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A Critical Review of Wind Energy Based Power Generation Systems

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Abstract: Wind energy based power generation is globally popular as renewable source of energy and nowadays it is bridging the gap of increasing energy demand of world. It is termed as one of the best solution to the usage reduction of fossil fuels and in turned fighting with the problem of global warming.

The presented manuscript not only enumerates the significance of wind power but also highlights the important issues associated with wind energy based power plants: important ones are social and environmental. A case study is also presented in the paper modeled as wind energy generation system. Researchers and scientists are welcomed to provide the solutions to these highlighted issues so that these solutions can be used worldwide. This will make wind energy more popular and will be promoted exponentially.

Keywords: Wind energy, renewable energy sources, environment factors, social issues.

Introduction

The world is facing many-fold energy requirements i.e. not fulfilling the demand of energy and the environmental hazards due to usage of these resources. Soaring energy demands, the tariffs and the environmental issues place the necessary role of affordable and clean energy in economic and environmental evolution. Chaurasiya et al. (2019) and Kar et al. (2015) evaluated that the conventional energy sources (diesel, coal fired plants etc.) are contributing hazardous and irreversible environmental damage. Increment in greenhouse gas (GHG) emissions in the outer environment is a crucial factor which is byproduct of non-renewable sources based systems. Total GHG emission in 2010 was 54 giga-tonne (Gt) CO_2 (eq.) and is proposed to grow to 70Gt CO_2 (eq.) by 2050, and this seems to be very dangerous to human kind. Wind energy sources can play a very important player in this context. This type of renewable energy sources are becoming very popular and adopted by many nations to fulfill their energy demands (Leung et al., 2012; Ritchie et al., 2020).

But lots of problems and issues are also associated with integration of wind energy based systems with the grid or off the grid. These issues arise because of intermittency of the nature of wind energy or such type of renewable energy sources. In India, National Institute of Wind Energy (NIWE), various scientists and researchers are operating in-line to implement these developments in the existing platforms through several researches, studies, workshops and training programmes. Ezio and Claudio (1998) focused on the intermittency of renewable energy sources which can be compensated using the hybrid combination of conventional and nonconventional energy sources. The hybridization of the conventional energy sources not only reduce the impact of intermittency but also results in the cost effective energy solutions.

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In the conventional power system the required reactive power is transported through the transmission lines to load centres. In the proposed hybrid energy systems the load is directly connected to generator terminals; therefore the required reactive power demand of loads is fulfilled locally. It is recommended to connect synchronous machine as conventional energy sources while an induction generator represents the nonconventional energy sources. Therefore hybrid power system can give full insight of the differences in the reactive demand of both types of machines.

Wind energy potential mainly depends upon parameters such as wind velocity, its nature and fluctuations intensities etc. India ranks 4th in the world in terms of total installed wind energy. Zouros et al. (2005) estimated that the projected growth of wind energy production is 4-5 times of present growth. As per National Institute of Wind Energy (NIWE) and Global Wind Energy Council (GWEC) report, 2016, wind energy is biggest energy provider among renewables which is more than half of total available energy sources (Figure 1).

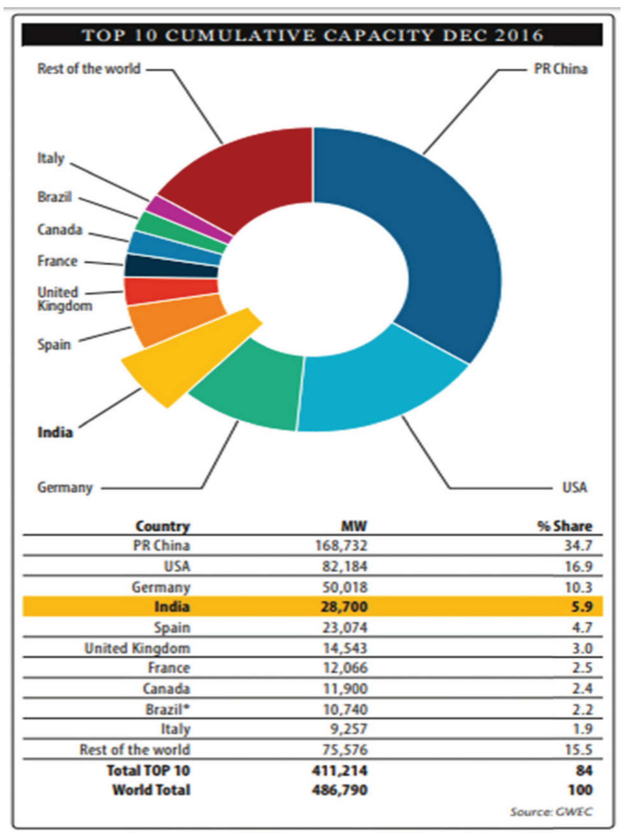

Figure 1: Top 10 cumulative capacity in the world (Dec 2016) [NIWE].

Table 1: State-wise installed capacity of Grid Interactive Renewable Power as on 31.01.2020 [NIWE] [GWEC]

Sr. No.	*Wind project*	*Capacity (MW)*
1.	Andhra Pradesh	4092.45
2.	Karnataka	4754.90
3.	Kerala	62.50
4.	Madhya Pradesh	2519.89
5.	Maharashtra	5000.33
6.	Rajasthan	4299.72
7.	Gujarat	7460.02
8.	Tamil Nadu	9285.49
9.	Telangana	128.10

Advantages of Wind Energy

Wind energy sources possessed many merits. The most desirable one is the environmental edges because of no harmful emissions. As a result, the carbon footprint from wind energy sources can be minimized. Ramachandra and Hegde (2016) and Muhammad Irfan et al. (2019) calculated that if 15 TWh/year power is generated from wind energy sources, a massive 7000 tons of CO_2 emissions could be avoided. Second advantage is that the generated power from wind sources is cost effective in comparison to coal or any other non-renewable energy sources. Another and most important advantage of wind energy sources is to connect the isolated rural areas which are not connected with grid. This will also uplift the development of these isolated rural areas without polluting the environment (Ming et al., 2010; Hammons, 2008).

Problem and Issues

Design Factor

The designing of turbines and induction machine are one of the main challenges in wind energy farms. Padgetl (1998) proposed a model for the optimum usage of wind turbines influenced by the pitch angle. Researchers studied the effect of many factors affecting the wind energy generation using adaptive neuro-fuzzy inference system (ANFIS). It is calculated that blade pitch angle is very important variable which affects the energy generation.

Petkovic and Shamshirband (2015) proposed a model which can predict strength of the fibrous materials used for designing the blades. It predicts the failure objects, which does not satisfy the strength levels. These research methodologies help in developing the blades which facilitate higher lift-to-drag ratio. Martinez et al. (2009), Tremeac and Meunier (2009) and many more researchers are also focusing on Building Augmented Wind Turbines (BAWT) with a motto of increasing the utilization of available wind energy.

Industry Challenges

Following issues are associated with industries:

(i) Location disadvantage: Wind energy is not available everywhere.
(ii) Another major issue is about design issue of outdated wind turbines.
(iii) Lack of financial support, increased the wind energy industry development
(iv) Same as other renewable energy sources, wind energy industries are also capital intensive. A very large financial support is mandatory to establish a new plant and machinery at remote locations.

Location Issues

A very large area is required for the wind farms. The main advantage for the choice of rural areas for the wind energy farms is because of ample land availability and alternate use of farms for agriculture purposes. The power developed in wind power systems depends on wind velocity. Wind velocity is usually affected by high rise buildings. Therefore it is preferable to set up the wind energy farms in open rural areas at required heights.

The other climatic factors which can affect the wind speed are changes in seasons, storms etc. These factors can introduce the fluctuations in the wind speed and as a result of that wind power quality is also affected. For such problems Flexible AC transmission system controllers can be used. But for reliable power supply some other conventional sources of energy is also required.

It is also necessary to develop a model for forecasting of availability of wind energy and its velocity. Weibull probability density function is one of the factors calculated to predict the wind velocity distribution. Scientists used Extreme Learning Machine (ELM) to calculate different elements of Weibull function and proved the worth of ELM method in terms of accuracy and precision (Magoha, 2003). Many more techniques like Support Vector Machine, Genetic algorithm, ANFIS etc. can also be used to forecast the wind velocity distribution.

Environmental Issues

There are mixed reviews about the environmental effect of wind energy sources as it can affect environment in both manners. It has both merits and demerits, estimated based on environmental effects. Energy produced by such farms never produce pollutants like carbon dioxide, sulfur dioxide etc. It is calculated that 1 kW wind farm can reduce the generation of 0.4–1.2 tonnes of carbon dioxide (Rebecca, 2009; Leung, 2012). However, it has many negative impressions also. There is significant negative effect on the wildlife. It can also affect the hearing and vision capability of human life.

Wildlife Issues

The wind energy farms can affect the wildlife directly and indirectly. The direct effect is the death of birds due to blades strikes and the indirect issue is habitat dislocation. Two federal scientists and the environmental consulting firm West Inc estimated that wind machines blades kill approx. 0.2-0.36 million birds yearly in comparison to the bird deaths because of strikes with communication towers and the 1.4 billion to 3.7 billion deaths from cats. Sovacool (2009) and Thaxter et al. (2017) estimated that the shape and location of wind farms do not decrease the bird death rate very significantly. Although, these negative issues related to wildlife must be treated very seriously so that the more penetration of wind energy sources are increased.

Cathy (2012) observed that the wind turbines having low hub heights, small rotors (high rotational speed) and little spacing between blades results in killing of more birds than big wind turbines of having large rotors. Figure 2 shows that larger turbines were responsible for more birds and bats strikes, although a large number of small turbines resulted in forecast of greater mortality rates. Nowadays avian radars are also developed for the detection of presence of birds in the proximity of turbine blades. These radars detect the presence of birds, and release the signal to the control system, which further stall the rotation of wind turbines immediately and restart those turbines after passing of birds.

Noise Impact

Noise pollution is one of the most critical environmental challenges faced by the wind farms. It usually reduced the property's value within the proximity of wind energy systems. These wind farms also produce the very high

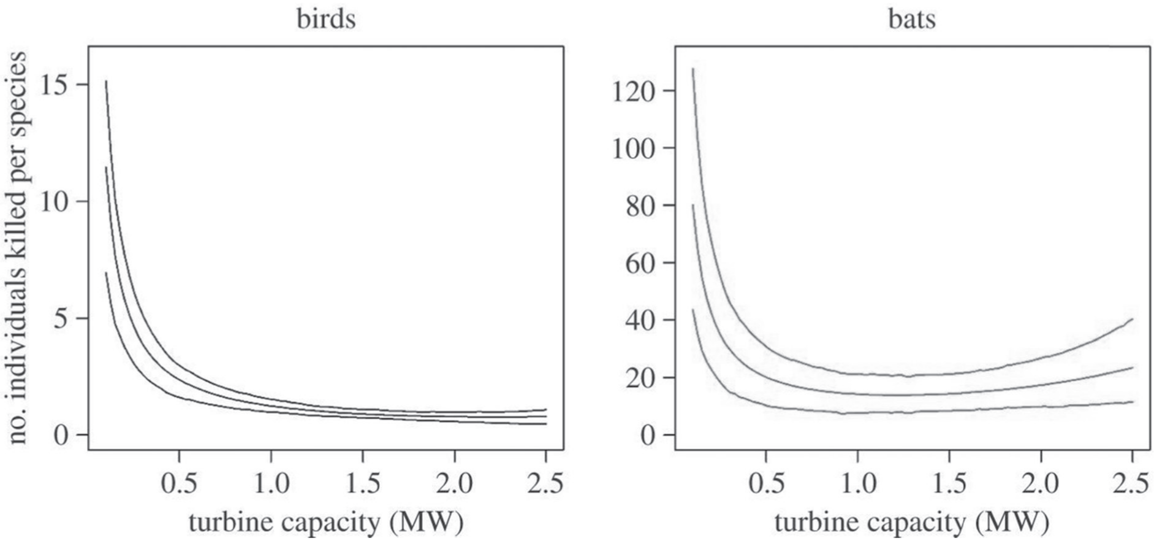

Figure 2: The mean total mortality rate across species for a hypothetical 10 MW wind farm (Qiao et al., 2009a)

decibels which is really dangerous to human health (Martin, 2004). Therefore it is highly desirable to find out the methods to curb the noise pollution generated by wind turbines. Figure 3 depicts the variation of decibels produced by turbines and changes in the wind velocity with respect to time. The continuous noise generated by wind machines is measured in decibels in L90 metric forms (Oerlemans et al., 2007).

Noise pollution produced by a wind turbine can be classified into two forms: aerodynamic and mechanical. Aerodynamic noise is resulted because of the air flowing through the blades and it is directly proportional to velocity of the rotor. The proper designing of the blades can reduce such type of noise levels. The rotating parts such as gearbox, generator, bearings etc. generate the other type of noise i.e. mechanical noise. Wear and tear, design lacunas and maintenance scarcity increases the levels of mechanical noise. Acoustic insulation curtains are used to reduce the mechanical noise levels.

Financial Challenges: High Investment

A very high capital investment is required for setting of a wind farm and large portion of investment is designated for the initial establishment. The initial investments are estimated as 80% of the total investment of the wind farm. Following are the divisions of total investment for setting of wind farms:

(i) Initial costs include wind machine, basic structure and integration with grid
(ii) Regular costs include operation and maintenance costs
(iii) Comparatively lower plant capacity factor
(iv) Financial repayment of the investment.

Due to the fluctuating nature of wind, high investment is required in the control system of wind farms that further lowers the return of investment value. Blanco (2009) proposed a model for appropriate layout of wind energy systems based on turbine interactions and various expenditures.

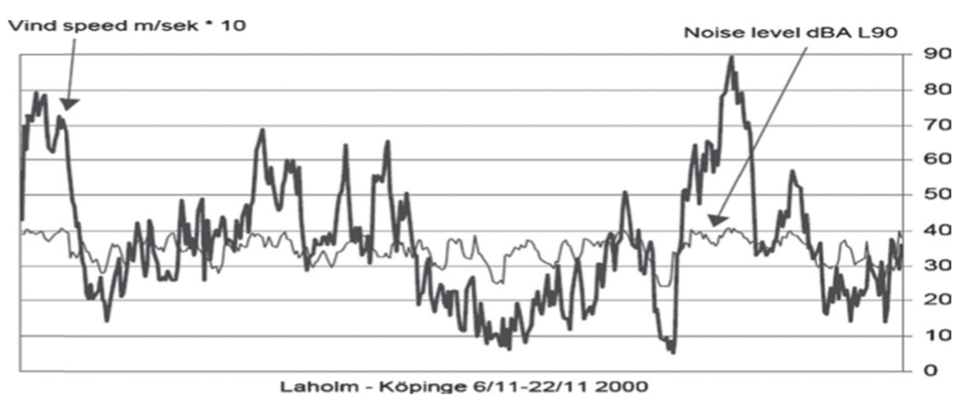

Figure 3: Wind speed and noise level in dBA L90 versus time.

Technical Challenges

Wind farms are usually located in rural areas or isolated locations due to the availability of land, higher wind speed and auxiliary usage of land. There are many issues associated with wind energy systems integrated with grid. In some cases i.e. locations, grid infrastructure is not available and even if grid is available, integration of wind power systems generates many technical issues like voltage instability, frequency disturbances etc. because of intermittency of wind energy (Qiao, 2009b).

The changes in voltage and grid frequency may affect the active and reactive power generated or required. Fluctuations in the wind power can introduce power quality problems (Ullah et al., 2009) such as reactive power deviations, low power factor and frequency and voltage fluctuations.

To combat these technical issues, these wind farms must be properly designed and flexible AC transmission system (FACTS) controllers can be used to control all such parameters of power systems. Bindeshwar Singh et al. (2010) and Gaztanaga et al. (2007) suggested many advanced FACTS devices like STATCOM, UPFC etc. which are available technically and can control both reactive power, voltage instability and also increase the active power flow of the system. For the reliable supply of power all the times it is necessary to integrate these wind farms with grid. If grid connection is not available then an auxiliary source of power may be used and this must be non-renewable type of power generation. This is required to overcome the turbulences of wind energy and preferable sources are diesel, thermal power systems etc. This will also bridge the gap of demand and supply of power and will act as energy reserves. During large wind availability periods there will be extra power (frequency variations) (Canizares et al., 2004). Hence, it is required to curtail the extra power generated by using converters or reducing the performance of the rotor. Further reactive power demand of the induction machines can be achieved by FACTS devices or other type of converters. This compensation of reactive power will also stabilize the voltages of the system.

Case Study

A test power framework is presented in Figure 4, comprising an induction generator, a diesel generator and a FACTS controller UPFC; these are embedded in four-Bus test framework. The scaffold between the era and request of dynamic and reactive power profiles are unmistakably introduced in this area. The two distinct sorts of machines have diverse reactive power request; in this way the two sorts of machines' profiles are used here. The work is performed in SIM power system tool of MATLAB programming shown in Figure 4. Two phases are canvassed in this examination: first when UPFC is not conveyed in the proposed hybrid detached interconnected framework and second when the UPFC is employed in the test system. Usually Induction Generator which is broadly utilized for wind vitality sources is retaining a lot of reactive power though synchronous is making a decent attempt to remunerate this. In any case, the breeze speed is additionally influencing the producing reactive power. In this manner

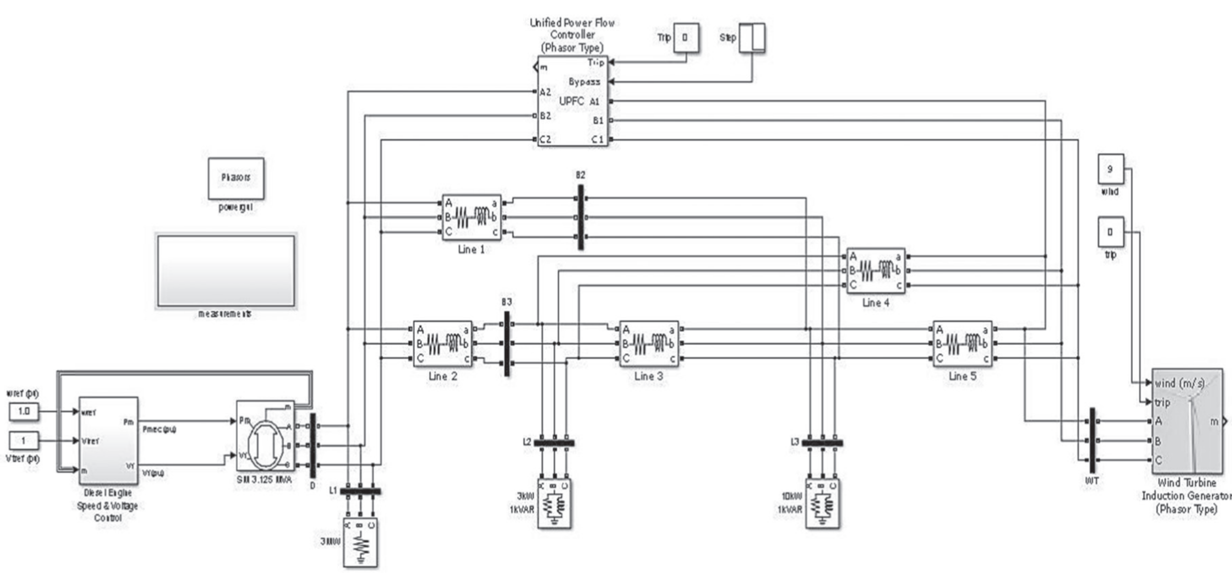

Figure 4: Simulation diagram of test system with UPFC.

two elements are influencing the voltage steadiness of framework, initial one is the variations in reactive power and the second one is the breeze speed which continues differing. As associating settled capacitors are not fit for giving dynamic compensation. At that time, the dynamic volt-ampere reactive requirement at these terminals that has to be provided by UPFC is chosen as the distinction between full-load and no-load compensation.

Figures 5 and 6 are presenting the real and reactive power requirement of different machines in the test system; it is also proved here that UPFC is continuously regulating the reactive power requirement of proposed system. UPFC has been inducted in the test system in these time based simulations at 10 seconds and within two seconds, it supplies the reactive power to induction machine/wind turbine system and also damping out the oscillations in the output waveforms of wind turbine generator system which is connected at bus 'WT'. UPFC is also absorbing the surplus reactive power which is supplied by synchronous generator/diesel system. Here also UPFC is deployed at time of 10 seconds and again UPFC stabilizing the P-Q profiles at bus 'D' within two seconds. So, in this manner, the equalization of reactive power of the system is achieved by the assistance of UPFC. Therefore, UPFC is playing important role of a dynamic compensator for the power system and to be verified as most dynamic FACTS controller.

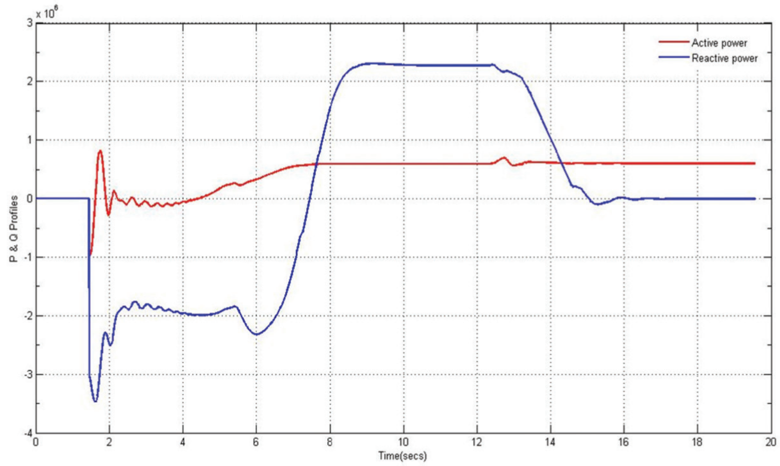

Figure 5: Active and reactive power of diesel generator of test system with UPFC.

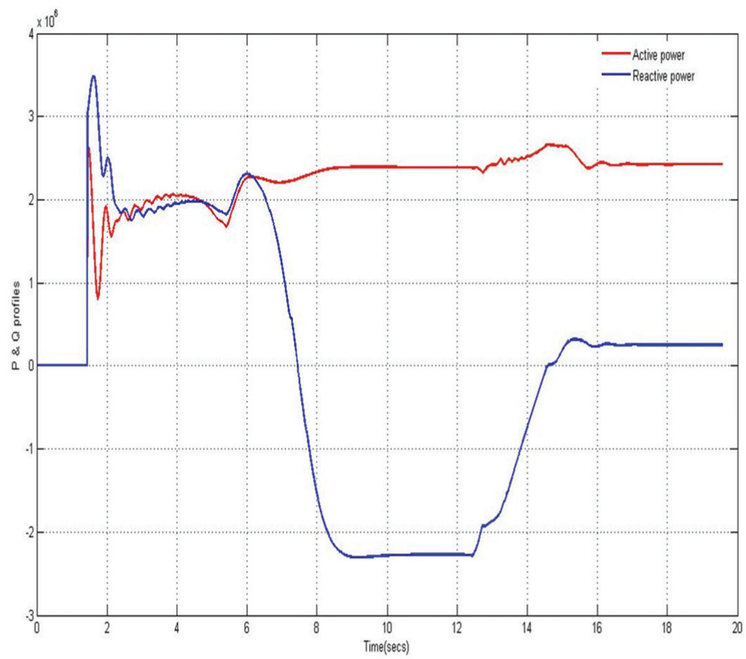

Figure 6: Active and reactive power of induction generator of test system with UPFC.

Conclusion

The importance of wind energy as well as the key issues or challenges associated with wind energy based power are highlighted and estimated. Important issues like social and environmental are specially emphasized. A very important technical issue of reactive power requirement is highlighted with the help of a case study presented in the paper modelled as wind energy generation system. Results shown through the case study clearly stated the demand of reactive power required by induction machines used in wind farms. Still wind energy is termed as one of the best solutions to the usage reduction of fossil fuels and in turn fighting with the problem of global warming. Researchers and scientists are welcomed to provide the solutions to these highlighted issues so that these solutions can be used worldwide. This will make wind energy more popular and will be promoted exponentially.

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