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Accelerating Smart Power & Renewable Energy
in India (ASPIRE) Programme

Grid Integration and Model Evacuation Framework for Offshore Wind Power Development

Focus State: Tamil Nadu

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Abbreviations

CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CFA	Central Finance Assistance
ckt km	Circuit kilometre
CTUIL	Central Transmission Utility India Ltd
FOWIND	First Offshore Wind in India
GEC	Green Energy Corridor
GOI	Government of India
GW	Gigawatt
GWEC	Global Wind Energy Council
InSTS	Intra State Transmission System
ISTS	Inter State Transmission System
LDC	Load Despatch Centre
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MVA	Megavolt-Amperes
NIWE	National Institute of Wind Energy
NLDC	National Load Dispatch Centre
O&M	Operations and Maintenance
OSW	Offshore Wind
OTM	Offshore Transformer Module
RE	Renewable Energy
RLDC	Regional Load Dispatch Centre
RPO	Renewable Power Obligation
SLDC	State Load Dispatch Centre
STATCOM	Static Compensator
STU	State Transmission Utility
VCS-HVDC	Voltage Source Convertor-HVDC
VGF	Viability Gap Funding

1. Introduction

1.1. Background

India pledged a target of Net Zero emissions by 2070 in COP26 and has also set an ambitious target of 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 [3]. India has an aspiration for offshore wind to play a significant role in meeting these targets, and offshore wind is poised to act as a cornerstone of energy systems internationally. Offshore wind can be deployed at a large scale with significant investment and economic benefit.

The capacity addition of Offshore Wind (OSW) plants is increasing worldwide to exploit the inherent OSW potential availability. It is supported by strong objectives set by countries to achieve their energy transition targets. The recent developments such as improved research and development activities, manufacturing of OSW components, and skilled manpower is providing thrust to cost reduction and thus OSW development in an international context. The OSW is now a matured and commercially deployable power generation technology majorly in Europe, the United States, China, etc. with an installed capacity of approximately 56 GW worldwide[4].

Ministry of New and Renewable Energy (MNRE) published a "National Offshore Wind Energy Policy" on 6th October 2015 *(hereafter referred to as "OSW Energy Policy 2015")*[5] to promote OSW projects in India. Feasibility studies have been carried out for the implementation of OSW power plants on the coastlines of Tamil Nadu in the past few years.

Based on the key inferences drawn from the studies and OSW Energy Policy 2015, MNRE published a "Strategy Paper for Establishment of Offshore Wind Energy Projects" in 2022. The Strategy Paper proposes to add a total of 37 GW of OSW generation capacity by 2030 at the coast of Gujarat and Tamil Nadu. Accordingly, the first bid for leasing out 4 GW equivalent offshore wind capacity sites in Tamil Nadu under Model 3 would commence by the end of 2022. Additionally, the Strategy Paper guides OSW plant construction, site selection, institutional mechanism for project development, and evacuation of power from the OSW plants up to the Inter-State/ Intra-State transmission network[2].

On 9th June 2022 Shri. R. K. Singh, Union Minister for Power and New & Renewable Energy held a meeting on transmission planning for Offshore Wind Energy projects in India. The GoI press notification regarding this meeting indicates the requirement of transmission and evacuation infrastructure for Offshore Wind Projects total capacity of 10 GW off the coasts of Gujarat and Tamil Nadu. This notification of GoI also directs the socialisation of the evacuation and transmission of power from the Offshore Pooling Substation to the onshore transmission for the development of OSW projects. The transmission and evacuation infrastructure would be developed as part of the overall scheme for all Offshore Wind capacities that will be bid out up to FY 2029-30[6].

1.2. Context

The UK Foreign, Commonwealth and Development Office (FCDO) has initiated the Accelerating Smart Power and Renewable Energy in India (ASPIRE) programme as part of the Forward Action Plan during the 3rd India – UK Energy Dialogue for Growth Partnership. The programme aims to support sustainable development and inclusive growth, for the mutual benefit of both countries. The programme has been divided into two projects- (i) the Smart Power (SP) project to be advanced in collaboration with the Ministry of Power (MoP) and (ii) the Renewable Energy (RE) project to be advanced in collaboration with the Ministry of New and Renewable Energy (MNRE).

Smart Power and Renewable Energy (offshore wind theme) are supporting OSW development in India. This multi-year technical assistance program will help the Indian government establish a project and commercial framework for offshore projects in India, based on the UK's expertise and incredible experience in offshore wind space. ASPIRE TA is an ongoing program (Nov.2021 onwards) under which the requirement for, this Model Evacuation Framework for Offshore Wind Power Development – Planning and Integration report is identified.

As a part of this Model Evacuation Framework the present report with a focus on Tamil Nadu is prepared. A similar study for Gujarat as the focus state has been already carried out.

1.3. Objective

The present report is prepared with the objective to guide the stakeholders involved in the planning of evacuation infrastructure and serve as a key reference document to the OSW project developers in Tamil Nadu. The report captures the need for evacuation planning and grid integration for the power generated from OSW plants in Tamil Nadu along with guidance on planning alternates for evacuation infrastructure.

This report also indicates the past transmission planning process for Tamil Nadu under GEC schemes and highlights the relevant gaps in the current process of development of transmission infrastructure for OSW projects that are required to be addressed before OSW projects are taken up for development.

This report subsequently deliberates on each of such alternates offering an assessment of the suitability of key components for evacuation for the 4 GW OSW project in Tamil Nadu and recommends its grid integration and planning measures.

1.4. Audience

The report is prepared considering the interests of various stakeholders involved in OSW development in India and it provides insights for the following key stakeholders:

- Ministry of New and Renewable Energy (MNRE)
- Ministry of Power (MoP)
- Central Electricity Authority (CEA)
- Central Electricity Regulatory Commission (CERC)
- National Institute of Wind Energy (NIWE)
- Central Transmission Utility of India (CTUIL)
- State Transmission Utilities (STU)
- National Load Despatch Centre (NLDC)
- Regional Load Despatch Centres (RLDCs)
- State Load Despatch Centres (SLDCs)
- RE Developers

2. Transmission System Planning in Tamil Nadu

2.1. Overview

Tamil Nadu has an installed generation capacity of ~35 GW comprising 15 GW thermal, 16 GW Renewables and remaining from Hydro and Nuclear energy as of March 2022 as shown in Figure 1. In the last 5 years, the State's generation capacity is increased with a CAGR of 3.5% for the period FY2017-18 to FY2021-22. The RE capacity addition is increased at a much faster pace with a CAGR of 7.6% during the same period [7].

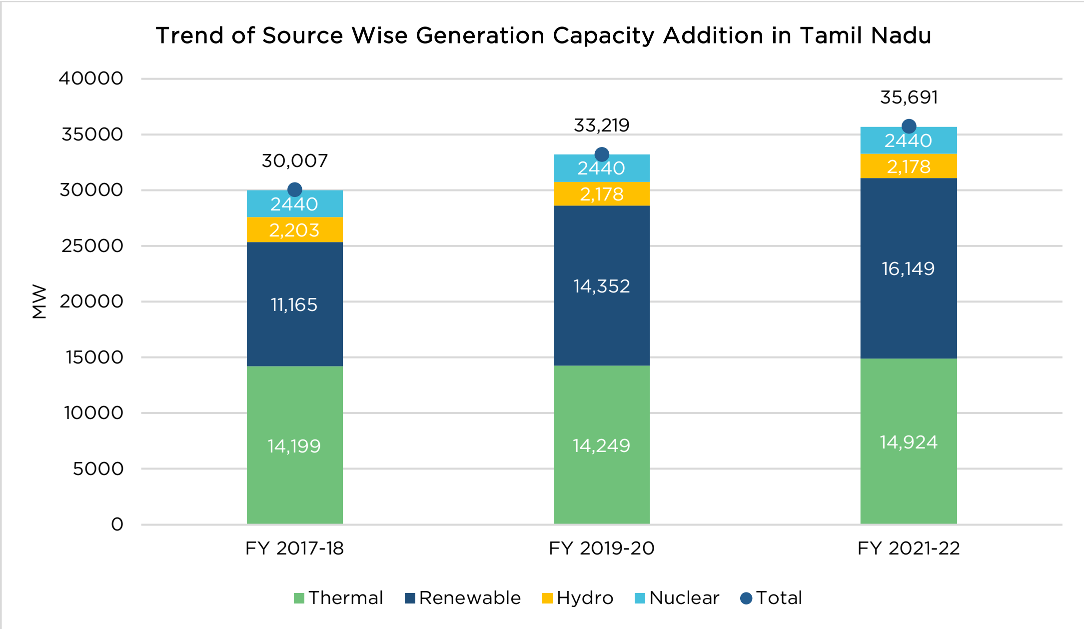


Figure 1: Source-wise Generation Capacity Addition in Tamil Nadu

At present Tamil Nadu has almost 45% of RE penetration into the Grid by wind and solar plants. Out of total RE generation in Tamil Nadu, the share of wind energy is almost 60% of the total RE portfolio of Tamil Nadu followed by solar [8] i.e., installed capacity of 9.8 GW and 5.6 GW respectively as on 31 July 2022. However, these wind capacities include only the onshore wind capacity.

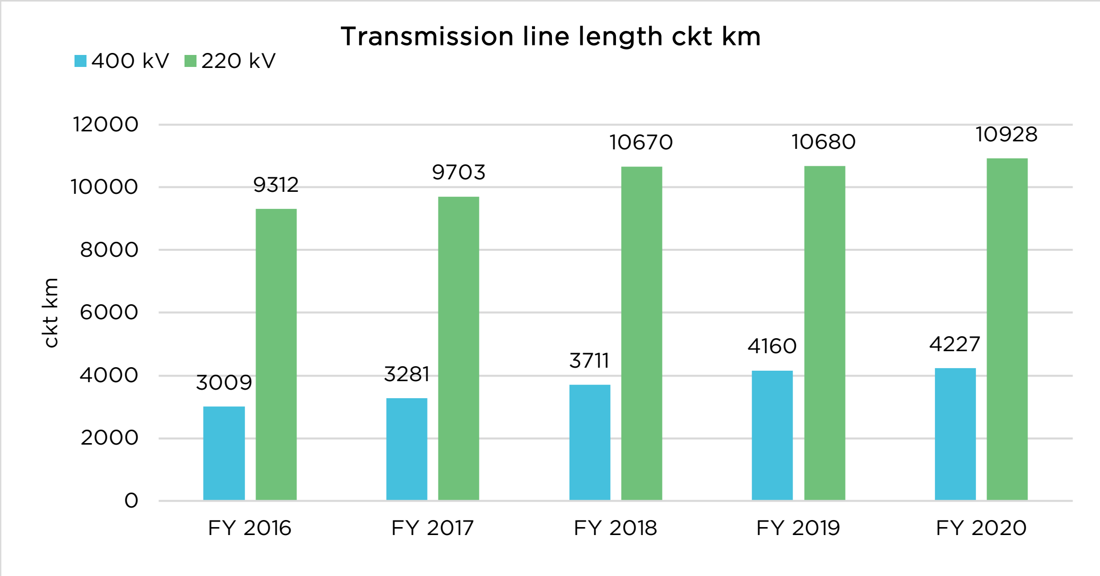


Figure 2: 200 kV and 400 kV Transmission Line in Tamil Nadu

Further, Tamil Nadu has a reliable grid infrastructure with a widespread InSTS network, and it is connected to the neighbouring states and other regions through the ISTS at 765 kV, 400 kV, HVDC, and 220 kV lines. Figure 2 shows the existing transmission network infrastructure of the state [9]. However, these transmission infrastructures were planned and constructed considering the present generation mix of Tamil Nadu which excludes power from the OSW projects.

Hence, for the development of OSW in Tamil Nadu under such a high RE penetration into the grid, the development of transmission and grid infrastructure should be taken well in advance for the smooth evacuation of power to the load centres. Further, the relevant schemes for RE transmission planning should be assessed to identify its applicability to the proposed 4 GW OSW project in Tamil Nadu.

2.2. Relevant schemes and studies for Tamil Nadu

RE capacity addition has its various challenges of power evacuation, grid integration, and maintaining grid safety and reliability. To synchronise increasing RE capacity with the grid, GoI introduced the Green Energy Corridor schemes. In the context of OSW development, grid integration is an important aspect that was studied in past by FOWIND. The recent Strategy Paper by MNRE also covers certain provisions regarding power evacuation from the OSW plant. As such it is pertinent to comprehend the knowledge base to develop the model evacuation framework for upcoming OSW projects in Tamil Nadu. Key features from the schemes and studies in past are summarised in the section below:

2.2.1 Green Energy Corridor (GEC) scheme for RE Transmission planning

Green Energy Corridor Phase-I

Green Energy Corridor Project aims at synchronizing electricity produced from renewable sources, such as solar and wind, with conventional power stations in the grid. Green Energy Corridor is a comprehensive scheme for the evacuation & integration of the renewable energy capacity addition of 32,713 MW during the 12th Plan Period. The first phase of the project was launched in the year FY 2015-16 with a budget of ~Rs. 10,000 Crores and is estimated to be completed by the year 2022 [11].

In the Green Energy Corridor study for Tamil Nadu, load flow has been carried out for two scenarios i.e., high wind/solar with low demand as well as low wind/solar with high demand. In the scenarios, the additional requirement of transmission system capacity arising out of RE injection has been assessed. Further, sensitivity analysis of the identified transmission system strengthening has been also carried out separately.

Renewable Purchase Obligation (RPO) is mandatory for all distribution licensees and bulk power consumers in India. It was observed that by 2016 -17, the RE capacity required to meet the projected RPO target of RPO obligated entities (i.e., Distribution Licensees and Bulk Power consumers) in Tamil Nadu will be ~4,700 MW whereas the maximum generation capacity of RE plants will be ~11,000 MW in off-peak hours. Considering the RE capacity available in Tamil Nadu versus the RE capacity required to meet the RPO, Tamil Nadu will have a 6,300 MW surplus RE capacity. This surplus RE capacity could be utilized to meet the RPO requirement of other RE deficit states. Hence for evacuation of the surplus RE power from Tamil Nadu, various ISTS and InSTS schemes were proposed for network strengthening as shown in Table 1.

Table 1: System Strengthening Schemes identified for Tamil Nadu in GEC Phase I

Requirement	Scheme
Inter-State strengthening requirements	• 765 kV transmission line: 60 ckt km • 400 kV transmission line: 370 ckt km • HVDC transmission line: 800 ckt km • New HVDC substation: 1 Nos. • HVDC Terminal capacity: 2,500 MW
System Strengthening within the state for the conveyance of ISTS transfer	• 400 kV transmission line: 1,180 ckt km • 230 kV transmission line: 1,500 ckt km • New 400/230-110 kV substation: 5 Nos. • 400/230kV Transformation capacity: 3,780 MVA • 400/110kV Transformation capacity: 2,200 MVA • New 230/110kV substation: 4 Nos. • 230/110kV Transformation capacity: 2,650 MVA
Intra State Transmission Schemes	• 400kV transmission line: 1500 ckt km • 230kV transmission line: 91 ckt km • 110kV transmission line: 45 ckt km • New 400/230kV substation: 2 Nos. • New 230/110kV substation: 1 No. • 400/230kV Transformation capacity : 1775 MVA • 230/110kV Transformation capacity : 300 MVA

For system strengthening schemes and network development in Tamil Nadu, identified capital cost requirement is as below:

- Estimated cost of transmission system connectivity for RE Plants (Intra State) in Tamil Nadu: INR 2,604 Crores
- Estimated cost of connectivity to ISTS: INR 247 Crores
- Estimated cost of Dynamic reactive compensation for Tamil Nadu: INR 173 Crores
- Estimated cost of real-time dynamic state measurement scheme: INR 83 Crores

Green Energy Corridor Phase-II

GEC Phase II scheme[12] is proposed for Intra-State Transmission System to provide an additional transmission line with a transformation capacity of 27,500 Megavolt-Amperes (MVA) of the substations in RE-rich states. Key provisions in the GEC Phase II scheme for Tamil Nadu are covered in Table 2.

Table 2: GEC Phase II scheme for Tamil Nadu

Tamil Nadu specific provisions	Length of transmission lines: 624 km The capacity of substations: 2,200 MVA RE Addition envisages: 4,000 MW Project Cost without IDC: INR 719.76 Crores Central Finance Assistance: INR 237.52 Crores
Tamil Nadu Specific transmission schemes	Under the GEC Phase II, 31 transmission schemes were proposed for Tamil Nadu. However, it is observed that in Tamil Nadu the Onshore and OSW sites are very near to each other. Therefore, a scheme under GEC for Tamil Nadu may be advantageous for OSW power evacuation. Transmission infrastructures development plans near OSW Zone A, B, C & D identified in Tamil Nadu are as below: • 1,400 MVA, 400/230/110 kV Samugarengapuram substation • 230/110 kV Muppandal Substation • 400 kV DC quad line on DC Towers from Udangudi switchyard to 400 kV Samugarengapuram substation – 40 km • 230 kV DC line from 230 kV S.R. Pudur and Muppandal substation to Samugarengapuram substation – 120 km etc. However, utilization of the above infrastructure for OSW is subject to spare corridor availability post allocation for the present generation.
Applicability of existing onshore SS on the OSW evacuation	• Mupandal SS as proposed under the GEC phase –II is a 230/110 kV SS near the OSW subzones. However, it should be upgraded to 400/220 kV for the OSW evacuation. • Considering the OSW evacuation at 220 kV, the Samurangapuram SS could be analysed for OSW evacuation. • This SS is anticipated to be commissioned by FY 2025 and has a capacity of 1,400 MVA, at 400/230/110 kV.

- The Maximum and Minimum distance of these two SS from each of the subzones as proposed under the MNRE Strategy Paper has been reviewed and tabulated in Annexure 1.
- 3 sites for Onshore pooling have been identified considering the subzones. These are Ganpathipuram, Kanyakumari, and Kodankoolam as shown in Figure 3. These Onshore pooling SS sites are solely for transmission planning. The actual site for Onshore pooling SS would be detailed by CTU in consultation with CEA.
- Further, the approximate distance of the onshore pooling site from these two substations has also been analysed.
- It was observed that connecting all the pooling SS to a single grid SS may increase the cost considering the higher overall distance between the two.
- Therefore, some pooling SS may be connected to Mupandal upon upgrading it to 220 kV and some are connected to Samurangapuram.
- Further, it is also observed that G1 should have separate OSW pooling S/S near Ganpathipuram. Further B1 & B4 and B2 & B3 should be clubbed together to connect at Onshore pooling SS at the coast of Kanyakumari and Kodankoolam respectively.

Figure 3: Subzone-wise distance from Coast (km)

Further, CTUIL is in process of transmission planning for the OSW projects in Tamil Nadu. In the 9th Consultation Meeting for Evolving Transmission Scheme in the Southern Region held on 29th July 2022 [13], CTUIL informed that GoI has set a target of 500 GW generation capacity from non-fossil fuel resources by 2030. In this direction, MNRE has identified an addition of 181.5 GW RE Potential in the States of Andhra Pradesh, Telangana, Karnataka, Rajasthan, Madhya Pradesh, and Tamil Nadu (Offshore). Out of the identified 181.5 GW RE Potential, 86 GW RE Potential is identified in the states of Andhra Pradesh, Telangana, Karnataka, and Tamil Nadu (Offshore) in the Southern Region. The transmission system for integration of 181.5 GW RE Potential is under the advanced stage of identification by CEA in coordination with CTU.

2.2.2 FOWIND Grid Integration Study for OSW Transmission Planning

In 2017, FOWIND Grid Integration Study for Gujarat and Tamil Nadu had been conducted by Global Wind Energy Council (GWEC) [14] to *facilitate* the progress of OSW in the country. It is herein referred to as *the FOWIND Grid Report*. In the present study, 'the readiness' of the existing transmission system to supplement the grid integration of OSW has been assessed.

In the study, 8 zones on the coast of Tamil Nadu were identified for OSW development [15]. It was observed that OSW potential sites in Tamil Nadu are near the present onshore wind potential sites as shown in Figure 4. It could possible that wind power (onshore and offshore) in the southern part of Tamil Nadu can be pooled together in a dedicated renewable pooling substation and serve the load centres in northern parts of the State. The surplus renewable capacity may be evacuated to neighbouring states through the projects commissioned under GEC as discussed in Table 2.

Further, in the FOWIND Grid Integration Study, a load flow analysis was performed for the evacuation of 500 MW OSW capacity considering the near areas of Manapad, Punnakayal, and Tuticorin. TANGEDCO suggested connectivity at 400 kV at the Samugarengapuram substation (planned to be commissioned by FY 2019, however, as per construction status available on the CEA website, it is now anticipated to be commissioned by FY 2025)[16], as it could be a suitable location for the evacuation of 500 MW OSW power. During the load flow study, it was found that the existing transmission infrastructure is capable of the evacuation of 500 MW OSW generation from the Samugarengapuram substation. However, if any other onshore wind projects (with a short gestation period) are approved for interconnection at this substation before 2021-22, then it could potentially limit the ability of the substation to accept a large-scale offshore wind project.

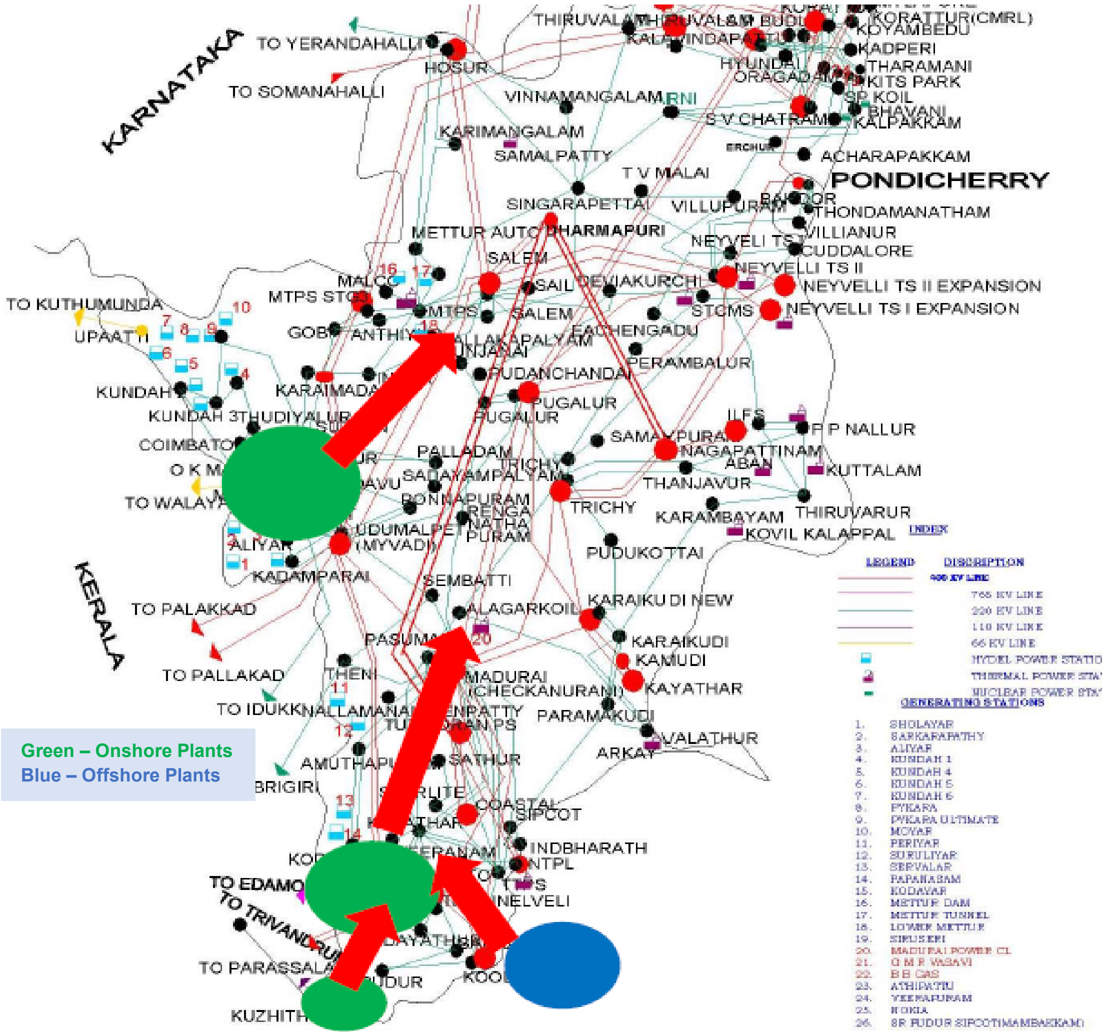
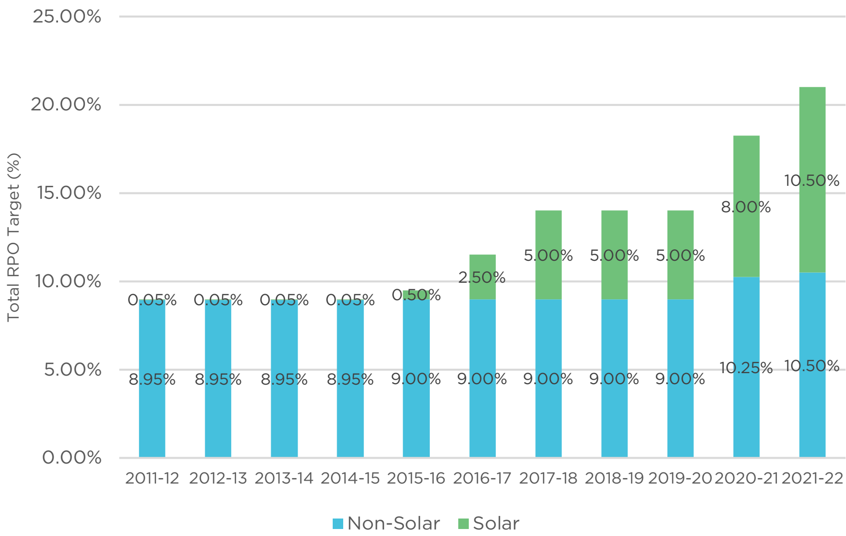


Figure 4: Potential Onshore and Offshore Wind Sites in Tamil Nadu

2.3. Power System Operating Challenges

From the background study summarised in the above section, it is observed that Tamil Nadu has a surplus of RE generation capacity. The percentage of RE in the grid is increased from 37% to 45%. Due to high RE penetration, operational issues are observed in the transmission system which is summarised below:

Table 3: Power System Operating challenges in Tamil Nadu

Issues	Key observations
Surplus RE Capacity Availability	• Present RE generation in Tamil Nadu is ~45 % w.r.t. overall generation capacity of the State including solar and non-solar. • In the last 10 years, RPO targets are increased significantly in Tamil Nadu. In FY 2011-12 Tamil Nadu's total RPO target was 9% (including both solar and non-solar), which increased to 21% in FY 2021-22 as shown in Figure 5.  **Figure 5: RPO Target for Tamil Nadu from FY 12 to FY 22** • Tamil Nadu is a RE Surplus State with 24% of excess RE generation compared to the RPO target. • The GEC schemes were introduced with the objective that surplus RE can be utilised to meet RPO targets by neighbouring states. The development of a transmission network to evacuate a large amount of RE is necessary for Tamil Nadu. • Further, the revised RPO targets from FY 2022-23 to FY 2029-30 [17] published by MoP separately focus on the wind generation from the plants installed after 31st March 2022 which needs strengthening of the ISTS network for the evacuation of surplus power to other states for meeting their RPO compliance.
System Balancing	• Around 2/3rd of the RE portfolio of Tamil Nadu is captured by the wind plants. • During the monsoon season which is a low-demand period, Tamil Nadu receives high wind. However, during this time hydro generation is also available at full capacity. Therefore, most of the demand is met by hydro, wind, and nuclear plants but a sudden variability of wind generation in this situation poses significant system balancing issues.
RE Curtailment	• During the summer season, hydro generating stations are halted, as water is being used for irrigation purposes. Therefore, most of the demand is met by thermal and wind generators.

Issues	Key observations
	• Due to various technical and commercial issues of thermal plants, the Load Despatch Centre (LDC) is not able to reduce the power generation from thermal generators which leads to wind curtailments. • To overcome the issue of RE curtailment, Tamil Nadu Electricity Regulatory Commission (TNERC) notified Forecasting, Scheduling and Deviation Settlement mechanism Regulations, 2019 [18] with the following objectives: 1. To facilitate Grid integration of Wind and Solar energy generated in Tamil Nadu while maintaining Grid stability and security as envisaged under the State Grid Code and the Act, through forecasting, scheduling, and a mechanism for the settlement of deviations by such Generators. 2. The SLDC shall make use of the flexibility provided by conventional Generating Units and the capacity of inter-Grid tie-lines to accommodate Wind and Solar energy generation to the largest extent possible subject to Grid security. • These regulations help reduce errors in forecasting and scheduling with the use of advanced tools and techniques. These eventually help RE generators and SLDC to maintain grid balancing and ensure the must-run status of RE plants.

2.4. International Best Practices to Mitigate Challenges

Issues	Remedies
Surplus RE Capacity Availability	• In the surplus RE condition, multiple technologies could be used to support the flexibility of OSW output. • Some of these solutions include battery storage, compressed air, etc. However, the feasibility of each technology would vary with scale and will have various regulatory, technical, and commercial challenges.
System Balancing	In the UK the National Grid electricity system operator (NGESO) manages system balancing and offers several services to do this, summarised below: • Balancing mechanism: It is the ESO's primary tool to balance supply and demand on UK's network on a second-by-second basis, to balance supply and demand in real-time. • Dynamic containment: It is designed to operate post-fault, i.e., after a significant frequency deviation to meet the most immediate need for faster-acting frequency response. • Fast Reserve: It provides rapid and reliable delivery of active power through the increasing output from a generation or reducing consumption from the demand sources. • Short-term operating reserve (STOR): Delivers extra power to manage actual demand of the system being greater than forecasted demand or unforeseen generation unavailability.

Issues	Remedies
	• **Obligatory reactive power service (ORPS):** At any given output, generators may be requested to produce or absorb reactive power to help manage system voltages close to its point of connection.
RE curtailment	• Long-term storage in the form of batteries of compressed air, etc, could be used to reduce RE curtailment.

3. Model Evacuation Framework for Offshore Wind – Tamil Nadu

3.1. Features of MNRE OSW Strategy Paper, 2022

MNRE published the Strategy Paper for the establishment of Offshore Wind Energy Projects in India in July 2022. Based on a multi-criteria approach involving the assessment of various parameters such as wind resource, bathymetry, etc., eight zones each off the coast of Gujarat and Tamil Nadu were identified as potential offshore wind energy zones. The potential 8 zones identified in Tamil Nadu are shown in Figure 6.

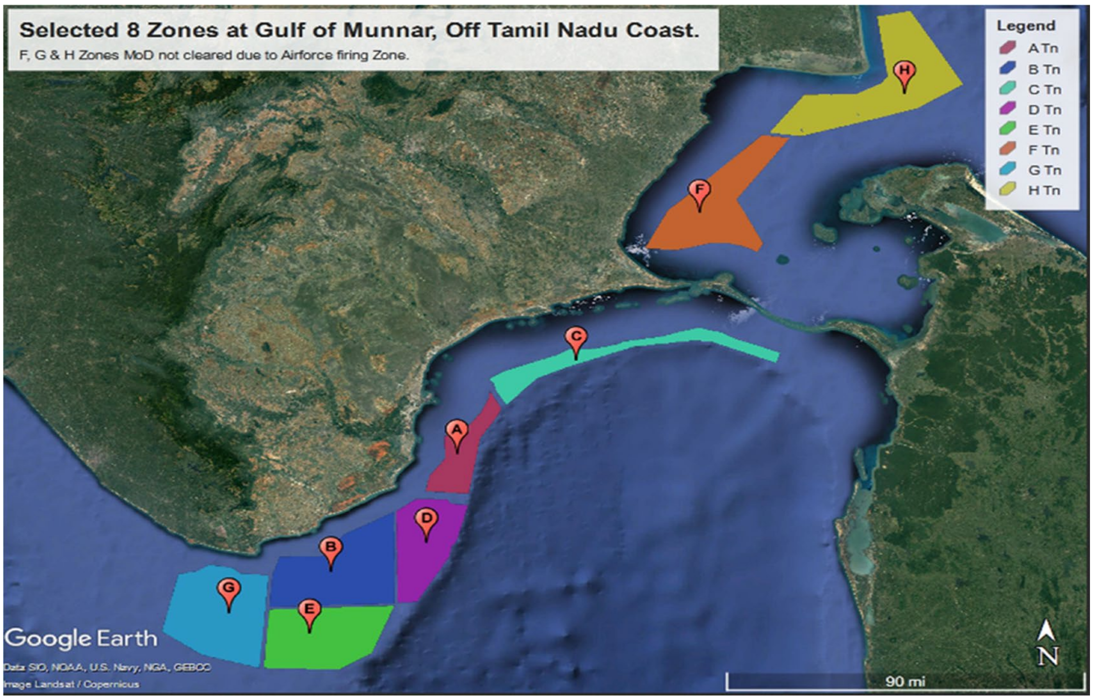


Figure 6: Demarcated Offshore wind site for Tamil Nadu

The present strategy paper is focused on the development of 37 GW OSW across Gujarat and Tamil Nadu coastal lines by 2030 with overall phase-wise planning for OSW development. To fast-track the process for OSW development, 3 models are proposed in the strategy paper as summarised in the table below:

Table 4: Salient features of models proposed under MNRE Strategy Paper

Model 1	Model 2	Model 3
1. Applicable for demarcated offshore wind zones for which MNRE/NIWE has carried out detailed studies/surveys. 2. Zone B3 (365 Sq.km) off the coast of Gujarat shall be considered in phase 1 of this model. 3. Viability Gap Funding (VGF) will be available under this model.	1. Applicable for offshore wind sites identified by NIWE for which detailed studies/surveys have not been carried out. 2. Developers need to select a wind site within the identified zone and carry out required studies/surveys with the approval of MNRE. 3. There are two types in this model: ➢ Model 2(A) with VGF ➢ Model 2(B) Without VGF where power sale can be under open access / open door mode	1. NIWE shall identify from time-to-time large offshore wind zones within the Exclusive Economic Zones (EEZ) but not covered either under Model 1 or Model 2. 2. Zones would be allocated for a fixed period on a lease basis through single-stage two envelope bidding. 3. The generated power shall be either used for captive consumption under open access mechanism or sold to any entity through a bilateral power purchase agreement or sold through Power Exchanges.

Key features of the strategy paper from the perspective of evacuation planning for OSW projects in Tamil Nadu are listed below:

- The project will be allocated under three business models, Model 1, Model 2 (A & B), and Model 3.
- NIWE has carried out the study for the 365 Sq.km seabed area of Zone B3 (1 GW), Gulf of Khambhat, off the coast of Gujarat. Model-1 has been proposed for this B3 zone, while the first tender for leasing offshore wind energy blocks equivalent to 4 GW capacity off the coast of Tamil Nadu is planned to be published by the end of 2022. This proposed 4 GW of OSW in Tamil Nadu would be developed under Model 3.
- Under Model 3, the allocation of the seabed shall be through bidding carried out under a single stage two envelope model for a total of 12 GW bidding wherein the bidder will be shortlisted based on their technical and commercial capability.
- For the shortlisted bidder's evacuation and transmission of power from offshore pooling substations (PSS) to onshore transmission will be provided free of cost for all offshore wind projects that will be auctioned up to FY 2029-30.
- The bidding for this initial 4 GW OSW project which is to be developed in Tamil Nadu will commence tentatively by December 2022.

- The potential sites for the proposed OSW plant in Tamil Nadu are shown in Table 4 below. As VGF will not be applicable under model 3, high windy sites with the potential capacity of ~ 8.1 to 10.8 GW are proposed for rationalisation of the Levelized Cost of Electricity (LCoE).

- Accordingly, 10 sites are proposed which are in zone B, E, and G in the southern part of the Tamil Nadu coast.

Table 5: Offshore Wind Potential Subzones in Tamil Nadu under Model 3

Potential	Sub-zone ID / State	Sea-bed area (sq. km)	Indicative Mean Wind Speed range @ 150 m height	Indicative water depth (m) range (as per GEBCO	Estimated Offshore Wind Potential (MW)			Min & Max Distance From Each Phase/Zone to Shore (km)
					Potential @ 4.5 MW/ Sq.km	Potential @ 5 MW/ Sq.km	Potential @ 6 MW/ Sq.km	
3.9 – 5.2 GW (Phase-I)	B1 -TN	203	10-11 m/s	20 – 40m	912	1013	1216	10 & 39
	B2-TN	184			828	920	1104	
	B3-TN	157			705	783	939	
	B4 -TN	180		20 – 50m	809	899	1079	
	G1-TN	146			655	728	873	
4.2 – 5.6 GW (Phase-II)	G2-TN	123	10-11 m/s	20 – 50m	555	617	740	10 & 39
	G3_TN	195			878	975	1171	
	B6 -TN	252	9-10 m/s	20 - 35m	1132	1258	1510	20 & 44
	B5-TN	269		30 - 50m	1209	1343	1612	40 & 60
	E1-TN	107			482	536	643	

During phase I, capacity addition of 3.9 to 5.2 GW will take place under subzones B1, B2, B3, B4 & G1. Planning for transmission system development for evacuation of power generation from OSW plants proposed in Tamil Nadu is discussed in the next section.

3.2. OSW Power Evacuation Planning Approach

Power evacuation facility is one of the important aspects of OSW development and proper planning for the development of grid infrastructure for OSW power evacuation is a critical task. Planning for Grid evacuation is based on project capacity, site, and the ideal arrangement of the offshore pooling substation.

For Tamil Nadu, the assumption is that the 1st bid will be for ~4 GW OSW under model 3 in Sub zone B1, B2, B3, B4, and G1. These subzones are shown in Figure 7 below (circled in green):

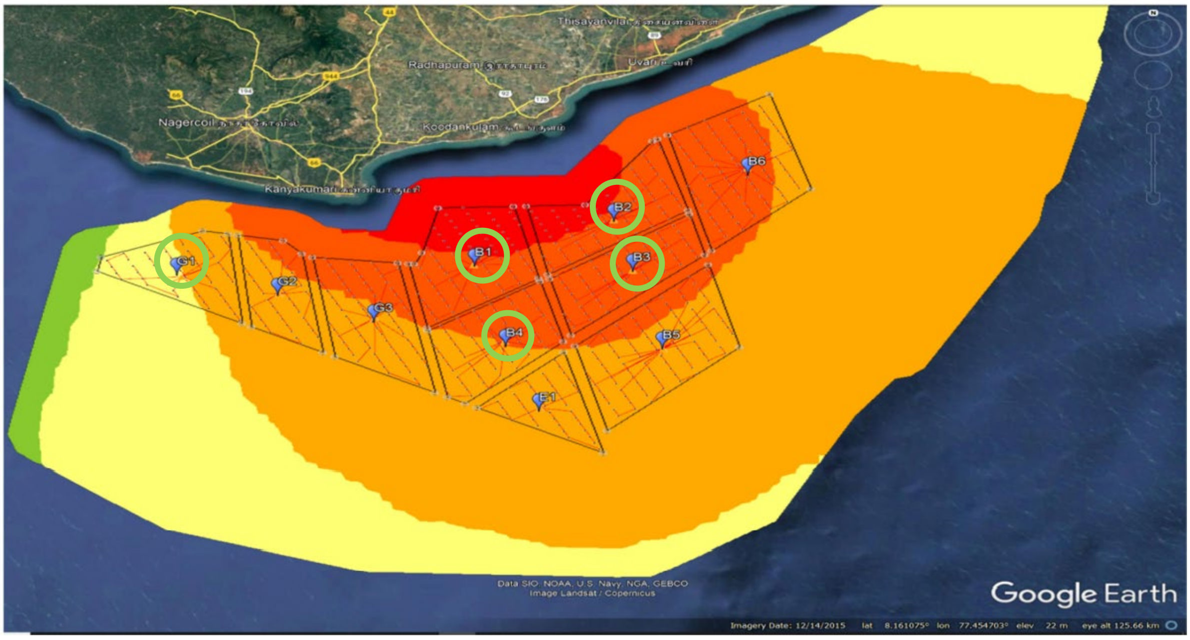


Figure 7: Proposed Block for Phase 1 as per MNRE Strategy Paper

As there are 4 different subzones, there could be multiple options for transmission system planning. Some important questions which need to be answered while preparing transmission system plans are as below:

1. How the bidding for 5 subzones will take place?
2. Is it possible that all the subzones are allotted to one bidder/ developer?
3. Is it possible to combine some sub-zones while preparing the transmission system plan?

There could be multiple alternatives for the development of a transmission system from the OSW plant up to the grid interconnection point. Further, the following guiding principles can be useful to analyse various alternatives for the planning of evacuation infrastructure:

1. OSW potential in each subzone and its distance from the coast
2. International Experience

OSW potential in each subzone and its distance from the coast

Available zone size will be a guiding factor for alternative development. OSW plants can be independently developed in each subzone, or they can be integrated as a combined capacity. This factor also largely depends on the bidding procedure and allotment of OSW capacity to developers.

For discussion on alternates, zones B1, B2, B3, B4, & G1 are taken into consideration for Phase 1. For each zone, there are 3 choices with varying wind potential estimates of 4.5, 5, and 6 MW/ Sq. km. For developing the alternatives, the estimated offshore wind potential capacity is taken at 5 MW/ Sq. km. Accordingly, the estimated capacity for each subzone is presented below:

Table 6: Sub zone-wise OSW Potential taken for alternative design

Sub Zone	OSW Potential (MW) @ 5 MW/ Sq. km
B1	1013
B2	920
B3	783
B4	899
G1	728

The subzones B1, B2, B3, and B4 are geographically contiguous, while subzone G1 is located at the southernmost tip and hence, it shall have separate treatment for developing a transmission system plan. The overall rating for B1, B2, B3 & B4 is approx. 3,615 MW at 5 MW/ sq km potential. Considering international experience, the planning of evacuation infrastructure can be suitable if the subzones B1, B2, B3 & B4 are clubbed together.

International Experience

Relevant case studies and learning in the Indian context are summarised in the following section, based on the study carried out by an international agency on learnings from the European OSW projects for India under ASPIRE Programme[19].

Case 1: Borssele Wind Farm

The Borssele offshore wind farm zone is in the Netherlands. The Borssele connection implements a multiconnection HVAC link, in which a centralised approach has been adopted. The transmission system operator TenneT is responsible for constructing the offshore substations and export cable which connects the four wind farm sites having a total combined capacity of 1.4 GW to the onshore Substation. The four wind sites Borssele I& II and Borssele III & IV are clubbed together with 2 substations with a capacity of 700 MW each as shown in Figure 8.

The present case study is relevant to the Indian market considering the proposed wind farm zones of 4 GW capacity in Tamil Nadu are of large capacities and close to each other and could use the multiconnection HVAC link. Further, the CTUIL is responsible for the power evacuation from the OSW plants as specified in the MNRE Strategy Paper.

Figure 8: Schematic of Borssele Wind Farms

Technical details of Borssele I, II, III, and IV are shown in the table below:

Table 7: Borssele Wind Farms-details

Features	Borssele I&II	Borssele III & IV
Status	Operational	Operational
Wind farm capacity	752 MW	731 MW
Wind Turbines	94 x 8 MW	77 x 9.5 MW
Distance from the coast	22 km	31 km
Inter-array cables	180 km of 65 kV	175 km of 66 kV
Offshore export cables	2 x 62.5 km of 220 kV	
Number of offshore substations	1	1

In the Case Study carried out by the International Agency, it is mentioned that,

"The Borssele multi-connection HVAC approach provides learnings for India for configurations to connect multiple wind farms to a central offshore substation, allowing a single connection to shore. These findings will be relevant to India in its long-term system planning for offshore wind and deciding to configure the offshore transmission system to be decentralised, similar to the UK, or centralised similar to Germany and The Netherlands."

Case 2: Beatrice Offshore Wind Farm

OSW projects smaller in scale or closer to shore offer the opportunity to utilise the lower-cost infrastructure. For example, smaller wind farms with short offshore export distances may be able to export power via medium-voltage cables direct to the onshore grid, without requiring an OSW Substation platform and high voltage cabling; this would likely be a less costly alternative, however, the increased cable installation costs and electrical losses would render such an option unfeasible for a large project.

From a Case study carried out by the International Agency, it is understood that,

"The Beatrice offshore wind farm in Scotland with HVAC connection uses Offshore Transformer Modules (OTMs) instead of an offshore substation. It is expected to provide a cost-saving of up to 40% compared to conventional substation solutions. It is located 13.5 km from the Caithness coastline in Northern Scotland and has a 588 MW capacity. Further, these Offshore transformer modules from Siemens are one-third smaller in size and weight compared to a conventional alternating-current (AC) platform........

In light of the choice to use Offshore Transformer Modules (OTMs) rather than the traditional offshore substation architecture to reduce the footprint and cost of the offshore substation, the Beatrice-UK Project offers crucial lessons for India.

Offshore Transformer Modules (OTMs) are used for the HVAC connection rather than traditional offshore substations. When compared to traditional substation systems, the OTM idea could result in cost savings of up to 40%. By using OTMs rather than traditional offshore substations, the Beatrice-UK project was able to reduce the cost of the offshore substation by saving on material and installation costs."

Details of OTMs designed by Siemens for Beatrice Wind Farm:

For the Beatrice wind farm, Siemens offered two units of its modular OTM concept[20], which saves space, weight, and cost. The technical specifications for the three transformer units were to deliver 310 MVA units for the 220-kV level in heavy-duty design with ONAN (oil natural/air-natural) cooling. To withstand the harsh environmental conditions, offshore design and an earthing transformer were mandatory. Synthetic ester was chosen as an insulation fluid to protect the sea from potential pollution in the unlikely case of oil spillage. In close collaboration between different Siemens units and the customer, a state-of-the-art offshore transformer module was designed. It contains an ultra-compact offshore transformer with a built-in earthing transformer and extremely low maintenance demand.

The minimum distance to the existing onshore Substation from the OSW potential zones in India is ~ 10 km for subzones G1, B1, and B2 in Tamil Nadu, which may use the option of exporting power via medium-voltage cables direct to the Onshore Grid Substation. However, based on distance from shore HVAC and HVDC substation options could be analysed along with a cost-benefit analysis.

3.3. Alternatives for Grid Evacuation Planning & Operation of OSW Plants in Tamil Nadu

The grid evacuation planning is dependent on project capacity, site, and optimal configuration of the offshore pooling substation. Further while grid evacuation planning, it is important to consider the overall system from wind turbines up to the grid interconnection point. OSW Pooling Substation is the critical interconnection point from where the evacuation restrictions need to be considered for smooth and reliable operation.

According to the proposed transmission network development by MNRE in Strategy Paper, the overall transmission grid is divided into 4 sections defined as Block A, B, C & D namely.

1. Block A: Offshore Generation blocks and the Array Cables to the Offshore Pooling Substation
2. Block B: Offshore Pooling Substation
3. Block C: Subsea Cables from the Offshore Pooling Substation to the Onshore Pooling Substation
4. Block D: Onshore Pooling Substation and the connection to the grid

The schematic in Figure 9 below depicts the OSW grid evacuation network with blocks A, B, C & D from OSW Generators up to the grid interconnection point.

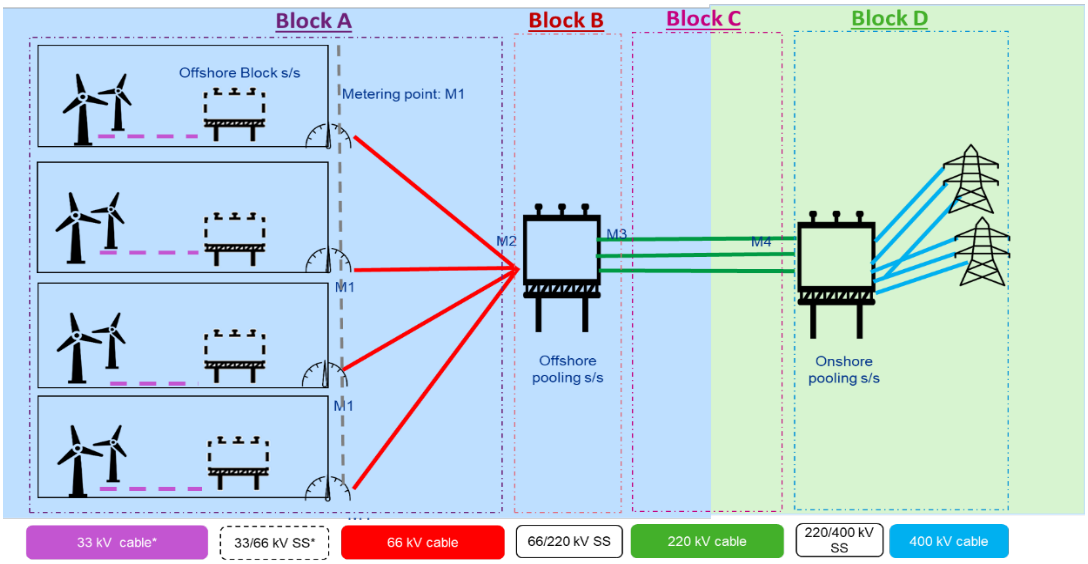


Figure 9: Schematic of OSW evacuation network

Generally, the OSW turbines are of a 7-8 MW capacity which generates power at 33 kV voltage and is further stepped up to 66 kV using the offshore block substation. Through 66 kV export cables, power is then evacuated to the OSW pooling substation. Moreover, as a general practice followed for OSW power evacuation, the power from the OSW pooling substation is evacuated at 220 kV level to the onshore substation through subsea cables. And further transmitted to the grid at 400 kV through OH/underground cables.

In the recent trend, the OSW projects across the world listed in Annexure 2 are commissioned with array voltage directly at 66 kV level.

As such, the Inter array cable 33 kV (shown in "Violet" colour) and the offshore block substation (33/66 kV) have a "dotted" representation in Figure 9. To gain the cost advantage, these 33 kV installations under developer scope, can be avoided for the higher capacity wind turbines capable of generating power up to 66 kV level or at an appropriate voltage depending upon the technological maturity as shown in Figure *10* below.

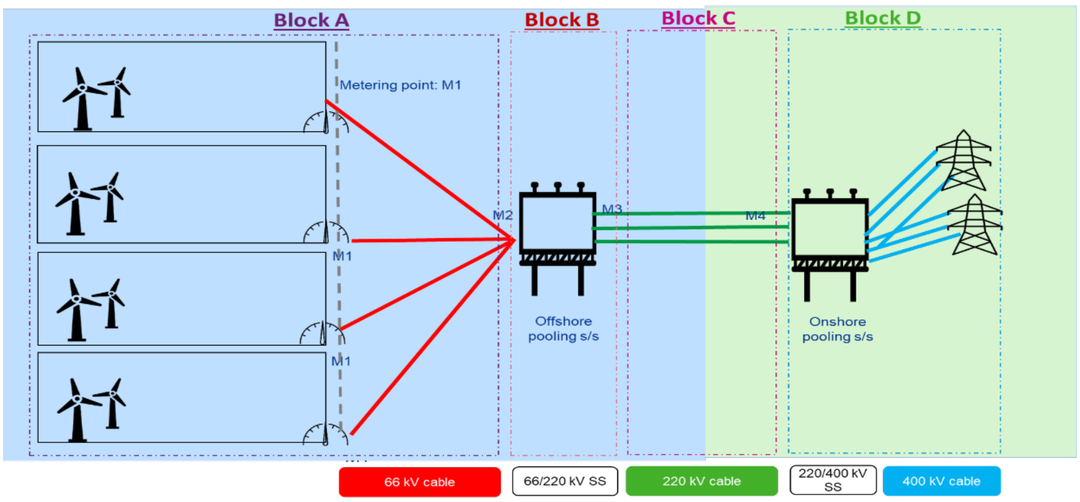
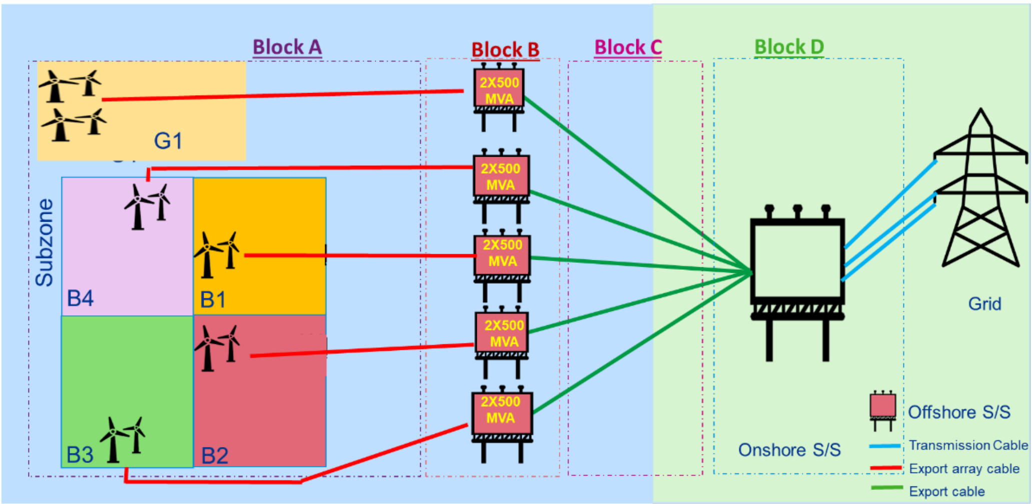


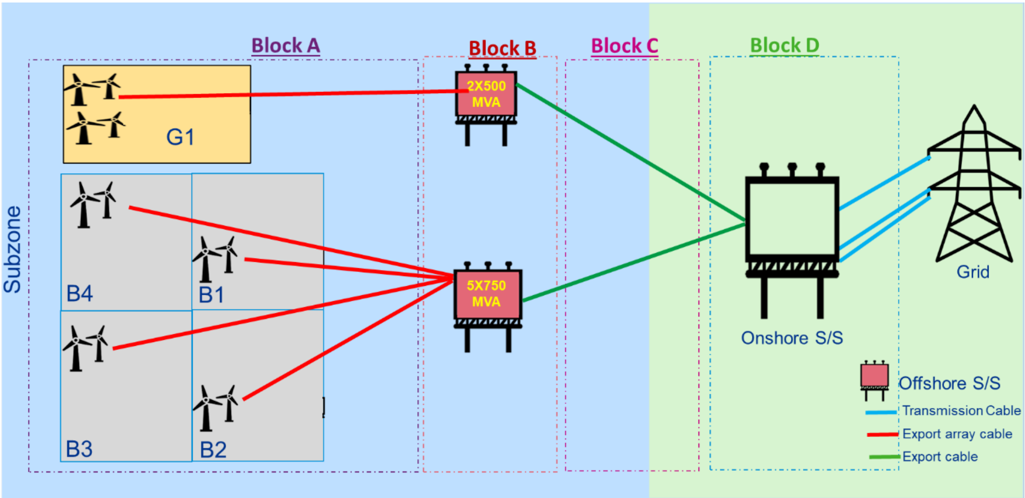
Figure 10: Schematic of OSW evacuation network considering technological maturity

In the case of Tamil Nadu 4 GW OSW development, there could be different configurations to develop the alternatives[1]. Wind turbine capacity in block A and OSW Pooling Substation can be configured with alternates to devise the installation, cost, and operational flexibility. The alternate configured are examined in the current section based on the electrical rating of the offshore substation and the scope division between the developer and the transmission utility to provide a thorough study of cost against operating reliability aspects as below:

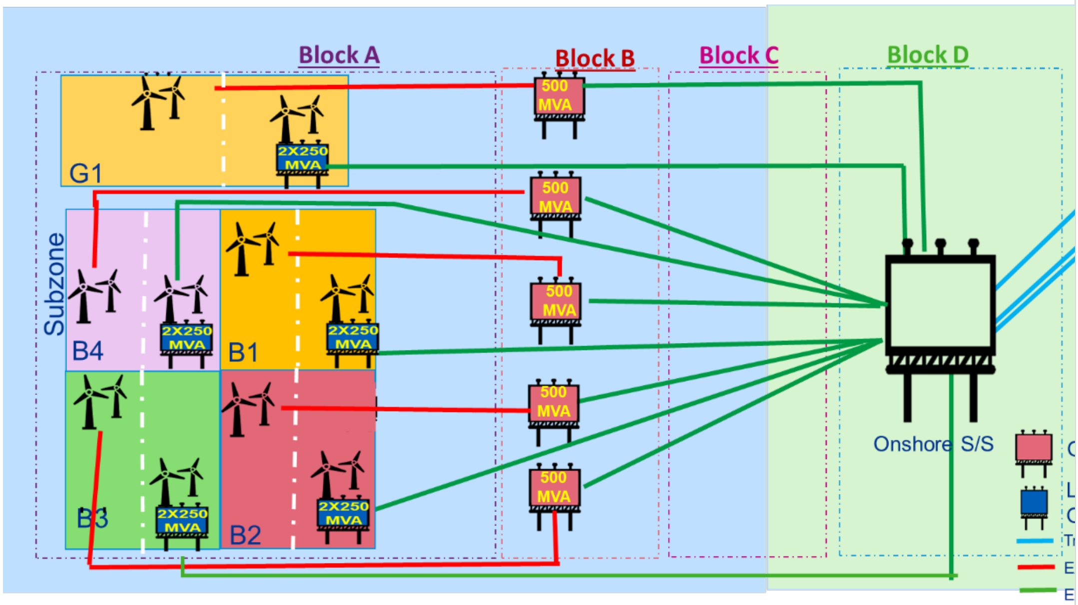
Table 8: Description of alternatives for Tamil Nadu OSW Power Evacuation

Particular	Configuration of OSW pooling substation	Applicability for subzones
Alternative 1	Offshore Pooling substation of 2 x 500 MW with 2 no. 220 kV Pooling substations each evacuating ~ 500 MW	Applicable to Subzone B1, B2, B3, B4, and G1, in which power from each subzone will be evacuated through a 2 X 500 MW Offshore Substation dedicated for each Subzone.
		
Alternative 2	Offshore Pooling substation of 5 x 750 MW with 5 no. 220 kV Pooling substation each evacuating ~ 750 MW	Applicable to subzones B1, B2, B3, and B4 for aggregate capacity greater than 3.6 GW which is to be developed together. The rating of each substation can be standardized based on the available transformer capacity selected. Further, subzone G1 can be treated as separate and developed as suggested in Alternative 1.

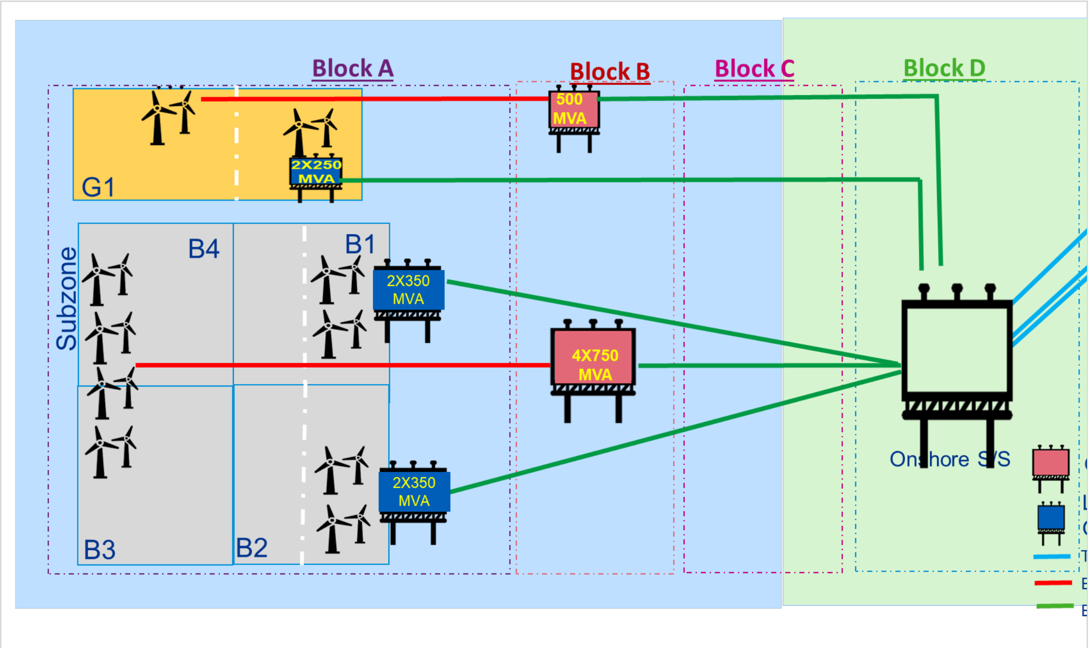
[1]Note: There could be multiple other alternate configurations for evacuation framework that can be firmed up upon stakeholder consultation, site conditions, and in compliance with the extant regulatory framework



Alternative 3	Offshore Pooling substation 1X500 MW and Offshore transformer module of 2X250 MW for each zone.	Applicable to Subzones B1, B2, B3, B4 & G1 individually. In this alternative, OSW generation can be evacuated via Offshore Pooling Substation & Lightweight Offshore Substation like Offshore Transformer Module (OTM). Lightweight offshore substations are suitable for evacuation of power from WTGs less than 20 km from the coast. Accordingly, based on the array design and location of WTGs in the subzone, Lightweight offshore substations can be used for power evacuation for the capacity of OSW which will be generated from WTGs less than 20 km distance from the coastline.



Alternative 4	Offshore Pooling substation of 3 x 750 MW and Offshore transformer module of 4 x 350 MW.	Applicable to subzones B1, B2, B3, and B4 which can be combined and G1 will be treated separately. In this alternative partial generation for zone B1, B2, B3, and B4 can be evacuated via the Lightweight offshore substations like OTM subject to its distance of fewer than 20 km, and the remaining generation capacity can be evacuated through an offshore pooling station. Generally, the OTM capacities are in the range of ~250-350 MVA. Further, subzone G1 is at distance from subzones B1, B2, B3 & B4 and hence power can be evacuated as suggested in Alternative 3.



(Note: Block D may have multiple onshore pooling substations based on parameters specific to substation location and grid connectivity. In the above schematic diagrams, the alternates consider only one onshore pooling substation only for representation purposes. Further, the separation of block A & block B is again for representation purposes. Block A & B can be developed based on the scope of the developer and transmission licensee in grid evacuation planning and design of the OSW plant.

Table 9: Comparison of alternatives for Tamil Nadu OSW Power Evacuation

Planning Aspects	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Topography Consideration	The transmission system for subzones is suggested to be planned individually. Accordingly, selecting a site for offshore and onshore pooling substations is an important aspect. The length of export cables and subsea cables will depend on the site location of both offshore and onshore pooling	Subzones B1, B2, B3, and B4 are to be combined and a power evacuation system is suggested to be developed. Accordingly, site locations for offshore and onshore pooling substations shall be selected.	The transmission system for subzones B1, B2, B3 & B4 shall be developed individually with offshore pooling substation and offshore transformer modules. Site locations for offshore pooling substations and Lightweight offshore substations shall be selected properly.	Subzones B1, B2, B3, and B4 are to be combined and a power evacuation system is suggested to be developed. Accordingly, site locations for offshore and onshore pooling substations and Lightweight offshore substations shall be selected.

Planning Aspects	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	substation blocks.			
Total cable length (km) required for different voltage levels from Block-A to Block-D	Longer cable length with moderate power carrying capacity as substation capacity is lower.	Short cable length compared to alternative 1 as interconnection points is less but cables with higher current carrying capacity will be required due to higher substation capacity.	High cable length compared to alternative 1 due to more interconnection points required for small size Lightweight offshore substations. However, cables with moderate power-carrying capacity will be required.	Less Cable length compared to alternative 3 as Lightweight offshore substations of larger capacities are used which would reduce the interconnection points.
Scalability of Blocks for bidding/ ownership	Scalability is good as each subzone may be allotted to one or more developers.	Scalability is reduced as subzones are combined and power would be evacuated from the maximum possible S/S capacity. There is a chance of allotting at most 5 developers in the combined subzone.	Scalability is good as each subzone may be allotted to one or more developers. Further, a smaller developer could also participate due to the use of Lightweight offshore substations.	Scalability is slightly reduced as subzones are combined but due to the lower capacities of Lightweight offshore substations, there is a chance of allotment of zones to more no. of developers.
Reactive compensation requirements and options to compensate absorb reactive power	**Based on Interconnection Points**			
	Moderate reactive power compensation will be required as interconnection points are more (2x5 no. (s)- 10 points).	Less reactive power compensation will be required as interconnection points are less (5+2, only 7 no. interconnection points).	Moderate reactive power compensation will be required as interconnection points are fewer, and one offshore substation is completely avoided. Better	Less reactive power compensation will be required as interconnection points are fewer, and one offshore substation is completely avoided. Better

Planning Aspects	Alternative 1	Alternative 2	Alternative 3	Alternative 4
			than alternative 1.	than alternatives 1& 2.
	Based on Cable length			
	Higher reactive power compensation will be required as Cable length will be high.	Moderate reactive power compensation will be required as Cable length will be less.	Moderate reactive power compensation will be required as Cable length will be less compared to alternative 1.	Less reactive power compensation will be required as Cable length will be less compared to alternatives 1&2.
The transmission loss of the system	Higher transmission loss but better system reliability in case of faulty conditions.	Less transmission loss but lesser system reliability.	Moderate transmission loss but better system reliability in case of faulty conditions.	Moderate transmission loss but lesser system reliability.
Reliability and operational flexibility	High reliability and operational flexibility due to two S/S of 500 MW in each subzone.	Moderate reliability and operational flexibility due to a single 750 MW S/S in each subzone.	Better reliability and operational flexibility than alternative 1 due to the selection of Lightweight offshore substations instead of OSW S/S.	Better reliability and operational flexibility than alternative 2 due to the selection of Lightweight offshore substations instead of OSW S/S.
Compliance with N-1	Compliance can be achieved with the availability of individual substations.	Partially complies with the availability of 2 substations.	Partially complies considering the availability of 2 substations.	Partially complies considering the availability of 2 substations.
Cost considerations – Capital Cost & Operational Cost	Block A: Capital cost will be dependent on array design, infrastructure, and cable requirements. Block B: High capital Cost with	Block A: Capital cost will be dependent on array design, infrastructure, and cable requirement Block B: Moderate capital	Block A: Capital cost will be dependent on array design, infrastructure, and cable requirements. Block B: Moderate capital Cost because of the use of	Block A: Capital cost will be dependent on array design, infrastructure, and cable requirements. Block B: Lower capital Cost because of the use of

Planning Aspects	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	separate S/S in each subzone. Block C: High O&M costs will be comparatively higher due to higher interconnections and cables.	Cost for higher capacity S/S Block C: Moderate O&M costs will be lower due to fewer interconnections and cables.	Lightweight offshore substations. Block C: High O&M cost will be comparatively lower than alternative 1.	Lightweight offshore substations and higher single capacity S/S. Block C: Moderate O&M cost will be comparatively lower than all other alternatives.
Metering arrangements	More meters will be required due to more interconnection points.	Comparatively fewer meters will be required due to fewer interconnection points.	More meters will be required due to more interconnection points.	Comparatively fewer meters will be required due to fewer interconnection points.
O&M flexibility	High reliability and flexibility due to more interconnection points.	Moderate reliability and flexibility due to fewer interconnection points.	High reliability and flexibility.	Moderate reliability and flexibility than alternative 2.
Ease of Erection, installation & maintenance	Need more equipment which will increase installation cost and maintenance costs. Further, proper planning will be necessary for handling more equipment.	Need less equipment which will increase installation cost and maintenance costs.	Due to Lightweight offshore substations, the erection could be comparatively easy with less installation & maintenance costs.	Due to Lightweight offshore substations, the erection could be comparatively easy with less installation & maintenance costs.

Each of the alternatives for OSW transmission planning has its advantages and disadvantages. Due to a lack of site-specific information such as the distance of each subzone from the shore and its potential, the exact capacity of substations or Lightweight offshore substations could not be arrived at. Further, choosing the alternatives in which the subzones are combined would majorly depend upon the bidding of the subzones. However, the above assessment would guide CTUIL on various possibilities of power evacuation from the OSW subzones.

4. Key Takeaways

Key takeaways from the overall study and assessment are as detailed out below:

- The generation and demand portfolio of Tamil Nadu is unique, experiencing high RE penetration in the grid. Hence, high-level planning from CTUIL and STU is required.
- The revised RPO trajectory published by MoP for FY 2022-23 to FY 2029-30 would have a major impact on the offtake of power from the proposed OSW projects. Moreover, the ISTS/ InSTS pooling substations and onshore evacuation infrastructure are required to be capable of off taking the power to the load centres outside Tamil Nadu to meet the Wind power RPO compliance.
- Given the high cost of the OSW power plant, the curtailment of generation from OSW projects will lead to a huge loss to OSW developers. Hence, the actions/ remedies for power system operating challenges are required to be taken up on priority as discussed in Section 2.4.
- Further, the first tender for leasing OSW subzones equivalent to approximately 4 GW capacity off the coast of Tamil Nadu is planned for the end of 2022. Hence, a detailed assessment of transmission planning alternates has been carried out, to guide CTUIL on various possibilities of power evacuation.
- The lessons are drawn out from the Borssele and Beatrice wind farms of Europe which may be well suited for the OSW sites of Tamil Nadu. It is suggested to have a multi-connection HVAC terminal along with lightweight offshore substations like OTMs for the near OSW wind sites.
- During the preliminary assessment, alternatives 3 and 4 discussed in Section 3.3 could be suitable for OSW power evacuation in Tamil Nadu, provided that the bidding for the subzones is carried out based on the distance from the shore i.e., the near OSW sites (less than 20 km) and far OSW sites. However, alternative 4 could turn out to be most suitable if the near subzones could be combined and a common export of power to the onshore is worked out.
- Alternative 1 can be suggested, if the bidding for the subzones is done separately and without combining near OSW subzones. The power is evacuated to an onshore pooling substation using an OSW substation even for the near OSW sites, considering the immaturity of the lightweight OSW substation technology.
- However, the alternatives discussed in this report are indicative, moreover, for undertaking the detailed planning of evacuation infrastructure around these alternatives, CTUIL would essentially need inputs on exact site-specific data, the technical and commercial feasibility of heavy and lightweight substation capacity, size of bidding, and type of the bidding (i.e., subzone-wise, or distance-wise). The timely availability of the inputs to CTUIL before the application of Long-Term Open Access by the developer would be an enabler to expedite the overall OSW project implementation duration as detailed in Annexure 3 of this report.
- The suggested alternatives are proposed to be deliberated with key stakeholders, under this ASPIRE program, for bringing in consensus on the most suitable alternative from all-encompassing aspects.

Annexures

Annexure 1: Distance of Subzones

1. The approximate distance of each subzone from the SS.

Distance from Substation--->	Samurangapuram		Mupandal	
Subzones	Minimum (km)	Maximum (km)	Minimum (km)	Maximum(km)
B1	33	52	27	44
B2	31	44	32	48
B3	43	55	44	54
B4	45	63	44	58
G1	47	62	33	46

2. The approximate distance (km) of the Coast from the SS.

Nearby Shore -->	Ganpathipuram	Kanyakumari	Kondankoolam
Substations			
Samurangapuram	42	32	18
Mupandal	26	20	20

3. The approximate distance of Subzones from the SS at the coast.

From Nearby Shore ->	Ganpathipuram		Kanyakumari		Kondankoolam	
Subzones	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
B1	33	49	12	24	13	25
B2	44	64	22	43	13	26
B3	50	67	29	49	26	35
B4	41	56	25	37	25	45
G1	13	29	15	32	33	54
Highlighted distance (km): Minimum/Maximum						

From Nearby Shore ->	Ganpathipuram		Kanyakumari		Kondankoolam	
distance from SS on the coast						

Annexure 2: Recently commissioned projects with an array voltage level of 66 kV

Wind Farm Name	Country Name	First Power (Year)
Aberdeen (EOWDC)	United Kingdom	2018
Blyth Offshore Demonstrator - phase 1	United Kingdom	2017
Borssele 1 and 2	Netherlands	2020
Borssele 3 and 4 - Blauwwind	Netherlands	2020
Borssele Site V -Leeghwater - Innovation Plot	Netherlands	2020
East Anglia ONE	United Kingdom	2019
Formosa II	Taiwan	2022
Greater Changhua 1 - South East	Taiwan	2022
Hollandse Kust Zuid Holland I and II	Netherlands	2022
Hollandse Kust Zuid Holland III and IV	Netherlands	2022
Hornsea Project Two	United Kingdom	2021
Huadian Yuhuan 1 North	China	2021
Moray East	United Kingdom	2021
Nissum Bredning Vind	Denmark	2018
Seagreen	United Kingdom	2022

Wind Farm Name	Country Name	First Power (Year)
Triton Knoll	United Kingdom	2021
WindFloat Atlantic (WFA)	Portugal	2019
Yunlin	Taiwan	2021

Source: 4COffshore

Annexure 3: Tentative timelines for OSW project (Tamil Nadu)

S. No.	Particulars	Agency Responsible	Timelines
1	Bidding	MNRE/NIWE/SECI	6-9 Months
2	Exploration Stage	Developer	7 years
3	Application of LTOA & Grant of Connectivity	Developer/ CTUIL	6-9 Months
4	Construction and Testing	Developer	5 years
4	Operations	Developer	25 years
5	Site restoration	Developer	5 years

Source for S. N. 3: Procedure For Planning of Inter-State Transmission System (ISTS) (Ctuil. In)

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