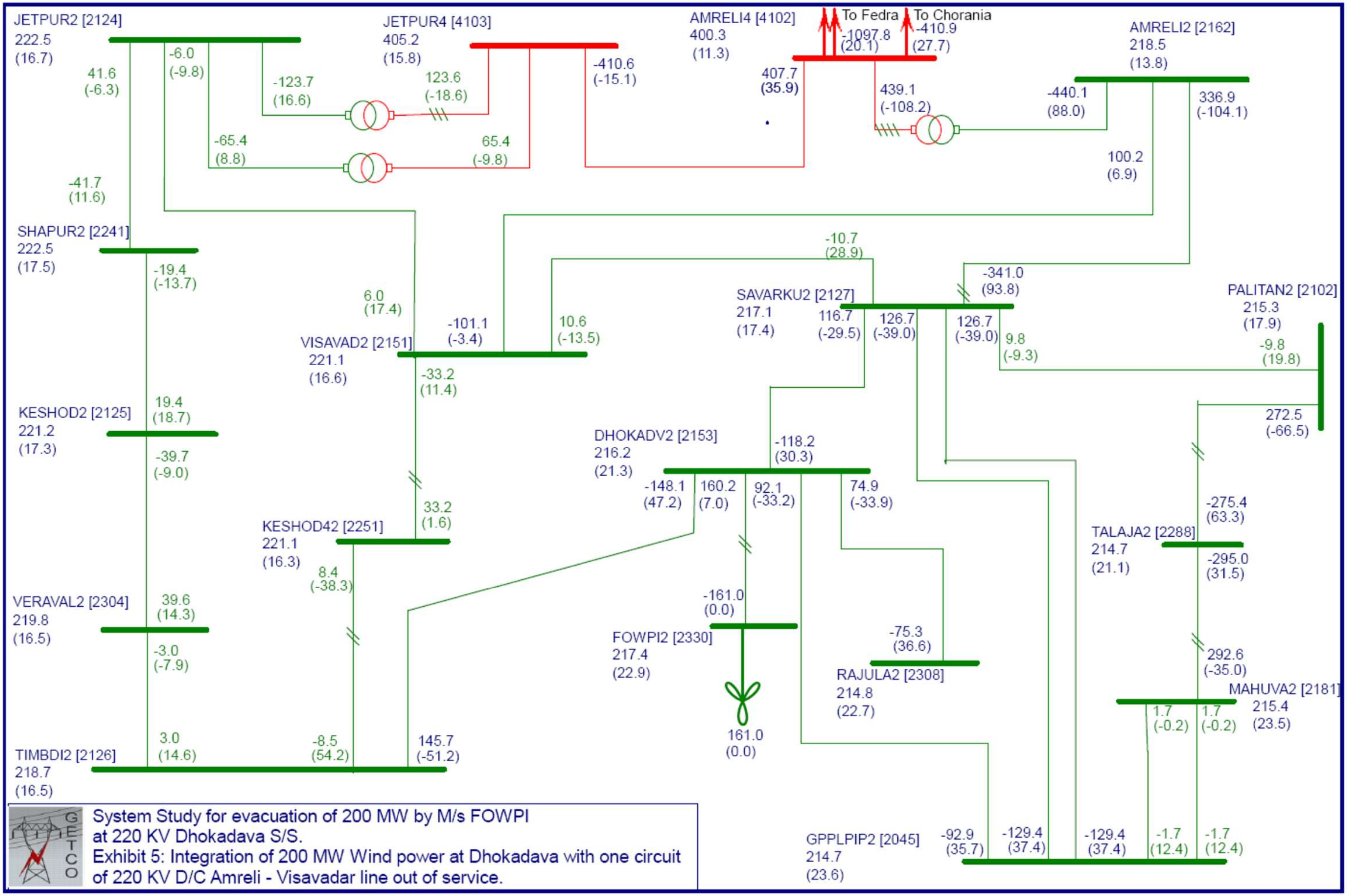
System Study for evacuation of 200 MW by M/s FOWPI
at 220 KV Dhokadava S/S.
Exhibit 2: Integration of 200 MW Wind power at Dhokadava with outage
of 220 KV D/C Dhokadava- Timbdi line.



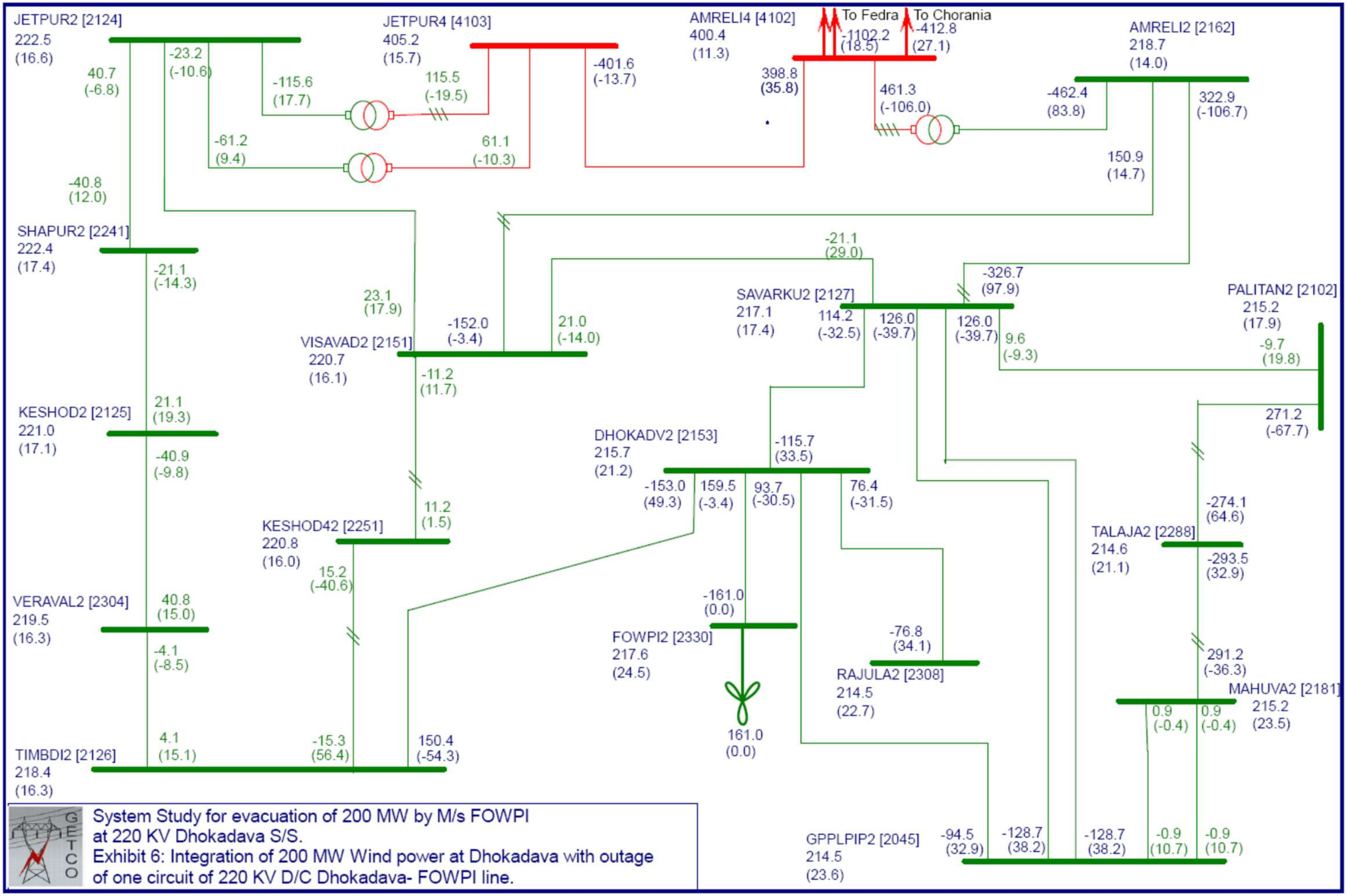
System Study for evacuation of 200 MW by M/s FOWPI at 220 KV Dhokadava S/S.
Exhibit 3: Integration of 200 MW Wind power at Dhokadava with outage of 220 KV D/C Dhokadava- Savarkundla line out of service.



System Study for evacuation of 200 MW by M/s FOWPI at 220 KV Dhokadava S/S.
Exhibit 4: Integration of 200 MW Wind power at Dhokadava with one circuit of 220 KV D/C Amreli - Savarkundla line out of service.



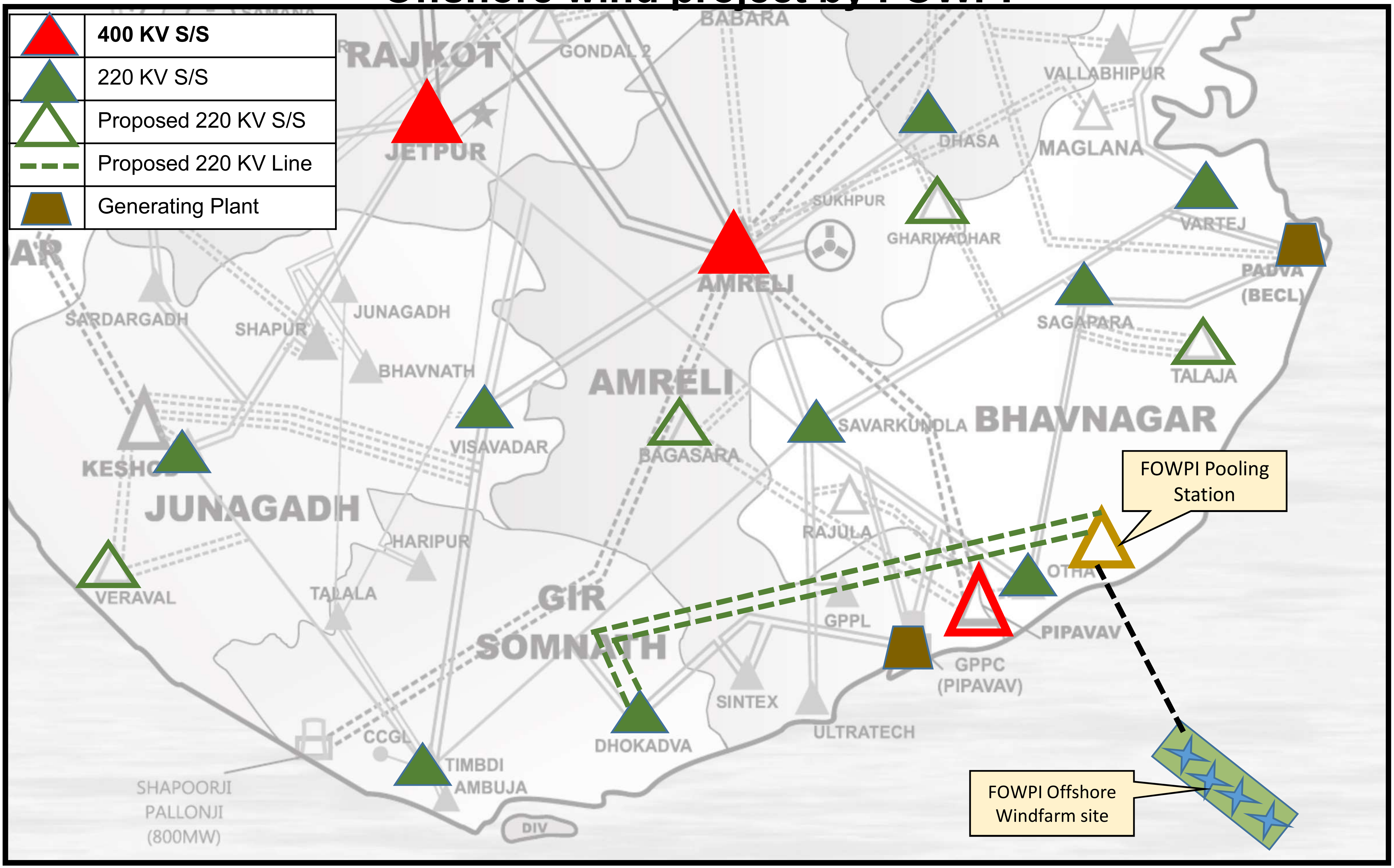
System Study for evacuation of 200 MW by M/s FOWPI
at 220 KV Dhokadava S/S.
Exhibit 5: Integration of 200 MW Wind power at Dhokadava with one circuit
of 220 KV D/C Amreli - Visavadar line out of service.

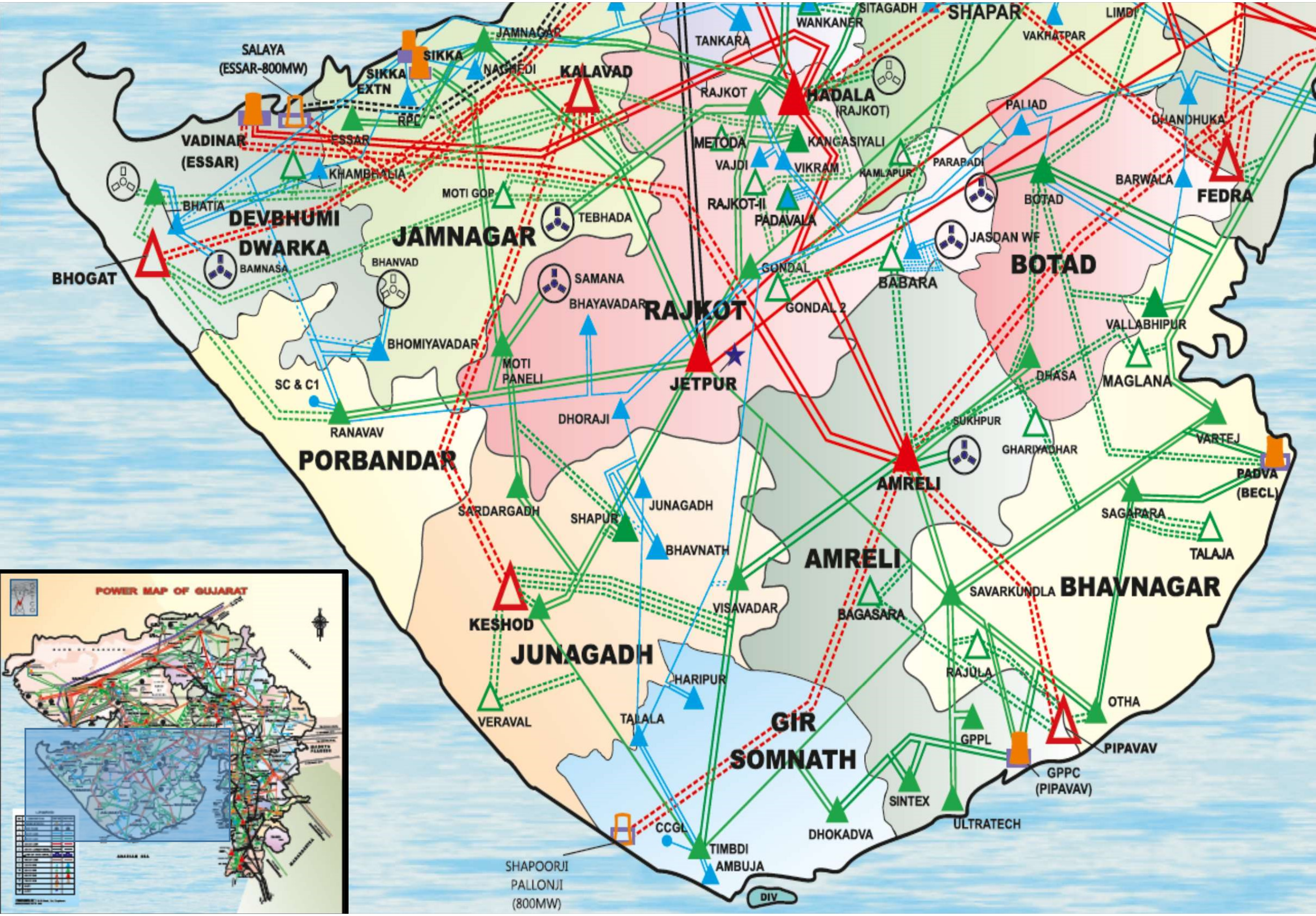


System Study for evacuation of 200 MW by M/s FOWPI at 220 KV Dhokadava S/S.

Exhibit 6: Integration of 200 MW Wind power at Dhokadava with outage of one circuit of 220 KV D/C Dhokadava- FOWPI line.

System Study for evacuation of 200 MW Wind power through Offshore wind project by FOWPI




SITAGADH
SHAPAR
LIMDI
WANKANER
VAKHATPAR
TANKARA
JAMNAGAR
SALAYA
(ESSAR-800MW)
SIKKA
SIKKA
EXTN
NAGHEDI
KALAVAD
RAJKOT
HADALA
(RAJKOT)
PALIAD
DHANDHUKA
RPL
VADINAR
(ESSAR)
ESSAR
METODA
KANGASIYALI
VAJDI
VIKRAM
KAMLAPUR
PARABADI
BARWALA
FEDRA
KHAMBHALIA
MOTI GOP
BOTAD
BHATIA
RAJKOT-II
PADAVALA
DEVBHUMI
DWARKA
TEBHADA
JAMNAGAR
JASDAN WF
BOTAD
BHOGAT
BAMNASA
BHANVAD
GONDAL
BABARA
SAMANA
GONDAL 2
BHAYAVADAR
RAJKOT
VALLABHIPUR
BHOMIYAVADAR
MOTI
PANELI
JETPUR
DHASA
MAGLANA
SC & C1
DHORAJI
SUKHPUR
RANAVAV
VARTEJ
GHARIYADHAR
PORBANDAR
AMRELI
PADVA
(BECL)
JUNAGADH
SARDARGADH
SHAPUR
SAGAPARA
BHAVNATH
TALAJA
AMRELI
SAVARKUNDLA
BHAVNAGAR
VISAVADAR
BAGASARA
KESHOD
JUNAGADH
RAJULA
HARIPUR
OTHA
VERAVAL
TALALA
GIR
SOMNATH
GPPL
PIPAVAV
GPPC
(PIPAVAV)
SINTEX
ULTRATECH
DHOKADVA
CCGL
TIMBDI
AMBUJA
SHAPOORJI
PALLONJI
(800MW)
DIV
POWER MAP OF GUJARAT

FOWPI

FIRST OFFSHORE WIND
PROJECT OF INDIA