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Recent developments in offshore wind energy systems: Technologies and practices

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ABSTRACT

This paper deals with offshore wind power generation technologies, power transmission and grid communication features, and associated power system studies for effective implementation of offshore wind energy systems, explaining its various stages of implementation. Also, this paper reviews the latest trends in offshore wind energy systems, addressing various aspects like large wind farm siting, power evacuation studies, cable selection, high-voltage direct current/flexible alternating current transmission systems (HVDC/FACTS) technology options, reliability evaluation, and autonomous monitoring. India's renewable power generation capacity through off-shore wind generation is also outlined to ensure low carbon energy emissions with improved energy efficiency. The policy and regulatory framework factors for reaching five gigawatts (GW) of offshore wind projects in the states of Tamil Nadu and Gujarat by the year 2032 using current methods and advanced technology are discussed here. This goal can be accomplished using current practices and advanced technologies. For effective implementation of offshore wind farms, suitable measures and likely actions by various stakeholders are suggested.

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1. INTRODUCTION

In recent years, developers of offshore wind farms have begun using turbines with capacities in the order of significantly higher megawatts. The offshore wind energy industry needs to have turbines, converters, foundations, cables, and other resources that have higher efficiency as well as less labor and other resources. When compared with onshore wind energy systems, offshore wind power generation has some advantages, as shown in Figure 1. These advantages include higher power generation due to less turbulence and roughness, higher plant load factor, and reduced bottlenecks in land acquisition and logistics management. These advantages are present although offshore wind power generation faces challenges such as foundation design in the sea, vessel management, and operation and maintenance aspects.

As of the 31st of January in the year 2022, the total installed capacity of wind farms in India to generate energy reached 40.10 gigawatts (GW). According to the aim set by the Ministry of New and Renewable Energy of the Government of India [1], it is predicted that an additional 20 GW would be accomplished on or before December 31, 2022. In the year 2020, the global installed capacity for the generation of wind power is expected to be around 743 GW, which will make wind energy a substantial component of the current and future energy supply systems. As can be seen in Figure 2, by the end of the year 2020, 35 GW worth of offshore wind power generation had been placed throughout the world. China, Europe, and the rest of the world made up the majority of this total, as can be seen in Figure 2. Along with Japan's ambition of having ten GW of offshore capacity by the year 2030, new actors from Asia such as the Republic of Korea and Taiwan have made their contributions.

The main wind power companies Enel (Italy), Equinor (Norway), Orsted, RWE (Germany), and Vattenfall (Sweden) have all announced their intentions to create hydrogen or methane from wind energy beginning in the year 2020. Major wind energy producers have been shifting their attention more and more toward the repowering of the wind power generator market sector around the globe, and notably onshore. There have been efforts made to repurpose old blades or develop blades made of entirely different materials, as well as efforts made to develop new solutions for recycling and reusing old blade composite materials [2]. In addition, there have been efforts made to develop new blades made of entirely different materials.

Figure 3 is an illustration of the increasing sizes of wind turbines between the years 1990 and 2020. It also shows the growth of power electronics with ratings and its functional significance in the context of the illustration. For offshore wind energy systems, floating platforms such as spar-buoy, tension leg platform, and semi-submersible are also available [3], [4].

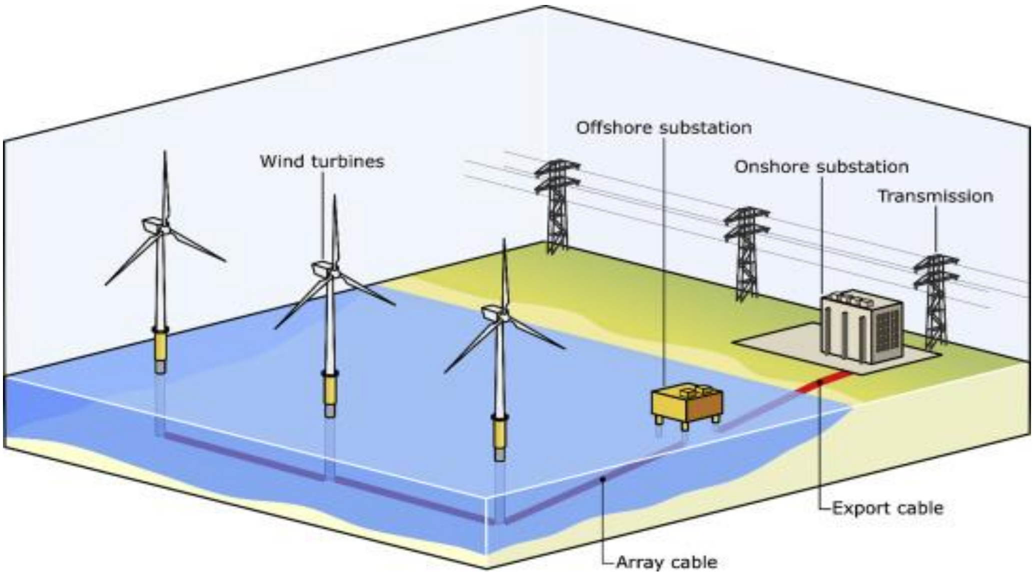

Figure 1. Schematic diagram of offshore wind power generation [1]

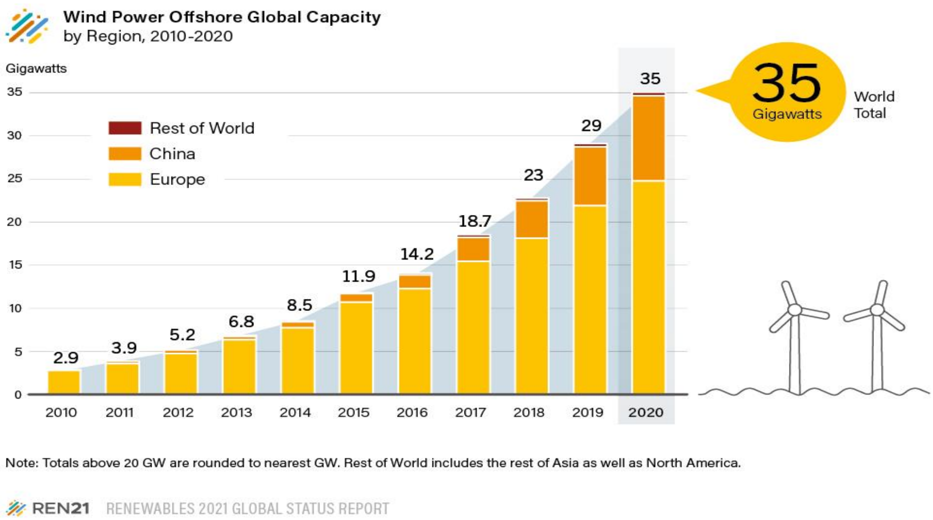

Figure 2. Statistics on global offshore wind capacity by region, 2010-2020 [2]

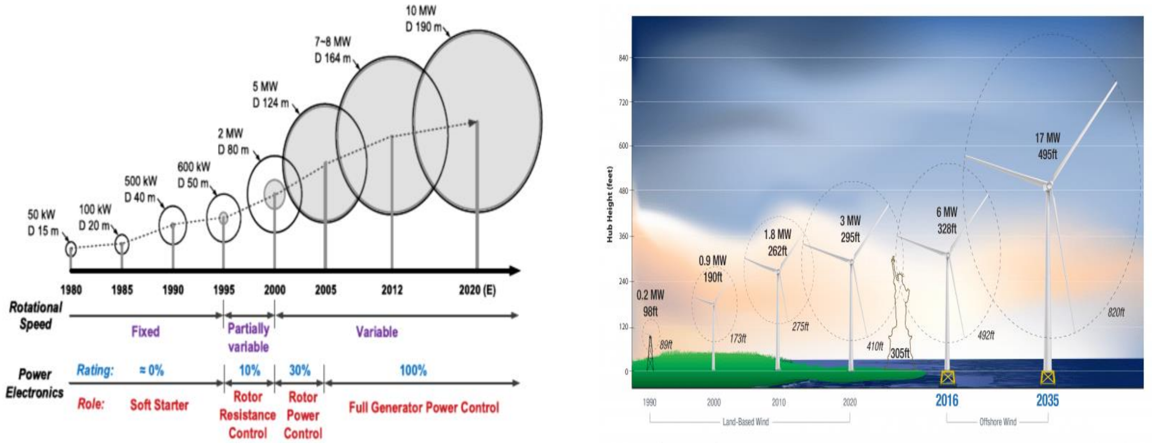

Figure 3. Development of wind turbines for onshore and offshore wind energy systems

2. VARIOUS TECHNOLOGIES AND TRENDS IN OFFSHORE WIND ENERGY SYSTEMS

2.1. Overview of offshore wind farms

Ali *et al*. [5] have studied the overview of offshore wind farms and it is associated issues like grid integration, power quality, stability, voltage control and frequency deviation, grid code requirements, energy storage solutions and low voltage ride through mechanisms. The most recent study on wind farm layout optimization and electrical system design, including cable connection techniques, was analyzed by Hou *et al*. [6]. Lakshmanan *et al*. [7] have conducted research on the various types of electrical collection systems found in offshore wind farms. These systems have been categorized as medium voltage alternative current (AC) collection, medium voltage direct current (DC) collection systems, and low frequency AC collection systems. Additionally, the researchers have elaborated on the operational characteristics and challenges associated with each type.

2.2. Design point of view

An electrical layout design optimization technique for offshore wind farms has been described by Chen *et al.* [8]. This method makes use of fuzzy c-means and binary integer programming methods in order to automatically assign wind turbines to the closest substations in the electrical network. They have improved the topological architecture of the cables that are utilized in the process of connecting wind turbines or turbines to substations. This is done to ensure that the expenses associated with connecting the cables and experiencing power loss during transmission are reduced to the greatest extent possible.

Jiang *et al.* [9] have discussed the cable size selection of an offshore multiplatform interconnected wind power system to achieve accurate optimization of its system planning through a mixed-integer linear programming expansion planning model. They have also presented the impact of the maximum penetration rate of wind power on the total cost of the system. Musasa *et al.* [10] looked into the possibility of using a DC collection grid in an offshore wind farm. This was accomplished by employing a radial connection of active rectifiers, which consisted of a three-phase half-controlled switch voltage source converter (VSC) cascaded with a single active bridge DC-DC converter. Using the power simulator software, simulations are run, and the resulting data is analyzed and compared to the performance of ring feeder configurations in terms of power loss, cost, voltage/current ripple, power factor, and other metrics. Furthermore, the software's control performance is illustrated.

2.3. Power evacuation perspective

Iosifidou *et al*. [11] have analyzed three types of power system interconnection of offshore wind farms: i) High voltage AC to the nearest onshore point of interconnection (POI); ii) High voltage DC with voltage source converter (HVDC-VSC) to the nearest onshore POI; and iii) Connecting to an offshore HVDC backbone running parallel to shore that interconnects multiple wind power plants and multiple POIs ashore in the Atlantic Ocean close to the cities of New York, Philadelphia, Annapolis, and Norfolk. Neumann *et al*. [12] discussed the advantages of using 66 kV for near-shore and medium-distance offshore wind farms for both United Kingdom (UK) and international demonstration wind farm projects. When compared to 33 kV systems for several close and medium-distance-to-shore wind farms, the techno-economic results show that lowering the quantity of undersea cable and related losses at the Blyth offshore demonstration site in the UK leads to a reduction in capital cost and full-life benefits.

Soleimanzadeh *et al*. [13] evaluated the cost-effective provision of reactive power in an offshore transmission system for a 295 megawatt (MW) offshore wind farm off the Dutch coast in order to achieve a unity power factor at the grid entry point in accordance with Dutch grid code criteria. Using the steady state electrical system design and analysis tool, EeFarm-II, in the MATLAB/Simulink environments, two distinct techniques for reactive power provisioning have been investigated and implemented. They were for 150 kV and 220 kV AC transmission voltage levels.

Ferr *et al.* [14] investigated the benefits of combining kinetic energy storage from wind turbines with DC-link energy storage of a voltage source converter-based high voltage DC (VSC-HVDC) link. It is to facilitate fast primary frequency control and system inertia to the existing ac network for the purpose of providing fast frequency response without the need for any auxiliary requirements. This was done in order to facilitate fast primary frequency control and system inertia.

Rúa and Cutululis [15] conducted a state-of-the-art review of electrical cable optimization in offshore wind farms. They analyzed the optimum sizing of electrical cables based on static-rated sizing, dynamic load cycle profile, and cable lifetime estimation under time-varying conditions with respect to the number and location of offshore substations versus onshore connection points. Additionally, they looked at how the optimal sizing of electrical cables affected the overall cost of the project.

Researchers [16], [17] developed a low frequency alternating current transmission scheme (16.7 Hz or 20 Hz) for the cost-effective connection of large-scale long distance wind energy in comparison to r high voltage alternating current (HVAC) and HVDC. This was accomplished by exploring the distance ranges with respect to offshore and remote onshore wind energy systems. A modular multiple DC transformer-based DC transmission system was described in detail by Hu *et al.* [18]. This system employed a permanent magnetic synchronous generator based offshore wind farm grid connection. This system had the benefits of fewer conversion stages, higher efficiency, and lower cost thanks to built-in power systems computer aided design/electromagnetic transients including DC (PSCAD/EMTDC) simulation, along with a down-scaled experimental prototype.

Ferdinand and Monti [19] studied the impact of electrical characteristics on the inrush current in the transformer in HVDC-connected offshore wind farms. Specifically, they focused on excitation, switching angle, and residual core magnetization as the electrical parameters of interest. Simulating electromagnetic transients and carrying out measurements in the field were two more methods they used to investigate how it operated. In order to lessen the impact of the inrush current, this was done.

Using wavelet noise reduction, Clarke's transform, Stockwell's transform, and decision tree (WRC-SDT). Wang *et al.* [20] presented a novel hybrid online detection method for offshore wind farm transmission lines. This method is used to classify different types of faults by obtaining the transmission line fault Eigenvalues.

Xue *et al*. [21] have worked on transient frequency control strategy for power system interconnected with offshore wind power through VSC-HVDC based on special sequence and sensitivities, which includes thermal units' regulation, wind power regulation, DC modulation and load shedding. Chen *et al*. [22] have developed a power optimization model using particle swarm optimization algorithm for the offshore wind turbines for maximum power generation by employing centralized voltage source converter.

Zhang *et al*. [23] looked into resonance-induced harmonic distortion and stability difficulties at an offshore wind farm that used doubly fed induction generators and was connected to a high-voltage direct current grid. They were also able to capture its dynamic features, which they used to highlight the significance of adding frequency coupling in sub-synchronous resonance stability evaluations using MATLAB/Simulink simulations.

Using simulations for the IEEE 118-bus system, Li *et al*. [24] have established an integrated planning model of optimum siting and size for VSC-HVDC link-based offshore wind farms. Additionally, they have used shunt capacitors to optimize the voltage profile and reactive power needs. Zhan *et al*. [25] have presented a hybrid modified total direct costs (MTDC) scheme as a means of integrating a number of offshore wind farms into onshore power grids at a variety of locations using PSCAD/EMTDC as the modeling platform. They used computer simulations to evaluate their plan under a variety of scenarios, including as start-up, changes in wind speed, and the disconnection of VSCs. This was done to guarantee that the system would run smoothly and that electricity would be distributed appropriately across onshore AC grids.

An optimization formulation was proposed by Sedighi *et al*. [26]. It was to find the optimal electrical interconnection configuration of wind turbines and the optimal cable sizing simultaneously using a harmony search algorithm. The goal of this formulation is to achieve lower costs to augment energy production portfolios.

Using the MATLAB/Simulink platform, Abu-Elanien *et al*. [27] analyzed the performance of the MTDC system by determining the types of outages necessary to maintain system transient stability under a variety of conditions, including sparsity of wind power, line over current, outage of lines connected to wind farms, and outage of lines connected to AC grids. These conditions were simulated using the MTDC system. The implementation of hierarchical control for the combined AC/MTDC grid that included the integration of offshore wind farms was given by Chachar *et al*. [28].

Kunjumuhammed *et al*. [29] provided a modal study of a large offshore wind farm that made use of permanent magnet synchronous generator type wind turbines coupled to voltage source converter HVDC. They observed various resonance frequencies for the purpose of stability investigations. Nguyen [30] evaluated hybrid control method based on distributed consensus control and central model predictive control to analyze the complexity of the communication network in a large-scale offshore wind farm in hardware-in-the-loop simulation using OPAL-RT technologies. This was done by simulating the wind farm using OPAL-RT Technologies.

2.4. Operational point of view

The effects of fatigue on a wind turbine's operating life have been researched by Qiu *et al*. [31] with the purpose of optimizing its design. They used a variety of turbulence scales to quantify gearbox load spectrum variation and cumulative fatigue damage, with the goal of predicting gearbox service life as a result of random wind speeds with a certain statistical distribution. This information can be used for the optimization of gearbox design for offshore wind turbines through simulation.

An enhanced unit commitment model with energy storage and flexible CO_2 capture was developed by Bruce *et al*. [32] by analyzing high resolution on/offshore wind data, probabilistic wind power forecasts, and model wind imbalances at operational timescales for the UK in order to illustrate the generation flexibility requirements and nonlinear impacts of increasing wind capacity on power plant operating regimes. This was done in order to help the UK meet its renewable energy targets. Researchers led by Tao *et al.* [33] have conducted research on wind turbines with decreased size in order to validate the circuit parameter formulae and circuit model for Chinese-made offshore wind turbines.

2.5. Based on reliability evaluation

Besnard *et al*. [34] have developed a model that can be used to optimize the maintenance support organization of an offshore wind farm. The model takes into account the location of maintenance accommodation, the number of technicians, the choice of transfer vessels, and the utilization of a helicopter. It also takes into account the reliability, the logistic costs, and the price of electricity.

Chao *et al*. [35] discussed the sequential Markov chain Monte Carlo model for reliability evaluation of offshore wind farms taking into consideration the impact of severe offshore weather. They did this by analyzing the failure rate of wind turbines due to wind speed and lightning, and they suggested effective solutions for the reliable operation of the farms. An examination of the supervisory control and data collection platform for monitoring the functioning of the Lillgrund offshore wind farm has been provided by Papatheou *et al*. [36]. This research uses a robust machine-learning technique to anticipate measurements of power output from each wind turbine.

Abeynayake *et al*. [37] suggested a comprehensive method for the availability evaluation of the radial large-scale Anholt wind farm that is situated in Denmark. This technique combines multi-state Markov processes with universal generating function.

A real-time simulation model has been developed by Song *et al*. [38] in order to investigate the performance losses of offshore wind turbines that are caused by ice creep loads. This was done in order to guarantee both safety and a high degree of power tracking capacity. The steady functioning of offshore wind turbines under different time delay circumstances has been analyzed by Tang *et al*. [39] in order to remove the steady state error induced by external disturbance and increase the stability of wind turbines.

2.6. Based on communication/autonmous operation

Ullah *et al*. [40] have conducted research on the combination of LoRaWAN massive machine-type connectivity (mMTC) technology with low earth orbit satellites for the purpose of remote monitoring of offshore wind farms. Hasager *et al*. [41] investigated the climate of the offshore wind in Iceland using satellite synthetic aperture radar, the measurements from coastal meteorological stations, and the results of two different atmospheric model data sets called HARMONIE and NORA10 to find wind speed and wind direction measurements. In order to cut down on inspection time, man hours, and the associated risk for the workers in the Walney offshore wind farm, Chung *et al*. [42] developed a placement optimization for unmanned aerial vehicles to use during automated inspections of turbines. This was done in order to reduce inspection time.

Mitchell *et al.* [43] developed a symbiotic system of systems approach that makes use of a symbiotic digital architecture to provide a cyber physical orchestration for safe and resilient autonomous robotics in offshore wind farms. This approach provides enhanced run-time operational resilience and safety compliance to beyond visual line of sight autonomous missions. Reddy and Stuber [44] have outlined the challenges of marine seismic acquisition and designed a buoy-based wireless backhaul network for high-rate data transfer over the ocean surface. They have also developed Wi-buoy for real-time, scalable, and energy-efficient data delivery through a buoy-based power-saving backhaul scheme. Wi-buoy was developed in order to save power while still delivering data in a timely manner.

3 STATUS OF OFFSHORE WIND POWER GENERATION IN INDIA

In order to ensure the nation's continued access to a reliable supply of energy over the long term, India, which has a coastline that is over 7,600 kilometers long, investigated the viability of using offshore wind energy as a "strategic energy source." The Indian government published its National Offshore Wind Energy strategy in September of 2015, and the Ministry of New and Renewable Energy was given the responsibility of acting as the Nodal Ministry to develop the offshore wind industry. In the context of initiatives supported by the European Union, such as Facilitating Offshore Wind in India (FOWIND) and First offshore Wind Project in India (FOWPI), India has begun the basic stages of the process of developing offshore wind power.

The National Institute of Wind Energy (NIWE) has started the preliminary assessment process by placing met masts, which serve as representatives for the evaluation of the offshore wind potential. Along the coast of India, the FOWIND consortium has conducted resource assessment and preliminary feasibility studies. Additionally, they have demarcated eight zones each in the Gulf of Khambhat in Gujarat and the Gulf of Mannar in Tamil Nadu. These zones cover a total area of 17706 km^2 and 10558 km^2 respectively. The FOWIND study served as the basis for NIWE's decision to begin verification and validation research in Gujarat and Tamil Nadu, the demographic regions of which are shown in Figures 4 and 5, respectively. Off the coast of Gujarat, in the Gulf of Khambhat, the FOWIND Consortium was successful in November 2017 in commissioning India's first offshore light detection and ranging (LiDAR) [45], [46].

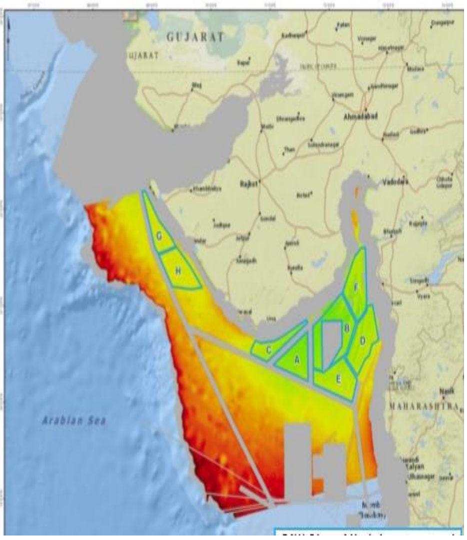

Figure 4. Gulf of Khambhat in the Gujarat

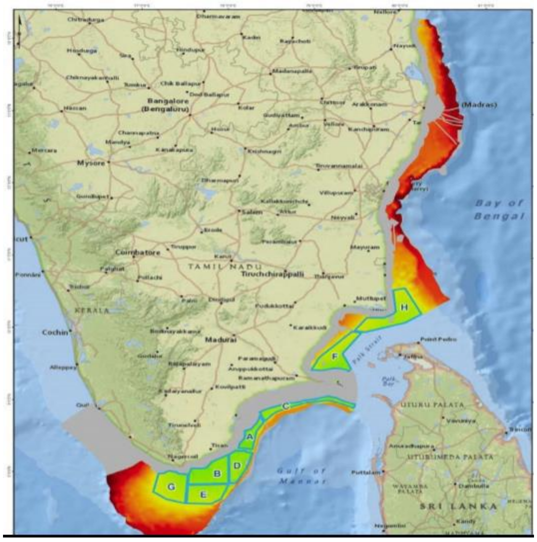

Figure 5. Gulf of Mannar, Tamil Nadu

Offshore wind power is being promoted via the FOWIND project, which is being sponsored by the European Union and is being directed by the global wind energy council (GWEC). This is being done to aid India's transition towards a future with less reliance on carbon-based energy. MeteoPole is a consulting firm based in France with an office in Hyderabad, India. They provide services at each stage of the development of wind farm projects, with a primary focus on reducing financial risks through the use of a variety of cutting-edge technologies. These technologies range from cloud-based wind simulations to LiDAR measurements (ZephyCloud). MeteoPole has been selected as the official LiDAR provider for the evaluation of offshore wind power by Collegiate Science and Technology Entry Program (CSTEP), acting on behalf of the FOWIND project consortium.

The windcube LiDAR equipment is portable, can be easily installed on any stable platform, it has very good accuracy and data availability at heights of 40 m to 200 m, speed variations up to 0.1 m/s and direction up to 20 at a sampling frequency of 1 Hz, averaged at 10 minute intervals. Additionally, the windcube LiDAR equipment can measure speed variations up to 0.1 m/s and directions up to 20. NIWE has provided two sets of offshore Lidar wind data, one covering the period from November 2017 to November 2018, and the other covering the period from December 2018 to November 2019, which together provide comprehensive recommendations for the development of offshore wind systems in India. During the month of December 2017, FOWIND published a report titled "From zero to five GW–offshore wind outlook for Gujarat and Tamil Nadu (2018-2032)". This report lists the policy and regulatory framework aspects of achieving 5 GW worth of offshore wind installations in the states of Gujarat and Tamil Nadu by the year 2032 [47].

4 STAGES INVOLVED IN OFFSHORE WIND POWER GENERATION

Offshore wind power generation has to address the following aspects [48]: i) Wind resource assessment (WRA), zone selection discusses the many instruments and methods used for offshore WRA to determine its potential, including as LiDAR and sound navigation and ranging (SONAR) technology; ii) Foundations and structures is where we talk about the many different kinds of foundations, such as monopile, gravity based, jacket type, tripods, high rise pile cap (HRPC), or for the newest floating type designs; iii) This section of energy yield's turbine/generator selection guide goes through the various kinds of wind turbines and how electricity is generated; iv) Sub-stations is concerned with both unmanned offshore and manned onshore types of sub-stations, which are used for the purpose of transferring electricity from an offshore wind farm to the grid located on the mainland; v) Sub-marine cabling provides in-depth information on a variety of power evacuation methods, underwater cabling, and the accompanying engineering for either AC/DC, depending on the budgetary constraints and scope of the project; vi) Supervisory control and data acquisition (SCADA) and communication explain international standards relating to network and communication for offshore wind power projects and their compliance. These standards are applicable to offshore wind power projects; vii) Marine and Ports is concerned with the prerequisites as well as the infrastructure at the ports that will be necessary for the development of an offshore wind farm and their corresponding O & M; viii) Vessels and other related equipment Vessels are a piece of equipment that is necessary for installing offshore wind turbines, building foundations, and erecting huge offshore structures. These vessels are particularly constructed and are the most significant component of the equipment; ix) Additional considerations such as energy output, operations and maintenance, the cost of energy, dangers, and social and environmental eco-systems; and x) The locating of possible growth areas for the company's future operations.

5 OFFSHORE WIND POWER GENERATION TECHNOLOGIES

As part of the process of planning the overall project, a decision must be made between HVAC and HVDC based on line commutated converter (HVDC LCC), or voltage source-based HVDC (HVDC VSC), or modular multilevel converter (MMC) for the transmission of power from an offshore plant to a grid connection point [49]. Offshore wind farms may choose to use smart grid technologies in order to address the electrical design issues that arise in offshore power networks. These technologies have the benefits of increased reliability, flexibility, and efficiency, and they can help mitigate the specific problems that arise with transmission and distribution of power, such as: i) high temperature superconducting cables and ii) flexible AC transmission systems (FACTS) devices including SVC, static synchronous compensator (STATCOM), fault current limiters, voltage control and VAR support devices, and unified power flow controller (UPFC) [50]. Figure 6 shows double fed induction machine (DFIM)-based wind turbine and Figure 7 shows a full size converter-based wind turbine. A typical technological solution for offshore wind farms connection is in Figures 8 and 9. They have VSC or MMC based HVDC power evacuation strategies as explained earlier.

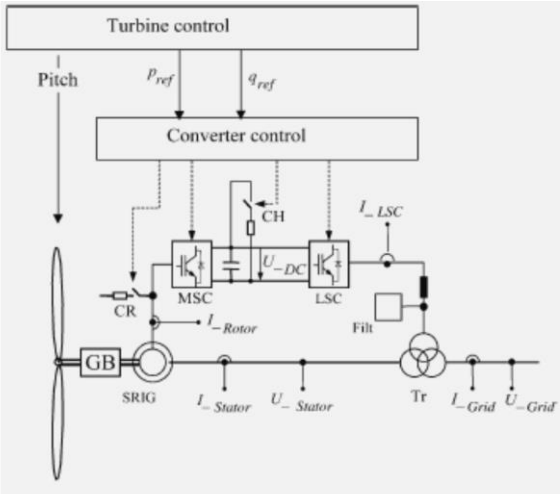

Figure 6. DFIM-based wind turbine [51]

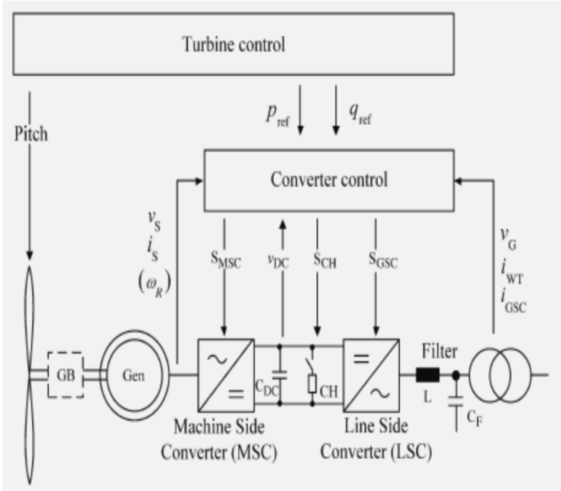

Figure 7. Full size converter-based wind turbine [51]

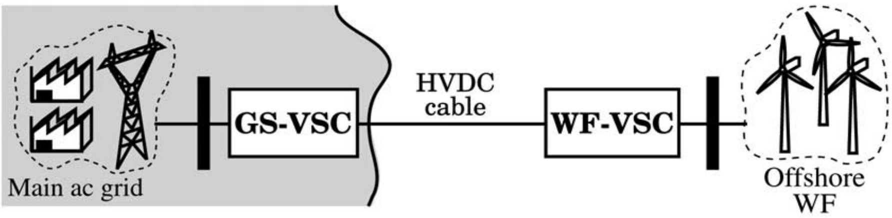

Figure 8. Offshore wind farm transmission [49]

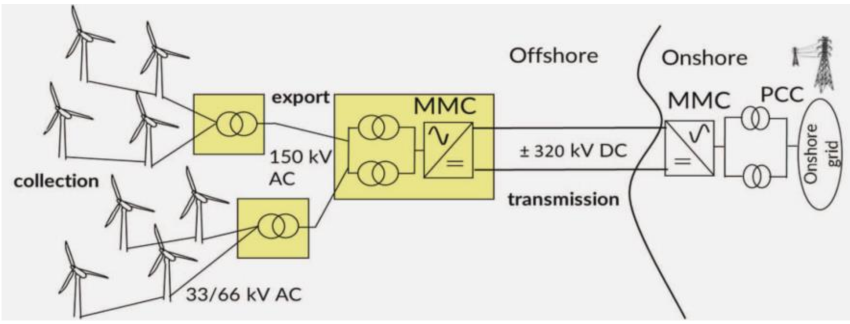

Figure 9. Long distance offshore wind farms connection [49]

6 COMMUNICATION INFRASTRUCTURE FOR OFFSHORE WIND FARMS

The wind power plant control system and the wind turbines are connected by a communications connection that is provided by the wind power plant communication network. This covers both the hardware components (wires, transducers, fiber optics, repeaters, and switches) and the software protocols (Ethernet, transmission control protocol/internet protocol (TCP/IP), wireless, Zigbee, and passive optical network) that are used to transport information between the wind turbines and the wind plant management system. Components that are necessary for the functioning of wind power plants are covered by the international standard known as IEC 61400-25 [52]–[54].

The communication network for the offshore wind farm is somewhat autonomous from the public power grid thanks to the SCADA technology that it uses. This link exists between the control center and each individual wind turbine. Even if the transmission distance of an offshore wind farm is rather lengthy in comparison to a local area network (LAN) for a substation network, the communication network inside an offshore wind farm may still be handled as a LAN, as shown in Figure 10. Here, the controller that is installed on each wind turbine receives all of the essential data from the devices that are attached to the wind turbine and then transfers that data to the control center of the wind farm. They distribute the orders that come from the control center to the various equipment that are used to operate the wind turbines. SCADA stands for supervisory control and data acquisition, and it is used to refer to the network that enables communication between controllers and the computer that serves as the control center.

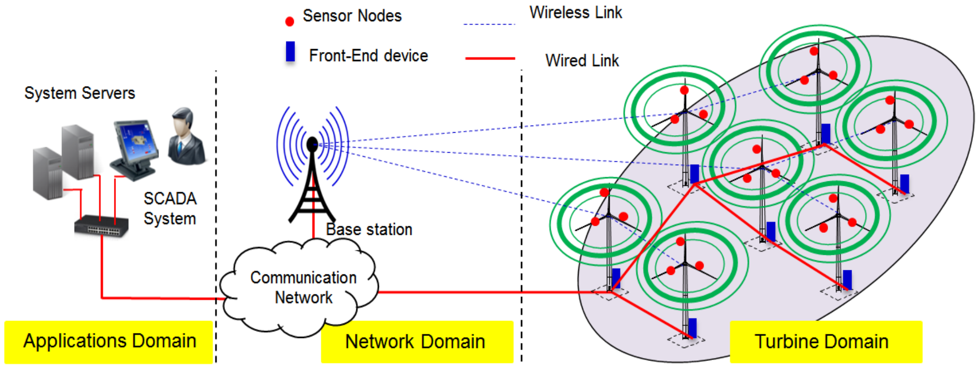

Figure 10. Communication network architecture for offshore wind farms [52]

7 TECHNOLOGY IMPACT ASSESMENT STUDIES IN OFFSHORE WIND FARMS

The research projects [55]–[57] have been carried out in order to evaluate the consequences, such as stability and power quality concerns, while connecting offshore wind power production to a power system: i) Risk evaluation of submarine HVAC/HVDC cable system design and protection studies for array and export cables; ii) Development of electrical grid design including FACTS devices and design guidelines for smart grid communication infrastructure with the existing power system; iii) Erection of offshore substation, HVAC/HVDC system and support structures for wind farms addressing lightning and emergency response protection due to onshore disasters/geo hazards; and iv) Impact study on power system stability and power quality improvement for wind power system.

Furthermore, onshore wind power project implementation needs: i) Grid planning and development; ii) Low-cost financing like viability gap funding and National Clean Energy Fund support; iii) Sectoral capital; iv) Carbon trading mechanisms; v) Environmental/met station/geophysical/geotechnical surveys; vii) Power evacuation studies; and viii) Inter-agency coordination by government/policy makers/tatutory/certification bodies. Competence in wind turbine/generator development, condition monitoring systems, global collaborations, and project financing by prospective project developers, suppliers, and manufacturers, and R & D investment is vital. Support from financial institutions and investors, marine developers and vessel operators, and cable manufacturers is also needed. It should also address future issues such as energy cost reduction, increased investor confidence, environmental and human impact assessment, and public acceptance.

8 CHALLENGES AND RECOMMENDATIONS FOR OFFSHORE WIND ENERGY

Offshore wind has few technical, regulatory and operational challenges in India [58]–[60], which includes: i) The increased complexity of the structures and foundations required for offshore wind turbines results in increased expenses for their installation; ii) Wind farms located at sea are notoriously tough to maintain financially and tricky to run when exposed to severe weather like hurricanes and typhoons; and iii) There are a limited number of local substructure manufacturers, installation boats, and skilled people.

A detailed set of recommendations detailing the necessary elements for building a policy, regulatory, grid integration, and funding framework for offshore wind energy system are provided. They are: i) Renewable purchase obligation: Through a mechanism known as a renewable purchase obligation, power distribution firms, open access customers, and captive users have the opportunity to make clean energy purchases as part of their overall electricity consumption; ii) Lower taxes: Good and service tax and excise duties should be exempted for various components of offshore wind energy systems and tax credits should be given at the early stage of project development; iii) Feed-in tariff: Discoms have the ability to implement feed-in tariff (FiT) laws and make the purchase of offshore wind electricity obligatory. The FiT may also be adapted to meet the specific needs of any offshore wind project. The inherent risk in the generation of renewable energy may be mitigated by the use of a long-term contract and price guarantee, which in turn encourages investment and growth. In addition, distribution companies should guarantee preferential payments for offshore wind energy projects; iv) Deemed generation provision: Concerns about curtailment need to be addressed, and state load dispatch centres (SLDCs) should be given the authority to evacuate substantial amounts of electricity. This may be accomplished by enabling "deemed generation provision." Offshore wind energy projects also need to be safeguarded. SLDCs and regional load dispatch centers are able to access the state or regional unscheduled interchange pool in order to fund compensation payments. The Power Grid Corporation of India Ltd. should be responsible for the development of the undersea power evacuation and the subsea substations; and v) Single window clearance: The National Institute of Wind Energy (NIWE) need to be granted the authority to provide single-window approval for all offshore wind energy projects in India.

Finding prospective solutions to mapping spatial competition, ocean space for energy and food, marine aquaculture, transportation, shipping services, maritime trade, merchant fleet, movement of special vessels, ship building, ports expansion, coastal and cruise tourism, desalination, deep sea minerals, energy transition, ocean health, capture fisheries, and regulation of oil and chemical spills are some of the other challenges associated with offshore wind energy systems.

9 CONCLUSION

The production of electricity using wind from offshore locations has undergone a substantial transition in terms of installed capacity and technological maturity, and it has tremendous development potential for the foreseeable future. This article presents a comprehensive literature review of offshore wind power production, including a discussion of recent technical breakthroughs as well as the steps that are involved in the implementation process. The current state and future prospects of offshore wind power generator in India are covered in this article, along with some suggestions for effective offshore wind power development. Also included are developments in technology linked with power transmission, smart grids, and communication infrastructure in offshore wind energy systems. The power system studies point of view is also included in this briefing on the technology impact evaluation of offshore wind power production.

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