POWER EVACUATION INFRASTRUCTURE STUDY

Requirements, costs, and timelines for offshore wind farms in Gujarat and Tamil Nadu

14 June 2024

Centre of Excellence
for Offshore Wind and Renewable Energy

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Credits

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Foreword

India’s ambitions for 500 GW of installed capacity of renewable energy by 2030 includes a target of 37 GW of offshore wind. With good wind resources, particularly off the south coast of Tamil Nadu and off the coast of Gujarat, and India’s strong track record in renewable energy deployment, the potential for offshore wind in the domestic energy supply is substantial.

Denmark, with its history and experience in offshore wind development, is supporting India on its journey. In 2021 the Centre of Excellence for Offshore Wind and Renewable Energy was launched through a government-to-government partnership between India’s Ministry of New and Renewable Energy and the Danish Energy Agency.

The work of the Centre is organised under thematic areas, which includes grid connectivity of offshore wind farms. This conceptual study explores the power evacuation infrastructure requirements for two offshore wind scenarios, one in Gujarat and another in Tamil Nadu. These sites are demarcated for development under the Strategy Paper for the Establishment of Offshore Wind Energy Projects.

The scope of the power evacuation study includes the offshore substation, export cable, landfall arrangement and onshore power system infrastructure. The work focuses on understanding the resource requirements, costs, and timelines for the associated preliminary site investigation campaigns, concept design and installation methods for power evacuation infrastructure.

The intention is to give policymakers, tenderees, contractors and developers an overview of the project scope for the electrical infrastructure for connecting the inaugural Indian offshore wind farms to the grid. The study will help facilitate decision making and ensure that planning of power evacuation infrastructure is appropriately acknowledged in the framework for offshore wind development in India.

Executive Summary

The Power Evacuation Study for Offshore Wind Farms analyses aspects for the establishment of electrical infrastructure for two projects in Gujarat and Tamil Nadu, which are demarcated in India's offshore wind development strategy. The scope includes offshore substations, export cables, landing arrangements, and onshore electrical power systems. To estimate costs and timelines for such complex projects, a concept design has been formulated including turbine layout and power system topology. There are many variables which will affect the outcome of these projects, and hence the analysis presented is intended as a preliminary study (pre-FEED) to give stakeholders an outline of the various development stages involved. The programme has been designed to target an operational offshore wind project in the second quarter of 2030 and highlights the importance of early planning to ensure the timeline can be met.

The assessment is divided into the following phases:

- Preliminary site investigations
- Power system concept design
- Offshore substation pre-FEED
- Offshore substation installation
- Export cable installation
- Programme and timeline

This study forms the preliminary stage in the project process; it outlines options and scenarios, which must be refined as the project progresses through to engineering design (FEED) to formulate a design basis used in contracting.

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Acronyms and Abbreviations

Following acronyms and abbreviations are used:

BoP	Balance of Plant (Power Infrastructure System between WTGs and to the PoC)
CBRA	Cable Burial Risk Assessment
CLV	Cable Laying Vessel
CPS	Cable Protection System
DoB	Depth of Burial (of cable)
EC	Export Cable
ECC	Export Cable Circuit
ECR	Export Cable Route
HDD	Horizontal Directional Drill (Ducts)
HFB	Harmonic filter bank
IAC	Inter Array Cables
IC	Interconnector
MPT	Main Power Transformer
OEC	Offshore Export Cable
OHL	Overhead line
OLTC	On-line tap changer (Transformer voltage regulation)
OnSS	Onshore Substation
OSS	Offshore substation
OWF	Offshore Wind Farm
PoC	Point of Connection to TSO grid
SC	Synchronous Condenser (Reactive compensation and short circuit support)
(V)SR	(Variable) Shunt Reactor (Fixed or Variable)
SS	Substation
STATCOM	Static Compensator
SVC	Static Var Compensator
TSO	Transmission System Operator
UG	Underground (cable system)
UXO	Unexploded Ordinance
VGF	Viability Gap Funding
WTG	Wind Turbine Generator

Introduction

This report outlines the Scope of Work encompassing two critical facets:

1) Preliminary Site Investigation Requirements

2) Concept design of Offshore Substation, Offshore Export Cable, and Landing Construction and Operation (C&O) Requirements for Gujarat and Tamil Nadu.

These crucial tasks are fundamental to creating a thorough plan for developing and putting in place a reliable power evacuation system.

Preliminary Site Investigation Requirements

The primary goal of this task is to conduct an analysis of the prerequisites for preliminary site investigation campaigns dedicated to power evacuation.

The focus is on understanding expected resource needs, associated costs, and establishing a realistic timeline for diverse power evacuation scenarios.

This section of the report will delve into the comprehensive mapping of different vessels, equipment, and personnel required for a full investigation campaign, spanning:

- offshore export cable corridors
- offshore substations
- cable landing infrastructure

The analysis will extend to evaluating costs and risks associated with each element. Additionally, an activity timeline will be developed to guide the execution of the investigation campaigns. As complementary material, a brief overview of the standard tender process and document details for each campaign, will be provided.

Concept Design

The objective of Offshore Substation, Offshore Export Cable, and Landing C&O Requirements is to conduct a thorough analysis of the installation, maintenance, and operational requirements for offshore substations (OSS), offshore export cables, and cable landings. Emphasis will be placed on understanding the needs of a generic 500 MW OSS.

These 2 sections for both Tamil Nadu and Gujarat site will feature a comprehensive analysis of the selected scenarios, focusing on several key aspects:

- Offshore Cable Selection
  Selection criteria considering distance, project capacity, soil conditions, and water temperature.

- Risk Assessment and Mitigation
  Evaluation of interface risks between OSS and export cable, with examples drawn from Danish offshore wind farm projects.

- Material Cost Estimation
  Detailed assessment of material costs for OSS (including Transportation & Installation) and subsea cable systems, incorporating the most updated available prices.

- Equipment, Vessels, and Manpower Requirements Analysis of necessities for cable laying campaigns, incorporating surveys and campaigns for potential dredging, boulder removal, and/or cutting operations.

- Landing Preparation Operations
  Assessment of equipment and personnel requirements for preparing the landing of offshore export cable systems.

In conclusion, this report aims to provide a comprehensive input to guide for the successful development and implementation of power evacuation infrastructure, ensuring efficiency, cost-effectiveness, and adaptability to the unique challenges of the Indian setting.

Assumptions

The Pre-FEED concepts developed in this study takes basis in the power infrastructure topology considering Asian conditions, as illustrated in the following block diagrams.[1]

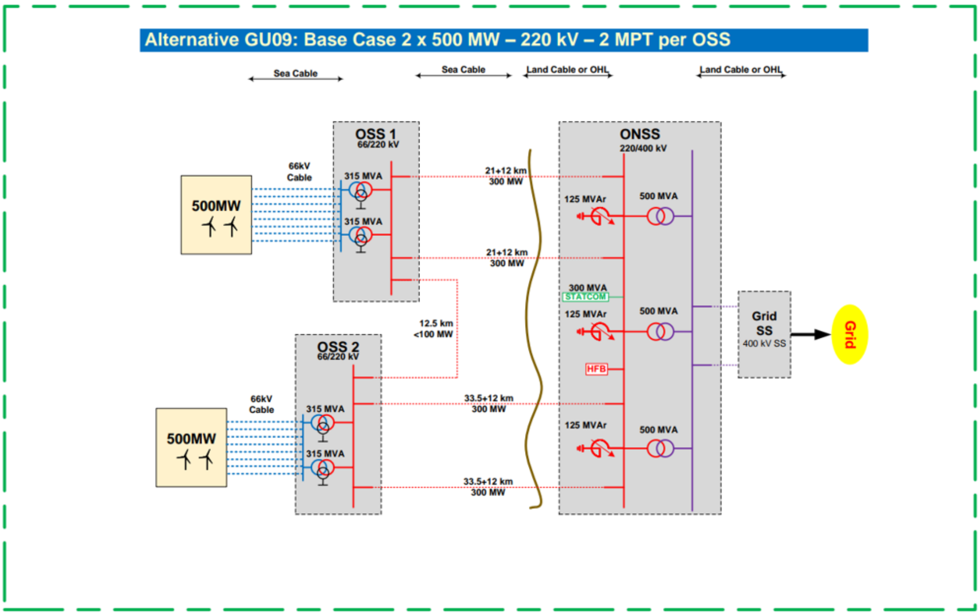

Figure 1 Gujarat HL Topology

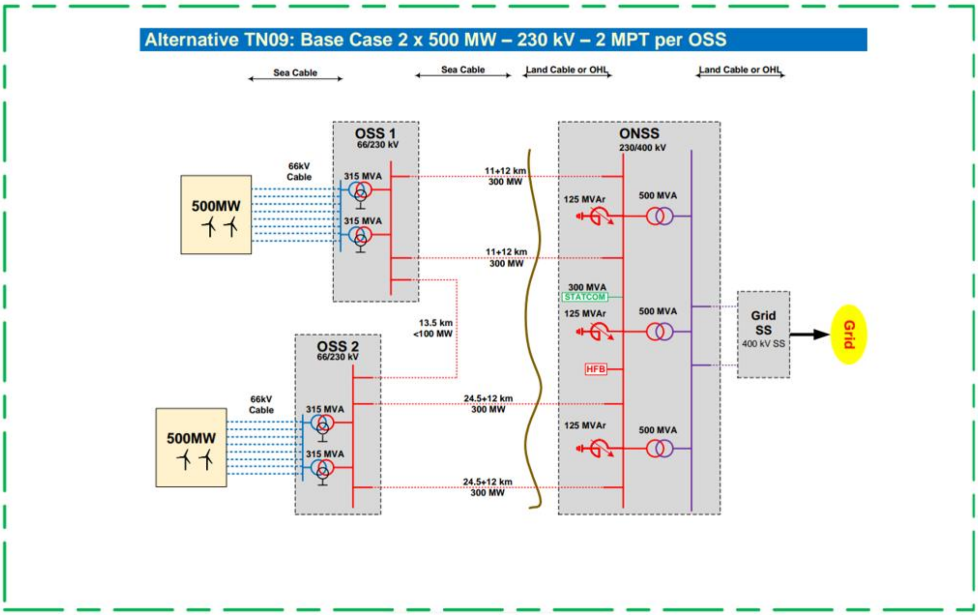

Figure 2 Tamil Nadu HL Topology

[1] *The topology diagram is high-level and simplified. It does not show the switching components (Circuit breakers, disconnectors/Earth switches) or instrument voltage–current transformers in the line bays. Reference is made to later diagrams and more details to be addressed in the FEED*

This assessment does not include the calculation of redundancy or availability but considers possible topologies applied/selected by developers. A robust selection of a BoP topology will consider reliability, N-1 criteria, loss of energy sales, and CAPEX/OPEX/LCoE. Such consideration should be taken and determined if a TSO makes a transmission asset available for OWF developers since a faulty/unavailable transmission system naturally will impose curtailment of the OWF’s ability to deliver power/energy to the grid.

The objective is to present a high-level topology that will serve as the basis for COWI's Pre-Feed. This topology will include the following elements for the development of a representative arrangement and outline of a 500 MW OSS:

- Wind turbine generators (WTG)
- Inter array cables (IAC)
- Offshore Substation (OSS)
- Export Cables (EC)
- Onshore Substation (OnSS)

It's important to note that it does not represent a solid or proven Balance of Plant (BoP) design for the two OWF sites. Further investigation and development will be required when more elaborate power system studies and FEED are implemented.

The following assumptions are made:

- Only simplified calculations are implemented.
- More accurate component ratings are anticipated with more robust load-flow and short circuit calculations implemented in PowerFactory (PF) Models as agreed.
- Cable sizing is based on preliminary site conditions that shall be verified and settled in an upcoming FEED.

The assessment will consider:

- Selecting a suitable turbine type takes the wind source regime from different topologies.
- Dividing the site areas into two equal portions of surface area.
- Making inter array cable layout for the whole site area.
- Constraints on subsea cable load capacity based on the available designs provided by the industry.

- High-level comparison of CAPEX, OPEX (including energy losses), and LCOE for two sites.

- Creation of an export cable route and corridor for each case.

  Considering Asian conditions, only one case will be utilized and investigated in the site areas of each region in the finalized topology.

OSS:

- The naming convention is as follows: OSS#1 refers to the one closer to the shore, while OSS#2 is the one further away from the shore.

- OSS#1 is located at the edge of the 500 MW VGF (Viable Grid Feed) zone, while OSS#2 is situated at the edge of the 500 MW Non-VGF zone.

- The WTG (Wind Turbine Generator) inter array cable for each OSS is rated for 66 kV, while the Export Cable connecting to the Onshore Substation (OnSS) is rated for 220 kV in Gujarat and 230 kV in Tamil Nadu sites.

- Each OSS is equipped with a MPT (Main Power Transformer) configuration consisting of two 315 MVA Power transformers with a voltage ratio of 66/220 (or 230) kV.

- The 66 kV Switchgear configuration for each OSS utilizes a Double Busbar with double sectionalized arrangement and includes 8nos. of WTG feeders and 2nos. of MPT feeders.

- The 220/230 kV GIS configuration for each OSS employs a Double Busbar with a Bus coupler arrangement, and consists of 2nos. of MPT feeders, 1no. of OSS interlink feeder, and 2nos. of OnSS export cable feeders.

- The Auxiliary Station Transformer configuration for each OSS includes 2 x 630 kVA Double-winding auxiliary grounding transformers. The primary winding is connected in a Zigzag configuration, while the secondary winding is connected in a star configuration with NER (Neutral-Earth Resistor) connection.

OnSS:

- The Point of Connection (POC) to the Grid Substation (Grid SS) from the OnSS can be achieved through either a 400 kV transmission overhead line or a cable.

- Each OnSS is equipped with a MPT configuration consisting of three 500 MVA transformers with a voltage ratio of 220(or 230) /400 kV.

- The GIS configuration for the 220 or 230 kV level includes a Double Busbar with Bus Coupler arrangement, 4 export cable feeders, 3 MPT feeders, 3 Shunt reactor feeders, 1 Harmonic Filter Bank (HFB) feeder, and 1 STATCOM feeder.

- The GIS configuration for the 400 kV level utilizes a Double Busbar with Bus Coupler arrangement and includes 3 MPT feeders and 2 Grid Substation cable or overhead line feeders.

- The 220/230 kV Shunt Reactor configuration consists of three units with a capacity of 125 MVAr each.

- The Harmonic Filter Bank is configured with one unit having a capacity of 50 MVAr.

- The STATCOM configuration utilizes one unit with a capacity of 300 MVA[2].

Export Cable

- The connection between the Offshore Substation (OSS) and the Onshore Substation (OnSS) will be established using two export cable circuits per OSS.

- The export cable selected up to the transition joint has a cross-section of 1run, 3cx1200 mm² or 3cx1400 mm² Aluminium and a rated capacity of 300 MW.

- From the transition joint to the OnSS, an export cable with a cross-section of 3runs, 1cx1000 mm² Aluminium and a rated capacity of 300 MW has been chosen.

- It is important to note that each site will have four export cables connecting the OSS-1 & 2 with the OnSS.

Interlink Cable

- The connection between the two OSS per site is established using a 1run, 3cx500 mm² aluminium cable. This cable circuit has a maximum rated capacity of 100 MW.

Inter array cable

- The connection from the Wind Turbine Generators (WTG) to the Offshore Substation (OSS) is established using 8 inter array cables per OSS.

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[2] *Rating is preliminary best estimate without supporting PSA. The STACOM rating/performance shall be addressed in the PSA/FEED when the BoP (incl. SR´s) is investigated against the prevailing grid code requirements.*

- The number of WTGs connected per inter array cable can be either 5 or 6, Refer to *Ref /2/ Ref /12/* for OSS SLD and *Ref /3/Ref /4/* for Arrey cables.
- Inter array cables selected have cross sections of 3cx300 mm² AL, 3cx630 mm² AL & 3cx1000 mm² AL.

Preliminary Site Investigation & Requirements

1.1 Introduction

For any construction it is crucial to understand the geology and soil conditions. It is even more crucial for offshore installations as the risks and associated costs offshore are much higher than for onshore installations.

Therefore, precise knowledge of the geological evolution and conditions, and geotechnical characteristics of the surface and subsurface at the actual sites of all components related to an Offshore Wind Farm, are of great importance to ensure the construction of the Offshore Wind Farm will be successful.

The geological investigations of the seabed and sub-seabed are the basis for a subsequent site investigation, planning, and construction. Areas can be de-selected based on the results of the preliminary geological investigations, the expense of geotechnical investigations can be planned, and, in some circumstances, alternative sites can be identified for offshore structures in areas where the seabed consists of localised areas with unsuitable ground conditions.

The design of the offshore wind farm layout, foundation structures and cables demand sufficient detailed knowledge of the ground conditions, geotechnical characteristics, and soil properties for the site of each structure. For these reasons, ground investigations must always be carried out with a scope that ensure all characteristics of the respective ground conditions can be established in good time before construction of the structures.

Both geological/geophysical and geotechnical site investigations and evaluations are highly specialized fields and must therefore be carried out by qualified experts, to ensure hazards are mapped, geology is understood, and geotechnical parameters are derived.

1.1.1 Reservations

All information related to pricing and time estimations set forth in this section are generalized and must be seen as indicative.

Further this section has not taken Government and local authorities' restrictions, requirements, and other constraints into consideration.

1.2 General

This section will give a general overview and information regarding, but not limit to, environmental considerations, site investigations, pricing, and survey timeline. Some section will be a short summary of already provided documents and here a reference to relevant documents will be made.

A more site-specific overview will be made in section 1.3 and 1.4 for Tamil Nadu and Gujarat respectively.

1.2.1 Environmental considerations

Previous studies have been conducted by COWI on analysing key environmental and social constraints in addition to identifying exclusion and restriction zones based on the environmental sensitivity of areas for development of offshore windfarm, which is documented in the Maritime Spatial Planning reports for Gujarat and Tamil Nadu (Ref /6/ and Ref /7/). In addition, a Rapid Environmental Impact Assessment (EIA) has also been conducted by National Institute of Wind Energy (NIWE) for the Gujarat area Ref /5/.

Based on these existing studies, an attempt has been made to provides a high-level overview of the environmental and social aspects that would require due consideration to prevent any adverse impact on the biodiversity of the selected zones and identifying any exclusion or restriction zones for development in the Gujarat and Tamil Nadu areas.

The following parameters have been considered to succinctly describe the relevant socio-environmental aspects:

Environmental considerations

- Legally Protected Areas (LPAs) and Internationally Recognized Areas (IRAs); These include areas of high significance for biodiversity conservation including marine national parks, nature reserves, sanctuaries, Ramsar sites, Key Biodiversity Areas (KBA's), Important Bird Areas (IBA's), Ecologically or Biologically Significant Marine Areas (EBSA's) and Important Marine Mammal Areas (IMMA's).

- Marine mammals: Important marine mammals include areas significant for Dugongs and other cetaceans including blue whales and humpback dolphins.

- Birds: Marine important bird areas could potentially include breeding colonies, foraging areas around breeding colonies, non-breeding concentrations, migratory routes and bottlenecks and feeding areas.

- Natural habitats: Natural habitats include marine ecosystems of seagrass, mangroves, coral reefs, and coastal sand dunes which are considered as no go areas for offshore windfarm development including landfall locations of underwater cables.

Exclusion zone refers to the areas of highest biodiversity sensitivity that needs to be excluded for development of offshore wind farms and associated infrastructure which entails the following:

LPA’s (KBA's, IBA's)
Turtle Nesting Sites (including 5 km buffer)

Restriction zones are considered as high-risk areas requiring detailed assessment, should they conflict with the development, which includes:
Dugong (including 25 km buffer)
IMMA’s

Social considerations

Potential social constraints taken into consideration comprised of the following topics:

- Marine traffic
- Fishing industry and aqua culture
- Cables and pipelines
- Oil and gas platforms and exploration areas
- Military defence
- Cultural heritage and tourism

A more site-specific overview will be presented in section 1.3.1 and 1.4.1 or Tamil Nadu and Gujarat development sites respectively.

1.2.2 Site investigations

A Geophysical survey can identify seabed and sub-surface ground conditions, describing their characteristics to determine their suitability for construction work. Geophysical surveys are an efficient method to get a general overview of the seabed and sub-seabed conditions within a short period of time for a selected area, however, the geophysical results must be verified ("ground-truthing") by geotechnical site investigations.

A Geotechnical site campaign is necessary due to specific requirements of the respective foundation or cable structures and soil situation. Planning of geotechnical investigations is based on the geological desk study and geophysical reconnaissance survey. All findings of the geotechnical campaigns should be compared with and preferable integrated with the findings of the geophysical surveys, in an integrated ground model.

The integrated ground model is a 3D representation of the ground conditions for a given area, informing on soil stratigraphy and lateral extent of soil units as well as soil characteristics for these soil units. An example is shown in Figure 3.

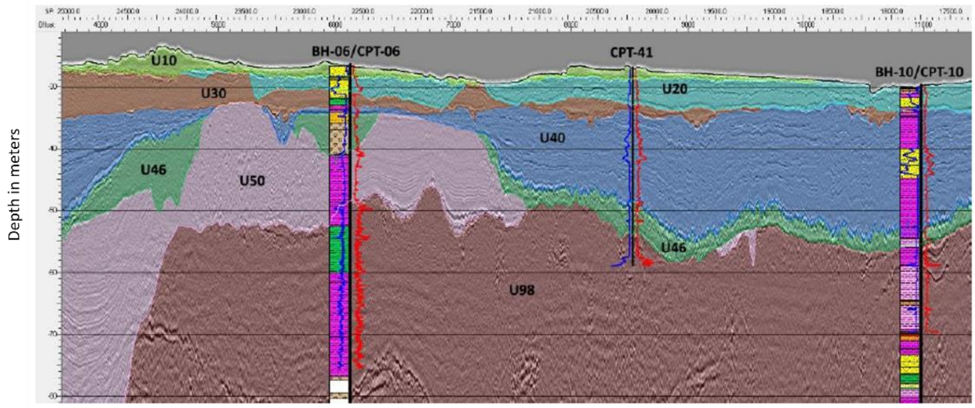


Figure 3 Example showing an integrated ground model. U refers to geological units interpreted from the seismic data and verified ("ground-truthing") by geotechnical drilling.

1.2.3 Site investigation objectives

The geophysical survey aims to obtain seabed and sub-seabed ground condition information by using several different sensors as, but not limited to, Single/Multibeam Echo-Sounder (SBES/MBES), Side Scan Sonar (SSS), Magnetometer (MAG), Sub-bottom profiler (SBP) and 2D ultra high seismic (UHRS).

The objective of the geotechnical campaigns is to obtain a comprehensive understanding of, but not limited to, soil strata, soil composition and soil strength to support foundation type selection, structural design, and cable burial design. For more details see Ref /1/.

1.2.4 Types of investigations

Geophysical surveys are the basis for the preliminary and main geotechnical site investigation campaigns and seabed mobility assessment. The geophysical survey also provide input to the WTG layout, foundation design, cable design and scour strategy. The geophysical site investigations are often divided into two phases, A geophysical reconnaissance (Recon) survey and a geophysical Route survey. For more details see Ref /1/.

An example of a Route survey line plan density is shown in Figure 4.

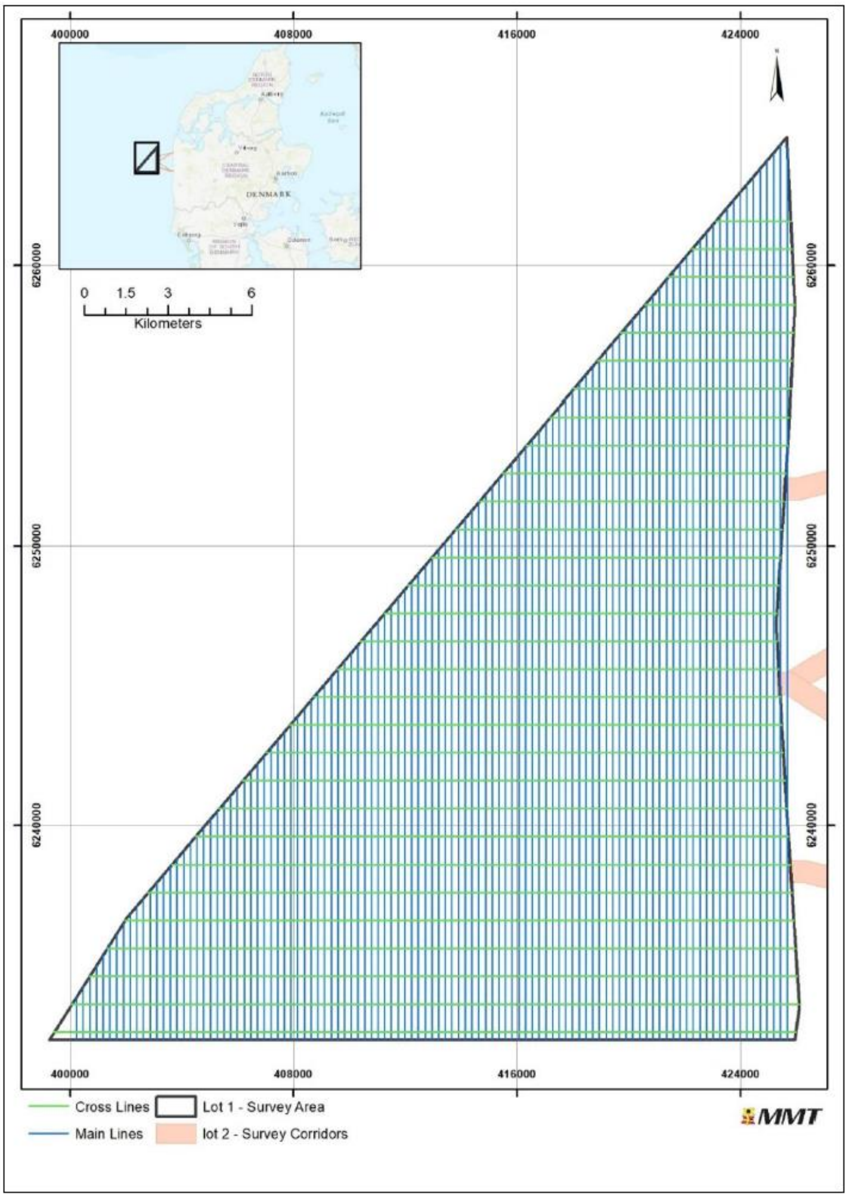


Figure 4 Example showing a route survey line plan from Thor OWF in Danish waters (Energinet, 2021).

Geotechnical campaigns are the basis for the WTG layout planning, foundation type selection and design, cable planning and design, and scour strategy. The geotechnical campaigns are often divided into two campaigns, A preliminary geotechnical campaign and a main geotechnical campaign. For more details see Ref /1/.

In addition, several different other surveys might be relevant to support the development of the OWF area and these surveys are, but not limited to, Benthic survey, supplementary geotechnical investigations, or 3D seismic survey. For more details see Ref /1/.

All survey activities should be supported by relevant site investigation reports, for more details see Ref /1/.

For planning survey activities considerations regarding, but not limited to, existing infrastructure, vessel traffic and fishery should be made to minimize the risk of delays in the different development phases. For more detail see Ref /1/.

1.2.5 Pricing

This section presents a general overview and an indicative overview of the basic pricing for site investigations related to Offshore Wind Projects.

Please be aware that every project is different, and pricing will depend on, but not limited to, vessel type solution, survey scope, amount of survey lines, challenging seabed conditions (soft soils), amount of soil samples, and weather conditions.

Please note that costs related to geotechnical laboratory testing and general reporting costs are not included as these are depended on the survey scope and therefore too volatile to include at this stage of the project. In addition, costs related to additional surveys such as Benthic Habitat survey or UXO survey are not included as the need for additional surveying is not known until a later stage in the project. For more details see Ref /1/.

Pricing for each of the two OWF sites are presented in section 1.3.3 and 1.4.3 General timeline – Offshore Geophysical/technical investigations.

Please note that the timeline shown in Table 0-1 is highly generalized and does not reflect a realistic detailed timeline as several factors, but not limited to, vessel availability, seasonal changes (weather window for optimal survey conditions) and granting of permissions, will have implications on the time schedule. The surveys will also be interdependent, so some cannot start until others are completed and, as a minimum, draft results are available; the table below generally reflects this interdependency.

Table 0-1 Generalized Timeline for Site Investigations related to Offshore Wind Development.

	Year 1				Year 2				Year 3				Year 4				Year 5				Year 6			
Survey	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Geological Desk study and geotechnical risk assessment																								
Geophysical Reconnaissance																								
Preliminary Geotechnical Campaign																								
Metocean Buoys																								
Initial Seabed Mobility Assessment																								
Geophysical Route Survey*																								
Geotechnical Main Campaign*																								
Geophysical nearshore																								
Geophysical onshore																								
Geotechnical nearshore																								
Geotechnical onshore																								
UXO inspection																								
Pre-Construction**																								

* Survey layout needed

** within a year before construction start

split between OWF site and ECR possible

survey execution

reporting

1.3 Tamil Nadu

This section will provide a site-specific overview for the Tamil Nadu OWF development area of site#1 including, but limited to, environmental and social considerations, preliminary layout, and site investigation pricing.

The Tamil Nadu OWF development site is in the Laccadive Sea at water depths ranging from 20-60 meters.

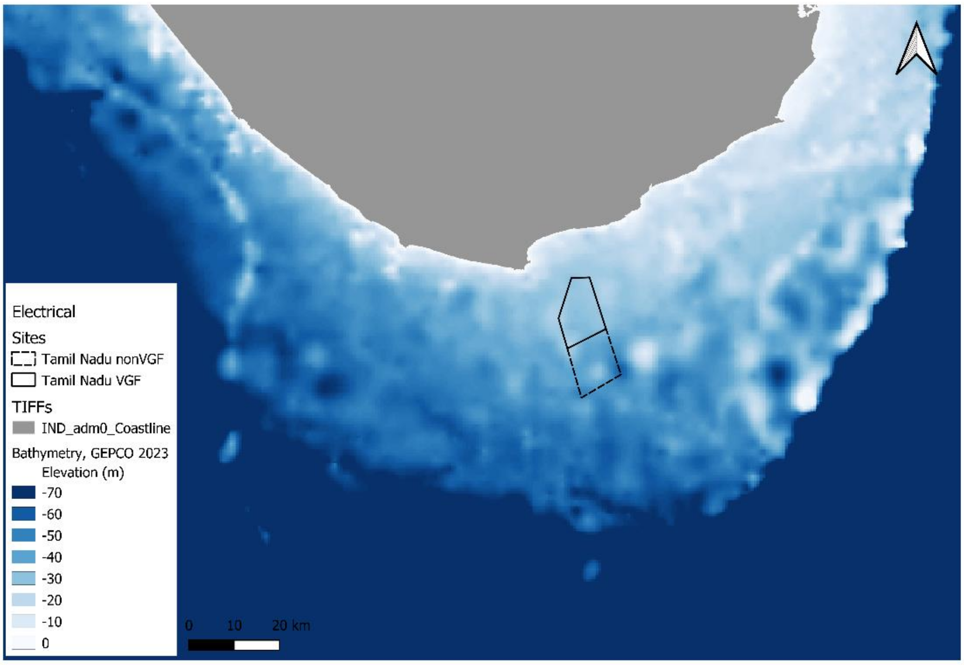


Figure 5 Bathymetry of Tamil Nadu OWF development site. (ENS, 2023).

1.3.1 Environmental and social considerations

This section will summarize the environmental and social considerations made for the Tamil Nadu OWF development site.

Exclusion and restriction zones

As seen Figure 6 and Figure 7 from the selected OWF sites for development at Tamil Nadu are not located within any environmental exclusion or restriction zones.

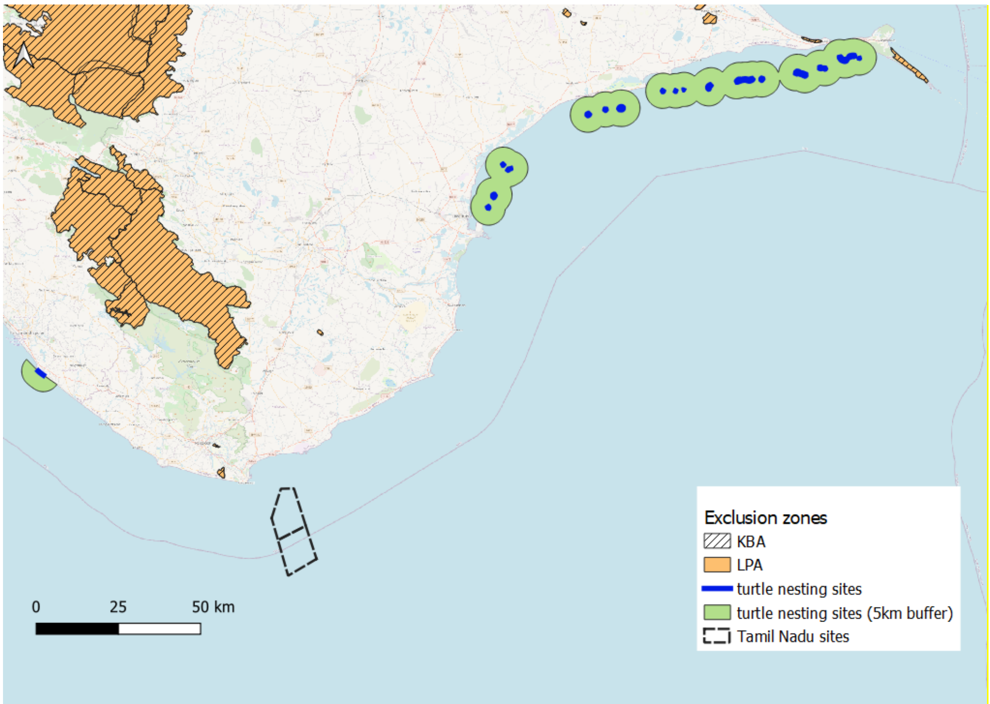


Figure 6 Map showing exclusion zones in Tamila Nadu.

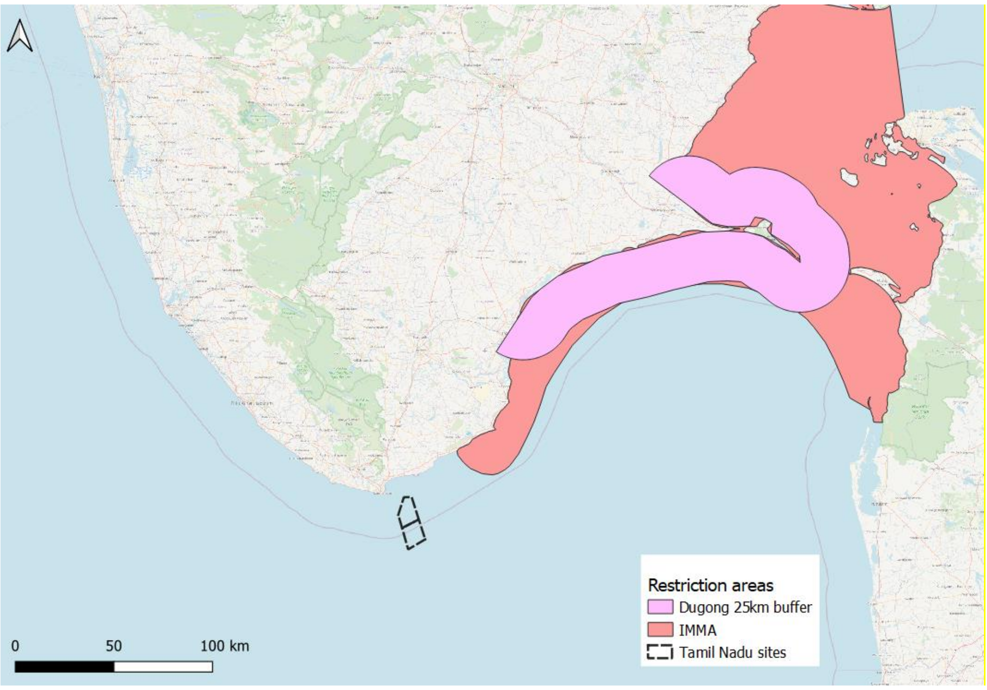


Figure 7 Map showing restriction zones for Tamil Nadu OWF development site.

Marine traffic

Based on the available data, it is observed that significant traffic majorly comprising of commercial vessels passes through the selected Tamila Nadu OWF development area, which primarily originates from Tuticorin port passing through these sites, Figure 8.

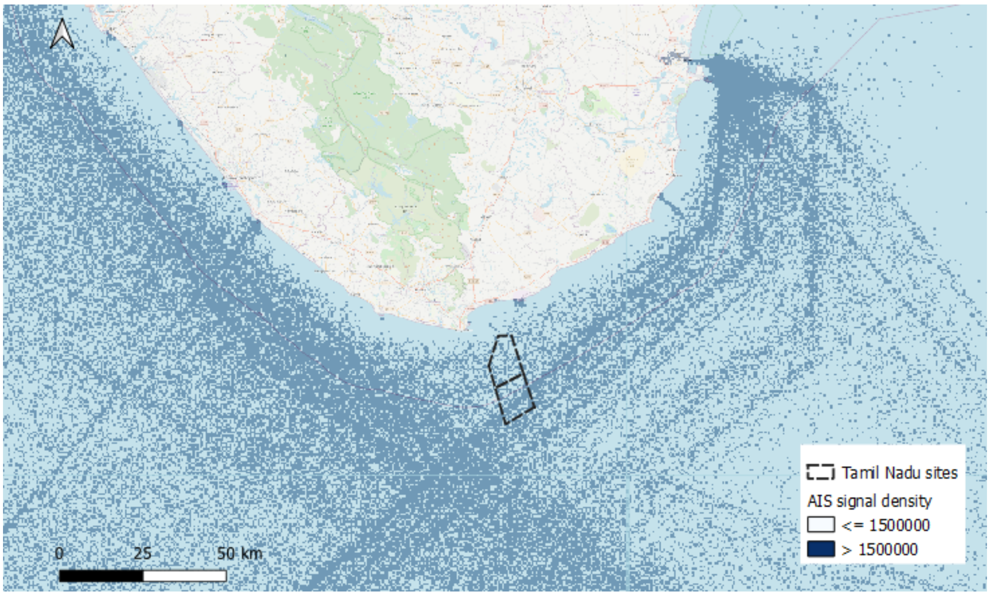


Figure 8 Marine traffic density for the area around Tamil Nadu OWF development sites.

Fishing industry and aqua culture

The Gulf of Mannar in Tamil Nadu is known to be a productive ecosystem with rich coastal biodiversity and abundant endemic fish species, making it one of the largest fisheries in India. The Kanyakumari area in the southern tip of the Indian peninsula is abundant in seaweeds and is well suited for seaweed farming, Figure 9.

Figure 9 Seaweed farming areas and fishing harbours near Tamil Nadu.

Cables and pipelines

Figure 10, shows submarine cables in southern coast of India and near Tamil Nadu with their corresponding landing points. No constraints are observed around the selected sites.

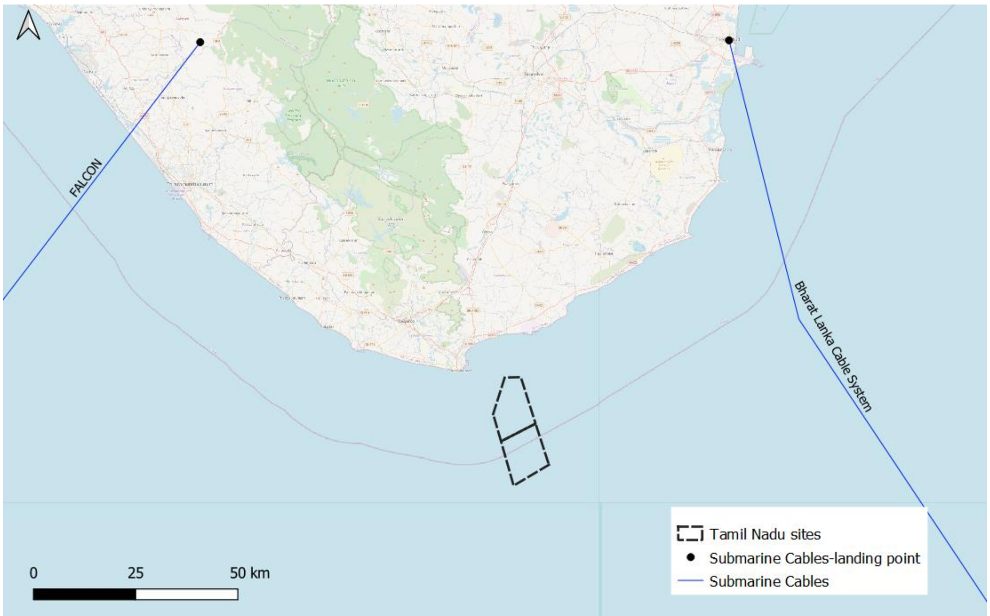


Figure 10 Submarine cables and landing points around Tamil Nadu Development site.

Oil and gas platforms and exploration areas

No oil and gas platforms and pipelines are known to be located within or in the proximity of the selected sites in Tamil Nadu, Figure 11.

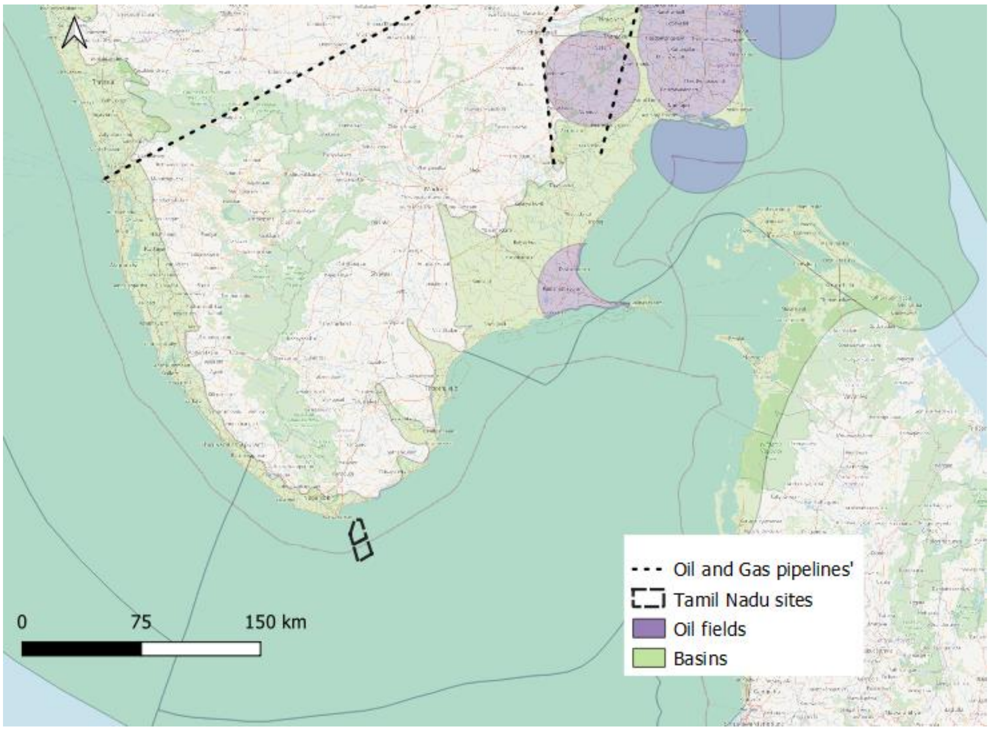


Figure 11 Oil and gas exploration areas around Tamil Nadu.

Cultural heritage and tourism

As seen from Figure 12, two ASI protected sites are located close to the selected site in Tamil Nadu.

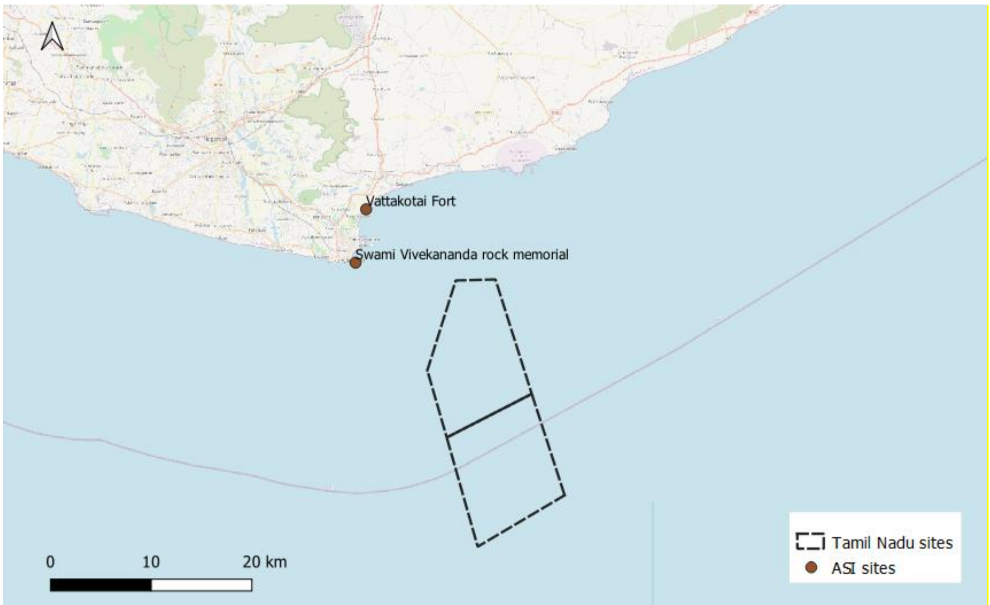


Figure 12 Cultural heritage sites near the selected sites in Tamil Nadu.

Military defence

It is understood that the Ministry of Defence (MoD) has previously given in-principal clearance for the sites in Tamil Nadu, Ref /6/. Therefore, conflict with defence site is not considered as a potential constraint.

Substations

Based on desktop study and preliminary assessment, nearest substations have been identified as shown in Figure 13 below. It is to be noted that for purpose of this study only 220 kV substations will be considered.

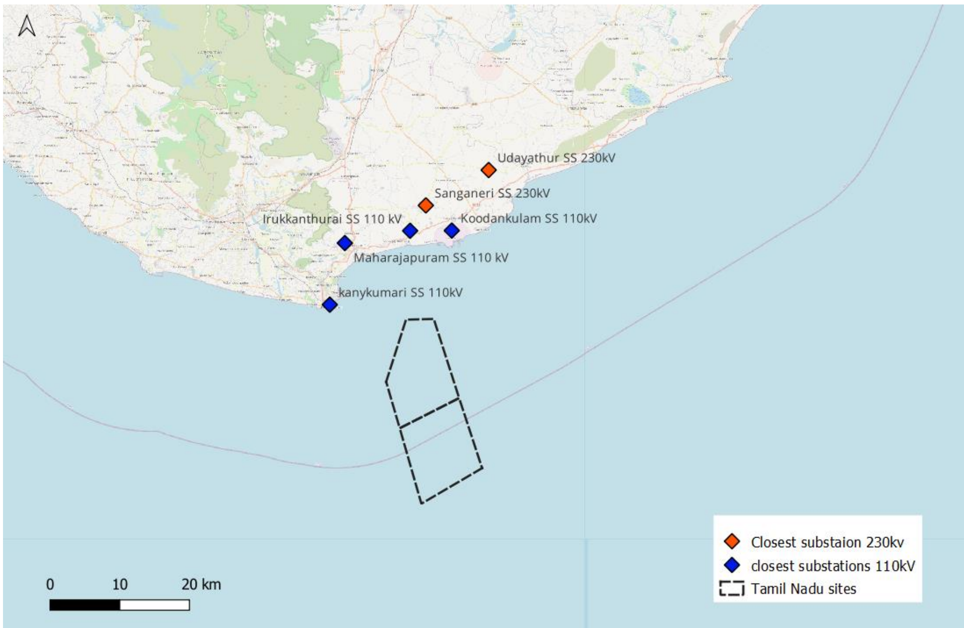


Figure 13 Nearest substations to Tamil Nadu sites.

1.3.2 OWF Layout

Tamil Nadu OWF preliminary site layout consist of 33 WTGs, two OSS, IACs approximately 146 km (1 GW area) and ECR approximately 23.8 km in length, Figure 14. The width of the ECR is assumed to be 1 km.

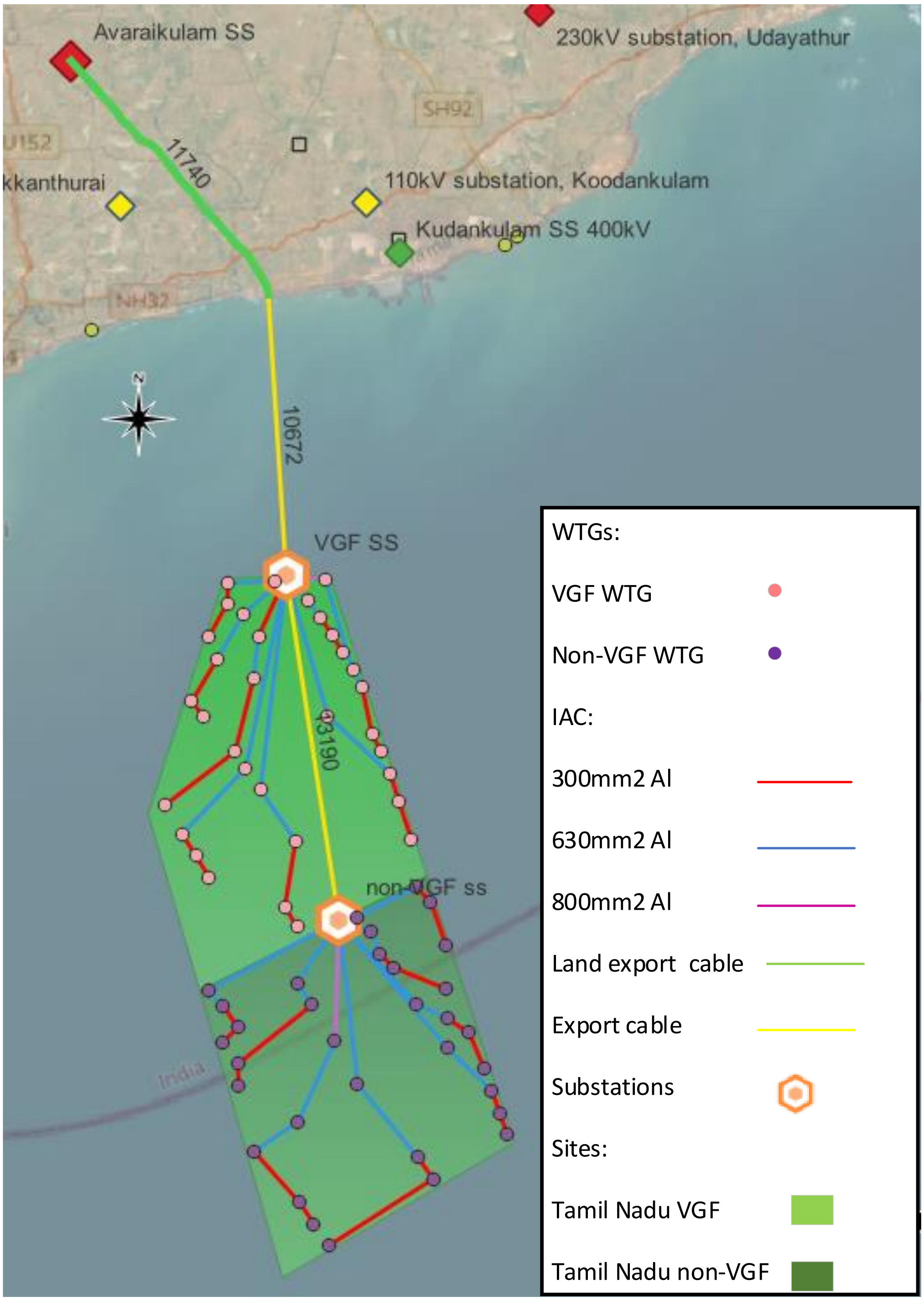


Figure 14 Tamil Nadu OWF preliminary Layout.

1.3.3 Pricing

Based on the current preliminary layout a rough price estimate is given in Table 0-2 for Tamil Nadu OWF development site. Note that pricing for phase 2 has increased (3%) form what was stated in Ref /1/ due to increase in ECR length.

Table 0-2 Rough costs estimates for Tamil Nadu based on the preliminary OWF layout. Note phase 2 total price has a 3% increase from what is shown in Ref /1/ due to increase in length of the ECR.

Area	Survey phase	Rough estimated survey costs (EUR)	Assumptions
Tamil Nadu	Phase 1 Power Evacuation	Total ~6,000,000	Seismic recon survey of ECR (SBP) (~23.8 km length & 1 km width), nearshore ECR area (SBP), and OSS (2D-UHRS); 10% geotechnical campaign (OSS positions (deep) + ECR (shallow)); and hydrographic survey. Incl. vessel mobilization and de-mobilization.
	Phase 1 OWF	Total ~10,000,000	Seismic recon survey of 500 MW OWF area; geotechnical campaign (10% WTG (deep) & IAC (shallow)), and hydrographic survey. Incl. vessel mobilization and de-mobilization.
	Phase 2 Power Evacuation	Total ~11,000,000	Full coverage seismic route survey ECR (SBP)) (~23.8 km length & 1 km width), nearshore ECR area, and OSS (SBP & 2D-UHRS); geotechnical campaign (OSS (2PCS) positions (deep) + full ECR (shallow)); and hydrographic survey. Incl. vessel mobilization and de-mobilization.
	Phase 2 OWF	Total ~48,000,000	

1.4 Gujarat

This section will provide a site-specific overview for the Gujarat OWF development area of site B3 including, but limited to, environmental and social considerations, preliminary layout, and site investigation pricing.

The Gujarat OWF development site is in the Arabian Sea at water depths ranging from 20-40 meters, Figure 15.

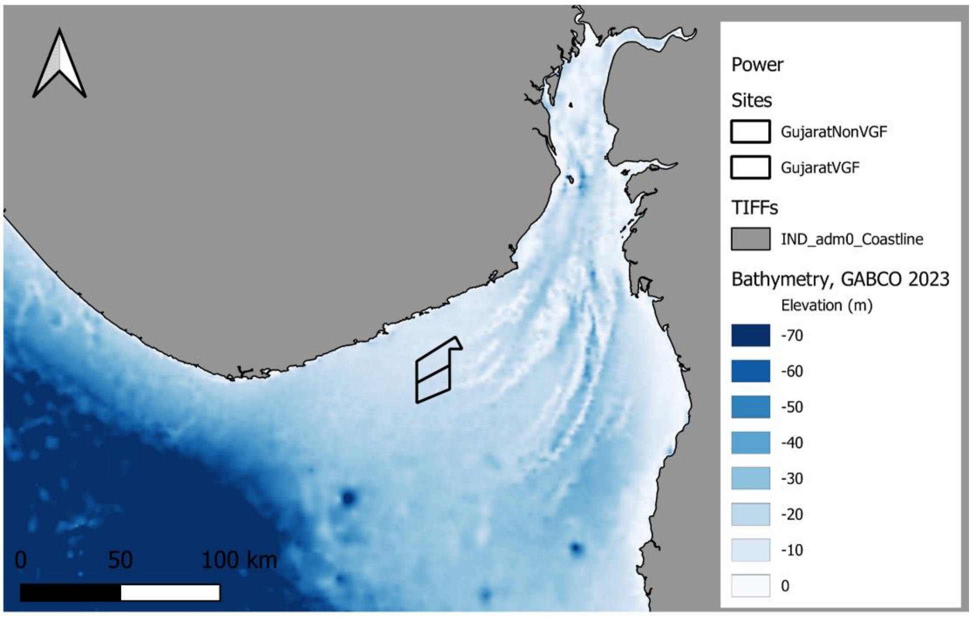


Figure 15 Bathymetry map of Gujarat OWF development site (ENS, 2023).

1.4.1 Environmental and social considerations

This section will summarize the environmental and social considerations made for the Gujarat OWF development site.

Exclusion and restriction zones

As seen from Figure 16 and Figure 17, the selected Gujarat development site is not located within any environmental exclusion or restriction zone.

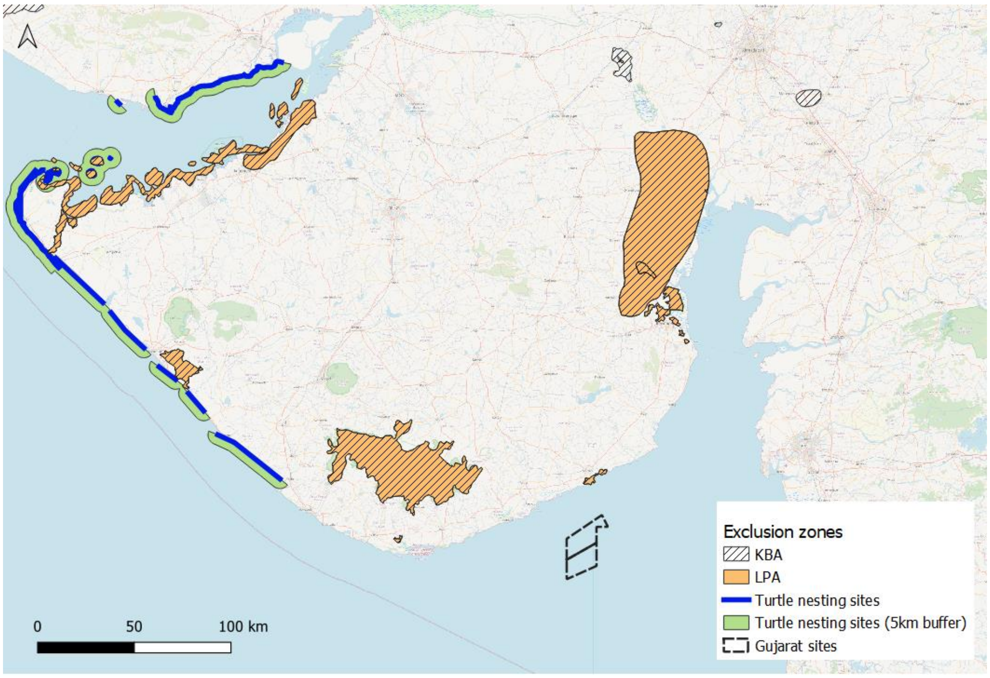


Figure 16 Map showing exclusion zones in Gujarat.

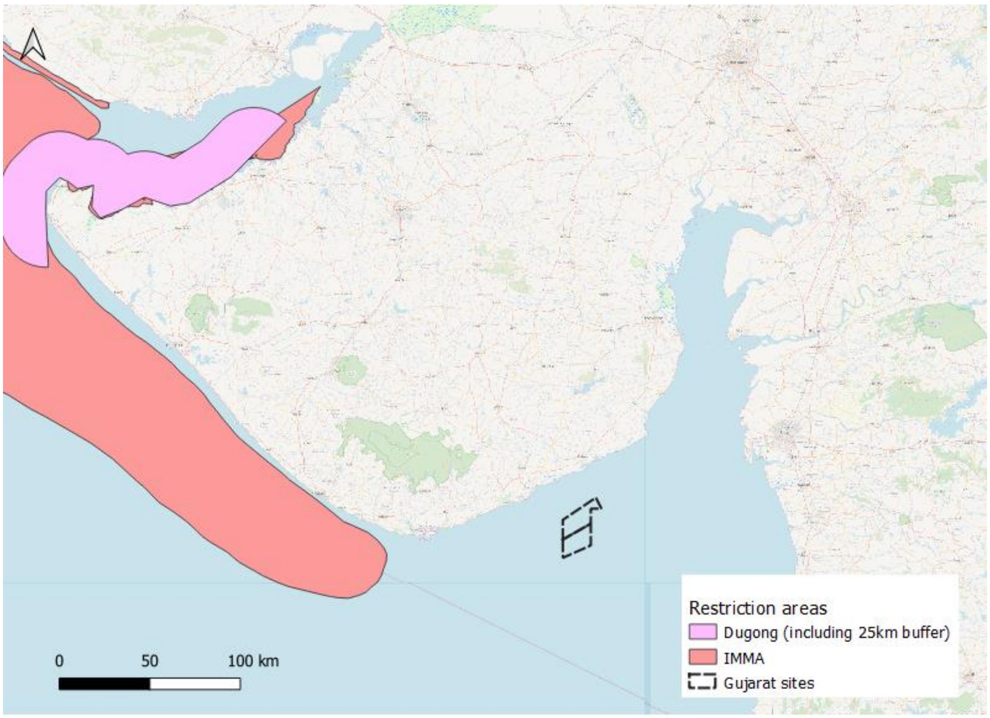


Figure 17 Map showing restriction zones in Gujarat.

Marine traffic

It is observed that majority of the traffic originating from Bhavnagar, Hazira and Porbandar port is passing through the selected sites which indicates a significant potential conflict, Figure 18.

It would therefore be prudent to conduct a detailed marine traffic plan including traffic separation schemes for the selected areas for mutual coexistence of marine traffic and Offshore Windfarms.

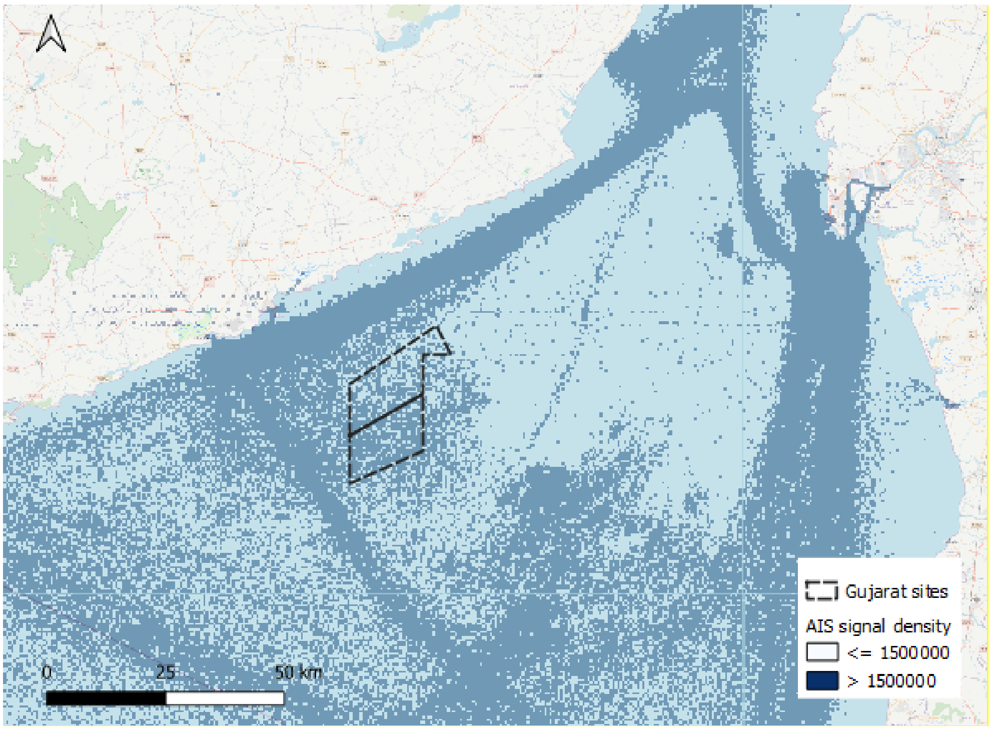


Figure 18 Marine traffic in and around the selected site in Gujarat.

Fishing industry and aqua culture

The entire coastline of Gujarat is known to be a productive ecosystem and fishing is therefore considered to be one of the key economic activities for the surrounding population. Few fishing harbours are located near Gujarat sites as shown in Figure 19.

Seaweed farming is predominant in the Gulf of Kutch areas and is not seen near the selected sites.

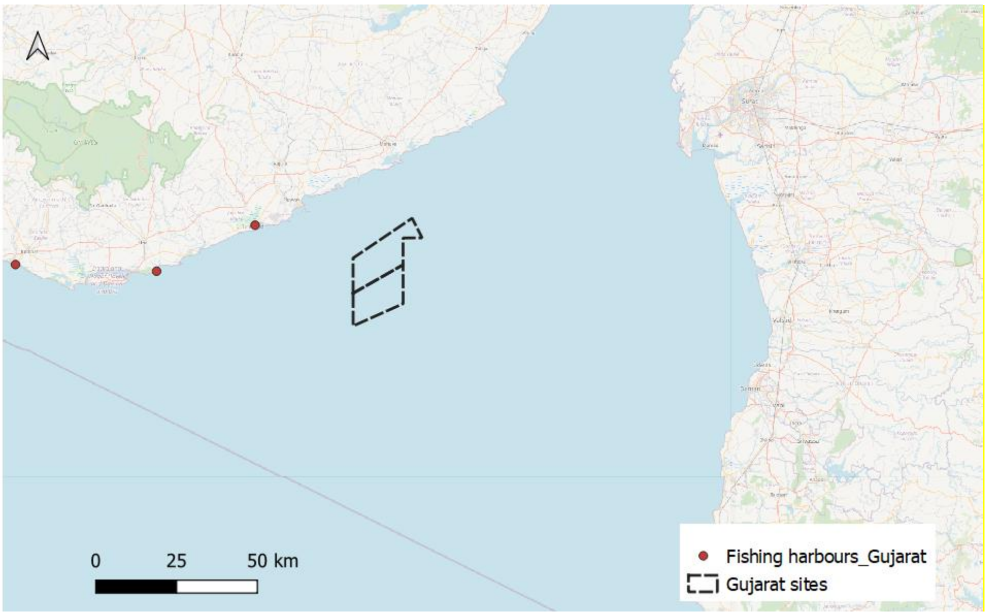


Figure 19 Fishing harbour near Gujarat site.

Cables and pipelines

Several submarine cables are known to be concentrated in the Arabian Sea. Figure 20, shows submarine cables in western coast of India and their landing points. Most of the cables however are seen to be landing in the coast of Mumbai. Therefore, no constraints are observed around the selected site in Gujarat.

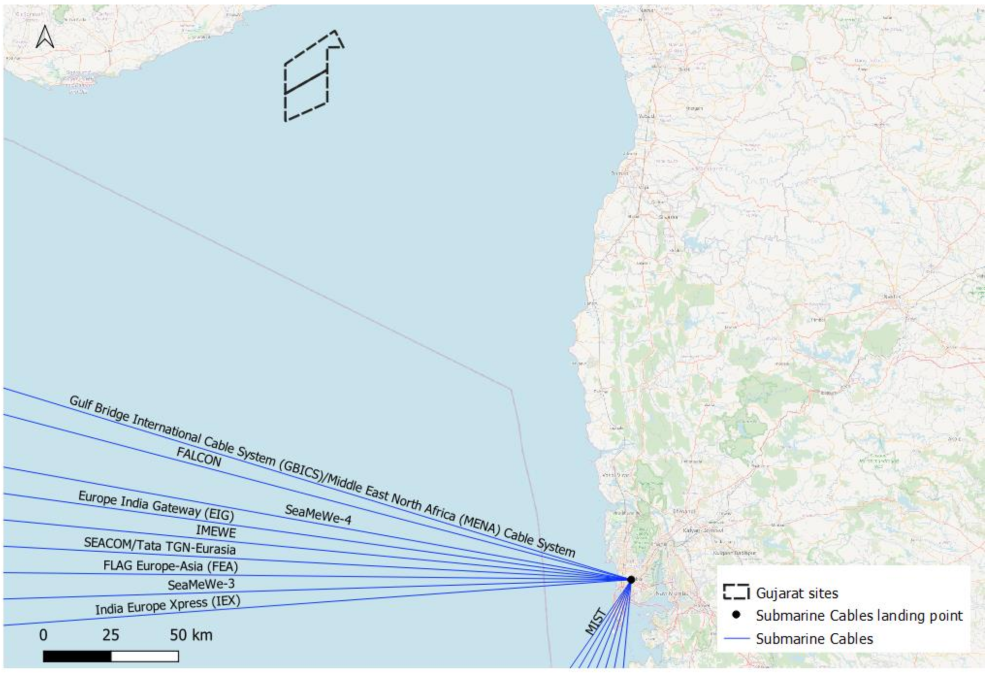


Figure 20 Submarine cables and landing points in the Arabian Sea.

Oil and Gas exploration activities

As seen from Figure 21, offshore areas of Gujarat primarily lie in the Saurashtra basin and the selected site falls within the oil fields which could be a possible constraint.

It would therefore be advisable to consult with the Ministry of Oil and Gas to confirm this assessment in early development stages to avoid any potential conflict.

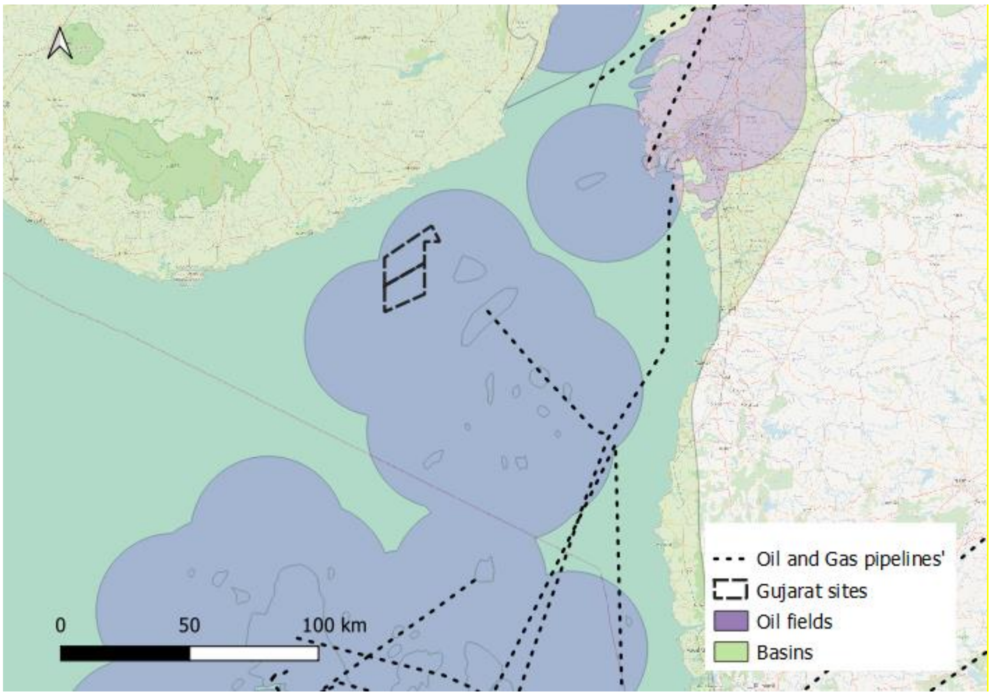


Figure 21 Oil and gas exploration areas near Gujarat.

Military defence

Based on previous report, Ref /7/, it is understood that the Ministry of Defence (MoD) has been given in-principal clearance for the selected site in Gujarat. Therefore, conflict with defence site is not considered as a potential constraint.

Cultural heritage and tourism

As shown in Figure 22, no sites protected by the Archeologically Survey of India (ASI) are near the selected site in Gujarat.

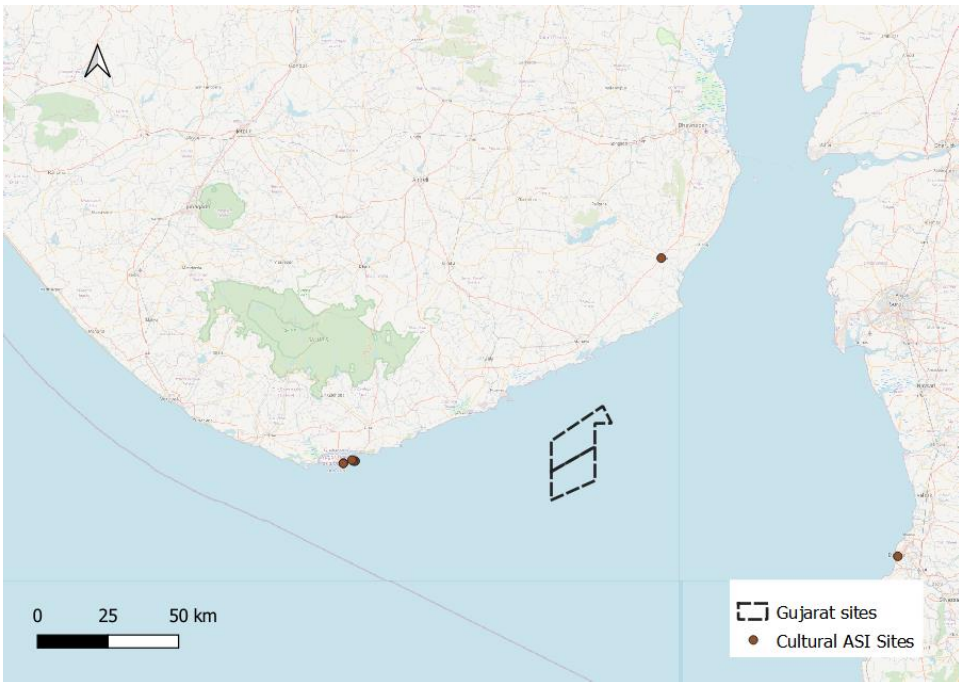


Figure 22 Cultural heritage sites in Gujarat.

1.4.2 OWF Layout

Gujarat OWF preliminary site layout consist of 42 WTGs, two OSS, IACs approximately 253 km (1 GW area) and ECR approximately 33.5 km in length, Figure 23. The width of the ECR is assumed to be 1 km.

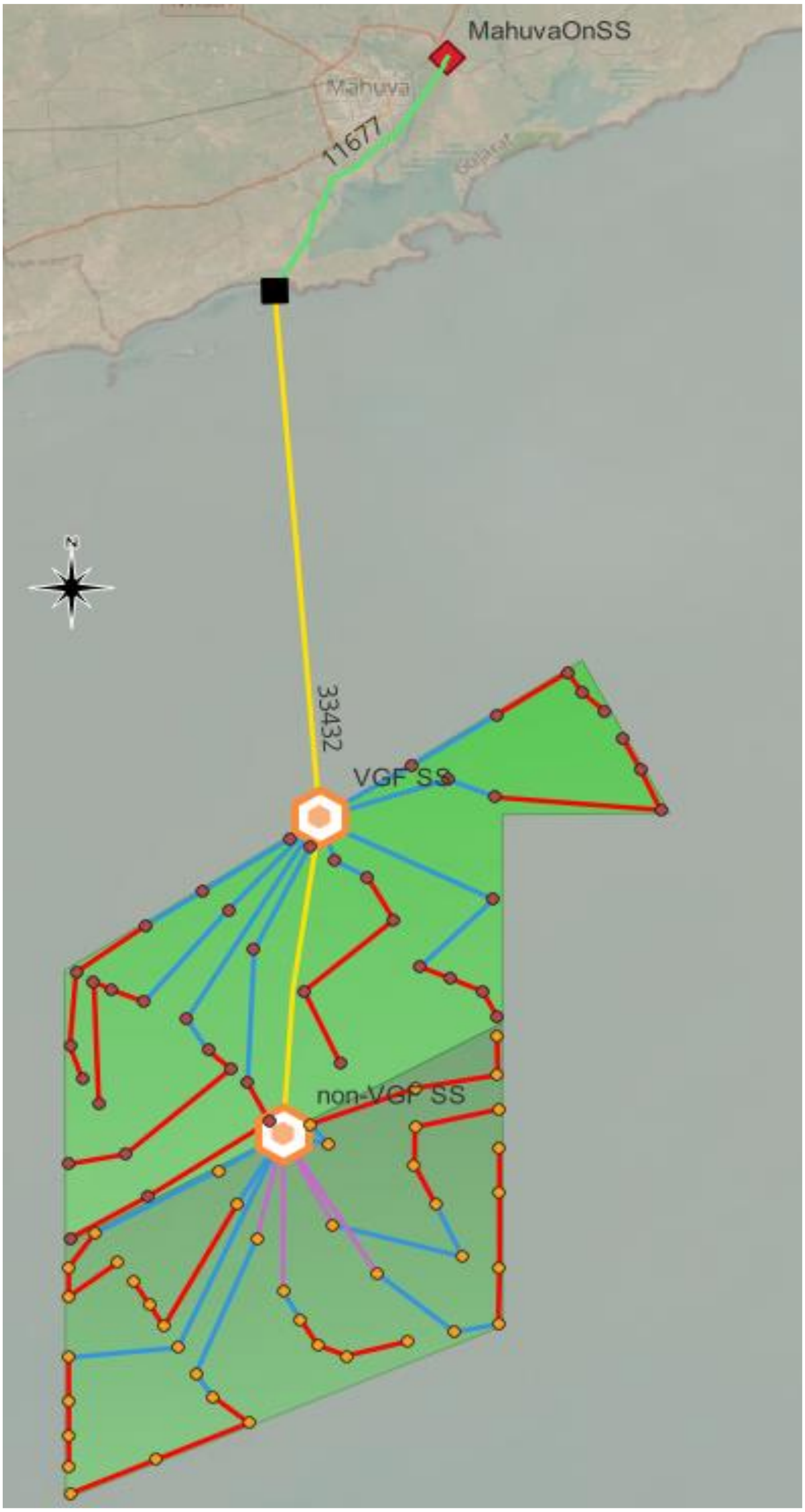


Figure 23 Gujarat OWF preliminary Situation Plan

1.4.3 Pricing

Based on the current preliminary layout a rough price estimate is given in Table 0-3 for Gujarat OWF development site. Note that pricing for phase 2 has increased (5%) form what was stated in Ref /1/ due to increase in ECR length.

Table 0-3 Rough costs estimates for Gujarat based on the preliminary OWF layout. Note phase 2 total price has a 5% increase from what is shown in Ref /1/ due to the increase of the ECR length.

Area	Survey phase	Rough estimated survey costs (EUR)	Assumptions
Gujarat	Phase 1 Power Evacuation	Total ~6,000,000	Seismic recon survey of ECR (SBP) (~33.3 km length & 1 km width), nearshore ECR area (SBP), and OSS (2D-UHRS); 10% geotechnical campaign (OSS positions (deep) + ECR (shallow)); and hydrographic survey. Incl. vessel mobilization and de-mobilization.
	Phase 1 OWF	Total ~10,000,000	Seismic recon survey of 1 GW OWF area (2 x 500 MW); geotechnical campaign (10% WTG (deep) & IAC (shallow)), and hydrographic survey. Incl. vessel mobilization and de-mobilization.
	Phase 2 Power Evacuation	Total ~12,000,000	Full coverage seismic route survey ECR (SBP)) (~33.3 km length & 1 km width), nearshore ECR area, and and OSS (SBP & 2D-UHRS); geotechnical campaign (OSS (2 PCS) positions (deep) + full ECR (shallow)); and hydrographic survey.

Area	Survey phase	Rough estimated survey costs (EUR)	Assumptions
			Incl. vessel mobilization and de-mobilization.
	Phase 2 OWF	Total ~49,000,000	Full coverage seismic route survey (500 MW OWF area) geotechnical campaign (all WTG (42 PCS.) (deep) & IAC (shallow)); and hydrographic survey. Incl. vessel mobilization and de-mobilization.

2 WTG Site Layout

2.1 Introduction

Comprehensive work has been done to establish optimal layouts for wind turbines, inter array cables, offshore substations (OSS), and export cables within Site B3 in Gujarat and Site #1 in Tamil Nadu. The site layout constitutes the basis for the IAC routing to the OSS locations that are necessary to obtain the concept design and CAPEX estimates.

The task started with choosing suitable turbine types based on the distinct wind resources in both regions.

The site areas have been divided into two equal portions designated as "sub-area with VGF support" and "sub-area with non-VGF support."

The primary goal was to create layouts that maximize annual energy production (AEP) while minimizing internal wake effects, restricting wake losses to a maximum of 10 %. The calculations and considerations for AEP and wake effects are detailed in the Layout optimization Memo for both Tamil Nadu and Gujarat in documents Ref /8/ and Ref /9/.

Optimized plans for the Gujarat and Tamil Nadu sites, focused on maximizing the annual energy production (AEP) while minimizing internal wake interference have been addressed in these reports.

2.2 Turbine selection

The wind turbine models selected for this analysis are non-binding and are subject to change. Them models were chosen based several factors, including the current market projections for large-WTG sites (10MW+) and average wind speed of the sites. Power curves comparable to large manufacturers were evaluated at various windspeeds to maximise production for Gujarat and Tamil Nadu's wind profiles.

	Average Windspeed [m/s]	Turbine Type	Capacity [MW]	Rotor Diameter [m]	No. turbines
Gujarat	7.8	Generic 12 MW	12	220	42 VGF + 42 nonVGF
Tamil Nadu	10.9	Generic 15MW	15	236	33 VGF + 33 nonVGF

2.3 AEP Optimisation

When optimising the complete system design, WTG placement was considered first before inter array cables, OSS, or export cables. An AEP optimiser was used the wind resource analysis software EMD windPRO, taking into account wind direction, speed, and distance constraints between the turbines. The simulation process was performed individually for the four sites (Gujarat VGF and nonVGF, Tamil Nadu VGF and nonVGF) using placeholder, equally spaced grids to represent external wind parks causing wake loss. The finalised optimisations have been used as a baseline for all further work in this document.

3 Power System Concept Design, Tamil Nadu

3.1 Topology & Situation Plan

The finalized topology presented in this initial study, consists of two Offshore Substations (OSS) named OSS#1 and OSS#2. OSS#1 is strategically located at the edge of the 500 MW Viability Gap Funded (VGF) zone, while OSS#2 is positioned at the edge of the 500 MW Non-VGF zone.

Below is the SLD snapshot of Tamil Nadu OWF concept, further details can be found in Ref /12/, sheet 1.

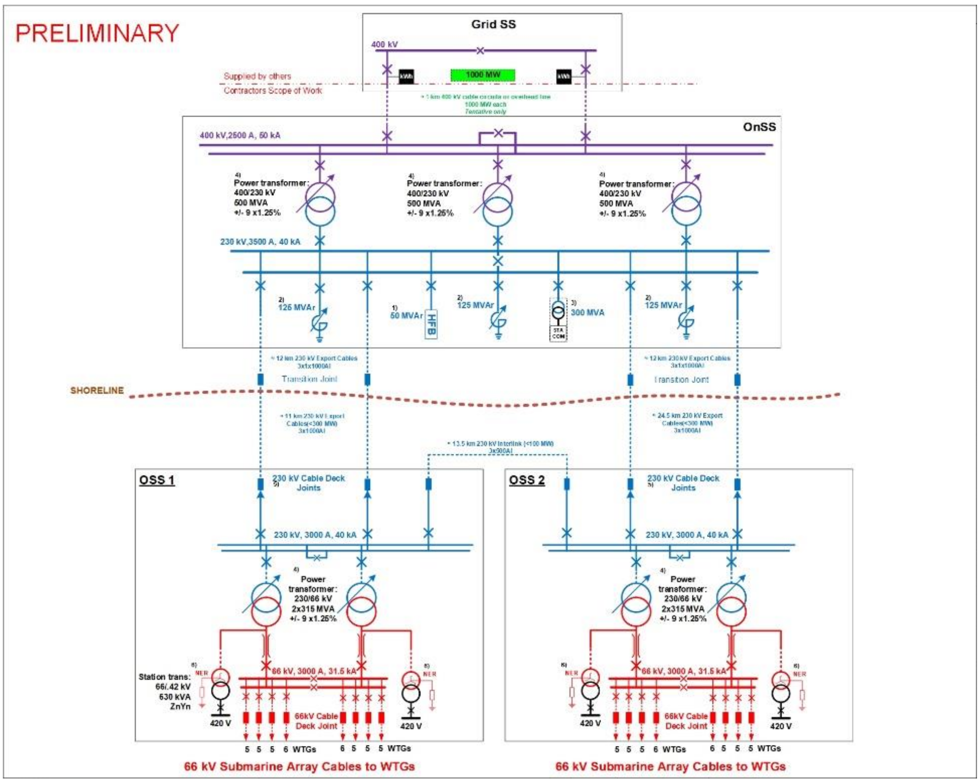


Figure 24 Tamil Nadu OWF SLD (taken from Ref /12/)

The power evacuation topology for the overall 1000 MW capacity is achieved through two Offshore Substations (OSS), each rated for 500 MW. Each OSS is equipped with two 315 MVA transformers with a voltage ratio of 66/230 kV. The inter array cables (IACs) from the Wind Turbine Generators (WTGs), totalling 16, are evenly distributed between the two OSS, with 8 IACs allocated to each OSS.

Each OSS features a 66 kV double busbar configuration with double sectionalizerd arrangement, with 4 IAC feeders connected to 2 x Mainlizer Power Transformers (MPT) respectively. The grounding for each 66 kV bus section is provided by an Auxiliary Grounding Transformer connected to the MPT feeder via a T module.

At the OSS 230 kV level, a double busbar configuration with a bus coupler arrangement is implemented. This includes 2 x Export cables with a maximum power capacity of 300 MW each. Additionally, there is an interlinking cable between the two OSS, supporting a maximum power capacity of 100 MW.

All four Export cables connect to a single Onshore Substation (OnSS), which is equipped with three 500 MVA Power Transformers operating at a voltage ratio of 230/400 kV. Both the 230 kV and 400 kV buses are configured as a double busbar system with a coupler arrangement. At the 230 kV bus, there are three variable shunt reactors with a capacity of 125 MVAr each, one Harmonic Filter Bank (HFB) with a capacity of 50 MVAr, and one Static Synchronous Compensator (STATCOM) with a capacity of 300 MVA. The connection to the Point of Connection (PoC) can be either a double circuit overhead line or an underground cable, depending on specific requirements and considerations.

Below is SLD snapshot of the OSS, further details refer to Ref /12/, sheets 2 and 3.

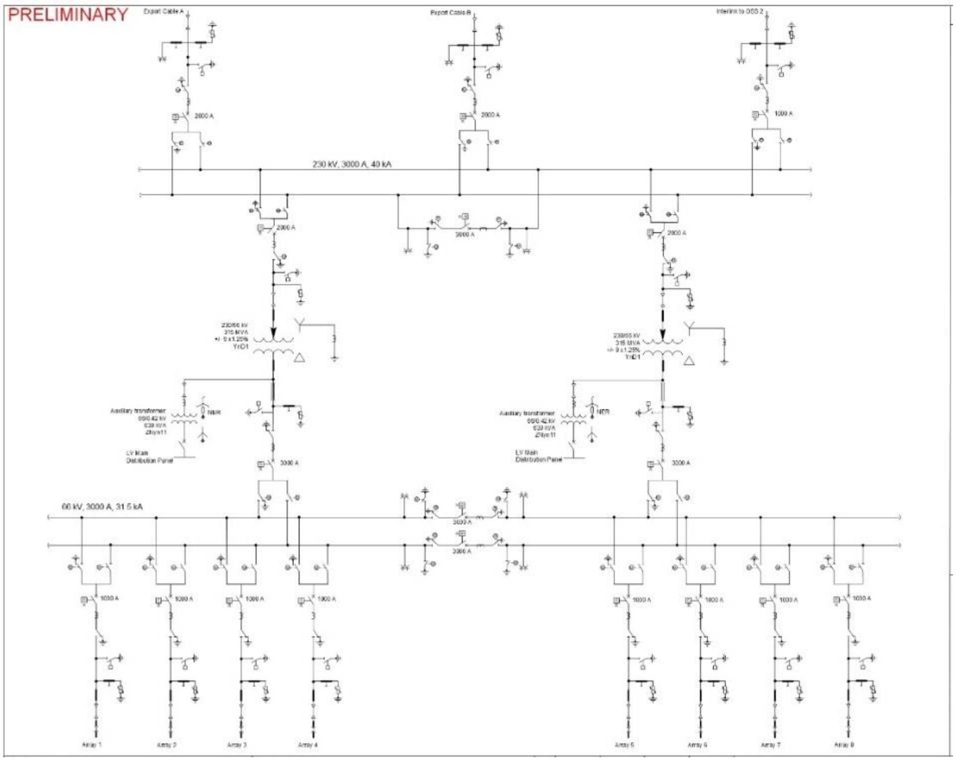


Figure 25 Tamil Nadu OSS#1 SLD (taken from Ref /12/)

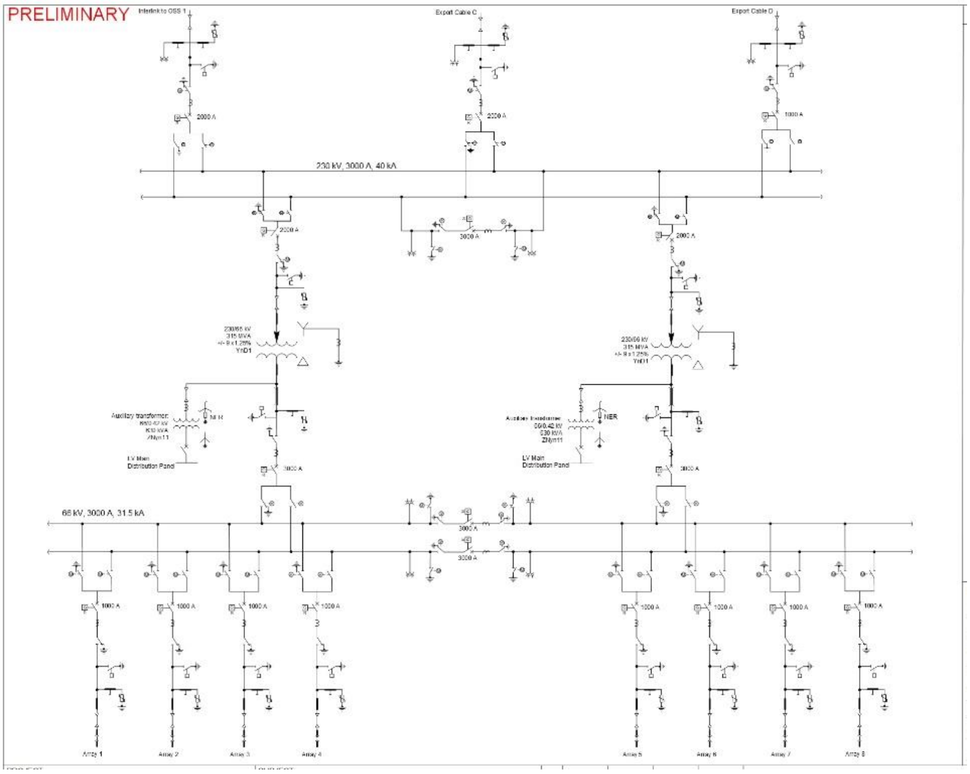


Figure 26 Tamil Nadu OSS#2 SLD (taken from Ref /12/)

Topology assessment

- The 66 kV double busbar with double sectionalized arrangement allows for the flexibility of transferring certain feeders to a second or adjacent bus during bus failure or maintenance, ensuring uninterrupted power supply.
- The 2x315 MVA MPT provides the flexibility to connect additional WTG feeders from an adjacent bus in case of MPT failure or maintenance, reducing wind turbine curtailment.
- The adoption of a 230 kV double busbar with a coupler arrangement provides the flexibility to transfer feeders to a second bus, ensuring full power transfer even in the event of bus failure.
- With 2 x 300 MW capacity export cables, rated for 230 kV, there is additional flexibility in power transfer. In the event of second export cable failure or maintenance, the remaining export cable can handle increased power transfer, minimizing wind turbine curtailment.
- A solid interconnection between the OSSs is considered, intended as back-up in case of fatal damage of the EC to shore (1–3-month repair time can be anticipated) for OSS powering and minor power transfer through the other ECs.

- The OSS does not include any shunt reactors, which can result in a voltage increase at the OSS terminals due to the long cable lengths connected to the OnSS. It is important to conduct thorough power system studies to confirm this.

- The OnSS is equipped with a STATCOM, HFB, and SRs for power factor correction, reactive power compensation, and harmonic distortion mitigation. The precise ratings and dimensions need to be established through comprehensive power system analysis.

- Considering potential voltage fluctuations imposed by the grid at the Point of Connection (PoC), the adoption of a Variable Shunt Reactor (VSR) may be required to ensure that the voltage at the OSS 230 kV remains below 245 kV. This requirement can only be determined through rigorous power system studies.

- Each OSS incorporates two auxiliary grounding transformers with Neutral Earthing Resistors (NER). They fulfil a dual function: ensuring dedicated grounding for inter array cable protection and providing both primary and backup auxiliary supply to the OSS low-voltage electrical system. Furthermore, by utilizing NER, the ground fault current can be confined to a safe limit, thereby offering protection to the transformer.

Situation Plan

Based on a layout indicated below:

- Two separate sites

- Two OSS with ≈ 13.5 km separation

- 2 x 33 x 15 MW WTGs → 2 x 495 MW installed.

- 66 kV inter array cables with an OWF layout and the location of WTGs as per below Figure 27 is anticipated.

- OSS#1 approx. 11 km subsea cable corridor to anticipated landfall.

- OSS#2 approx. 24.5 km subsea cable corridor to anticipated landfall.

- ≈ 12 km onshore cable corridor from landfall to anticipated OnSS/Grid SS.

Figure 27 Situation plan in Tamil Nadu

Illustrated IAC routing is tentative only and will be elaborated further. Offshore crossing of the export and IAC cables is seldom and always a planned routing.

3.2 Offshore Export & Interlink Cable Systems

3.2.1 Cable Size Selection

The 230 kV export cable sizing takes basis in the required load capacity in conformity with Figure 2 Tamil Nadu HL Topology and the preliminary selection tables presented in Appendix A.

- 230 kV Export cables
  300 MW, 245 kV 3x1200 mm² XLPE- AL

- 230 kV Interlink cable
  100 MW, 245 kV 3x500 mm² XLPE- AL
  (400 mm² can be used if available)

3.2.2 Cable Burial & Protection

The DoB of the sea-cables will depend on the properties of the seabed and the need for mechanical protection against external damage caused by anchors or fishing trawling.

The target DoB and installation methods shall be determined in Cable Burial Risk Assessment and Cable Burial Assessment that take basis in the G/G surveys, ship traffic data, seabed movement history etc. Also crossing of shipping lanes where eventual future dredging activities are to be considered may impact the target DoB. Below is only generic and preliminary since proper CBRA and CBA shall be done (also to satisfy the Insurance companies that are reluctant to insure offshore cables because of "huge losses" during the last 1½ decade in Europe when the OWF outbuild commenced.

- Bedrock or little sediment thickness
  Burying the cables will require rock blasting that is not environmental acceptable or economical feasible on a larger scale.

  The sea cables can be surface laid and covered with either a rock berm, sandbags or concrete mattresses. Ref /10/

  On sections were large vessels and risk of anchor damage is insignificant the surface laid cable can be protected by pre- or post-installed protection sleeves that will eliminate the risk of abrasion damage from movement of the cable during its operational lifetime. (Movement caused by impact from waves/currents etc.)

- Hard clay
  Target dept will be in the range of 1 – 1.5 m since the anchors very likely will not penetrate and damage the cables. (Fishing trawls may go down to 0.5 m).

  Dependent on the hardness a cable plough operation can be made for 1.5 – 3 m DoB.

In harder seabed a cable trencher or trench cutter as a post lay burial operation can be designed.

- Sand “loose or medium loose”
  This is the most favourable condition for cable installation since a simultaneous cable laying/burial either with a cable plough or ROV (jetting) operation can be implemented.

  Target depth will be in the range of 1.5 – 2.5 m and depend on the anchor damage risk and impact from seabed movement.

  If sand exist and a shipping channel shall be crossed and prepared for future dreading then up to 6 – 10 m DoB may be required. This can be achieved with a vertical injector being mobilized on a special CLV.

The export cables for the site are anticipated buried into the seabed at a 1.5 m target depth, whereas the ampacity rating assumes up to 3 m to account for eventual seabed movement. No outcropping bedrocks is anticipated, and simultaneously laying/burial bey utilisation of cable plough or jetting/trenching tool/methods are anticipated.

A first mapping of environmental constrains, existing services etc. is illustrated in Figure 28. No environment constrains are identified for the far shore, near shore or at the landfall.

A shipping traffic corridor is observed and shall be considered in regard to the detailed location of the OSS. The export cables appear not to be influenced, but the IAC may be considered with larger DoB to counteract anchor damage or (unlikely) future dredging of the seabed.

No existing pipelines or cables have been identified in the export cable corridor.

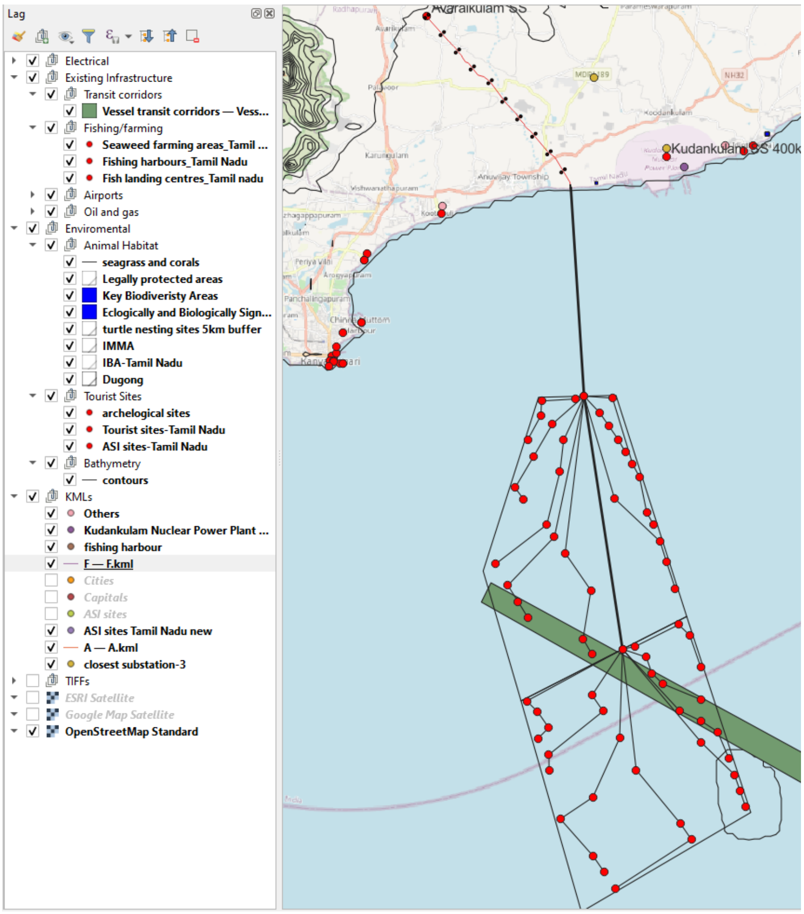


Figure 28 Export cable corridor - constraint mapping

3.2.3 OSS Export Cable Installation

The export (and interlink) cables shall be terminated to the respective HV GIS line bays at the OSS main deck and the integrated fibre cable spliced to an Optical Distribution Frame for connection to the OSS fibre network.

The cables shall be routed from the seabed via **C**able **P**rotection **S**ystems (bending restrictors) to the bell-mouth of the J-tube attached to the OSS. substructure.

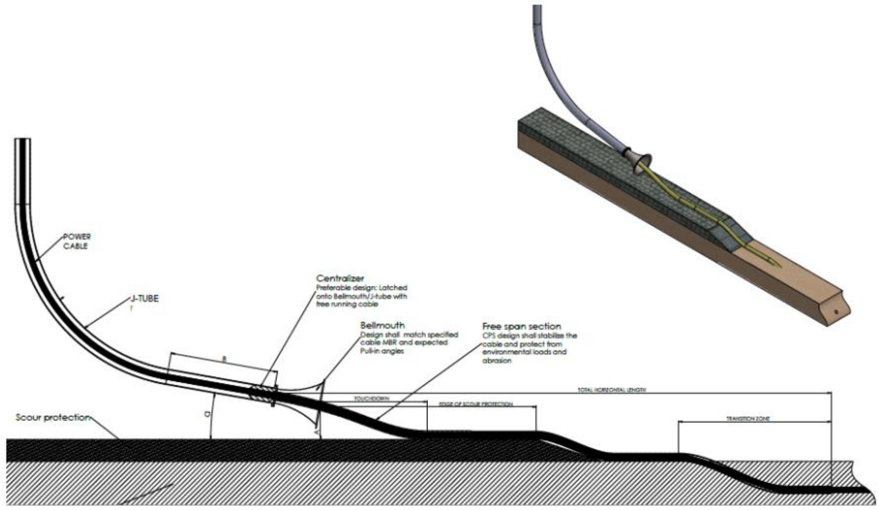


Figure 29 Sea cable entry to J-Tube

The cable pull-in to the OSS is preferable planned as a direct operation from the CLV where the cable end is inserted in the CPS prior to the pulling operation.

Figure 30 CPS prepared at CLV

After the cables are pulled on to the OSS preparation and termination works at the cable- and main deck shall be undertaken.

Figure 31 OSS Cable Pull-in Method

Depending on the OSS layout, some designs are with a cable deck joint since this can be beneficial since a less complicated offshore assembly can be planned and the HV GIS termination can be completed at the shipyard prior to topside load out. Below illustration shows the main principles for a cable deck joint approach.

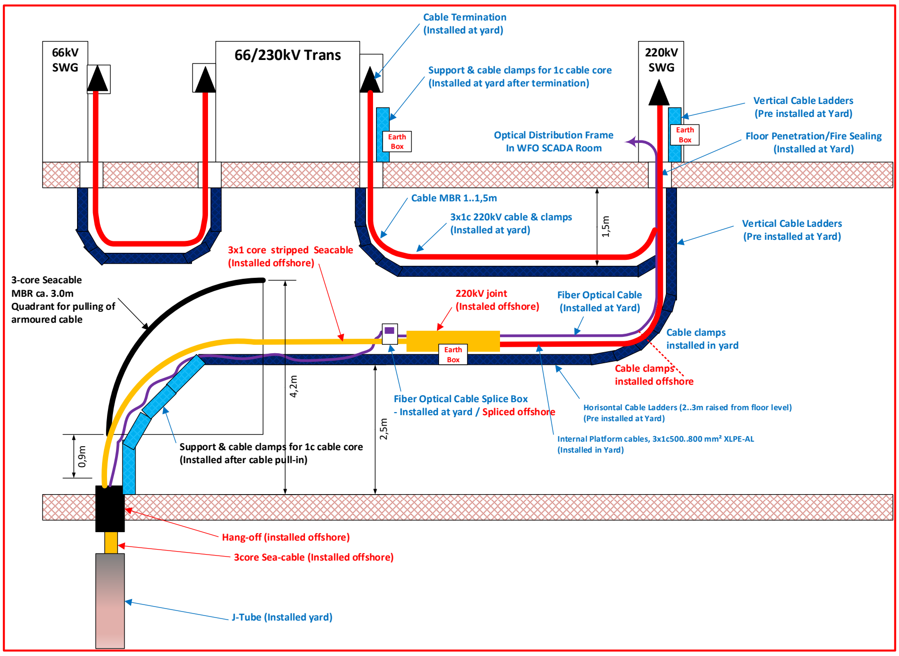


Figure 32 OSS Cable Deck Joint Principal Approach

The installation of offshore cables at the OSS also involves cable hang-offs and fibre optical splice boxes as illustrated below.

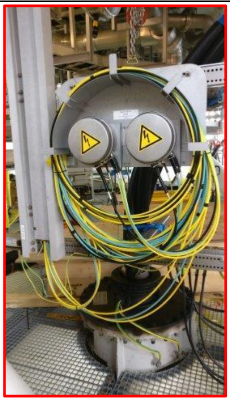
220kV cables prepared at with male parts ready to be plugged in GIS	**220kV cables pulled to GIS ready for assembly of termination**
	
220kV Straight Joints assembled offshore at OSS cable deck	**FOC splice boxes at cable deck**
	
220kV cable attachment with cleats	**220kV & 66 kV cable hang-off assembly**
	

Figure 33 OSS Cable Accessories Installation

3.3 Export Cable Landfall Arrangement

At landfall the offshore export cables are laid to shore where they are connected to the onshore export cables at the Transition Joint Bay (TJB). For the landfall typically two principal methods are available, direct burial (most likely with "open cut" method) and installation within a pre-installed duct (most likely "Horizontal Direct Drilling (HDD)" method). More details to the different landfall arrangements can be found in section 7.4.2.

The preliminary landfall position for Tamil Nadu is shown below, more details of the landfall position can be found in document Ref /14/.

Figure 34 Preliminary landfall position for Tamil Nadu

The landfall location is preliminary with the transition joint bays approximate 20 m from shoreline separated by 10 m.

Environmental and social considerations are not yet considered, but an open excavated trench approach from the TJB into the sea is anticipated viable at the location. Thus, the offshore cables can be floated in from the CLV with an installation approach as indicated in the following.

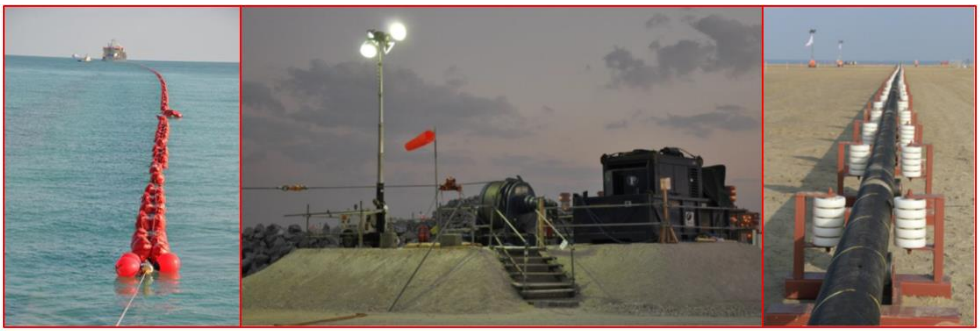


Figure 35 Landfall cable pulling operation

Reference is also made to section 7.4.2.

Fact finding survey at the particular location is necessary for the Pre-Feed and FEED.

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 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.

An example of a transition joint bay (TJB) is shown below, more details of the TJB can be found in document Ref /15/.

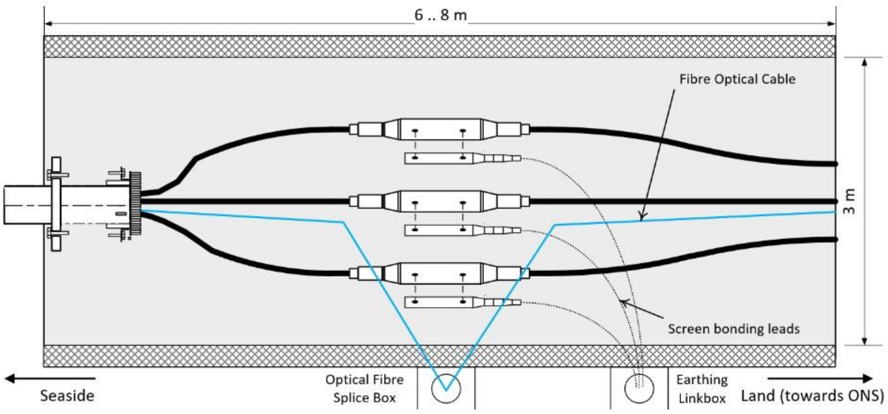


Figure 36 Sea-Land Transition Joint Bay

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 37 TJB Examples

3.4 Onshore Power System Infrastructure

The onshore power system infrastructure will comprise.

- Two 230 kV overhead lines or underground cable circuits
- One 230/400 kV Onshore substation
- One or two 400 kV interconnectors to existing grid substation, Avaraikulam SS
- One or two 400 kV line bay extensions in Avaraikulam SS

This study report is not addressing the onshore power infrastructure systems, thus only very high level and indicative concepts are illustrated below.

Figure 38 Onshore OHL / Cable Corridor

A tentative outline of the HV cable standard trench is illustrated below:

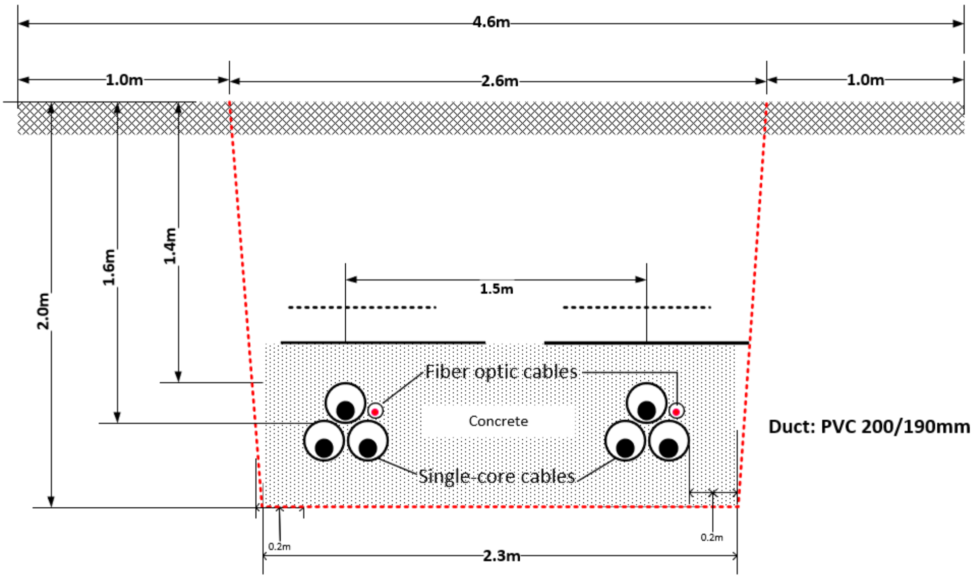


Figure 39 Two Circuit HV Cable Trench with pre-laid ducts

Crossing of main roads, railways, environmental sensitive areas can be designed with horizontal directional drilling of ducts. An example with four parallel cable circuits is shown below.

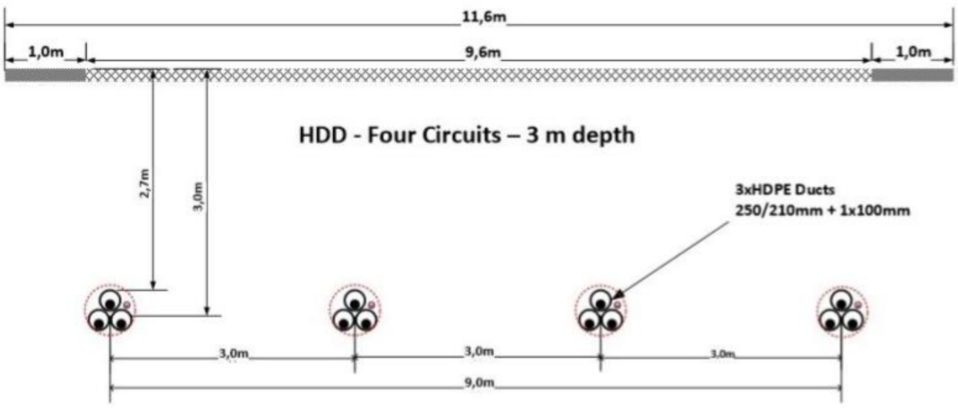


Figure 40 HDD Concept

Depending on the cable conductor cross section and the soil properties it might be necessary to install the cable ducts in a flat formation (imposing three individual ducts per cable circuit) to mitigate against overheating of the cables.

3.5 Cost Estimate

Costs related to site investigation is too volatile to breakdown at this stage in the project as pricing will depend on, but not limited to, vessel type solution, survey scope, amount of survey lines, challenging seabed conditions (soft soils), number of boreholes, amount of soil samples, and weather conditions. A general and indicative overview is given in sections 1.3.3 and 1.4.3,0 and Ref /1/.

The cost estimate should be viewed as indicative and **not as a comprehensive CAPEX** for the HV power infrastructure. Its purpose is to provide a simple cost comparison for a possible finalized layout. Therefore, it should not be construed as a definitive CAPEX estimation. For accurate pricing relevant to the Indian context, market dialogues with the supply chain will be necessary to obtain updated price levels. Additionally, a more comprehensive FEED, supplemented by power system studies, will be needed for a solidly developed estimation.

The major cost components such as onshore HV harmonic filters, STACOMS/SVC, OnSS building & civil work, compensation to landowners/others, inter array cable systems, and developer engineering/project management are not factored into the cost comparison.

The cost estimate on OSS topside & foundation structural, mechanical, F&S, LV power system, utilities, SCADA etc. are only considered by a best guess proportion of an 800 MW OSS being scaled down and with a very simple proportional % on the steel volume/cost as for the different OSS sizes.

Unit costs from recent project either completed or in progress have been applied.

Costing of offshore components will always be extremely dependent on the site conditions and availability of installation vessels – consequently (and due to the time given) no suppliers or EPCI contractors have been approached for indicative pricing.

Direct cost related to the new line-bays and OnSS at the Grid SS are considered as GIS. Cost related to eventual reinforcement of the back-bone transmission system is not known or considered at this stage. If the OnSS is regarded as AIS, the associated costs would be reduced.

Annual energy losses in the WTG power transformers, OSS MPT’s, IAC and the ECC’s also have been factored in.

A tentative CAPEX/OPEX on the agreement topology is presented below:

Power Electrical Infrastructure Financial Assessment	Tamil Nadu
	230 kV
	TN 09
OWF	66x15MW
OSS	2x500MW
OSS MPT	2x315MVA
OSS Shunt Reactor	0x0MVar
Export Cable to shore	4x230kV
Interlink cable corridor	1x230kV
OHL Nearshore - Grid OnSS	--
Export Cable	
Subsea cable export Cable Route [km]	71.0
Interlink cable corridor [km]	13.5
Land cable corridor [km]	12
CAPEX [mio Eur]	
Inter Array Cable System *	
Offshore Substations	296.9
HV Offshore Export Subsea Cable System	115.7
Onshore Export Cable System to OnSS	30.1
Overhead Transmission Line	0.0
Onshore Substation - Near Shore	0.0
Onshore Substation - Near Grid SS	80.8
Grid Interconnector-Cable "OnSS-Grid SS"	0.0
Grid SS Extension	0.0
Total	**523.5**
Installed [MW]	990
Euro/MW installed	**528,816**
LCoE assessment	
Indicative WTG AEP [MWh/year]	5,268,381

Yearly energy losses [MWh/year]	146,283
Annual energy losses [%]	2.8%
AEP at OnSS [MWh/year]	5,122,098
Yearly energy losses [mio Eur/year]	11.7
NPV Cost CAPEX & OPEX [mio Eur]	646,175
NPV AEP [GWh]	59,695,843
LCOE [Eur/MWh]	**10.8**
Key Unit Cost	
Offshore export Cable [€/m]	1,369
Onshore export Cable [€/m]	1,254

*) The OWF developer will be responsible for the IAC system. The cost has been included since the OSS location optimisation analyse considered the IAC cost component for different design options.

In Figure 41 the breakdown of CAPEX for each electrical part (including OSS, OFC, ONC, OnSS) is illustrated in Tamil Nadu.

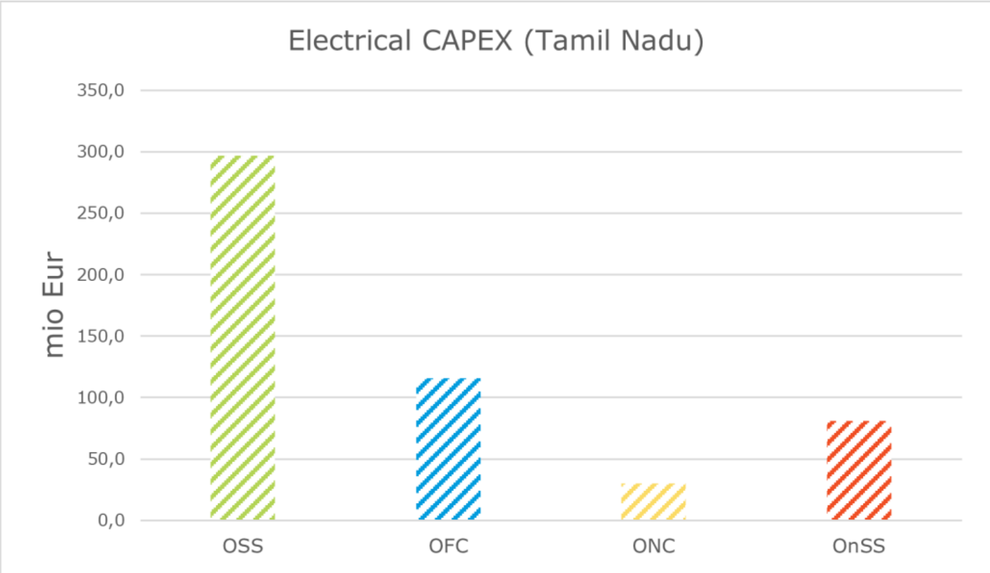


Figure 41 Breakdown of electrical Capex in Tamil Nadu

It is observed that.

- CAPEX falls within 524 mio€
- OPEX *"NPV Energy losses"* falls 123 mio€
- CAPEX&OPEX falls 647 mio€
- CAPEX investment is distributed to (approximate average % of total)
    -
    - OSS: 57 %
    - OFC: 22 %
    - ONC: 6 %
    - OnSS: 15 %

Three 230/400 kV 500MVA transformers are considered at the OnSS to convert to extra high voltage level.

4 Power System Concept Design, Gujarat

4.1 Topology & Situation Plan

The finalized topology presented in this study, consists of two Offshore Substations (OSS) named OSS#1 and OSS#2. OSS#1 is strategically located at the edge of the 500 MW Viability Gap Funded (VGF) zone, while OSS#2 is positioned at the edge of the 500 MW Non-VGF zone.

Below is the SLD snapshot of Tamil Nadu OWF concept, further details can be found in Ref /2/, sheet 1.

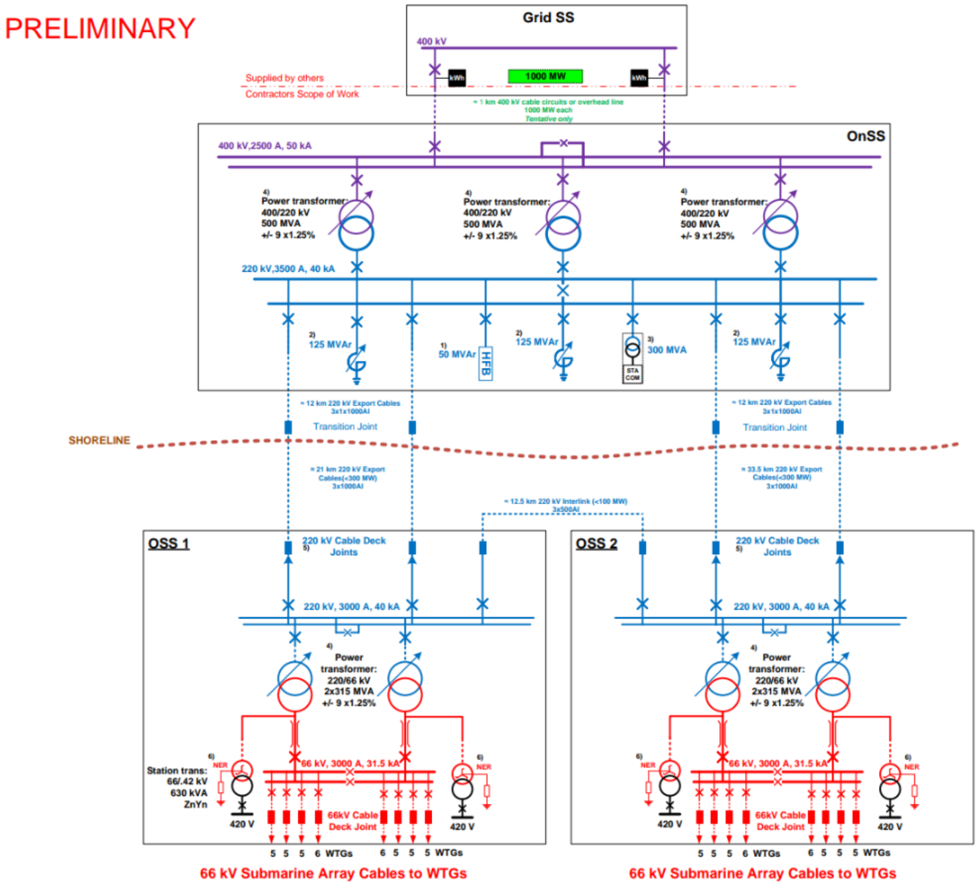


Figure 42 Gujarat Singel Line Diagram

The above topology has been considered all with two OSSs and with 220 kV on EC voltage level, number of ECs, number of OSS MPTs and eventual interlinks between the two OSSs.

General reference in respect to power system functionality is given to section 3.1.

Situation plan based on a layout indicated below:

- Two separate sites

- Two OSS with ≈ 12.5 km separation
- ≈ 21 km subsea cable corridor to anticipated landfall.
- ≈ 12 km onshore cable corridor from landfall to anticipated OnSS/Grid SS.
- 2 x 42 x 12 MW WTGs → 2 x 504 MW installed.
- 66 kV inter array cables with an OWF layout and the location of WTGs as per below is anticipated.

Illustrated IAC routing is tentative only and will be elaborated further. Offshore crossing of the export and IAC cables is seldom a planned routing.

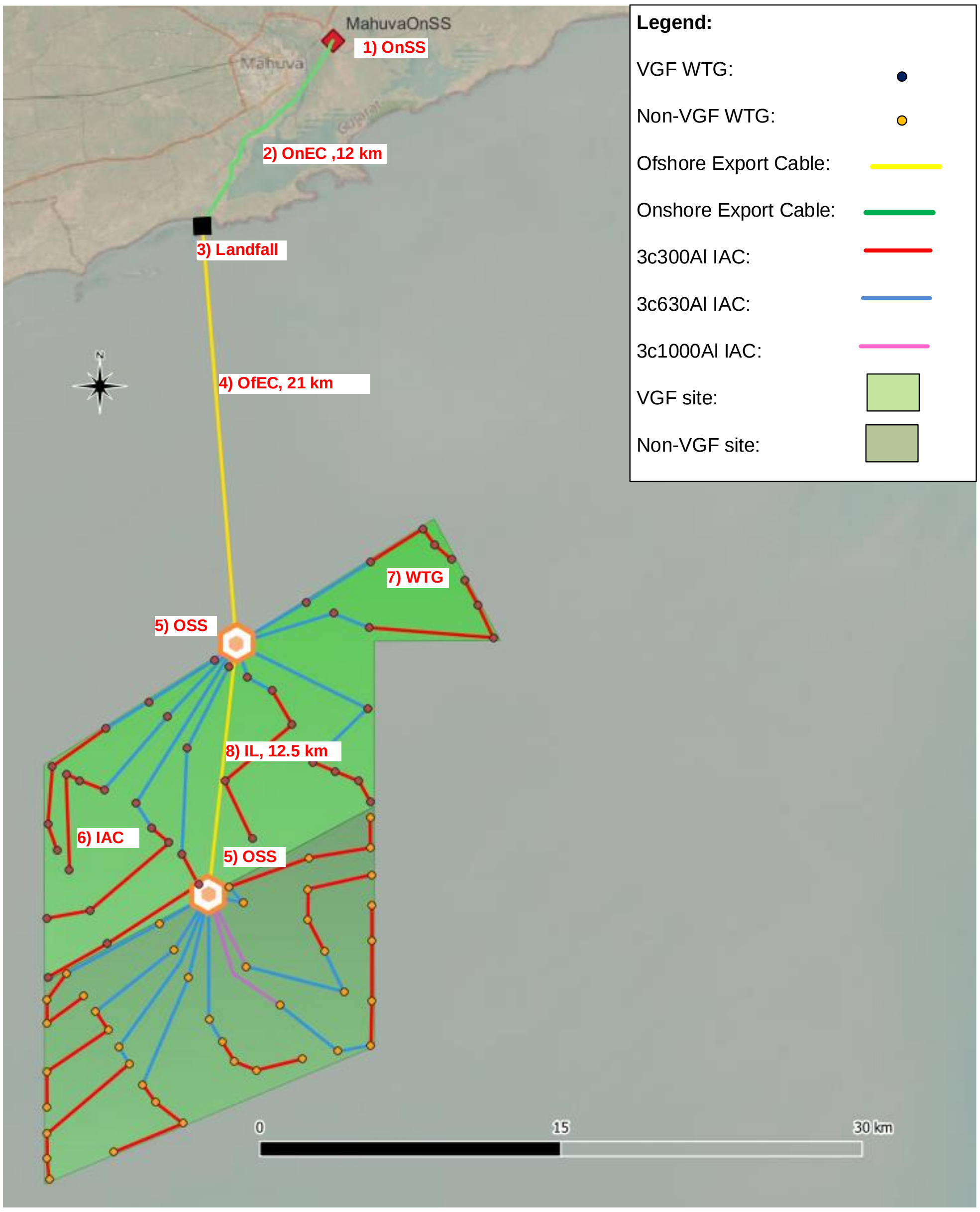


Figure 43 Situation plan in Gujarat

4.2 Offshore Export Cable & Interlink Systems

4.2.1 Cable Size Selection

The 220 kV export cable sizing takes basis in the required load capacity in conformity with Figure 1 Gujarat HL Topology and the preliminary selection tables presented in Appendix A.

- 220 kV Export cables
  300 MW, 245 kV 3x1400 mm² XLPE- AL

- 220 kV Interlink cable
  100 MW, 245 kV 3x500 mm² XLPE- AL
  (400 mm² can be used if available)

4.2.2 Cable Burial & Protection

General reference is made to section 3.2.2.

The export cables for the site are anticipated buried into the seabed at a 1.5 m target depth, whereas the ampacity rating assumes up to 3 m to account for eventual seabed movement. No outcropping bedrocks is anticipated, and simultaneously laying/burial bey utilisation of cable plough or jetting/trenching tool/methods are anticipated.

A first mapping of environmental constrains, existing services etc. is illustrated in Figure 28. No environment constrains are identified for the far shore, near shore or at the landfall.

No existing pipelines or cables have been identified in the offshore export cable corridor.

It is observed that the OWF sites and consequently the export cables are located within an area potential considered as oil exploration. It is anticipated this already is addressed in the screening and selection process of the OWF site. Thus, this is not considered a hard constrain for the export cable (or the OSS) installation but naturally should be planned with relevant authorities in the future.

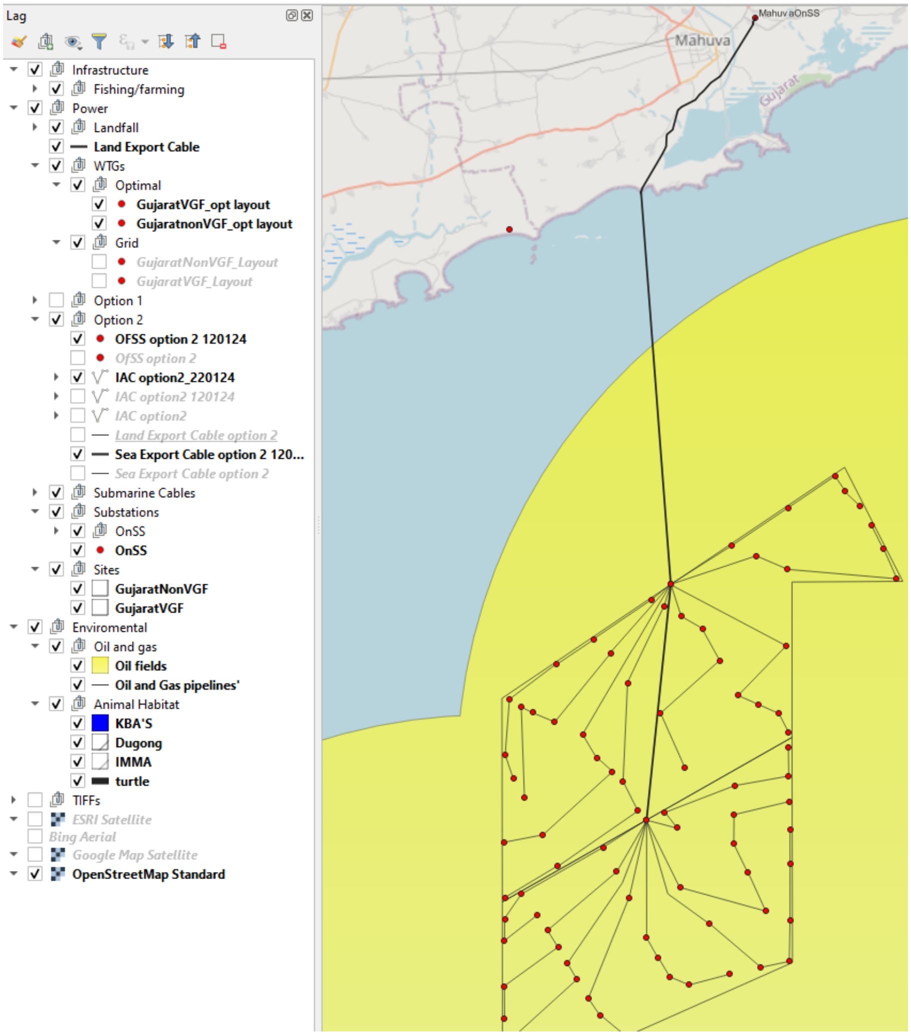


Figure 44 Export cable corridor - constraint mapping

4.2.3 OSS Export Cable Installation

General reference is made to section 4.2.3.

4.3 Export Cable Landfall Arrangement

General reference is made to section 3.3 and section 7.4.2.

Figure 45 Preliminary landfall position for Gujarat

4.4 Onshore Power System Infrastructure

General reference is given to section 3.4.

The onshore power system infrastructure will comprise.

- Two 220 kV overhead lines or underground cable circuits.
- One 220/400 kV Onshore substation.
- One or two 400 kV interconnectors to existing grid substation, Mahuva SS.
- One or two 400 kV line bay extensions in Mahuva SS.

This study report is not addressing the onshore power infrastructure systems, thus only very high level and indicative concepts are illustrated below.

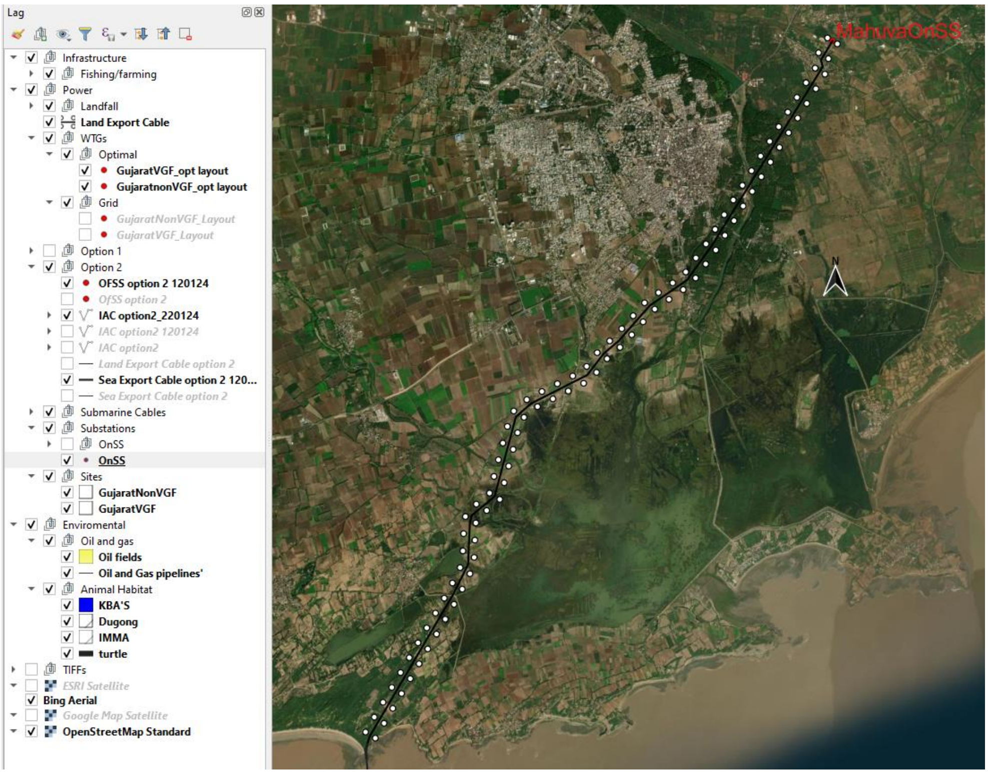


Figure 46 Onshore OHL / Cable Corridor

The corridor approached an existing city and other settlements that shall be considered when the final routing is determined. An overhead line is considered possible if environmental constrains and local acceptance can be obtained.

4.5 Cost Estimate

The cost estimate should be viewed as indicative and **<u>not as a comprehensive CAPEX</u>** for the HV power infrastructure. Its purpose is to provide a <u>simple cost comparison</u> for a possible finalized layout. Therefore, it should not be construed as a definitive CAPEX estimation. For accurate pricing relevant to the Indian context, market dialogues with the supply chain will be necessary to obtain updated price levels. Additionally, a more comprehensive FEED, supplemented by power system studies, will be needed for a solidly developed estimation.

The major cost components such as HV harmonic filters, STACOMS/SVC, OnSS building & civil work, compensation to landowners/others, inter array cable systems, and developer engineering/project management are not factored into the cost comparison since they will be equal for the scenarios compared.

The cost estimate on OSS topside & foundation structural, mechanical, F&S, LV power system, utilities, SCADA etc. are only considered by a best guess proportion of an 800MW OSS being scaled down and with a very simple proportional % on the steel volume/cost as for the different OSS sizes.

Unit costs from recent project either completed or in progress have been applied.

Costing of offshore components will always be extremely dependent on the site conditions and availability of installation vessels – consequently (and due to the time given) no suppliers or EPCI contractors have been approached for indicative pricing. The offshore cable component costs include a number of cost elements as

- Preliminaries: Project management/design/interface management/insurance etc.
- Cable Manufacturing, FAT and loadout
- Installation engineering, RAMS
- HDDs at landfall[3]
- T&I for the offshore cables[4]
    - Installation vessels mobilisation & demobilisation
    - Loadout, Transit,
    - Pre- & post laying installation surveys
    - Pre-Lay Grapnel Run (PLGR) & Route Clearance
    - Laying and burial of the cable
    - One offshore crossing assuming ≈300 m rock berm.

Direct cost related to the new line-bays and OnSS at the Grid SS are considered as GIS. Cost related to eventual reinforcement of the back-bone transmission system is not known or considered at this stage. If the OnSS is regarded as AIS, the associated costs would be reduced.

Annual energy losses in the WTG power transformers, OSS MPT's, IAC and the ECC's also have been factored in.

A tentative CAPEX/OPEX on the agreement topology is presented below:

Power Electrical Infrastructure Financial Assessment	**Gujarat**
	220 kV
	GU 09
OWF	84x12MW
OSS	2x500MW
OSS MPT	2x315MVA
OSS Shunt Reactor	0x0MVar
Export Cable to shore	4x220kV
Interlink cable corridore	1x220kV

[3] *Open cut approach might be possible – but could also be challenged by environmental challenges. The landfall design and installation approach will also depend on the soil conditions since seabed erosion shall be considered.*

[4] *Day rates for installation vessels are given in sections 9.6 & 9.7*

OHL Nearshore - Grid OnSS	--
Export Cable	
Subsea cable export Cable Route [km]	109.0
Interlink cable corridor [km]	12.5
Land cable corridor [km]	12
CAPEX [mio Eur]	
Inter Arrey Cable System*	
Offshore Substations	296.9
HV Offshore Export Subsea Cable System	150.9
Onshore Export Cable System to OnSS	30.1
Overhead Transmission Line	0.0
Onshore Substation - Near Shore	0.0
Onshore Substation - Near Grid SS	80.8
Grid Interconnector-Cable "OnSS-Grid SS"	0.0
Grid SS Extension	0.0
Total	**558.7**
Installed [MW]	1,008
Euro/MW installed	**554,307**
LCoE assessment	
Indicative WTG AEP [MWh/year]	3,714,274
Yearly energy losses [MWh/year]	144,580
Annual energy losses [%]	3.9%
AEP at OnSS [MWh/year]	3,569,695
Yearly energy losses [mio Eur/year]	11.6
NPV Cost CAPEX & OPEX [mio Eur]	679,968
NPV AEP [GWh]	41,603,249
LCoE [Eur/MWh]	**16.3**
Key Unit Cost	

	Offshore export Cable [€/m]	1,242
	Onshore export Cable [€/m]	1,254

In Figure 47, the breakdown of CAPEX for each electrical part (including OSS, OFC, ONC, OnSS) is illustrated in Gujarat.

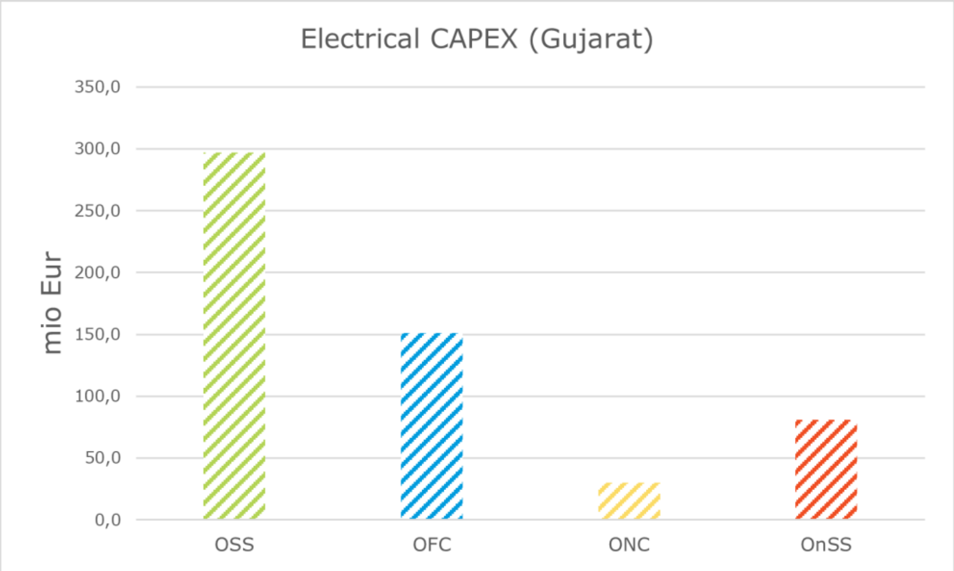


Figure 47 Breakdown of electrical CAPEX in Gujarat

It is observed that:

- CAPEX falls within 559 mio€
- OPEX *"NPV Energy losses"* falls 121 mio€
- CAPEX&OPEX falls 680 mio€
- CAPEX investment is distributed to (approximate average % of total)
    - OSS: 53 %
    - OFC: 27 %
    - OnEC: 5 %
    - OnSS: 15 %

Three 230/400 kV 500MVA transformers are considered at the OnSS to convert to extra high voltage level.

5 OSS Design Pre-FEED

5.1 Overview of the OSS Topside

Description

The arrangement of the OSS is shown on the layout drawings in Ref /13/ A268066-ALL-GCD-008 - 500 MW OSS General Arrangement. The topside is constructed as a multi-storey steel structure with five decks. The decks are arranged as follows: Levels are relative to Top of Steel (TOS) for the Cellar Deck (part of the jacket structure).

- Roof Deck: TOS EL +17.000 m (Slope requirements to be discussed later).
- Utility deck: TOS EL +13.000 m
- Cooler Decks: TOS EL +9.000 m
- Main Deck: TOS EL +6.000 m
- Cable Deck: TOS EL +0.000 m
- Cellar Deck (part of the jacket structure): TOS EL -3.000 m

A four-legged jacket structure supports the topside. Access to the topside cable deck is provided by stairs from the cellar deck. External stairways provide access to the remaining decks on the topside access. The emergency evacuation provisions, sump tank, and wastewater tank are located on the cable deck. The HV transformers, MV switchgear, HV switchgear, and control rooms 1 and 2 are located on the main deck. On the cooler decks the transformer coolers are placed. The EAT rooms, workshop, HVA/C rooms 1 and 2, firefighting room, public room, locker room, toilet, battery rooms, and LV/communication room 3 are located on the utility deck. The main crane, antenna mast, auxiliary diesel generator, diesel tank, Air Handling Unit, and dry coolers are located on the roof deck which also gives space for O&M containers and temporary containers. A helicopter winch area is also located on the roof deck. The overall dimensions of the topside are L x W x H: 50 m x 30 m x 18 m, not including the height of the antenna mast and the main platform crane.

Interface

The interface between the substructure and the topside is at level (+)2.000 m. The topside and jacket are joined by welded connections at the four main columns. The interface is 21 m x 17 m.

Main Structure

The top part of the OSS topside, from main deck and up, is a box structure with plated walls and decks. The box structure sits on a lattice structure between main deck and cable deck. Lateral and vertical load on the structure will be transferred through the walls to the decks and bracing to the main columns and further to the jacket structure.

Decks

The cable deck is in general a grating deck. Other decks are in general plated except for the external walkways, which are covered with grating. Decks are in general provided with beams below equipment. Laydown areas are plated decks. In transformer rooms grating deck will be provided. Fire retardant grating is recommended for safety reasons.

Walls
The walls are orthotropic stiffened plates. The walls are provided with insulated cladding elements or passive fire protection as required.

Hang-offs for Array and Export Cables
The hang offs for inter array cable (8 No.) and export cable (2 No.) are located at the jacket cellar deck and are not part of the topside design SOW.

Drip trays
Drip trays are provided below the HV transformers and coolers. No drip trays will be provided under the EAT equipment. Instead, a bunded area will be arranged around the EAT equipment.

Lifting Equipment and Laydown Areas
The main crane on roof deck will serve the external laydown areas on cable deck, main deck, utility deck and roof deck. The crane will be a fixed boom crane type with boom rest. A runway beam shall be located below utility to allow for transfer of materials between cable and cellar deck. Traverse cranes with capacity of 2 tons shall be installed in the MV and HV GIS rooms for material handling of GIS components.

Cable Pull-in
The cable pull-in is assumed to be performed from cellar deck. Whether pull-in padeye for support of a snatch-block and additional secondary padeyes for temporary cable support shall be installed above each J-tube shall be discussed.

Topside Stairs
The stairs and ladders will be according to ISO 14122-3. The stair pitch will be 38°.

Topside / Substructure Mating System
The topside will be provided with stabbing pins below two of the four main columns interfacing the jacket. The stabbing pins will stab into top of the corresponding jacket legs and guide the topside into final position. Length of pins shall be discussed. The stabbing pins will be located diagonally opposite. The stabbing pins will be designed with a gap between outside pin and inside jacket leg to allow for fabrication tolerances. The topside will be checked for worst case installation misalignments between the topside and jacket.

Equipment Handling
Deck structure and walkways shall be checked for loads occurring during equipment handling. It is suggested that a Material Handling Report is carried out and the necessary pad eyes, monorails and hoists is designed for.

Weight Estimate OSS Topside

Item	Net Weight	Gross Weight

	[metric tons]	[metric tons]
Equipment	1,054	1,191
Structural Steel	1,013	1,216
Structural Steel Connections	118	142
Grating	110	132
Stairs and Ladders	23	28
Railing	21	25
Ventilation Houses	26	31
Insulation	92	110
Doors & Windows	14	17
Painting	18	22
Liquids (Water, Diesel etc.)	25	30
Piping	7	8
HVAC incl. ducts and supports	17	20
HV & MV Cables incl. trays and supports	43	52
LV Cables incl. trays and supports	83	100
Total Weight Estimated	**2,664**	**3,123**

5.2 OSS Foundation

The OSS foundation is proposed to be a jacket structure which is fixed to the underground via post installed piles.

The jacket will have a Cellar Deck on the top, J-tubes as required, boat landing and access ladders. At seabed level the jacket is assumed to have mud mat and pile cluster for 2 piles at each jacket leg.

Cable pull-in is assumed to be performed from the Cellar Deck.

For the current estimate the following assumptions have been made:

1. Water depth is 38 m.

2. Soil condition is poor.

3. 2 piles at each of the 4 jacket legs.

Reference is given to drawing: A268066-ALL-OSS-009 500 MW OSS Substructure & Pile Arrangement.

Item	Net Weight [metric tons]	Gross Weight [metric tons]
Jacket (incl. Cellar Deck, J-tubes and boat landing)	3,000	3,600
Piles 8 no. L=100 m, t = 65 mm, OD = 3000 mm	3,800	4,560
Total Weight Estimated	**6,800**	**8,160**

5.3 Electrical systems

The electrical system of the OSS consists of:

- HV systems (230 kV)
- MV systems (66 kV)
- LV systems (<1 kV)

In general, this section applies also for Tamil Nadu with the only difference that the HV level in Tamil Nadu is 230 kV and not 220 kV as in Gujarat.

5.3.1 HV System

Main Power Transformer (MPT)

Two 66/220 kV oil-immersed power transformers with rated power of 315 MVA, monitoring and protection systems, bushings and cable connections, earthing connections, etc.) are installed on the main deck of the OSS. The required coolers for the MPTs are located on the cooling deck.

The MPTs transform the voltage level of the WTGs (66 kV) to the voltage level of the export system (220 kV).

220 kV switchgears

The 220 kV gas-insulated switchgears (GIS) are located on the Main deck. The 220 kV GIS provide protection functions for the MPTs and the 220 kV subsea cables and also the clear disconnection of the connected 220 kV components.

HV cables, busbars and GIB ducts

The connection of the 220 kV components (MPTs, HV switchgears) installed on the OSS is done either by HV cables, busbars or gas-insulated bus (GIB) ducts. The HV cables/busbars/GIB ducts have to be dimensioned considering the rated currents of the connected components and also the maximum possible occurring short-circuit currents in the different paths. For connection to the 220 kV components the HV cables, busbars and GIB ducts have to be equipped with suitable termination systems.

5.3.2 MV system

Earthing and auxiliary transformer (EAT)

Two 66/0.42 kV oil-immersed auxiliary transformers with rated power of 630 kVA each are located on the utility deck whereas the connected coolers are located on the cooling deck. The auxiliary transformers transform the medium voltage level (66 kV) to the low voltage level (0.42 kV) that supplies all LV auxiliary systems of the OSS.

The star point of the 66 kV winding is connected to the earthing system via a neutral earthing resistor (NER). With this NER installed the single-phase fault current of the 66 kV system (inter array cable system that connects all WTGs with the OSS) is limited as much as possible to minimize the impact of a single-phase fault current on the inter array cable sheaths/screens.

66 kV switchgears

The 66 kV gas-insulated switchgears (GIS) are located on the Main deck. The 66 kV GIS provide protection functions for the WTG inter array cables, the auxiliary transformers and the 66 kV winding of the MPTs and also the clear disconnection of the connected 66 kV components.

MV cables, busbars and GIB ducts

The connection of the 66 kV components (auxiliary transformers, MV switchgears, 66 kV windings of the MPTs) installed on the OSS is done either by MV cables, busbars or gas-insulated bus (GIB) ducts. The MV cables/busbars/GIB ducts have to be dimensioned considering the rated currents of the connected components and also the maximum possible occurring short-circuit currents in the different paths. For connection to the 66 kV components the MV cables, busbars and GIB ducts have to be equipped with suitable termination systems.

5.3.3 LV systems

LV power distribution system and LV switchboards

The LV power distribution system of the OSS comprises of two AC main switchboards, AC power and lighting distribution switchboards, two redundant 110 VDC sets (incl. rectifiers, batteries, distribution boards), two UPS systems incl. switchboards, emergency switchboards, DC distribution boards, other secondary distribution boards, LV cabling, auxiliary diesel generators, power outlets.

A general overview of the LV power distribution system is given in document A268066-ALL-GCD-010-0.

The sizing of all switchboards depends on the required power, defined during FEED and included in the consumer load list.

Auxiliary diesel generator

Two auxiliary diesel generators (420/240 V) will be installed together with sufficiently dimensioned diesel storage day tanks and cooling system on the roof deck of the top side. These diesel generators provide electrical LV power in case of abnormal situations such as grid loss, power outage or maintenance work on the HV/MV system in order to continue the electrical power supply of the LV system. To avoid an oversizing of the diesel generator, not the complete LV system shall be supplied but only the emergency services, such as emergency lighting, navigation lights, structure marking, active fire protection, protection and control systems, communication systems, alarm systems and HVA/C system. The minimum required duration time of the diesel generators shall comply with the requirements specified in DNV-ST-0145.

The sizing of both diesel generators depends on the required power, defined during FEED and included in the consumer load list.

UPS system

For the supply of the AC emergency services during abnormal situations where the general LV power supply is not given, two separated and redundant AC UPS systems will be installed on the OSS each designed with its own independent static bypass, charger and inverter. The UPS systems are supplied either by the LV distribution system (during normal operation) or by the DC system (during abnormal situations) and will provide power to the emergency switchboards. The minimum required duration time of the UPS systems shall comply with the requirements specified in DNV-ST-0145. The sizing of both UPSs depends on the required emergency power, defined during FEED and included in the consumer load list.

DC system

Two redundant 110 VDC systems will be installed on the OSS consisting of charger, DC batteries and DC distribution boards, where the UPS systems and control & protection panels will be connected to. The DC system will supply power to the connected systems and consumers in case of abnormal situations (grid loss, power outage, etc.).

The minimum required duration time of the DC systems shall comply with the requirements specified in DNV-ST-0145. The sizing of both 110 VDC systems depends on the required power, defined during FEED and included in the consumer load list.

LV & Control cables

All LV systems (AC and DC) and control systems installed on the OSS will be connected via LV cables, correctly dimensioned for the continuous and short-circuit current ratings. The dimensioning of all cables will be done during FEED taking the consumer load list as basis.

In general, the rated voltage shall be 0.6/1 kV for power and control cables and cables of shielded type shall be used.

All used LV cables shall have following features: halogen free, no corrosive gases, low smoke density, non-flame propagating. In addition to that, cables for safety-relevant services shall be of fire-resistant type. All wiring accessories of plastic materials, such as cleats and strapping shall be non-ignitable or resistant to flame propagation.

The installation of all LV and control cable shall be done using cableways, cable glands shall be used where cables enter cabinets and enclosures.

Lighting system

The lighting system on the OSS consists of following systems: Normal lighting, emergency lighting, escape lighting.

All working areas, accommodations areas, walkways, stairs and escape route shall be illuminated with sufficient illumination levels in accordance with IEC 61892-2, annex G.

The normal lighting system is powered by the LV distribution whereas the emergency and escape lighting systems are UPS-powered to maintain sufficient illumination during grid loss or power outage on the OSS.

Besides these three lighting systems, also navigation lighting system shall be installed on the OSS. For the design of the navigation lighting system the local and national requirements shall be observed.

Power outlets

On the topside low voltage power outlets (single-phase and three-phase) will be installed to be used for any system or equipment. Those sockets are fed from low voltage switchboards.

Equipotential bonding and lightning protection

All electrical and mechanical systems on the topside will be connected to the earthing system via equipotential bonding to avoid any potential electrical hazards to the personnel due to insulation damages on the OSS. The topside main steel structures will be utilised as an integral part of the earthing system. The topside main steel structures will be connected to the jacket foundation structure via the main structural connections. In case non-metal-to-metal connections are used between structural parts such connections must be bridged with earthing connections. The earthing system on the topside consists of several main earth bars, connected to the topside module main structure via earth bosses.

All exposed components shall be protected by lightning protection. The lightning protection system (LPS) consists of external LPS and internal LPS. External LPS consists of air terminal capturing systems and down conductors, and it must be installed in accordance with lightning protection level 1. The topside structure itself is an integral part of the lightning protection system making maximum use of the large metal structures and electromagnetically shielding of metal walled rooms. For the internal LPS, all LV circuits connecting any device in exposed outdoor areas include SPD protection directly after the penetration point to a different LPZ.

5.3.4 Mechanical systems

Main Crane

On the Roof Deck the Main Crane will be installed. This electrical fixed boom crane will be suitable for heavy load lifting operations and the boom outreach will be designed to access and lift equipment located on the OSS Topside to laydown areas and supply vessels. The lifting capacity of the Main Crane will be defined during FEED according to the weight and requirements of the heavy equipment and the material handling study.

David Crane

This smaller electrical or hand driven crane will be located on the Cable Deck to lift smaller equipment and tools from/to supply vessels but will be also able to lift the life raft. The lifting capacity of the David Crane will be defined during FEED.

Equipment lifting and handling

For material lifting and handling of equipment with a weight above 200 kg permanent arrangements like overhead cranes and runway beams, beam clamps, pad eyes and lifting points, will be installed on the OSS topside on locations where needed.

Water storage system

Water for cleaning and showering hands (not for drinking!) will be stored in a Water Tank on the Cable Deck. This tank will provide water to the Public Room, several Deck Wash locations with hose connections on the OSS outside and the Oil Separator. The shrink in the Public

Room will be connected to the Wastewater Tank for collecting the (grey) wastewater. The Water Tank needs to be re-filled and the Wastewater Tank needs to be emptied from a supply vessel on a regular basis depending on the use of water for cleaning.

Water for drinking will be provided in bottles in the public or locker rooms.

Drainage system

A drain system for handling leakages of fuels, lubricants, transformer oil/ester and water/water-glycol/water foam mixtures from cooling, firefighting and other technical systems will be installed on the OSS Topside. Contaminated liquids will be collected in drip trays/sumps, drained and conducted via pipes to the Sump Tank.

Non contaminated water and rainwater will be drained overboard to the sea, open decks will have suitable slopes and drains to conduct the rainwater to the sea.

Fluids shall be drained by gravity with suitable slope in pipes and tanks. If draining by gravity is not possible pumps shall be used.

Water cleaning system

Water from Topside areas and rooms where a contamination with oils, lubricants and other mixtures (please see above) can occur will not be directly drained to the sea. This black water will be conducted via suitable pipes and collected into a Sump Tank on the Cable Deck. The water from the Sump Tank will be cleaned by an Oil Separator, the cleaned water drained to the sea or stored in the Wastewater Tank and the separated oil slush pumped backs to the Sump Tank. The Sump Tank needs to be emptied on a regular basis and the contend will be brought via supply vessel to a harbour for a save disposal according to HSE regulations.

The concept for the Water storing, draining and cleaning systems will be developed during FEED. The OSS Topside will be designed to have zero impact on the marine environment.

Firefighting system

The OSS Topside rooms will be equipped with a Fire Detection and active Firefighting System. The Firefighting System will consist of different systems of firefighting techniques, e.g. water/water mist, foam and inert gas extinguishing, depending on the room´s equipment requirements for firefighting. The fire extinguishing medias will be stored in tanks and bottles in the Firefighting Room on Utility Deck. Firewater and foam will be conducted by electrical pumps via pipes and fire extinguishing gas will be conducted by overpressure in the storing bottles via pipes to the rooms in case of a detected fire.

Passive firefighting will be done by using fireproofed insulation in walls and doors, by using fireproofed cable transits and pipe transits and by using fire dampers in air ducts.

Main Diesel Tank

The Auxiliary Diesel Generators of the LV System located on the Roof Deck will only have a day tank for operations of about 24 h. A Main Diesel Tank on the Roof Deck will provide both

Diesel Generators with new fuel when the day tanks will run close to empty. The Main Diesel Tank will be connected to the Auxiliary Diesel Systems day tanks by pipes and valves and the Diesel fuel will be transported via electrical pumps. The Main Diesel Tank needs to be re-fuelled from a supply vessel. The content of the Main Diesel Tank shall provide the Diesel Generators typically for 1-2 weeks of operation under full load.

HVA/C

The centralized HVA/C (heating, ventilation and air conditioning) system will be installed so that the Topside rooms shall, as a minimum, maintain an environment that meets the temperature and humidity requirements specified by the manufacturer of the equipment installed. Also, a slight indoor overpressure shall be maintained in order to reduce the ingress and concentration of saltwater aerosols, dust and water particles within the rooms and keep the indoor air clean especially for toilets, battery rooms and rooms with explosive gas or fumes.

The ventilation system comprises of a working air handling unit (AHU) on the Roof Deck that can ensure either redundancy or with a standby air handling unit with cooling coils connected to chiller in order to control the humidity inside the spaces. Ventilation fans will be installed in the rooms, connected with the AHU via adequate duct systems. Additionally, pressure relief dampers, fire dampers and filters are part of the system. For active cooling systems, chiller units with water-cooling system are used, required heating is provided via heaters installed within the ducts.

The purpose of cooling/ventilating the technical rooms is to remove the heat transmission, heat dissipation and fumes or gases from the electrical installations to keep the temperature/ indoor air quality within an acceptable range as per equipment vendors.

At least following rooms shall be provided with mechanical ventilation and/or HVA/C: Crew rooms, battery rooms, control rooms, toilets, diesel generator rooms, technical rooms, workshops, LV switchgear rooms, 66 kV and 220 kV GIS rooms.

Solid Waste Disposal

The preference will be not to store solid waste on the OSS Topside during operation times. Waste materials shall be segregated at source and removed by the technicians in their lifting bags or barrels when they leave the OSS. Thus, no room for waste disposal will be designed. Segregation shall adhere to consent conditions and relevant regulations, as well as good practise, and include as minimum:

- Recyclable materials
- Industrial materials
- Hazardous material

- Domestic waste
- Organic waste

The OSS Topside will be designed to have zero impact on the marine environment.

Winching Area
On the Roof Deck a Helicopter Winching Area will be established. This area is not designed for Helicopter landing operations but for winching goods and personal up and down from arriving Helicopters in a save way. This Winching Area will be clearly marked as winching area. Sizing will be done during the FEED.

5.3.5 Communication & SCADA

Communication systems
The communication systems installed on the OSS consists of following systems:

- IP telephone system for the voice communication within the OWF locations and to the external telecommunication system
- VHF (very high frequency) communication system for voice communication between Marine coordinators and the ships working within the OWF. The VHF is a first line of communication if any vessel is approaching the site on a collision course.
- AIS (automatic identification system) for broadcasting information on position and type of the Offshore Substation for offshore vessel traffic. Based on best practises for offshore structures Class B transponders shall be installed.

SCADA systems

The purpose of the SCADA system is to provide monitoring and control of all systems/assets installed on the OSS and in the connected WTGs and provide protocol interfaces to employer SCADA and Onshore control system. The system shall monitor and control all HV, utility and ancillary equipment installed on the OSS and within the connected WTGs. One SCADA workstation is installed on each OSS and one SCADA workstation is installed in the onshore substation.

IT network

The general communication network between the wind turbines and the OSS and between the OSS and the onshore substation is done using fiber optic cables, usually installed within the subsea cables. The internal network within wind turbines and within the OSS is suitable LAN cabling.

5.3.6 HSE

The OSSs shall be equipped with adequate and effective facilities for safe and controlled emergency response during defined accidental events (e.g., fire, explosion, toxic fumes/smoke, severe structural damages, loss of electrical power, etc.).

This includes the provision of at least one muster area where the personnel are protected from the effects of the emergency while waiting for controlled evacuation. For safety-reasons it is recommended to include two muster areas (primary and secondary) in the OSS design. The two muster areas shall be separated from each other as widely as practicable on the OSS. All muster areas shall be located close to the arrangements for evacuation such as:

- boat landing for evacuation via transfer vessel
- lifeboat launching station for evacuation via davit-launched lifeboat or free-fall lifeboat
- helicopter deck for evacuation via helicopter

The OSS shall be equipped with at least one lifeboat with the capacity of the maximum defined manning.

From all areas and rooms on the OSS defined escape routes towards the muster areas must be defined. These escape routes shall be illuminated with sufficient illumination levels in accordance with IEC 61892-2, annex G.

Communication and alarm systems shall be provided to alert all personnel on the OSS, at any location, of an emergency. The systems shall be suitable to provide instructions for emergency response.

Orientation and safety plans showing escape routes, muster areas, embarkation areas shall be strategically located at major circulation points on the OSSs (e.g. near the main stairways).

Further guidance is to be found in section 9 of DNV-ST-0145 “Offshore substations”.

5.4 OSS Interface Risk Assessment

The subsea cables (inter array cables and export cables) that are connected to the OSS are laid through J-tubes to the cellar deck of the OSS where the cable hang-offs are installed that provide mechanical support of the cables. From the cellar deck the subsea cables are laid to the cable deck where the connection to the HV system of the OSS is done via cable joints.

Prior to drafting technical requirement for the OSS supply a RACI shall be setup for establishing a sound and unambiguous understanding of the design, supply and installation responsibilities between the parties. The procurement process and number of EPCI Contracts needs being settled prior to elaboration of the RACI. Standard practice is splitting the works in a following work packages:

- Export Cables
- Interarray Cables

- Offshore Substations

The marked and developers currently aims at full EPCI Contracts where the design, supply and T&I. Multi split of supply/installation introduces interfaces that have both design and contract management complications.
The design and installation risk between the OSS and cable packages relates to

- Cable deck layout and routing of the sea cables at the OSS
- Design, supply and installation of supports and accessories on the OSS cable deck.
- Coordination/alignment of SAT cold and hot test during commissioning
- HSE management since only one part (OSS Employer) can be responsible for this activity.
- Coordination of site installation works at OSS (Cable pulling, installation, termination/jointing , testing)
- Transfer of staff to the OSS site during construction & SAT/commissioning.

Inside the J-tubes the cables are protected against mechanical hazards. Along the subsea cable routes the cables are protected against mechanical hazards either by burial protection or non-burial protection methods. More information about subsea cable protection methods is given in Ref /10/.

For mechanical protection of the subsea cable section between the J-tube and the buried part of the subsea cables, the subsea cables are laid inside Cable Protection Systems (CPS). At the end of each J-tube a so-called “bellmouth” is installed where one end of the CPS is mechanically connected to. The other end of the CPS is buried in the seabed so that continuous protection of the subsea cables against mechanical hazards is provided. To evaluate the influence of waves and underwater currents on the stability of the CPSs, stability calculations and vibration analyses shall be performed. If the outcome of these is that sufficient seabed stability over the operational lifetime is not guaranteed, additional protection measures (such as rock berms, flexible concrete mattresses, etc.) shall be installed at the touch down point of the CPS on the seabed.

During the operational lifetime of the OWF the Cable Protection Systems and the touchdown points on the seabed shall be inspected regularly to identify any insufficient protection and potential hazards to the subsea cables.

6 OSS Installation

The OSS installation process consists mainly of four phases:

- Mobilisation of vessels/transportation barges, ½ - 1 month

- Load Out
    - Preparation and weight control, 1 month
    - Lifting operation, 1-2 days
    - Sea fasting at transport vessel, 1 week

- Sea Transportation, 1 week – 1½ months, *(Weather dependent and shelter port planning might be necessary)*
  Depend on distance from yard to site and if temporary storage in site construction port is planned.
- Offshore Installation
    - Scour Protection, 1 week offshore
    - Pile installation, 2-3 weeks
    - Jacket Installation, 1-10 days, *(Weather dependent)*
    - Topside Lift operation, 1-10 days *(Weather dependent)*
        - Grouting, 1-2 week, *(Weather dependent)*
        - Offshore hookup work, 2-4 weeks, *(Weather dependent)*
    - Stabbing / Mating

The timeline for design and construction is also addressed in **Ref /11/ A268066-ALL-GCD-006 BoP Execution Plan** where the overall activities for the OWF and BoP project components are aimed presented in a sequence of logit events.

6.1 Load out

During the Load Out operation the topside will be transferred from assembly area to the quay side by Self-propelling Modular Trailers (SPMTs). The topside will then either be rolled directly onto the barge/vessel or be lifted from quay side to the transport barge/vessel by a heavy lift barge (inshore lift). The SPMTs will be supporting the topside below the cable deck in gridline 3 and 5.

The load-out is expected to be on a smooth ground with ground protection mats. Furthermore, the SPMTs will be able to level out any deformations, hence effects from displacements of the trailers are considered negligible for the topside/OSS. It is assumed that the trailers are coupled, thus forming a statically determinate support system. The load-out route is assumed flat with a maximum inclination angle of 2 degrees from horizontal in any direction. Verification of the vessel for the load from SPMTs shall be done by the fabrication contractor. It will however be checked that the load from the SPMTs is acceptable for typical vessel characteristics.

6.2 Sea Transportation

The topside/OSS will be fabricated on a yard chosen by the client and transported to the installation site in India.

Initially the following assumption are recommended for the sea transportation. The initial Ultimate Limit State (ULS) sea transport design shall be based on DNV-ST-N001 and the following assumption:

- A large cargo barge
- Weather unrestricted criteria worldwide using LRFD approach
- Loading caused by roll, quartering and pitch cases are considered
- Loadings caused by wind pressure
- Topside is placed on the transportation.
- Height of lower+upper grillage = 2.0+3.0 m = 5 m
- Freeboard = 5 m
- Topside is placed centrally on the vessel with COG maximum 2 m and 35 m from the roll and pitch axis respectively.

Static load (set-down load) is taken in the four main columns in grids.

If the transport fatigue is deemed necessary to consider, the Fatigue Limit State (FLS) will be assessed according to DNV-RP-C203. The influence of the distance and duration of the transport on the fatigue state of the components shall be analysed for transports over 500 nautical miles. Ref /17/

The SESAM software will be used for the fatigue analyses. In the following, the analysis procedure is given in points:

The following summarizes the fatigue assessment of the topsides during sea transport. Note that the scatter diagrams mentioned below for any relevant sea transport scenarios and RAO data for the vessel with the topside are to be provided by the Employer. Voyage duration will be depending on which fabrication yard is chosen. Initially no extra waiting period at site will be assumed. 200 metric tons of rigging is assumed placed on the Roof Deck of the OSS.

6.3 Bubble Curtain

During installation of monopiles and jackets at sea, the noise generated by high-energy piling may harm the marine environment. To mitigate the risk of noise for marine life, governments have adopted noise limits for pile-driving operations in their permits for offshore construction projects. Air bubble curtains reduce the sound-levels. A looped hose on the seabed - pressurized by air compressors – generates the bubble curtain. Currently, engineers base the bubble curtain designs on previous experience and not on scientific research. Companies experience large variations in the current performance of bubble curtains. A better understanding of the noise generation and mitigation mechanisms would enable better engineering of the bubble curtains, leading to screens that are more effective and to lower costs. Improved screens will control better the noise levels and will reduce the risk not to comply with the specific noise requirements per piling project.

Figure 48 Bubble curtain

6.4 Offshore Lift

The lift is currently assumed to be performed as a four-point single hook lift by a floating crane vessel. No spreader bar or intermediate lifts are currently considered. This can be discussed later depending on availability of installation ships.

The weight of the topside in the analysis will correspond to the upper bound weight in the weight report, as required by DNV-ST-N001.

The lift points will be double trunnions with sling eye to the trunnion.

6.5 Stabbing / Mating

The topside will be checked for the case of stabbing/set down on to the substructure, the analysis weight of the topside will correspond to the expected (upper bound) weight in accordance with the weight report.

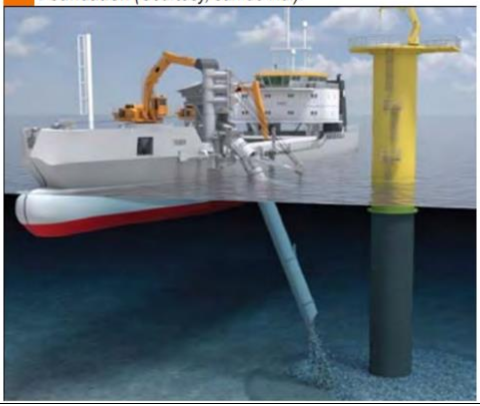
The stabbing pins will be designed in accordance with DNV-ST-N001 and regarded as a pin/bucket type.

6.6 Pricing

This section gives a general and indicative overview of the pricing of the different vessels required during T&I phase related to Offshore Wind Projects.

All prices listed in this section are an estimate based on experience from the western Europe Offshore industry and must be seen as indicative.

Following table indicates average pricing based on experience from other projects.

Component / Operation	Description	Day Rates
Scour Protection		
Figure 72. Rock Placement at a Wind Turbine Foundation *(Courtesy, Jan de Nul).* 		≈125 k€/day
Topside Transportation		
	Transport barge: ≈50 x 150 m One or two tugs during transportation	≈60 k€/day for full offshore spread in operation.
Jacket Transportation		
	Transport barge: ≈50 x 150 m Two or three tugs during transportation	≈80 k€/day for full offshore spread in operation.
Pin-Piles Transportation		

	Transport barge: ≈50 x 150 m Two or three tugs during transportation	≈100 k€/day for full offshore spread in operation. *Tugs may not be required during loadout.*
Pin-Piles & Jacket Installation		
		≈450 k€/day for full offshore spread in operation.
Bubble Curtain Vessel		
		≈100 k€/day
Jacket Installation		
	Heavy Lift vessel + 5000t	≈450 k€/day
Topside Installation		

	Heavy Lift vessel + 5000t	≈450 k€/day for full offshore spread in operation.
Support Vessel		≈50 k€/day
Crew Transfer Vessel		≈10 k€/day

7 Export Cable Installation Methods

7.1 General

The offshore export cables are connecting the OWF with the onshore grid system meaning that all produced electrical energy is passing these cables. If one or more OECs fail during operation due to cable damages (internally or externally caused) not the full energy or, as worst case, no energy can be transported to the onshore grid. Therefore, correct installation and sufficient protection of OECs have a high relevance for stable operation and high availability of the OWF. This section describes the general methods of cable installation and cable protection. Also, possible types of cable laying vessels are described herein.

The installation and protections methods for the offshore export cables have to be defined already during design phase of the cables since these are relevant input parameters for the cable dimensioning.

The requirements for the laying and protection of the export cables are explained in following two subsections. First, investigations and assessments of the site conditions have to be performed for the selected export cable routes. Based on this, the cable protections methods are defined (e.g., cable burial with defined burial depth, non-burial protection methods). Based on the defined protection methods, the installation requirements are specified, and corresponding tools and vessels will be selected.

For general descriptions of investigations and assessments initiated prior to cable laying operations and post-cable laying operations including Cable Burial Risk Assessment (CBRA) reference is made to Ref /1/ and Ref /10/.

7.2 Cable Route Investigations & assessment

Basis for the definition of required cable installation and protection methods are investigations and assessments performed along the selected export cable route between the Offshore substations (OSS) and the landfall. The results of these investigations and assessments are a crucial input since they deliver the ground and soil characteristics as well as identify potential hazards that can cause severe cable damages during installation and operation phase of the OWF.

The relevant site investigations and studies include following:

- Geophysical site investigation
- Geotechnical site investigation
- Metocean conditions investigation

- Seabed mobility risk assessment study and scour assessment study
- Unexploded ordnances (UXO) investigation
- Investigation of maritime traffic density, fishing activities and military activities

During these investigations and assessments also any obstacles within the cable corridor are identified that might require a re-routing of the export cable, such as shipwrecks, boulders, benthic habitats, unexploded ordnances (UXO), etc.

Besides the site investigations it is also of high importance to plan for potential obstacles e.g. maritime traffic density, fishing activities and military activities (if any) along the export cable corridor. The aim is to identify possible manmade hazards along the export cable e.g. anchors, fishing gear and nets, etc. A high-level overview of maritime traffic and fishing activities for the two project sites is shown in section 1.3.1 and 1.4.1. Also, more details can be found in Ref /6/ and Ref /7/.

It is relevant to identify the size of the vessels crossing the export cable corridor as this can give an estimated size and weight of the vessels anchor. The anchor size and weight are relevant for estimating the potential penetration depth, the anchor can have on the seabed. The same applies for fishing gear and fishing nets used around the export cable corridor.

In addition, it is important to map out the military activities around the export cable corridor as these activities can pose a risk for the cable itself but also pose a risk for the cable installation process. Therefore, an UXO risk assessment can be crucial to conduct as such an assessment maps out the risk of encountering potential UXO during installation.

Basis for the definition of cable installation methods and cable protection methods are investigations performed along the selected export cable route. The results of these investigations are a crucial input since they deliver the ground and soil characteristics as well as identify potential hazards that can cause severe cable damages during operation phase of the OWF.

Usually, following investigations and assessments are performed for offshore export cables:

- Geophysical site investigation
- Geotechnical site investigation
- Metocean conditions investigation
- Seabed mobility assessment and seabed mobility risk assessment
- Cable burial risk assessment (CBRA)
- Unexploded ordnances (UXO) investigation
- Maritime traffic density and fishing activities

More detailed information about these investigations and assessments are included in section 0.

7.3 Cable Burial Risk Assessments

The CBRA is the most important input for the definition of the required subsea cable installation and protection methods. With input from the other above listed investigations and assessments the CBRA is taken to define the required depth of burial (DoB) of the subsea cables in the seabed along the export cable route to protect the cables against environmental hazards as well as hazards caused by maritime traffic and fishing activities.

All site-specific data obtained from the different site investigations and assessment studies are used as input for the CBRA to define the required depth of burial (DoB) of the subsea cables. To support cable burial design potential manmade and natural hazards e.g. fishing gear, protected habitats, or seabed bedforms, must be identified and mapped.

A common practise is to bury or jet the cable into the seabed but if DoB cannot be achieved, specific non-burial protection methods have to be defined/selected in order to achieve full protection of the cable. Non-burial protection methods can be, but not limited to, following:

- Rock covering (e.g., rock berms or stone bags)
- Covering with concrete mattresses
- Cable installation with pipe

The specified minimum DoB for the subsea cables along the export cable route has to be observed for the complete cable route. The common practice to achieve the DoB is to bury the subsea cables in the seabed.

If the DoB can’t be achieved in sections of the export cable route due to one or more of following aspects, specific non-burial protection methods have to be defined/selected in order to provide fully protection against hazards that can cause cable damages:

- specific soil conditions (heavy clay, rocky/stony, reef) where cable burial is not possible or too expensive.
- crossing of existing facilities (subsea power or telecommunication cables, pipelines, etc.)
- Too high thermal resistivity characteristics of the soil that would cause overheating of the buried subsea cable in this specific section of the route.
- landfall point of export cable

A commonly used guidance for the offshore wind industry on CBRA best practice can be found through this link www.carbontrust.com. Full link can be found in Ref /16/.

7.4 Cable Installation Methods

7.4.1 Along the subsea cable route

Installation and burial methods for subsea cables are addressed in a vast number of guidelines and recommendation. For this study reference is made to DNVGL-RP-0360 “Subsea power cables in shallow water” and CIGRE Technical Brochure TR 883 “Installation of Submarine Power Cables”.

The installation of the subsea cables should aim at as few different burial methods as possible since:

- The mobilization cost will increase.
- Changing tool/methods offshore involves an increased risk of damage to the cable.

Today different tools are available and suitable for various burial depths and soil conditions.

Figure 49 is an extract from DNV-RP-0360, which provides a basis to define which tools should be considered for installation in a range of soil conditions.

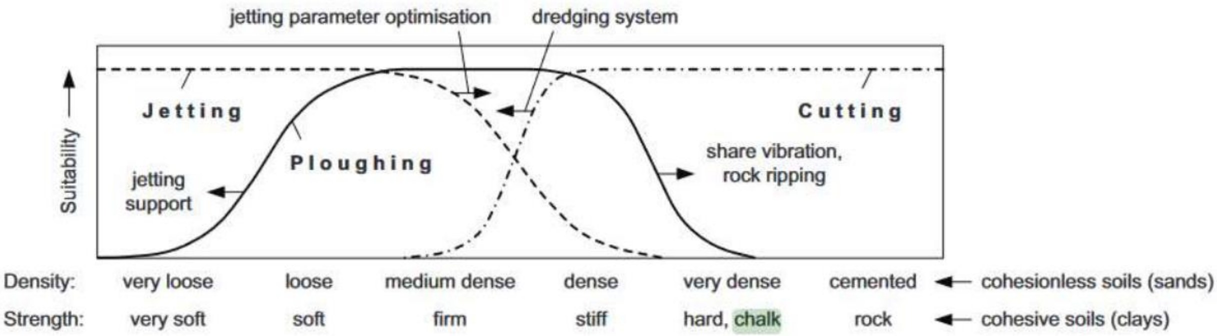
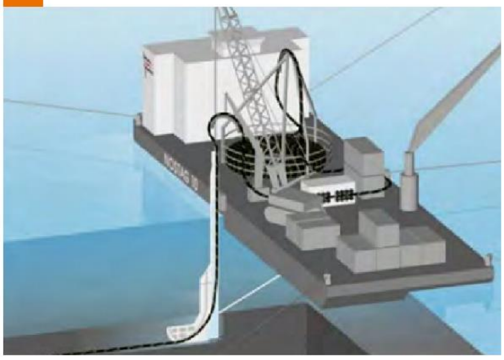


Figure 49 High level tool selection

Two general methods are used, (a) the subsea cable is laid on the seabed and after that buried (“post lay burial”) or the cable laying and burial is done simultaneously. The following table lists common cable laying and burial tools/methods used in OWF installation.

Figure 50 Installation methods for subsea cables

Simultaneous lay and burial	
	Operational Characteristics
Subsea Cable Plough	
Intertidal Zone *(Courtesy, Boskalis).* 	All ploughs are towed either from a CLB or CLV or in the case of landfall approaches pulled in from a fixed anchor point. Burial depth up to 3 m. Reported to work from 5 kPa soil. Ploughs cover a large range of soil types and are well suited to long relatively straight routes. Fast cable laying/burial operation Operation in very soft soil might be difficult due to skid sinkage.
Jetting Sleds	
(Courtesy, ETA Engineering Ltd.). 	Operated either from a CLB or CLV. Burial depth up to 8 m. Being barge mounted they can operate at shallow water but are limited to ≈30 m water depth. Jet sleds are a hybrid of a jet trencher and a cable plough. They are not usually self-propelling requiring to be towed or pulled but they often include a pumping system and jet legs.
Vertical Injector	
(Courtesy, NSW/General Cable). 	Barge mounted and operated independently of seabed slope and sand waves, and they work on the same principal as jet trenchers with high pressure water jets fluidizing the soils. Burial depth up to 10...15 m in the right soil conditions. Being barge mounted they can operate a shallow water but are limited to max. 30 - 40 m water depth. Good performance record in soft soils. Often a preferred approach where large burial depths are required.
Deep Dig-It Trencher – Van Ord	

	The Deep Dig-It is a so-called "Tracked Remotely Operated Vehicle" (TROV), which drives unmanned over the seabed, creating a deep trench for the cables, while simultaneously inserting the cables and then closing the trench again. Special about this new trencher is that it is the largest and most powerful machine in its class. The trencher weighs 125,000 kilos, is more than 17 m long, well over 8 m high, and 11 m wide. It has an installed power of 2,500 HP, making it possible to bury cables into very hard soils. Next to the large power installed, the depth of burial that can be achieved by the trencher is unmatched: well over 5 meters. The Deep Dig-It will be controlled from Van Oord's offshore installation vessel MPI Adventure, which is equipped with a crane that launches and recovers the Deep Dig-It into the sea.
Post Lay Burial	
Q1400 Trenching System (Jet trencher)	
	Mobilised on a special host vessel. The jetting tool has twin-legged parallel jet swords. The system is designed for trenching up to 3 m in soil conditions ranging from 5 KPA to 100 kPa. Can be mobilised with buoyancy module thus operation < 5 kPa is possible. One or two runs will be necessary to obtain target depth. Jet trenchers are best suited to fine to medium grained sands and soft clays.
Mass Flow Excavator	
Positioning System *(Courtesy, The Aleron Group).* 	The MFE, operated from a special mobilized host vessel, jets the seabed soils creating a large open excavation. 2 – 4 m burial depth can be achieved. Rarely used for long sections. In loose sand the operation will provoke large sediment transport that might be a challenge in regard to environmental consent.

7.4.2 At landfall

At landfall the offshore export cable is laid to shore where it is connected to the onshore export cable at the Transition Joint Bay (TJB). For the landfall typically two principal methods are available, direct burial (most likely with "open cut" method) and installation within a pre-installed duct (most likely "Horizontal Direct Drilling (HDD)" method).

The installation of the subsea cable will be done from a Cable Laying Vessel or a Cable Laying Barge with the subsea cable loaded on a turntable. The CLV/CLB will position itself as close as possible to the beach and the subsea cable will be pulled into the TJB where a cable pulling winch is mobilised.

7.4.3 Open cut method

Only advised if a stable cable trench in the seabed approaching the beach can be expected.

- Eventual pre-constructed cable trench
- CLV/CLB arrival as close to beach as possible
- Floating of the cable to the beach where cable rollers are mobilised
  Possible length will depend on water currents along the coastline
- Backfilling of cable trench or post-lay burial (PLB) of cables
  Stability of excavated trench shall be considered
  PLB with Remotely operated vehicle (ROV) or cable plough mobilisation / operation will depend on water depth and seabed characteristics. PLB may be implemented by the CLV/CLB or a special mobilised host vessel for the ROV.

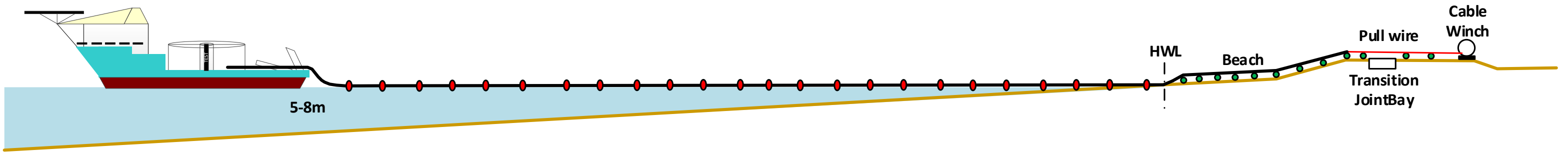


Figure 51 Landfall pulling operation with open cut method.

7.4.4 HDD method

Typically, a HDPE duct (with pulling/messenger wire inside the duct) will be installed via horizontal direct drilling method.

- Installation of duct via HDD (*indicated green in* Figure 52)
- Recovery of duct prior to pulling operation
- CLV/CLB arrival as close to beach as possible
  Location will be determined by the water depth and draught of the CLV/CLB

- Floating of the cable to the duct and pulling to the TJB.

- PLB of the cable from the seaside duct entry towards the OSS
  Selection of CLB or ROV host vessel will be determined by the water depth and eventual challenges in respect to eventual anchor handling requirements.

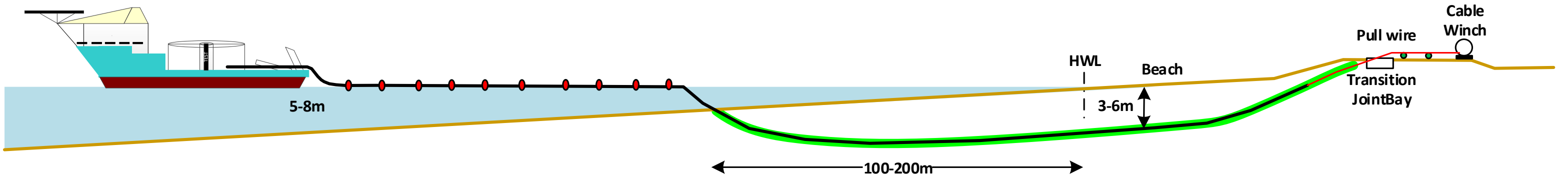


Figure 52 Landfall pulling operation with HDD method

7.5 Cable protection methods

It is of high importance to protect the subsea cables against external mechanical damages caused by ship anchors, fishing nets/gears, dropped objects (e.g., cargo from ships), etc.

The most common method for mechanical protection of subsea cables is to bury the cables in the seabed at the minimum Depth of Burial coming from the CBRA. If it is not possible to achieve the required minimum DoB with cable burial due to one or more of reasons, then additional cable protection methods have to be considered for the affected sections along the subsea cable route. Common non-burial protection methods applied at OWFs are following:

- Covering of cable with rocks (e.g., rock berms or stone bags)

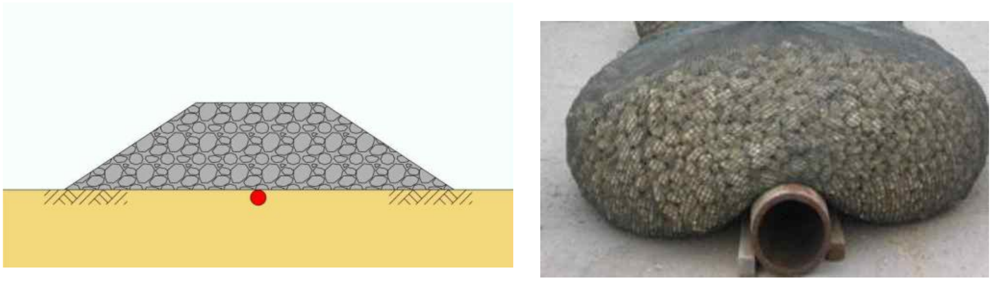


Figure 53 Cable covered with rock berm (left) or stone bags (right)

- Covering of cable with concrete mattresses

Figure 54 Concrete mattress

- Installation within pipe (made of e.g., steel, HDPE, etc.)

Figure 55 HDPE pipe

The chosen non-burial cable protection method might have an influence on the thermal behaviour of the subsea cable. Therefore, the protection methods along the subsea cable route have to be considered in the cable dimensioning calculations to avoid any overheating/overloading of the cables.

7.6 Cable laying vessel (CLV)

The installation of OECs for offshore wind farms requires specific cable laying vessels that are capable of fulfilling the technical characteristics of the export cables (e.g., cable dimensions, weight, pulling forces, bending radius, etc.) under the harsh offshore conditions at the actual project site. Therefore, it is crucial to verify already during design phase that the vessels are adequately selected based on the technical characteristics of the assets to be installed.

Currently there are different types of CLVs available in the market and further are under development due to high demand. A very preliminary survey on installation vessels presently available on the market is shown below.

Large Cable Laying Vessels	
NKT Cables - Victoria	Prysmian – Leonardo da Vinci
 Main deck TT 7000 t Below deck TT: 4500 t Max. TT load: 9000 t Design draught: 7.2 m	 TT1: 10.000 t TT2: 7.000 t Max. TT load: 13.000 t Design draught: 8.5 m
Medio size Cable Laying Vessels	
Nexans – Skagerrak- DP2	Prysmian – Giulio Verne
 TT: 9.373 t Draught: 5.4 - 6.3 m	 TT: 7.000 t Draught: 5.4 m
JDN - Willem de Vlamingh	KT Submarine - Segero
 TT: 5.400 t Draught: 5.4 m	 TT: 2x3900 t Draught: 7.8 m
Cable Laying Barges	
Nexans – Barege UR141k	Boskalis – Stemat Spirit

 TT: 7.000 t Draught: 5.4 - 6.3 m	 TT: 4.400 t Draught: 1.9 – 4.2 m – Beach able
JDC - H.P Lading	Stemat - Pontra Maris
 TT: 1.800 t Draught: 3.3 m	 TT: 1.600 t Draught: 1.3 – 3.1 m

Figure 56 Overview of CLVs and CLBs

- Large and medium size CLVs have higher TT capacity with possibility to load long cable lengths but may have challenges in the cable landfall section with shallow water due to the higher draught.

- The Cable Laying Barges (CLBs) can also operate in shallow waters (3-5 m water depth, e.g., at landfall) but may be required to reload the cables due to a limited TT capacity.

For the selection of the CLVs or CLBs the cable lengths (inter array cables, export cables) and the specific water depth of the cable routes must be considered.

7.7 Pricing

For installation of subsea export cables CLVs and CLBs are required (which type depends on cable length, water depth) and also CTVs (Crew transfer vessels) are needed for supporting tasks during cable laying/burial operations.

Besides the actual costs for the site operation, additional costs for mobilisation (time for preparation of planned work and transfer to project site) and demobilisation (time for return to harbour) have to be considered as well.

Following table indicates average pricing based on experience from other projects.

<table>
<tr><th>Vessel</th><th>Mobilisation / demobilisation
Rate per day</th><th>Cable installation
Rate per km</th><th>Cable installation
Rate per day</th></tr>
<tr><td>CLV</td><td rowspan="2">~720,000 €/day</td><td>~70,000 €/km</td><td>~160,000 €/day</td></tr>
<tr><td>CLB</td><td>~60,000 €/km</td><td>~140,000 €/day</td></tr>
<tr><td>CTV</td><td>~250,000 €/day</td><td>~13,000 €/km</td><td>~12,000 €/day</td></tr>
</table>

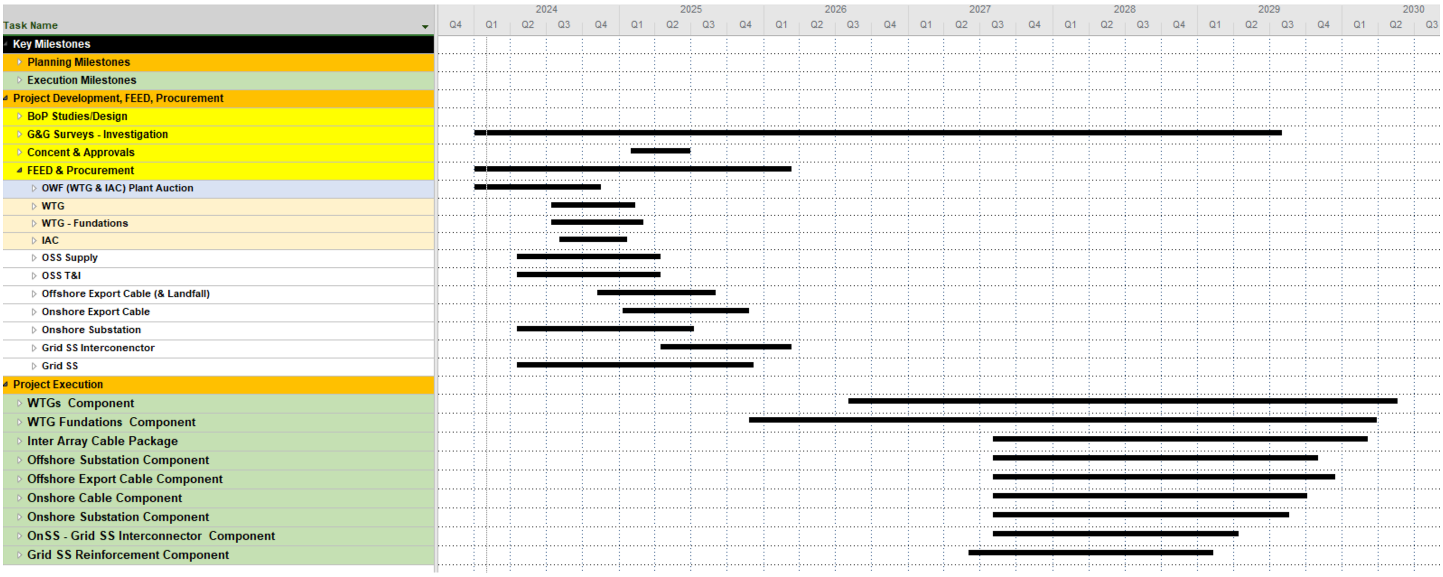
Note: The costs for cable installation can be indicated either by "rate per km installed subsea cable" or by "rate per day". The daily progress of cable installations mainly depends on weather and sea conditions.

8 Program

A tentative program for the development of an OWF including the BoP is illustrated in the following Gantt charts supplemented with narrative on the bottlenecks and critical paths.

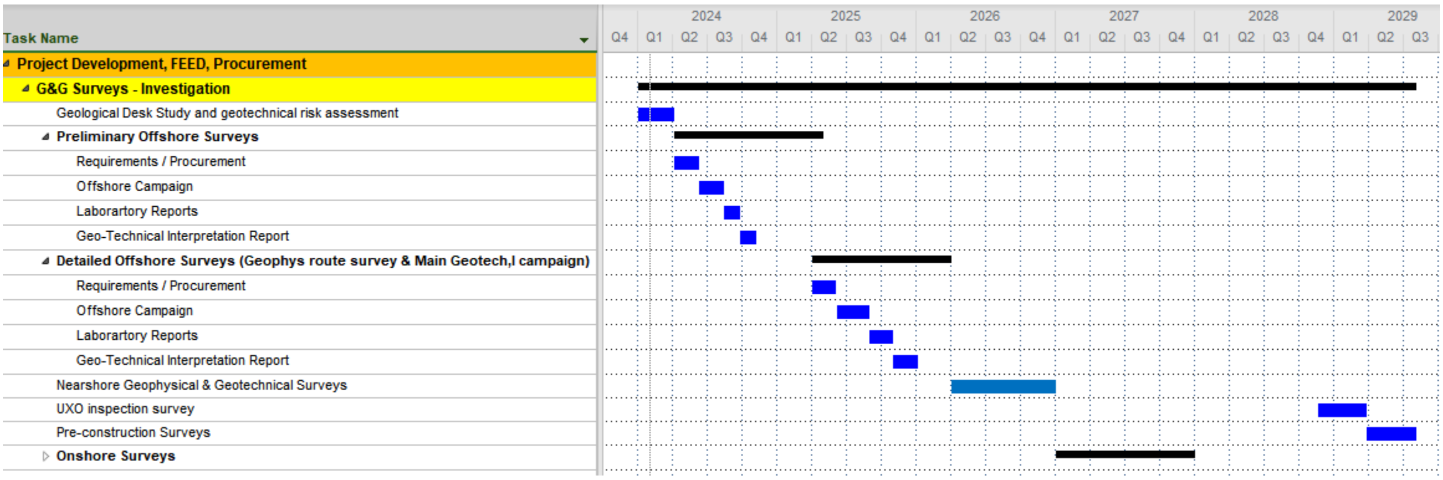
Reference is also given to Ref /11/ where the full expanded program is presented.

Level 1 Timeline



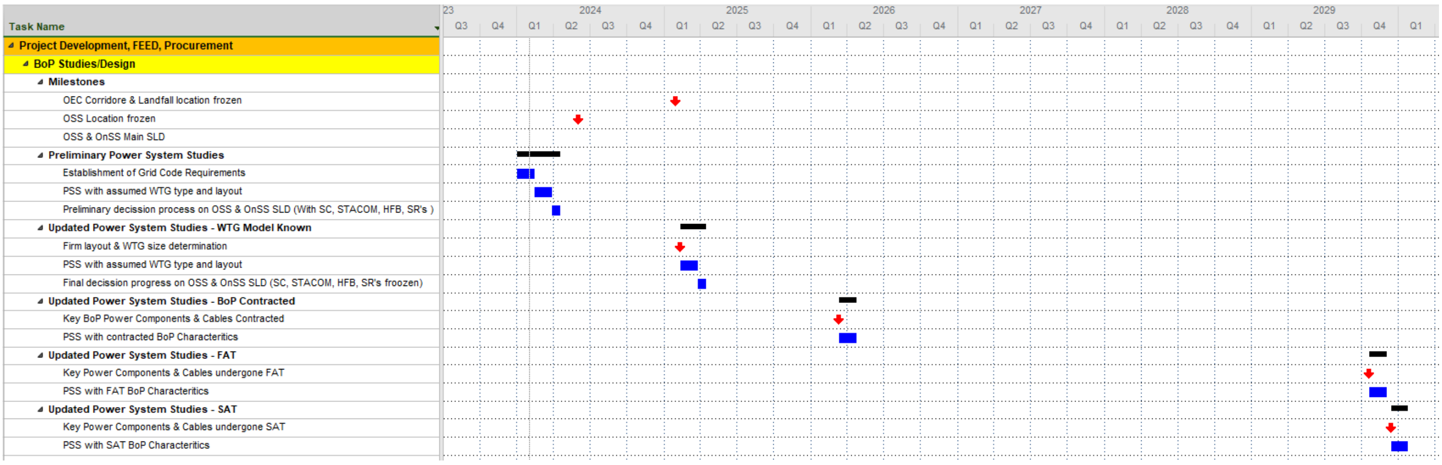
- The program aims at OWF production in 2Q30.
- FEED and procurement are anticipated in 2024-2025
- Float before firm contracts in 2026-2027 exist.
- Acceleration of preferred supplier agreements for the OSS and Offshore Cables is recommended to secure production slot and installation vessels.

Offshore Geotechnical- Physical Investigations



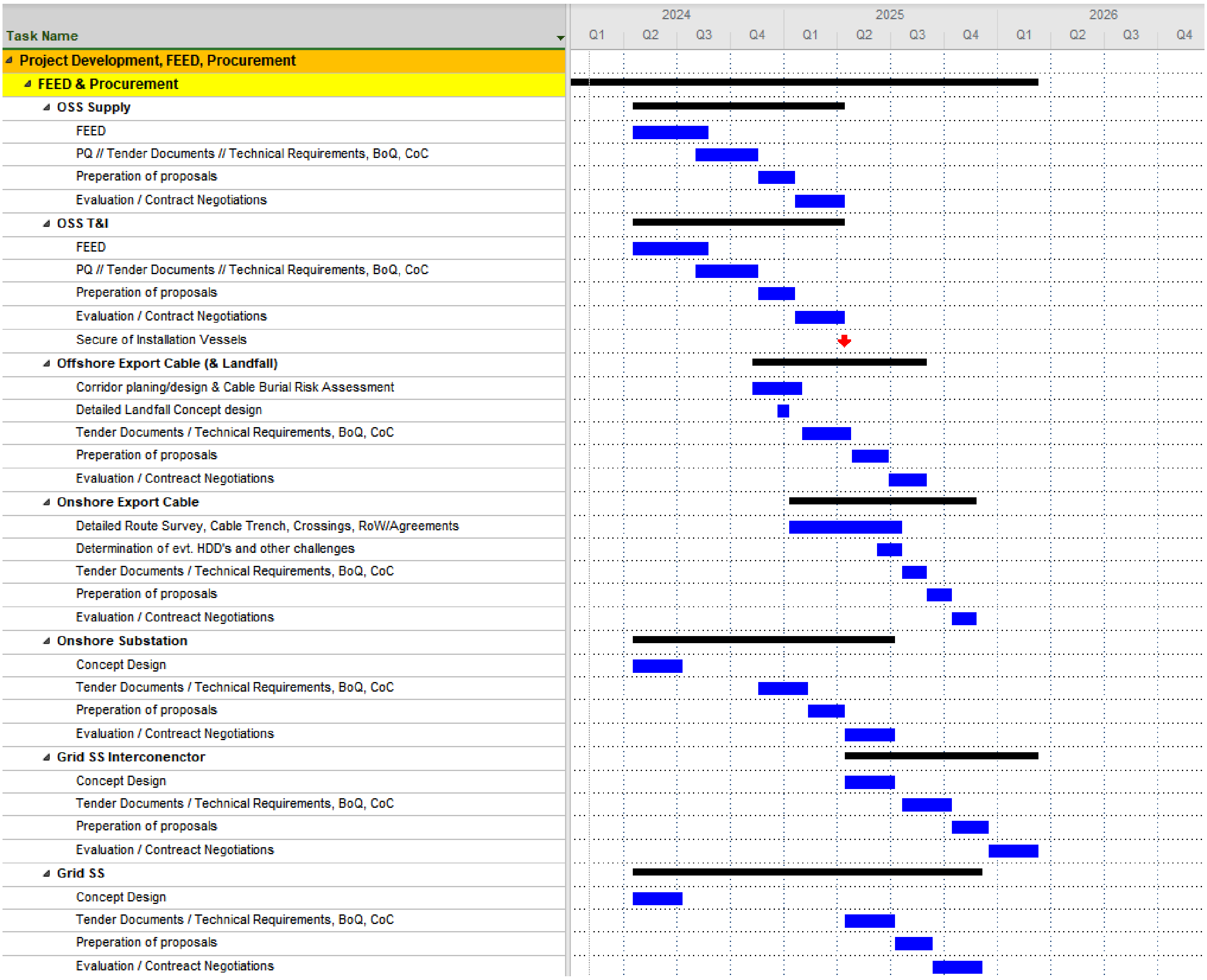
- Preliminary offshore investigations are vital input for the CBRA that should form part of technical requirements issued to the offshore cable suppliers/installers.
- Detailed geo-technical investigations should await determination of the OSS location.
- UXO and pre-construction surveys can be implemented by the cable installation contractor.

Power System Studies / Component Identification - Rating



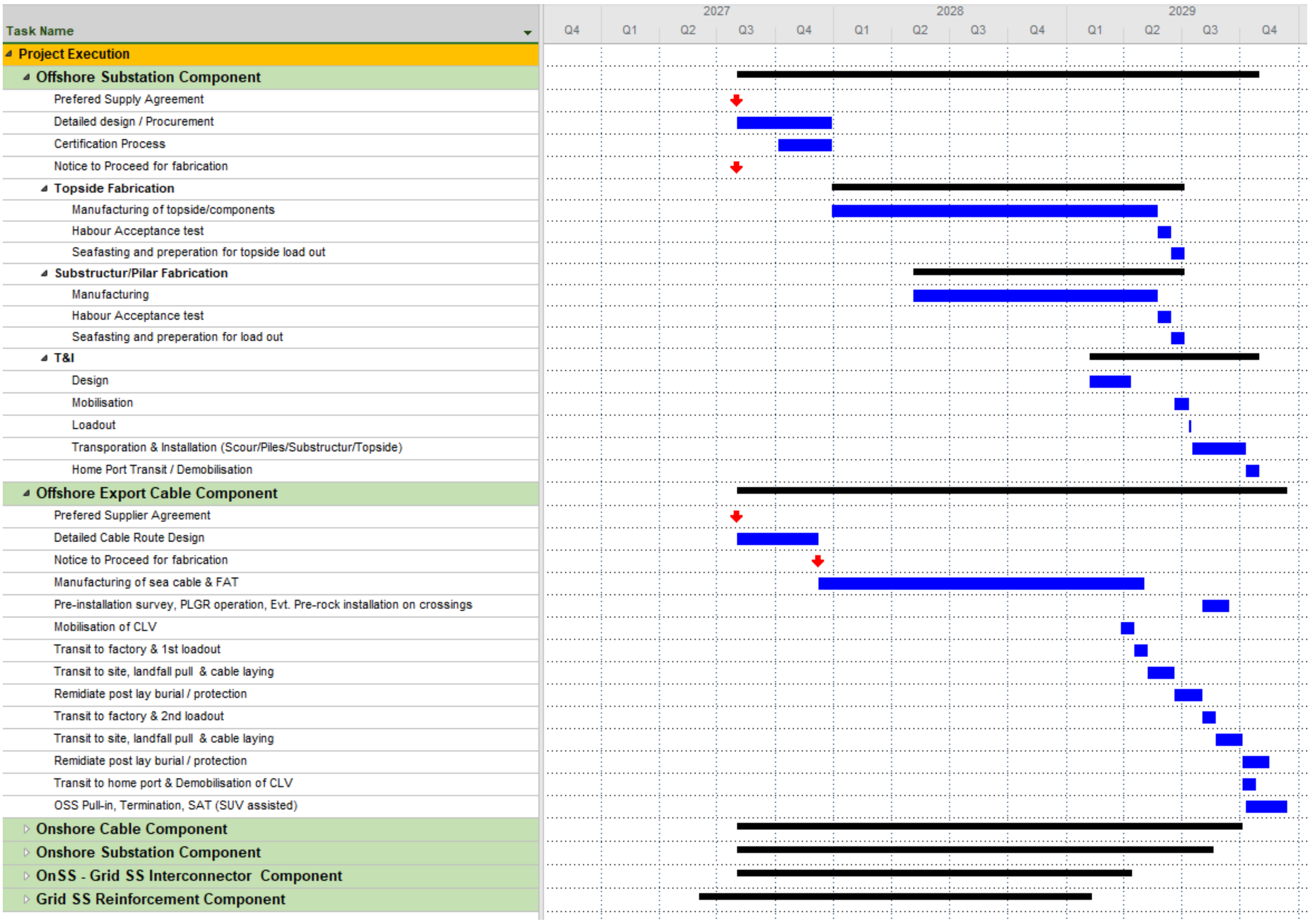
- Preliminary PSS aim to determine topology and component rating forming the basis of the technical requirements of the OnSS and OSS procurement documents.
- PSS with WTG model understood will firm up the design of eventual shunt reactors, STATCOMs and harmonic filter banks.
- PSS with contracted component/cable characteristics is an opportunity to modify rating/performance specification of OnSS components.
- PSS with FAT data will allow for preparation of the SAT & commissioning tests.
- PSS with site measured data will give most accurate input to TSO’s power system model for further planning/operation of his transmission grid

BoP Procurement & Preferred Supplier Agreements



- Given the long deliverable time for the main components and to secure offshore installation vessels an early planning of the procurement process is recommended.
- The number of OWF projects worldwide is large and supply bottlenecks today are present. Consequently, the contractors are selective on entering a proposal process.
- Onshore the TSO can adapt a multi shopping approach, this is not recommended for the OSS.
- Splitting up the OFC works into supply and T&I is possible but will introduce interfaces to be managed. This approach is not suggested unless the developer/Employer is experienced with offshore cable projects.

BoP Offshore Execution – Manufacturing – T&I



- Manufacturing of the main power transformers and the topside will be long lead items critical for the overall execution phase of the project. (18 … 24 months are assumed with the current supply chain situation)
  Consequently, an accelerated procurement and preferred supplier agreement shall be aimed at to allow early design and secure the heavy lift vessels for the T&I.
- Preferable sequence of activities is
  - Onshore SS and export cable installed.
  - OSS ready to receive export cables.
  - Landfall ready to receive cable.
  - Laying/installation of the offshore cables
  - Assembly transition joint for onshore/offshore cables
  - Energisation of OnSS HV busbar
  - Energisation of Export cable(s) and OSS
  - IAC Pull-in to OSS
  - IAC string energisation
  - 1st power from WTGs

9 References

Ref /1/. A268066-ALL-GCD-005 GG-requirement

Ref /2/. A268066-GU-GCD-002-0 OSS SLD

Ref /3/. A268066-GU-IAC-002-V2

Ref /4/. A268066-TN-IAC-002-V2

Ref /5/. Rapid Environmental Impact Assessment Report-1GW, Gulf og Khambhat, Off Gujarat coast. (2020). National Institute of Wind Energy (NIWE).

Ref /6/. Maritime Spatial Planning for Offshore Wind Farms in Tamil Nadu. (2022). Centre of Excellence for offshore Wind and Renewable Energy.

Ref /7/. Maritime Spatial Planning for Offshore Wind Farms in Gujarat. (2022). Centre of Excellence for offshore Wind and Renewable Energy

Ref /8/. A268066-GU-GCD-001 WTG Layout Memo

Ref /9/. A268066-TN-GCD-001 WTG Layout Memo

Ref /10/. A268066-ALL-GCD-004 Offshore Wind – BoP T&I approach – Vessel Assessment

Ref /11/. A268066-ALL-GCD-006_R0-BoP_Ex_plan

Ref /12/. A2686066-TN-GCD-002-0 OSS SLD

Ref /13/. A268066-ALL-OSS-008 500 MW OSS General arrangement

Ref /14/. A268066-TN-LF-001 Tamil Nadu Landfall General Arrangement

Ref /15/. A268066-ALL-GCD-015 Landfall Arrangement – Sea Land Transition Joint Bay Details.

Ref /16/. Cable Burial Risk Assessment Methodology – Guidance for the Preparation of Cable Burial *Depth of Lowering* Specification. (2015). Carbon Trust, Vol no. CTC835. Cable Burial Risk Assessment (CBRA) guidance | The Carbon Trust

Ref /17/. DNV Standard Transport and installation of wind power plants. DNVGL-ST-0054

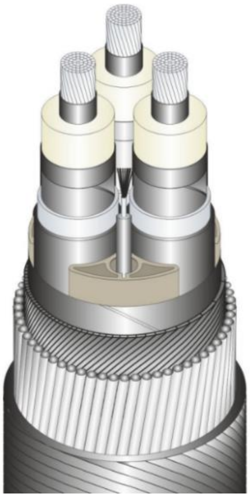
Appendix A Cable Selection Approach

This appendix gives a description of the high-level assumptions and approach adopted for the selection of the offshore and onshore cable types. The approach is preliminary only but is anticipated reasonable for the Pre-FEED consideration and CAPEX and cost comparison investigations performed.

Offshore Cables:

Three-core offshore cables are anticipated in a traditional design, both for inter array cables (66 kV) and export cables (220-275 kV).

	66 kV	**220-275 kV**
Conductor *)	Stranded – Cu or Al	
Insulation	Inner/Outer Screen: Conductive PE Insulation: XLPE	
Screen	Cu-wires	Lead
Water Barrier	Foiled Aluminium	
Core sheath	Conductive PE	
Armouring	SWA: Single Layer Galvanized Steel Amour Wires **)	SWA: Single Layer Galvanized Steel Amour Wires SSWA: Single Layer Stainless Steel Amour Wires ***)
Outer Cover	Polypropylene Yarns	



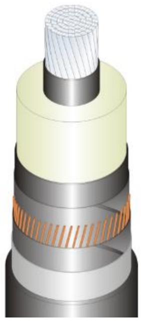
**) Segmented (Milliken) conductors will add a significant boost of the capacity – but is not suppliers preferred design.*
***) 70% reduction of IEC calculated amour losses is considered.*
****) Amour losses are anticipated 0 W/m as per recent CIGRE recommendations.*

The design represents a typical subsea cable – changes/improvements especially on the amour component can be agreed with the cable manufacturer when technical requirements and tender documents are compiled/negotiated.

Onshore Cables:

Single core XLPE cables are anticipated in a traditional design.

	220-230 kV
Conductor	Stranded – Cu or Al Milliken – Cu or Al
Insulation	Inner/Outer Screen: Conductive PE Insulation: XLPE
Screen	Cu-wires *)
Water Barrier	Foiled Aluminium *)
Core sheath	Conductive PE



**) Can be designed with extruded Al or Lead as an alternative*

The current rating of the cables takes basis in below generic site conditions:

	Soil Temperature	DoB	Specific Thermal Resistivity	Grouping / Parallel Run
Offshore	20 °C	3 m	0.8 K·m/w	N.A.
Onshore *)	20 °C	1.5 m	1.2 K·m/w **)	1.5 m

*) Two circuits separated by 1.5 m // pre-laid ducts // Trefoil // Cross bonded screens.
**) Thermal stable backfill or concrete embedment assumed to prevent soil dry out.

With site conditions different from the generic – the following derating factors have been used.

Rating factor Offshore Cable | **Rating factor Onshore Cable**

Laying depth		Soil Temp		Thermal Resistivity		Temp	TR
m	Factor	oC	Factor	K.m/W	Factor	Factor	Factor
1	1.06	10	1.07	0.6	1.08	1.07	
1.5	1.02	15	1.04	0.7	1.04	1.03	
2	**1.00**	**20**	**1.00**	**0.8**	**1.00**	**1.00**	1.07
2.5	0.98	25	0.96	0.9	0.97	0.96	1.03
3	0.97	30	0.93	**1**	0.94	0.93	**1.00**
4	0.95			1.1	0.91		0.97
5	0.94			1.2	0.88		0.95
6	0.93			1.5	0.82		0.88
				2	0.73		

Offshore Cables – Selection Table

66 kV Inter Array Cables between WTGs and to OSS

Cable Type	Electrical Impedance			Load Assessment				
	R [90oC] 50 Hz [ohm/km]	jXr 50 Hz [ohm/km]	Capacitanc µF/km [ohm/km]	Imax Site Specific [Amp]	Imax Generic [Amp]	Pn_max [MW]	Sn_max [MVA]	Max. WTGs
66_3c185Al/ST-SWA	0.2275	0.2275	0.2164	327	338	36.4	37.3	3.0
66_3c240Al/ST-SWA	0.188	0.188	0.220	371	384	41.3	42.4	3.4
66_3c300Al/ST-SWA	0.156	0.156	0.223	414	429	46.1	47.3	3.8
66_3c400Al/ST-SWA	0.127	0.127	0.242	467	483	52.0	53.3	4.3
66_3c500Al/ST-SWA	0.105	0.105	0.254	523	542	58.3	59.8	4.9
66_3c630Al/ST-SWA	0.088	0.088	0.286	584	604	65.0	66.7	5.4
66_3c800Al/ST-SWA	0.075	0.075	0.315	643	666	71.6	73.5	6.0
66_3c1000Al/ST-SWA	0.065	0.065	0.345	710	735	79.1	81.1	6.6
66_3c1200Al/ST-SWA	0.060	0.060	0.358	756	783	84.3	86.5	7.0
66_3c1400Al/ST-SWA	0.057	0.057	0.371	796	824	88.7	90.9	7.4
66_3c500Cu/ST-SWA	0.074	0.127	0.254	629	651	70.1	71.9	5.8
66_3c630Cu/ST-SWA	0.064	0.122	0.286	689	714	76.8	78.8	6.4
66_3c800Cu/ST-SWA	0.057	0.118	0.315	745	771	83.0	85.1	6.9
66_3c1000Cu/ST-SWA	0.052	0.115	0.345	806	835	89.8	92.1	7.5
66_3c1200Cu/ST-SWA	0.049	0.113	0.358	845	875	94.2	96.6	7.8
66_3c1400Cu/ST-SWA	0.047	0.112	0.371	884	916	98.5	101.0	8.2

Cable Type	Electrical Impedance			Load Assessment	Load Capacity								
	R [90oC] 50 Hz [ohm/km]	jXr 50 Hz [ohm/km]	Capacitanc µF/km [ohm/km]	Imax Site Specific [Amp]	Imax Generic [Amp]	DoB [m]	DoB Factor	TR [K.m/W]	TR Factor	Soil Temp [oC]	Soil Temp Factor	Pn_max [MW]	Sn_max [MVA]
No Cable	0.0000	0.0000	0.0000			3	0.97	0.8	1.00	30	0.93		
245_3c500Al/ST-SWA	0.103	0.149	0.137	550	570	3	0.97	0.80	1.00	30.00	0.93	204.3	209.5
245_3c630Al/ST-SWA	0.086	0.142	0.148	616	638	3	0.97	0.80	1.00	30.00	0.93	228.9	234.8
245_3c800Al/ST-SWA	0.073	0.135	0.169	682	706	3	0.97	0.80	1.00	30.00	0.93	253.2	259.7
245_3c1000Al/ST-SWA	0.064	0.131	0.182	742	768	3	0.97	0.80	1.00	30.00	0.93	275.6	282.7
245_3c1200Al/ST-SWA	0.059	0.127	0.195	782	810	3	0.97	0.80	1.00	30.00	0.93	290.7	298.1
245_3c1400Al/ST-SWA	0.056	0.125	0.207	814	843	3	0.97	0.80	1.00	30.00	0.93	302.3	310.0
245_3c1600Al/ST-SWA	0.053	0.123	0.220	845	875	3	0.97	0.80	1.00	30.00	0.93	313.9	321.9
245_3c1600Al/ST-SSWA	0.037	0.123	0.220	973	1,008	3	0.97	0.80	1.00	30.00	0.93	361.6	370.9
245_3c2000Al/ST-SWA	0.049	0.118	0.244	890	922	3	0.97	0.80	1.00	30.00	0.93	330.8	339.2
245_3c2000Al/ST-SSWA	0.034	0.118	0.244	1,041	1,078	3	0.97	0.80	1.00	30.00	0.93	386.8	396.7
245_3c1200Cu/ST-SWA	0.048	0.127	0.195	881	913	3	0.97	0.80	1.00	30.00	0.93	327.4	335.8
245_3c1400Cu/ST-SWA	0.046	0.125	0.207	906	939	3	0.97	0.80	1.00	30.00	0.93	336.7	345.4
245_3c1600Cu/ST-SWA	0.045	0.123	0.220	932	965	3	0.97	0.80	1.00	30.00	0.93	346.1	355.0
245_3c1600Cu/ST-SSWA	0.029	0.123	0.220	1,113	1,153	3	0.97	0.80	1.00	30.00	0.93	413.6	424.2
245_3c2000Cu/ST-SWA	0.043	0.118	0.244	969	1,004	3	0.97	0.80	1.00	30.00	0.93	360.0	369.2
245_3c2000Cu/ST-SSWA	0.027	0.118	0.244	1,174	1,216	3	0.97	0.80	1.00	30.00	0.93	436.2	447.3
275_3c500Al/ST-SWA	0.103	0.149	0.137	566	586	3.00	0.97	0.8	1.00	30	0.93	262.7	269.5
275_3c630Al/ST-SWA	0.086	0.142	0.148	634	657	3.00	0.97	0.80	1.00	30.00	0.93	294.5	302.1
275_3c800Al/ST-SWA	0.073	0.137	0.162	701	727	3.00	0.97	0.80	1.00	30.00	0.93	325.7	334.1
275_3c1000Al/ST-SWA	0.064	0.132	0.174	764	791	3.00	0.97	0.80	1.00	30.00	0.93	354.6	363.7
275_3c1200Al/ST-SWA	0.059	0.129	0.184	804	833	3.00	0.97	0.80	1.00	30.00	0.93	373.4	383.0
275_3c1400Al/ST-SWA	0.056	0.127	0.197	837	867	3.00	0.97	0.80	1.00	30.00	0.93	388.7	398.7
275_3c1600Al/ST-SWA	0.053	0.125	0.210	870	901	3.00	0.97	0.80	1.00	30.00	0.93	404.0	414.3
275_3c1600Al/ST-SSWA	0.037	0.125	0.210	1,007	1,043	3.00	0.97	0.80	1.00	30.00	0.93	467.6	479.6
275_3c2000Al/ST-SWA	0.049	0.119	0.233	923	956	3.00	0.97	0.80	1.00	30.00	0.93	428.6	439.6
275_3c2000Al/ST-SSWA	0.033	0.119	0.233	1,088	1,127	3.00	0.97	0.80	1.00	30.00	0.93	505.3	518.2
275_3c800Cu/ST-SWA	0.055	0.137	0.162	820	849	3.00	0.97	0.80	1.00	30.00	0.93	380.8	390.5
275_3c1000Cu/ST-SWA	0.050	0.132	0.174	874	905	3.00	0.97	0.80	1.00	30.00	0.93	405.9	416.3
275_3c1200Cu/ST-SWA	0.048	0.129	0.184	905	937	3.00	0.97	0.80	1.00	30.00	0.93	420.2	431.0
275_3c1400Cu/ST-SWA	0.046	0.127	0.197	932	965	3.00	0.97	0.80	1.00	30.00	0.93	432.6	443.7
275_3c1600Cu/ST-SWA	0.044	0.125	0.210	958	993	3.00	0.97	0.80	1.00	30.00	0.93	445.0	456.4
275_3c1600Cu/ST-SSWA	0.029	0.125	0.210	1,152	1,193	3.00	0.97	0.80	1.00	30.00	0.93	534.8	548.5
275_3c2000Cu/ST-SWA	0.042	0.119	0.233	1,004	1,040	3.00	0.97	0.80	1.00	30.00	0.93	466.4	478.3
275_3c2000Cu/ST-SSWA	0.026	0.119	0.233	1,229	1,273	3.00	0.97	0.80	1.00	30.00	0.93	570.7	585.3

220-275 kV Cables Subsea between OSS and to landfall

245 kV cable rating relates to 220 kV operational voltage and an assumed dynamic factor 107.5% (Raised permissible load current to counter for the fluctuating WTG production). 245 kV cables operated at 230 kV will have same permissible load current but will offer 230/220 → ≈ 5% higher MW transit.

220-275 kV Cables Landfall

The landfall often constitutes a thermal bottleneck/hotspot for the subsea export cables. Below table indicates the impact of cable buried 6 m and with increased thermal soil resistivity 1.0 K·m/W considered as an absolute worst-case scenario. (The dynamic factor is increased to 110%).

Cable Type	Electrical Impedance			Load Assessment		Load Capacity							
	R [90oC] 50 Hz [ohm/km]	jXr 50 Hz [ohm/km]	Capacitanc µF/km [ohm/km]	Imax Site Specific [Amp]	Imax Generic [Amp]	DoB [m]	DoB Factor	TR [K.m/W]	TR Factor	Soil Temp [oC]	Soil Temp Factor	Pn_max [MW]	Sn_max [MVA]
No Cable	0.0000	0.0000	0.0000			6	0.93	1	0.94	30	0.93		
245_3c500Al/ST-SWA	0.103	0.149	0.137	502	570	6	0.93	1.00	0.94	30.00	0.93	186.5	191.3
245_3c630Al/ST-SWA	0.086	0.142	0.148	563	638	6	0.93	1.00	0.94	30.00	0.93	209.1	214.4
245_3c800Al/ST-SWA	0.073	0.135	0.169	622	706	6	0.93	1.00	0.94	30.00	0.93	231.2	237.2
245_3c1000Al/ST-SWA	0.064	0.131	0.182	677	768	6	0.93	1.00	0.94	30.00	0.93	251.7	258.1
245_3c1200Al/ST-SWA	0.059	0.127	0.195	714	810	6	0.93	1.00	0.94	30.00	0.93	265.4	272.2
245_3c1400Al/ST-SWA	0.056	0.125	0.207	743	843	6	0.93	1.00	0.94	30.00	0.93	276.0	283.1
245_3c1600Al/ST-SWA	0.053	0.123	0.220	771	875	6	0.93	1.00	0.94	30.00	0.93	286.6	294.0
245_3c1600Al/ST-SSWA	0.037	0.123	0.220	889	1,008	6	0.93	1.00	0.94	30.00	0.93	330.2	338.7
245_3c2000Al/ST-SWA	0.049	0.118	0.244	813	922	6	0.93	1.00	0.94	30.00	0.93	302.0	309.8
245_3c2000Al/ST-SSWA	0.034	0.118	0.244	951	1,078	6	0.93	1.00	0.94	30.00	0.93	353.2	362.2
245_3c1200Cu/ST-SWA	0.048	0.127	0.195	805	913	6	0.93	1.00	0.94	30.00	0.93	299.0	306.6
245_3c1400Cu/ST-SWA	0.046	0.125	0.207	828	939	6	0.93	1.00	0.94	30.00	0.93	307.5	315.4
245_3c1600Cu/ST-SWA	0.045	0.123	0.220	851	965	6	0.93	1.00	0.94	30.00	0.93	316.0	324.1
245_3c1600Cu/ST-SSWA	0.029	0.123	0.220	1,017	1,153	6	0.93	1.00	0.94	30.00	0.93	377.7	387.4
245_3c2000Cu/ST-SWA	0.043	0.118	0.244	885	1,004	6	0.93	1.00	0.94	30.00	0.93	328.7	337.1
245_3c2000Cu/ST-SSWA	0.027	0.118	0.244	1,072	1,216	6	0.93	1.00	0.94	30.00	0.93	398.3	408.5
275_3c500Al/ST-SWA	0.103	0.149	0.137	517	586	6.00	0.93	1	0.94	30	0.93	239.9	246.1
275_3c630Al/ST-SWA	0.086	0.142	0.148	579	657	6.00	0.93	1.00	0.94	30.00	0.93	269.0	275.9
275_3c800Al/ST-SWA	0.073	0.137	0.162	640	727	6.00	0.93	1.00	0.94	30.00	0.93	297.4	305.1
275_3c1000Al/ST-SWA	0.064	0.132	0.174	697	791	6.00	0.93	1.00	0.94	30.00	0.93	323.8	332.1
275_3c1200Al/ST-SWA	0.059	0.129	0.184	734	833	6.00	0.93	1.00	0.94	30.00	0.93	341.0	349.7
275_3c1400Al/ST-SWA	0.056	0.127	0.197	764	867	6.00	0.93	1.00	0.94	30.00	0.93	354.9	364.0
275_3c1600Al/ST-SWA	0.053	0.125	0.210	794	901	6.00	0.93	1.00	0.94	30.00	0.93	368.9	378.4
275_3c1600Al/ST-SSWA	0.037	0.125	0.210	919	1,043	6.00	0.93	1.00	0.94	30.00	0.93	427.0	438.0
275_3c2000Al/ST-SWA	0.049	0.119	0.233	843	956	6.00	0.93	1.00	0.94	30.00	0.93	391.4	401.4
275_3c2000Al/ST-SSWA	0.033	0.119	0.233	993	1,127	6.00	0.93	1.00	0.94	30.00	0.93	461.4	473.2
275_3c800Cu/ST-SWA	0.055	0.137	0.162	749	849	6.00	0.93	1.00	0.94	30.00	0.93	347.7	356.6
275_3c1000Cu/ST-SWA	0.050	0.132	0.174	798	905	6.00	0.93	1.00	0.94	30.00	0.93	370.6	380.1
275_3c1200Cu/ST-SWA	0.048	0.129	0.184	826	937	6.00	0.93	1.00	0.94	30.00	0.93	383.8	393.6
275_3c1400Cu/ST-SWA	0.046	0.127	0.197	851	965	6.00	0.93	1.00	0.94	30.00	0.93	395.0	405.2
275_3c1600Cu/ST-SWA	0.044	0.125	0.210	875	993	6.00	0.93	1.00	0.94	30.00	0.93	406.3	416.8
275_3c1600Cu/ST-SSWA	0.029	0.125	0.210	1,052	1,193	6.00	0.93	1.00	0.94	30.00	0.93	488.3	500.9
275_3c2000Cu/ST-SWA	0.042	0.119	0.233	917	1,040	6.00	0.93	1.00	0.94	30.00	0.93	425.9	436.8
275_3c2000Cu/ST-SSWA	0.026	0.119	0.233	1,122	1,273	6.00	0.93	1.00	0.94	30.00	0.93	521.1	534.5

It is observed that the landfall with increased burial depth or HDD established likely will constitute a thermal bottleneck if the same conductor size as for the far shore section is installed. Mitigations (aiming to prevent a larger cross section at the landfall) can be:

I. A closer calculation of the actual load current at the landfall (since it depends on the shunt reactor sizing and the length of the export cable circuits)
II. Inject bentonite in an eventual HDD duct.
III. Applying an open trench excavation at limited DoB < 2.0 m
IV. Solid determination of the thermal resistivity at the landfall