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Review of renewable energy sources and offshore wind turbine technology

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Abstract— This paper is a state-of-the-art that aims to highlight all the new developments for wind renewable energy sources, wind turbine system, vertical axis wind turbine and the included components to find the best solution for an offshore vertical axis wind turbine that supplies ships with energy in the outer harbor. This review could help to understand the potential future choices in the design of vertical-axes wind turbine in order to reduce pollution in marine environment.

Keywords— renewable energy; vertical axis wind turbine; wind turbine system; generators; controler; invertor; energy storage technology, offshore wind turbine structure;

I. INTRODUCTION

Many researchers around the world, try to provide solutions to increase energy savings and predict or increase the renewable energy generation/potential etc., to increase the use of renewable energy and lowering the harmful effects of the global warming.[1]

Global warming and inconsistent weather patterns were found to be the after effects of over dependency on fossil fuels. This discovery underscored the urgency of using clean energy resources to replace fossil fuels. Further research and development are required to bring down the cost of extracting energy from renewable sources since they cannot match conventional sources in terms of cost, availability and power system stability as of yet. [2]

In the middle of a continuous and exponential development of renewable energies trend, generated by the increasing price of the conventional fuels which are quickly draining, and facing the fact that we have tremendous messages sent by our polluted Planet, the IMO (International Maritime Organization) returned its face to environment concerns in 2008. During time IMO has realized a series of environment impact studies of maritime domain and, in concordance with this idea, developed IMO's Marine Environment Protection Committee (MEPC). MEPC has given extensive consideration to control of greenhouse gas (GHG) emissions from ships which are implemented in MARPOL Annex VI as a new Chapter 4, entitled “Regulations on energy efficiency for ships”. [12] We strongly believe that there will be a rapid grow in the number of ships which will use in the outer harbor of the ports renewable energy as wind turbine with vertical axes in order to reduce the offshore pollution in our environment.

II. WIND TURBINE TECHNOLOGY

Wind power is still the most promising renewable energy in the year of 2013. The wind turbine system (WTS) started with a few tens of kilowatt power in the 1980s. Now, multimegawatt wind turbines are widely installed even up to 6-8 MW. There is a widespread use of wind turbines in the distribution networks and more and more wind power stations, acting as power plants, are connected directly to the transmission networks. As the grid penetration and power level of the wind turbines increase steadily, the wind power starts to have significant impacts to the power grid system. Therefore, more advanced generators, power electronic systems, and control solutions have to be introduced to improve the characteristics of the wind power plant and make it more suitable to be integrated into the power grid. Meanwhile, there are also some emerging technology challenges, which need to be further clarified and investigated.[5]

The state-of-the-art configurations and roles of power electronics in the wind turbine system show that the behavior/performance of wind turbines can be significantly improved by introducing more advanced power electronic technologies. By proper controls and grid regulations, it is possible for the wind farms to act like conventional power plants and actively contribute to the frequency and voltage control in the grid system, thus the wind energy nowadays is more suitable to be integrated into the power grid.[5]

For points of maximum power operation revealed that for low wind speeds, fast and significant changes in wind speed, wind system does not always work at the points of maximum power. [6]

In keeping with the orientation of turbines:

According to orientation, the turbine could also be classified into two sorts.

Horizontal Axis wind turbines (HAWT).

Vertical Axis wind turbines (VAWT).

In vertical axis wind turbines additionally known as crosswind axis machines, the rotating axis is perpendicular to wind direction. The primary profits of VAWT over commonplace HAWT square measure that VAWT square measure Omni directional that is it affirms the wind from any heading. Those disentangle its style & kills the matter obligatory by turning mechanism compels on the rotor of common machines in light of the fact that the turbines yaw into the wind. The pivot of vertical pivot allows, mounting the generator & unit at the bottom level. On the opposite hand VAWT needs man wires attached to the support at higher level.[7]

Wind turbines are mainly categorized into horizontal and vertical axis wind turbines. Vertical axis wind turbines are known for their many advantages, including their independence with respect to wind direction, stable force, easy installation and maintenance, and low starting wind speed. These turbines are especially suitable for offshore floating wind power systems. Direct-drive turbines without a gearbox have been extensively studied for their high reliability, low maintenance cost, and high efficiency. Compared with traditional radial flux rotation generators, axial flux generators have a higher generator diameter-to-length ratio and are suitable for direct coupled wind turbine applications, such as vertical axis and direct-coupled wind turbines . These generators also have a large power-to-weight ratio, highly flexible field and winding design, improved cooling, and potential application in modular construction. [8]

New concept of Vertical Axis Wind Turbines with stationary multi-vanes

Drag-type vertical-axis wind turbines have a large starting torque and excellent self-starting performance, and are non-directional with respect to wind. In addition, because the maximum output occurs at a tip speed ratio of 1 or less, these turbines can be operated in a lower speed range compared with lift-type wind turbines. However, drawback of drag-type wind turbines is that their output is lower per unit sectional area than that of the lift-type wind turbines. Experimental results so far have shown that the wind turbine output is increased by using stationary vanes.[9]

Fig. 1 shows an outline of a drag-type multi-blade vertical-axis wind turbine with stationary multi-vanes. The wind turbine has a structure containing stationary multi-vanes that guide the wind flow at a fixed angle to the rotating multi-blades. [9]

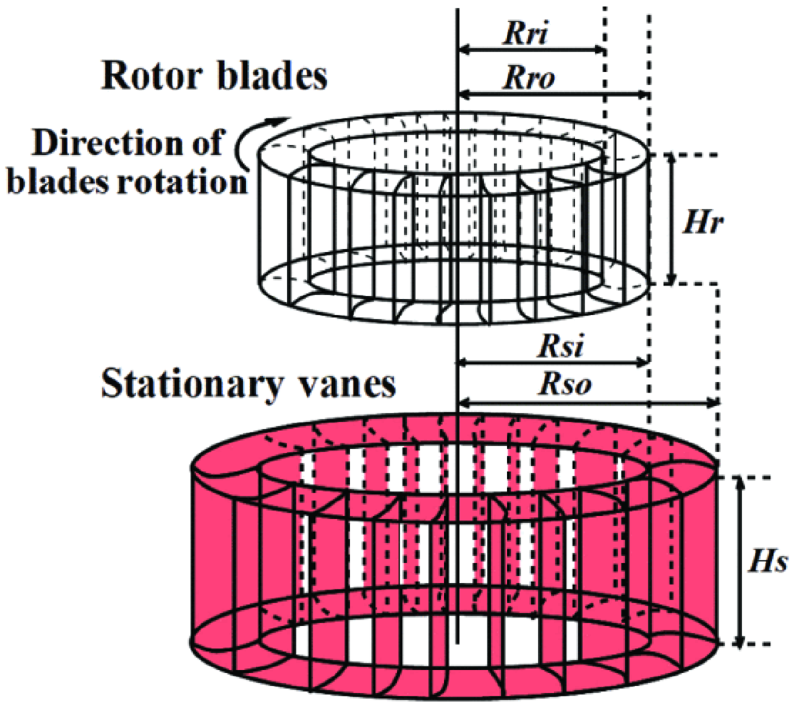


Fig.1. Multi-blade turbine.

Fig. 2 shows a diagram of wind acting on rotor blades. We define the set wind speed as V_{set}, the wind speed flowing through the stationary vane as V_m, the tip speed of the rotor blade as V_t, and the relative wind speed as W_m. β is the angle of incidence between the wind speed V_m and the rotor blade, and α_m is the angle between the relative wind speed W_m and the rotor blade. In this paper, assuming that the angle of installation of the stationary vane is varied, the wind turbine characteristics are obtained for varying the angle of incidence β to the rotor blade. [9]

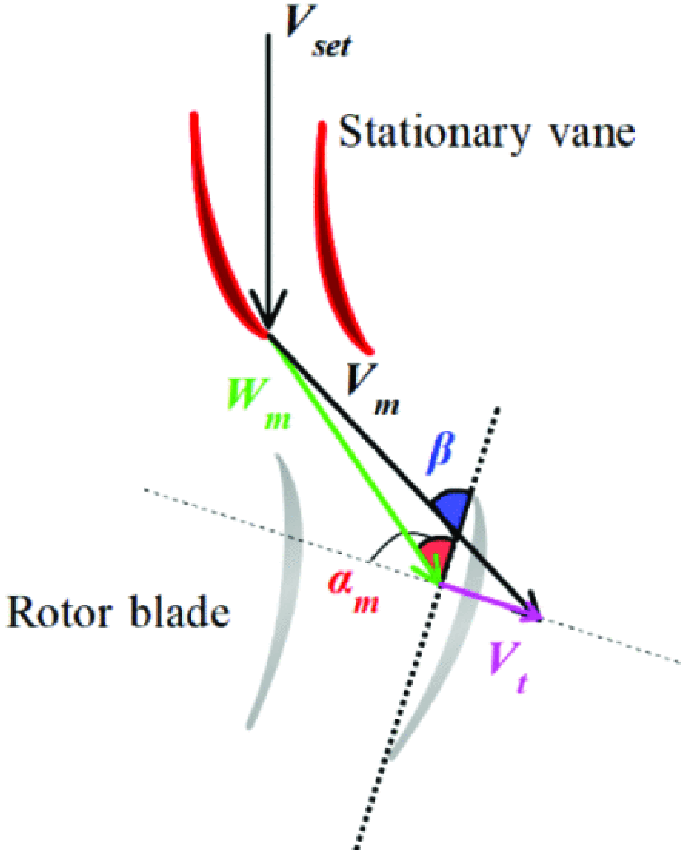
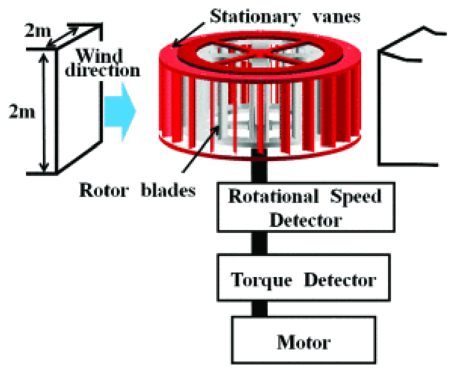


Fig. 2. The diagram of wind acting on rotor blades.

The wind turbine power measurements were taken by the following steps. First, a wind was supplied using the wind tunnel Fig. 3. Next, the rotation speed was controlled arbitrarily in the range of the wind turbine stopped state to the unloaded rotation speed using a three-stage induction motor (Mitsubishi Electric SF-JR, 200V, 1.5 kW) connected to a regenerative inverter (Mitsubishi Electric FR-A221E-5.5K). Data were sampled into a measurement computer via a torque display unit (Ono Sokki TS3600B) and a GP-IB from a torque sensor (Ono Sokki SS-500) and a rotation speed sensor (Ono Sokki MP-981), and the measured values were average by software. [9]



(a) Measurement system of turbine.

(b) Outline of wind tunnel and turbine.

Fig. 3. Experimental equipment of turbine.

III. POWER ELECTRONICS TECHNOLOGY FOR INDIVIDUAL WIND TURBINES

Wind Energy Conversion System (WECS) is typically composed of three major components, which are mechanical, electrical and control systems. [10]

The main components employed for energy conversion from wind to electricity in a typical wind turbine system (WTS) include the rotor with the turbine blades, possibly a gearbox (which is eliminated in direct-drive solutions), an electric generator, a power electronics converter, and a transformer, as illustrated in Fig. 4. [11]

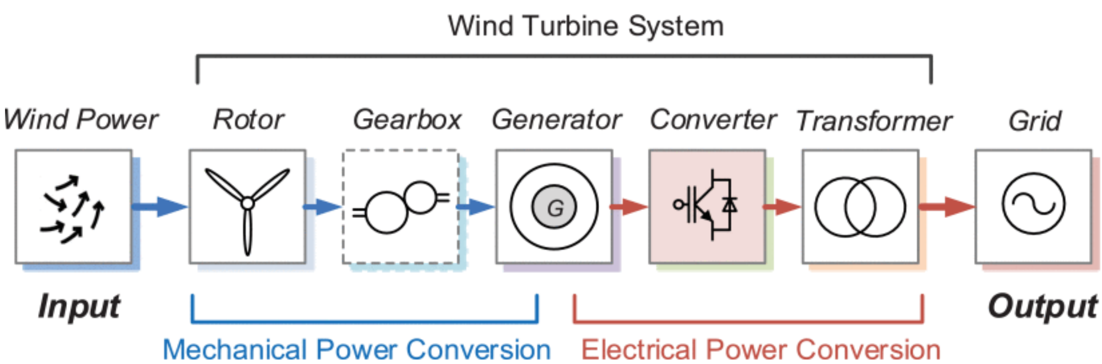


Fig. 4. Power conversion stages in a typical WTS (gear box is avoided in some systems).

IV. COMPONENTS OF AN INDIVIDUAL OFFSHORE WIND TURBINES

GEARBOX

Wind gearing is a challenging application due to the continually varying loads impressed by the turbine rotor. Gearbox reliability has been a major industry issue with a high cost of gearbox replacement. One solution is a direct-drive power train that entirely eliminates the gearbox. This approach has been successfully adopted by Enercon and is being investigated by other turbine manufacturers; however it is still not widely adopted in the industry due to the weight of the large diameter low speed generator. A less radical alternative uses a medium speed generator and reduces the number of stages in the gearbox from three to one or two, which enhances reliability by reducing parts count. The fundamental gearbox topology can also be improved, as was done by Clipper Windpower with their innovative multiple-drive-path gearbox - shown in Figure 5 - that divides mechanical power among four generators. The multiple-drive path design radically decreases individual gearbox component loads, thus reducing gearbox weight and size, easing erection and maintenance demands.[4]

Fig. 5. Clipper Windpower multiple-drive-path gearbox

GENERATORS

It seems that direct-drive generators were the most suitable for high-power conversion systems since they present high efficiency, good reliability and reduce maintenance cost. Nevertheless, the fundamental issue for these generators is their large structure (mass, diameter, volume). Researchers put forward many solutions to avoid this drawbacks such as the semi -direct drivetrains, aluminum alloys and generator bearing adjacent to the air-gap and supporting them with rails to reduce respectively the diameter, the weight and the stiffness. Furthermore, flux concentrated Permanent Magnet Synchronous Generator (PMSG) with ferrite magnet, electrical excitation and hybrid excitation were proposed to bypass the volatile prices of rare-earth Permanent Magnet (PMs) in the case of PMSG. Despite the fact that it is not a mature technology, high temperature superconducting generators are always considered as possible solution to reduce the weight of ultra-large generators. Its reasonable to assume that the suitable generator system for multi-megawatts wind turbines continue to be a major issue for researchers in the electrical machines design community.[13]

Different axial flux generators have been proposed for direct-drive wind power generation, such as axial flux permanent magnet generators, axial flux doubly fed induction generators, and axial flux flux-switching generators. With their high power density, permanent magnet synchronous generators have received widespread attention and application in vertical axis wind turbines. [8]

Another important concept, which is popular for newly installed wind turbines, is shown in Fig. 6, Asynchronous/Synchronous Generator With Full-Scale Power Converter. Dc-excited synchronous generator (DCESG), and permanent magnet synchronous generator (PMSG) have been reported as possible solutions. By introducing a full-scale power electronics converter and transformer to interface the power grid and the stator windings of the generator, the generated power from the wind turbine can be fully regulated. Compared to the doubly fed induction generators (DFIG)-based concept, the main advantages can be identified as the elimination of slip rings, simpler or even eliminated gearbox, and extended power and speed controllability, as well as better grid support capability. However, more stressed and expensive power electronics components as well as the higher power losses in the converter stage are the main drawbacks; this is the main reason why this concept is not always used in newly erected onshore wind turbines.[11]

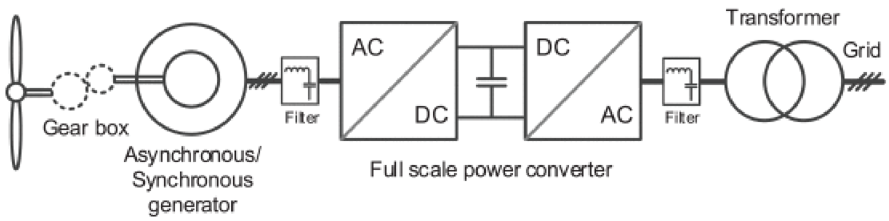


Fig. 6. Wind turbine concept with full-scale power converter.

Advantages PMSG [14]

- This device is light weighted and small size in construction.
- It has Low losses and high efficiency.
- There is no need of external excitation current.
- No need of gearbox is required.

Disadvantages PMSG [14]

- It is used for small wind turbines, but for large wind turbines, large size of the magnet is required.
- Due to atmospheric conditions, demagnetization of permanent magnet is a big problem.

But because of the above advantages, its high efficiency and direct-drive applications make PMSG based WECS very promising. Therefore this is the most attracting area in research point of view.[14]

New concept generator, asymmetric-primary axis-flux hybrid-excitation generator (APAFHG)

Axis-flux generators are suitable for those vertical axis wind turbines with short axial length and easily module a combination of multiple generators according different power requirements. Fig. 7 shows the structure of the proposed asymmetric-primary axis-flux hybrid-excitation generator (APAFHG) with a vertical axis wind turbine.[8]

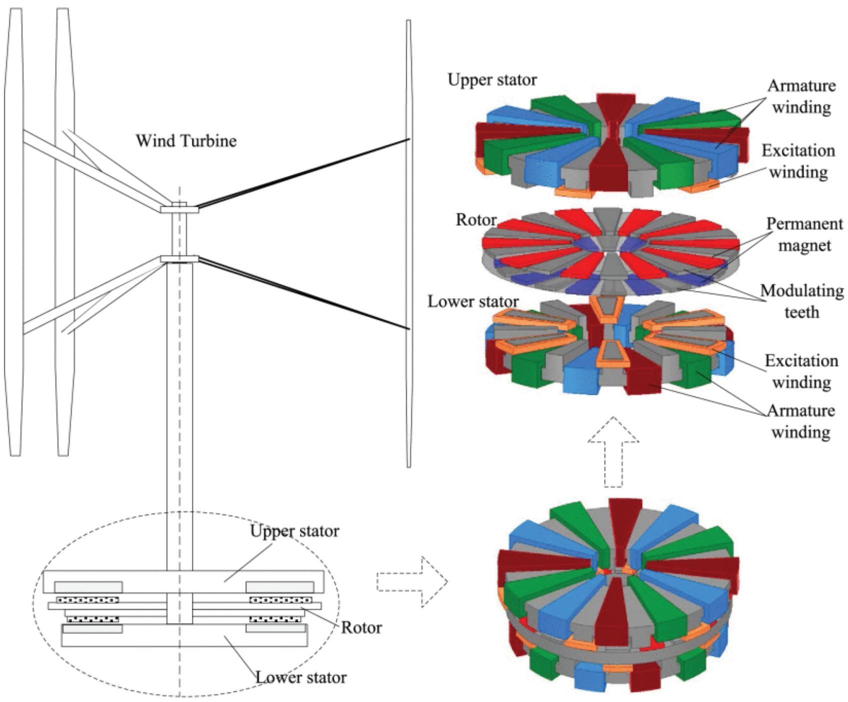


Fig. 7. Structure of the proposed asymmetric-primary axis-flux hybrid-excitation generator

The proposed generator has an upper and lower stator and one rotor, which in turn comprises permanent magnets, rotor teeth, and yoke back iron. The rotor teeth are made of a steel sheet, whereas the yoke is made of a whole piece of steel. To measure the levitation force acting on the rotor, two stators with different diameters are used. However, to keep the terminal voltage of two stators consistent, the winding turns of upper and lower stators should be different. The cross-section of the proposed generator is shown in Fig. 8. Stator teeth are made of steel sheets, whereas the stator yoke is made of a whole piece of steel. The armature windings are wound around on the stator yoke slots, and the excitation windings are wound around the stator teeth. Compared with the rotor excitation generator, this design facilitates thermal management due to the easy heat dissipation in its stator . Instead of both winding armature and excitation on the stator teeth, an improved insulation between the armature and excitation windings can be achieved for a limited contact area. Two stators have a half slot pitch shift to reduce the cogging torque. The current direction of excitation and the magnetization direction of the permanent magnet are shown in Fig. 8.[8]

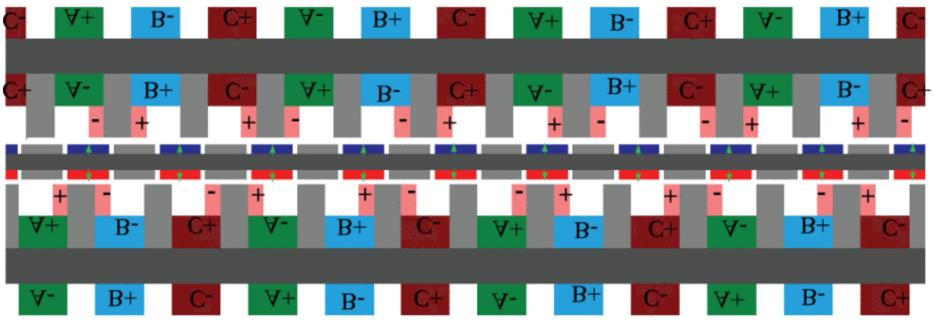


Fig. 8. Circumferential cross section of the proposed generator.

CONTROLER

Wind driven generator system connection diagram is shown in figure 9, the parameters of the generator output voltage, output current, output power and speed et al. can be measured by controller.[15]

Fig. 9. Wind driven generator system connection diagram.

The design of Linear–quadratic–Gaussian (LQG) controllers for pitch regulated, variable speed wind turbines where the controller is used primarily for controlling the pitch angle through a collective pitch angle in the high wind speed in order to guarantee the power regulation. The results show that LQG controller have good performance than proportional–integral–derivative (PID) controller. The simulation results validate that the LQG controller has good follow performance, the rotor speed not large fluctuation, and the output power is maintain a constant power output. The method makes up the shortage of PID control and makes wind power generator to possess well robust stability and dynamic performance.[16]

INVERTOR

The control algorithms for generator speed control and grid tie operation are well understood and are presented in Figure 10 to illustrate the changes needed in the control side to achieve stand-alone and grid-connected modes of operation with seamless transitions.[17]

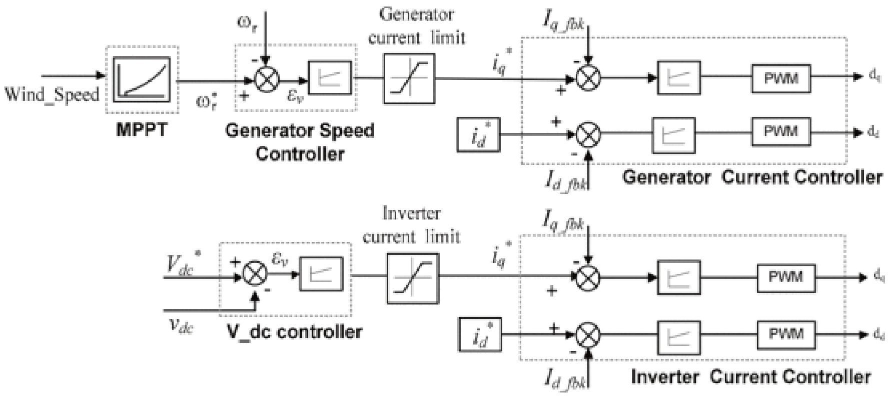


Fig. 10. Conventional converter - inverter control

Data analysis shows that the wind turbine system needs to operate at low wind speed most of the time and wind turbine power electronic systems (inverters) should be designed accordingly to maximize wind potential. Case studies are completed to assess the effect of inverter circuit light load efficiency improvement on the energy yield. If light load efficiencies of the power electronics converter (inverter) of the wind turbine systems could be improved, considerable energy savings could be achieved.[18]

ENERGY STORAGE TECHNOLOGY (EST)/ ELEMENTS

Energy Storage Technology (EST) refers to the process of converting energy from one form to a form that can be stored. The energy could be reserved in various mediums and then converted back to electrical energy when needed. These process are classified as shown in figure 11.[3]

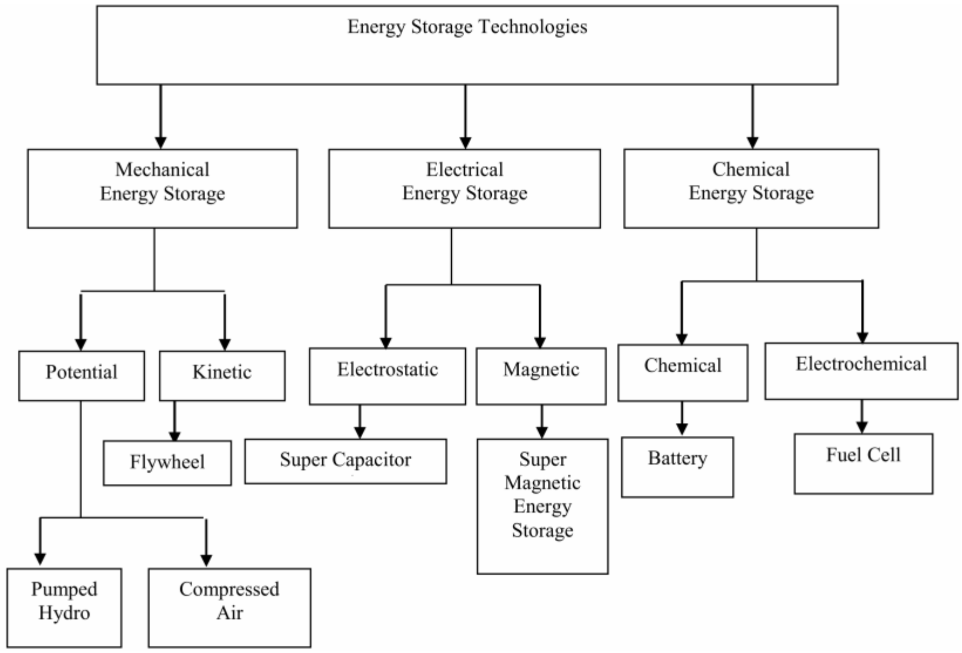


Fig. 11. Classification of energy storage technologies

The major drivers for increasing the use of energy storage are:

- Energy system resources efficiency improvement
- Increasing the integration of variable renewable resources
- Increasing self-consumption and self-production (distributed generation) of energy (electricity, heat/cold);
- End-use sector electrification improvement (e.g., electric vehicles)
- Improved access to energy (e.g., off-grid electrification
- The need for grid stability, reliability and resilience[3]

To feature a wind turbine system with the capability to operate under grid-connected and off-grid modes, an energy storage device is needed to cope with the variability of the wind and the stochastic nature of the load. Furthermore, to transition seamlessly between operation modes without changing the control structure, a new control strategy is required which can reacts to these changes based on the information obtained from the converter's current and voltage measured at the terminals. Figure 12 shows the proposed system configuration where energy storage elements are used to decouple the source dynamics from the load dynamics and to ensure stable operation during transients.[17]

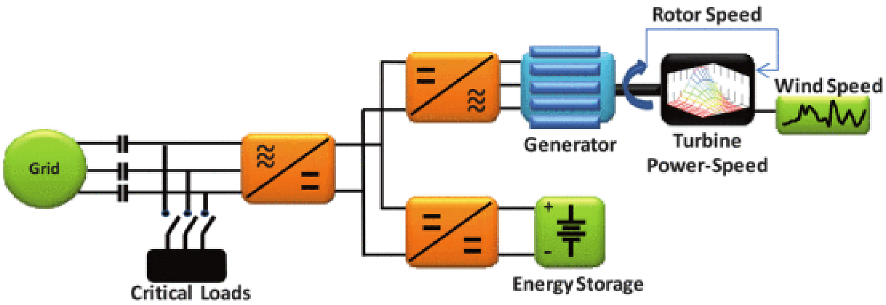


Fig. 12. System configuration for grid and off-grid mode of operation

To demonstrate the feasibility of the proposed system simulation results using average models are presented for a 1 MW wind turbine and a 180 kWh lithium ion battery. The energy storage device used in this simulation is based on a 24V 60Ah battery module from Altairnano. [17]

V. OFFSHORE WIND TURBINE STRUCTURE

Current shallow-water foundations have reached a practical depth limit of 20–30 m. Foundation development is required for deeper water sites and both fixed-bottom and floating turbine foundations concepts are under investigation (Fig. 13). Although not directly applicable to wind foundations, oil and gas design industry practice offers guidance for deeper water.[4]

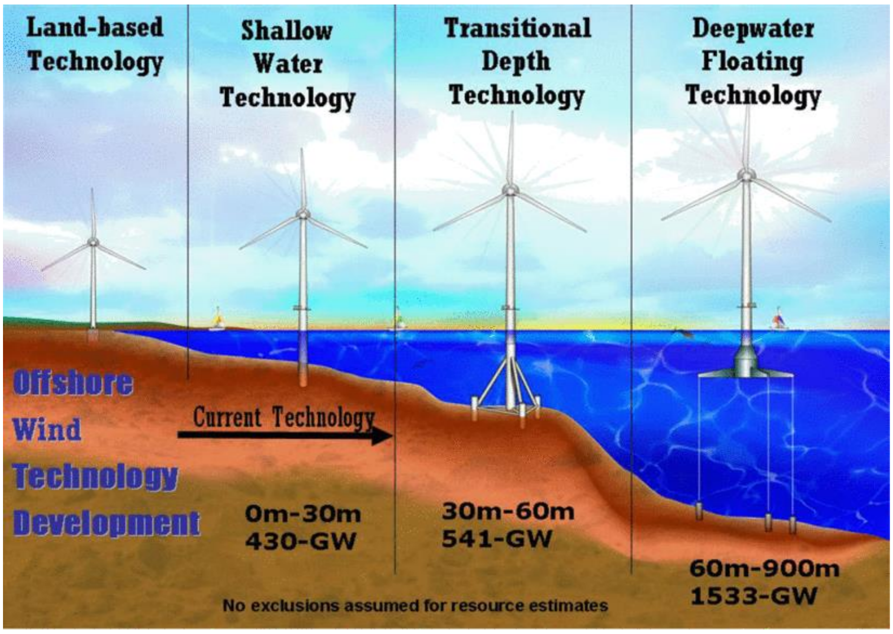


Fig. 13. Offshore wind technology development

Tripod foundation

As shown in Fig. 14 , the tripod foundation consists of a standard 3-leg structure, made of cylindrical steel tubes with driven steel piles, and is well known from the offshore oil & gas industry. Use of tripod foundation has been made down to 450m water depth in the oil & gas industry, but with wind turbine systems there is little experience. The tripod foundation is developed based on the simplicity of the monotower and enhanced by the additional stiffness and strength from the braced structure. The central steel shaft of a tripod structure provides a basis for the transition to the wind turbine tower, similar to the principles for a mono-pile. Numerous steel tripods are installed in the Danish part of the North Sea in water depths ranging from 30 to 60 metres. And the tripod solution is expected to be economical and technical feasible at offshore wind farms at deeper water depths.[19]

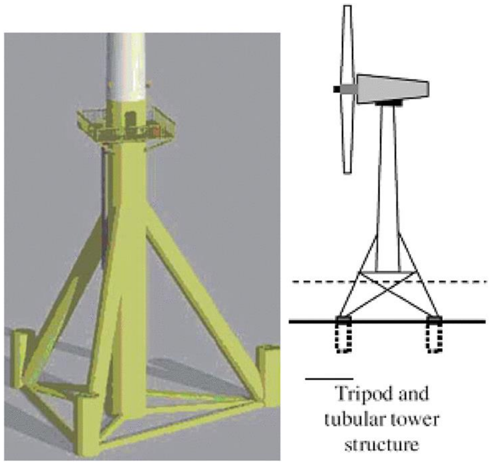


Fig. 14. Tripod foundation for offshore turbines

Floating foundation

Floating offshore wind turbines, on the basis of a buoy concept, are a candidate mainly in shallow water. Currently they have the drawback of high cost, but future solutions may increase their potential. Occasionally, floating platforms on the high seas are also proposed for offshore wind energy utilisation. Such platforms, which are attached to the sea floor by means of lines, are known in offshore technology. They are not an economic alternative for wind turbines in the water depths currently seriously considered for offshore wind energy utilisation. It remains to be seen whether in the far distant future, wind energy will also be utilised at great distance from the coast and thus in water depths which can only be exploited by means of floating platforms.[19]

Conclusions

This paper helps us to find the suitable structure and compound of vertical-axes wind turbine for offshore environment . Additionally, recent developments on generators are introduced including some examples of their implementation in ultra-large operational wind turbines. Finally, this review could help to understand the potential future choices in the design of vertical-axes wind turbine in order to reduce pollution in marine environment.

Bibliografy

[1] M. Beken, B. Hangun, and O. Eyecioglu, “Classification of turkey among european countries by years in terms of energy efficiency, total renewable energy, energy consumption, greenhouse gas emission and energy import dependency by using machine learning,” *8th Int. Conf. Renew. Energy Res. Appl. ICRERA 2019*, pp. 951–956, Nov. 2019, doi: 10.1109/ICRERA47325.2019.8996583.

[2] R. T. Jacob and R. Liyanapathirana, “Technical Feasibility in Reaching Renewable Energy Targets; Case Study on Australia,” *Proc. 4th Int. Conf. Electr. Energy Syst. ICEES 2018*, pp. 630–634, Aug. 2018, doi: 10.1109/ICEES.2018.8443251.

[3] M. Simeon, A. U. Adoghe, S. T. Wara, and J. O. Oloweni, “Renewable Energy Integration Enhancement Using Energy Storage Technologies,” *2018 IEEE PES/IAS PowerAfrica, PowerAfrica 2018*, pp. 864–868, Nov. 2018, doi: 10.1109/POWERAFRICA.2018.8521075.

[4] J. P. Lyons, M. C. Robinson, P. Veers, and R. W. Thresher, “Wind turbine technology - the path to 20% US electrical energy,” *IEEE Power Energy Soc. 2008 Gen. Meet. Convers. Deliv. Electr. Energy 21st Century, PES*, 2008, doi: 10.1109/PES.2008.4596953.

[5] F. Blaabjerg and K. Ma, “Future on power electronics for wind turbine systems,” *IEEE J. Emerg. Sel. Top. Power Electron.*, vol. 1, no. 3, pp. 139–152, Sep. 2013, doi: 10.1109/JESTPE.2013.2275978.

[6] O. Cristea, M. O. Popescu, F. Deliu, and A. S. Calinciuc, “Dynamic performances of a wind power system,” *2014 Int. Symp. Fundam. Electr. Eng. ISFEE 2014*, Feb. 2015, doi: 10.1109/ISFEE.2014.7050635.

[7] N. S. Patil and Y. N. Bhosle, “A review on wind turbine generator topologies,” *Proc. 2013 Int. Conf. Power, Energy Control. ICPEC 2013*, pp. 625–629, 2013, doi: 10.1109/ICPEC.2013.6527733.

[8] J. Liu, Q. Zhang, R. Zhang, J. Hu, L. Zhang, and B. Cai, “An Asymmetric-primary Axis-flux Hybrid-excitation Generator for the Vertical Axis Wind Turbine,” *IEEE Access*, 2021, doi: 10.1109/ACCESS.2021.3091466.

[9] K. Naoi and M. Shiono, “Relationship between Incident Angle of Wind on Rotor Blade and Output of a Drag-type Multi-blade Vertical-Axis Wind Turbine with Stationary Multi-vanes,” *2021 11th Int. Conf. Power, Energy Electr. Eng. CPEEE 2021*, pp. 147–152, Feb. 2021, doi: 10.1109/CPEEE51686.2021.9383349.

[10] J. Alshehri, A. Alzahrani, and M. Khalid, “Wind Energy Conversion Systems and

Artificial Neural Networks: Role and Applications," *2019 IEEE PES Innov. Smart Grid Technol. Asia, ISGT 2019*, pp. 1777–1782, May 2019, doi: 10.1109/ISGT-ASIA.2019.8881404.

[11] F. Blaabjerg and K. Ma, "Wind Energy Systems," *Proc. IEEE*, vol. 105, no. 11, pp. 2116–2131, Nov. 2017, doi: 10.1109/JPROC.2017.2695485.

[12] O. Cristea, M. O. Popescu, and A. S. Calinciuc, "A correlation between simulated and real PV system in naval conditions," *2014 Int. Symp. Fundam. Electr. Eng. ISFEE 2014*, Feb. 2015, doi: 10.1109/ISFEE.2014.7050571.

[13] A. Bensalah, M. A. Benhamida, G. Barakat, and Y. Amara, "Large wind turbine generators: State-of-the-art review," *Proc. - 2018 23rd Int. Conf. Electr. Mach. ICEM 2018*, pp. 2205–2211, Oct. 2018, doi: 10.1109/ICELMACH.2018.8507165.

[14] P. Chimurkar and P. Kothavade, "A review of different power converter topologies for PMSGs wind turbine," *Proc. Int. Conf. Commun. Electron. Syst. ICCES 2016*, 2016, doi: 10.1109/CESYS.2016.7889987.

[15] C. Zhao, J. Luo, S. Xie, and H. Li, "Experiment validation of vertical axis wind turbine control system based on wind energy utilization coefficient characteristics," *2015 IEEE Int. Conf. Cyber Technol. Autom. Control Intell. Syst. IEEE-CYBER 2015*, pp. 1640–1644, Oct. 2015, doi: 10.1109/CYBER.2015.7288191.

[16] X. Yao, C. Guo, Z. Xing, Y. Li, S. Liu, and X. Wang, "Pitch regulated LQG controller design for variable speed wind turbine," *2009 IEEE Int. Conf. Mechatronics Autom. ICMA 2009*, pp. 845–849, 2009, doi: 10.1109/ICMA.2009.5246272.

[17] L. Arnedo, S. Dwari, S. Motapon, and V. Blasko, "System level wind turbine controls with seamless transitions between standalone and grid connected mode," *PEMWA 2012 - 2012 IEEE Power Electron. Mach. Wind Appl.*, 2012, doi: 10.1109/PEMWA.2012.6316389.

[18] S. Ozdemir, U. S. Selamogullari, and O. Elma, "Analyzing the effect of inverter efficiency improvement in wind turbine systems," *3rd Int. Conf. Renew. Energy Res. Appl. ICRERA 2014*, pp. 572–575, Jan. 2014, doi: 10.1109/ICRERA.2014.7016449.

[19] L. Li and J. Ren, "Offshore wind turbines and their installation," *CICC-ITOE 2010 - 2010 Int. Conf. Innov. Comput. Commun. 2010 Asia-Pacific Conf. Inf. Technol. Ocean Eng.*, pp. 248–251, 2010, doi: 10.1109/CICC-ITOE.2010.69.