

Wind Energy: Trends and Enabling Technologies

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Abstract: *With attention now focused on the damaging impact of greenhouse gases, wind energy is rapidly emerging as a low carbon, resource efficient, cost-effective sustainable technology in many parts of the world. Meta-analysis of net energy return for wind power systems also places wind in a favorable position relative to other forms of power generation. This paper summarizes the trends in wind energy development over the years across the globe. Despite higher economic costs, offshore appears to be the next big step in wind energy development alternative because of the space scarcity for installation of onshore wind turbine. Among various factors, the wind farm layout design is an extremely important component for ensuring the profitability of a wind farm project. Latest technological developments taking place in the area of reliability of wind turbines and improvements in the properties of the materials used will make wind energy more competitive in the next decade. Although wind energy faces many technical, social and environmental challenges, it will become a viable choice amongst the renewable sources of energy both for developed and developing nations and will play a key role in preserving green environment. This paper presents the global scenario for wind energy, the importance of offshore wind energy, the wind farm layout design, the off-shore wind turbine technological developments, the role of sensors and the smart grid, and the challenges and future trends of wind energy.*

I. INTRODUCTION

Non-renewable energy is limited, expensive and pollutes the environment. Public and policymakers must understand the nature of global energy crisis and should have an appreciation of the underlying science. Increased world population and integrated global economy contribute to larger demands of electricity. Many countries are still heavily dependent on oil and gas, which will eventually get depleted within next few decades, and the cost of extraction will skyrocket for the remaining oil deposits. In its 2008 World Energy Outlook, International Energy Agency (IEA) predicts that average price of crude oil will reach \$100 per barrel by 2015, and about \$120 by 2030 [1]. From these predictions, it appears oil prices are not going to decrease further and that price fluctuation will continue [2][3].

As shown in Fig. 1, coal is still by far the major source for energy generation. If such a high dependence on coal continues and energy demand continues to increase, coal will be depleted during the lifetimes of children born today. Combustion of coal is one of the largest causes of carbon dioxide emissions and acid rains leading to global warming [4]. Nuclear energy is considered a health, safety and environmental threat and a potential source for nuclear proliferation as well as leads to problems associated with the disposal of nuclear waste. Though efforts are being undertaken to bring down the cost, currently photovoltaic or solar energy

continues to be far too expensive [5][6]. A recent survey of wave energy by the Carbon Trust in Britain found that the current cost of wave energy is about 10 times the price of electricity from fossil fuels so this still has a long way to go before becoming competitive [7]. Production of bio fuels results in loss of animal habitats, increased food prices and carbon dioxide emissions.

Wind energy, an emission-free renewable source of energy is becoming a very attractive alternative to volatile fossil fuels. Currently it generates less than 1% of the world's electricity today, however, the stable technological growth of wind power suggests that it could become an indispensable energy source for many nations in the next decade [8][9]. Wind energy releases no pollution into the air or water, and does not contribute to global warming. Unlike most other electricity sources, wind turbines do not consume water and unlike fossil fuels no extraction from the earth happens at great environmental cost. Instead, wind turbines make use of a boundless supply of kinetic energy in the form of wind which is a freely accessible source of energy. And unlike other power plants, wind energy systems require minimal maintenance and have low operating expenses [10]. Though the average cost for a commercial scale wind turbine is anywhere between \$1.2 million to \$2.6 million, per MW of nameplate capacity installed, wind turbines are potentially very reliable, thus making kWh costs competitive to thermal energy. Among renewable sources, wind energy technology is much more mature and developed than solar or wave energy today [11].

Wind has the advantages like stable generation costs, low operating costs, being renewable, short energy payback, less time-to-market, being abundantly available, and not causing pollution. Meta-analysis of net energy return for wind power systems also places wind in a favorable position relative to other forms of power generation, and it is also suggested that wind energy could yield significant economic and social benefits relative to other power generation systems [13]. Ongoing technical progress in wind energy technology will undoubtedly lead to further energy cost reductions.

The paper is organized as follows. Section II presents the global energy picture. Section III discusses the offshore/onshore scenario and challenges. Section IV presents latest offshore technological developments. Section V discusses wind farm layout design. Section VI focuses on the reliability issues related to wind turbines. Section VII discusses smart grids. In section VIII, latest sensor technologies and the advantages of wireless sensor networking are briefly discussed. Section IX discusses cost of wind energy generated electricity. Section X presents some present challenges facing wind energy. Section XI focuses on wind energy and its future. Finally, section XII presents summary and conclusion.

II. GLOBAL SCENARIO OF WIND ENERGY

Over the years, wind energy developments have led to increased turbine size and capacity, while greatly reducing the cost. The wind energy market is rapidly expanding worldwide. Fig. 2 shows the increase in the global installed wind capacity from 1.7 GW (1700 MW) in 1990 to 100 GW in 2008, over 27 GW of which came online in 2008 alone. From 1997, it increased at a rate of 35% per year, and the market has grown at a rate of 29%. In 2008, six countries, namely United States, China, India, Germany, Spain and Italy added capacities of more than 1 GW. In 2009, the installed wind power capacity in the EU reached 74.7 GW (up from 64.7 GW at the end of the

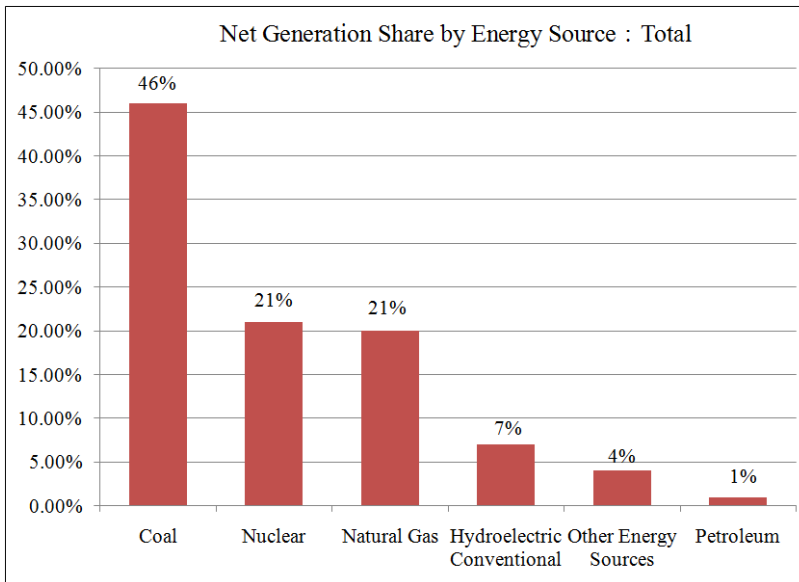


Fig. 1. Net energy generation share by energy sources in U.S.A.

previous year), with Germany leading the European countries with 25.7GW of installed capacity. Asia has also experienced the strongest increase in installed wind power capacity. According to an official of National Energy Administration (NEA), China's installed wind power capacity has been increased from 0.8 GW (2004) to 12GW (2008) and is estimated to be more than 20GW in 2010. The estimated figure will lift China to the third place following the United States and Germany [14]. By the end of year 2009, the Indian wind energy sector had an installed capacity of around 11 GW putting India at fifth place in the world in terms of wind power. India has the potential of 70,000MW of wind power, and this may go up to 200 GW by exploring new wind areas and using larger and latest turbines. This growth could lead to exciting opportunities for collaboration between developed and developing nations on the wind-energy front in new installations, upgrading existing installations, energy production, transport, storage, and efficient utilization.

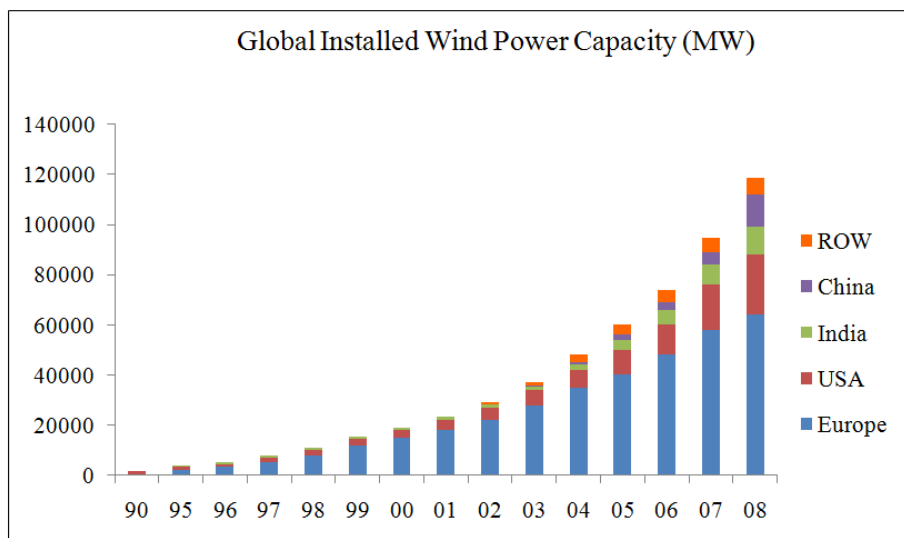


Fig. 2. Global installed capacity of wind power [15]

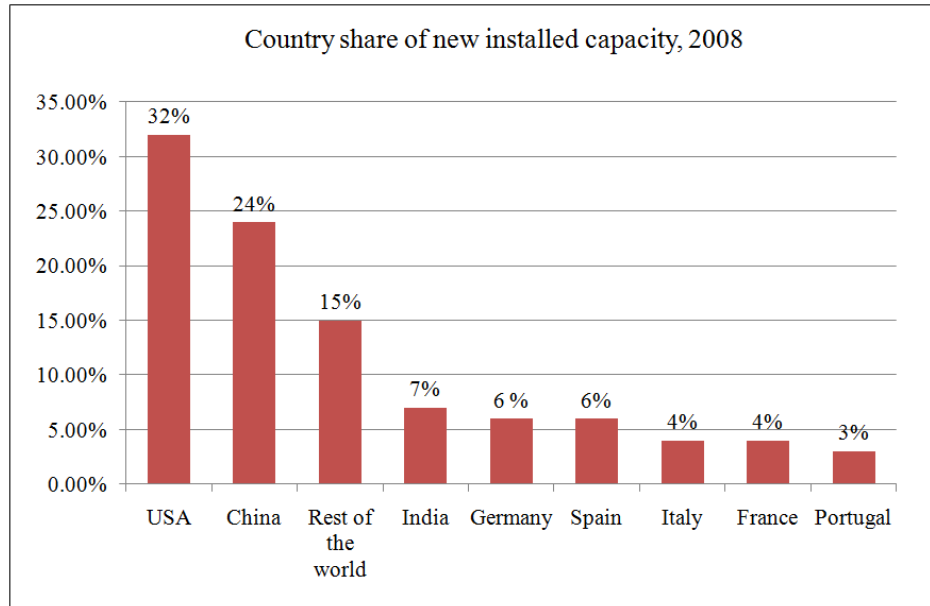


Fig. 3. Country share of new installed wind power capacity, 2008 [17]

Since 1998, the market for new wind turbines has increased by ten times. According to the latest figures, USA overtook the global number one position from Germany, and China took the lead in Asia getting ahead of India for the first time. The USA and China accounted for 51% of the wind turbine sales in 2008 as shown in Fig.3. Denmark is still a leading wind energy producing country with a wind power share of around 20% of the electricity supply and plans to reach 50% [16]. In the light of the threefold global crisis– the energy crisis, the economic crisis and the environment/climate crisis – wind energy has a place in the solution of these challenges

III. ONSHORE AND OFFSHORE WIND ENERGY

Onshore wind farms in hilly or mountainous regions are generally located three kilometers or more inland from the nearest shoreline. This is done to exploit the topographic acceleration as the wind moves over a ridge. The additional wind speeds gained in this way make a significant difference to the amount of energy that is produced. Onshore wind farms have several advantages including cheaper foundations, cheaper integration, low maintenance costs, easy integration with electric grid, easier access and operations. However, they are often subject to objections due to their negative visual impact or noise, land disputes, and restrictions associated with buildings, mountains, etc. These factors explain the reduction in the onshore wind farm installations with a high percentage of denied applications [18].

Offshore wind power is still in its infancy, compared to the onshore wind energy. Denmark was the pioneer in this field as it built the first offshore wind farm in the world in Vindeby in 1991. It has now eight operating wind farms, including the biggest one in the world, located at Horns Rev in the North Sea composed of 80 turbines producing 160 MW generating enough power to meet the demand of 150,000 Danish homes (Fig. 4). Offshore wind is itself environmentally benign; it generates no routine emissions; it disturbs the sea-bed to a very limited extent. Wind turbines can be sited offshore, where the wind blows harder and larger turbines can be installed. Many offshore wind farms are being proposed and developed today in densely populated Europe, where there is limited space on land and relatively large offshore areas with shallow water. There



Fig. 4. Horns Rev offshore wind farm, Denmark [21]

is some concern about the impacts of wind energy on birds. Birds can be affected due to collisions caused by the rotating turbine blades, but incidence levels are not high when compared to other causes of bird fatalities like transmission lines, vehicles, pesticides, cats, etc. However preventive steps like turning turbines off during the migratory periods can minimize the number of bird fatalities. Considerable additional research on operational wind facilities is required to provide a comprehensive assessment of the potential magnitude of these risks. There could be an environmental impact from carrying out work offshore, such as localized disturbance of the seabed but again the level of disturbance is small as compared to the size of the oceans [19].

There are various key issues attached with offshore wind farm industry including response of the turbine structure to joint forces, operating at different frequencies - such as those due to winds, waves, currents, and rotor movements; impacts of extreme events in currents, tides, winds, and waves (including breaking waves); sediment scour and accretion through and around the farm site; cable routing-hazards, burial depths, land/sea interfaces; shipping and aviation risks, including collision; operating conditions for maintenance and repairs etc., all of which need to be addressed [20]. Offshore wind data has different characteristics versus onshore, and there is little data available for coastal waters directly. The variation in wind speed in the coastal zone needs further research and accurate wind forecasting for grid control. With increased size of projects, turbines should be optimized for conditions pertaining to a particular site (e.g. temperature, air density, corrosion, tower height, blade length, rpm output, etc).

The higher economic costs of offshore wind power relative to onshore wind power could be justified, if the ecological or social costs of offshore wind were significantly different from onshore wind power, but this is not the case at present. Both on and offshore wind powers face local opposition due to user conflicts [22]. But the potential of offshore wind energy may be exploited near major population (energy load) centers where energy costs are high and land-based wind development opportunities are limited [23]. This is seen today in the UK where a new offshore wind farm known as “London Array” is about to be built with up to 341 turbines generating 1 GW located just 12 miles offshore in the outer Thames estuary. The ecological

impacts of offshore wind power affect a very different ecosystem than onshore wind power, and as a result, their ecological impacts are not directly comparable. However, like onshore wind, it is clear that offshore wind power does have ecological impacts with the potential for population level effects. Decreasing wind turbine costs and/or legislations capping greenhouse gas emissions could increase the profitability of offshore wind, but would not change the fact that onshore wind will be a less expensive alternative considering the transmission costs.

IV. OFFSHORE WIND TURBINES AND TECHNOLOGICAL DEVELOPMENTS

Economics of offshore wind turbines are dependent on the water depth. Floating systems may have unique advantages as compared to fixed systems depending on the topology, wave, sea ice, and seabed conditions. The benefits of various engineering solutions are quite different for shallow and deepwater applications [16]. Fig. 5 shows the technological progression of offshore wind turbines.

- i) **Shallow Water Foundations:** Offshore wind energy began in shallow waters of North Sea, where the abundance of wind and other site conditions are more favorable compared to land-based alternatives. The first shallow water installation was in Sweden with a single 300 kW turbine in 1990, and the industry has grown slowly over the past fifteen years.
- ii) **Medium Depth Water Foundations:** Weather model assessments indicate a sharp increase in wind speed as the distance from shore increases. Wind turbine sitting options also increase, as there are more feasible wind sites, less visual impacts, and less number of contending users of sea bed. These favorable conditions will progressively attract developers to deeper waters [24]. Much of the technology required to set up the wind turbines in deeper water is already available with the petroleum, oil and gas industry. However, new technology is still required to make wind energy economically more competitive when compared to other renewable alternatives [25]. Tripod steel structures are considered a better option in deep waters however concrete gravity based structures are also being considered if piling is not an option.
- iii) **Floating Platform Concept:** Floating wind energy systems have emerged as a promising technology for the utilization of offshore wind resources. Floating wind turbines significantly reduce the overall weight of the structure and can be assembled onshore. Floating platform configurations may vary widely. Typically, the architecture of a floating platform is determined by the stability analysis, size and type of final design. Fig. 6 shows the three categories of floating platforms based on distinct principles, namely, ballast, mooring lines and buoyancy systems. A typical seabed anchor system is shown in Fig. 6. However, variation could be added to its design by including piles, piled anchors and gravity bases as required. Not all of the above developments are economically acceptable and require detailed cost studies before being accepted.

Ballast systems use weights and mooring lines in tension, whereas buoyancy systems use distributed buoyancy to achieve stability. Each of these approaches for achieving stability can be thought of an ideal vessel with limited properties; some of these characteristics may be desirable and some may be undesirable for use on a floating wind turbine [26].

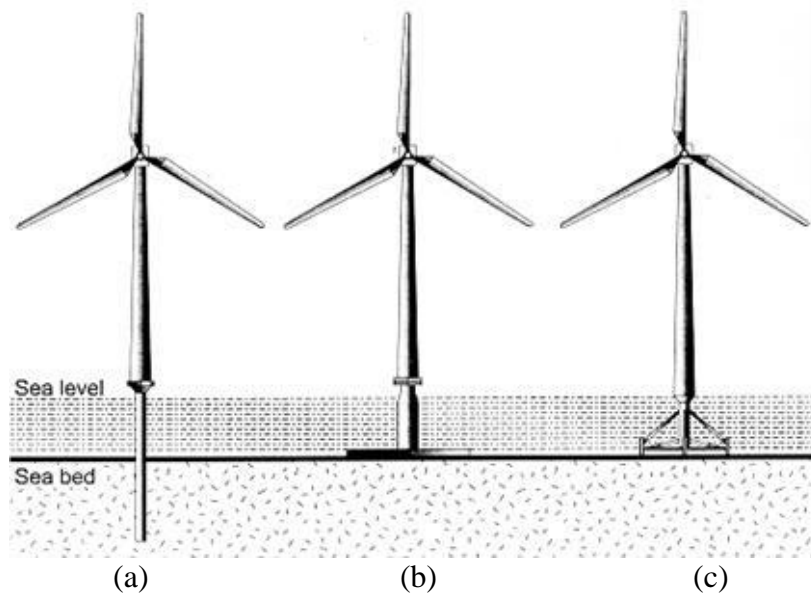


Fig. 5. (a) Mono-pile, (b) Gravity, and (c) Tripod Offshore Wind Turbines [27]

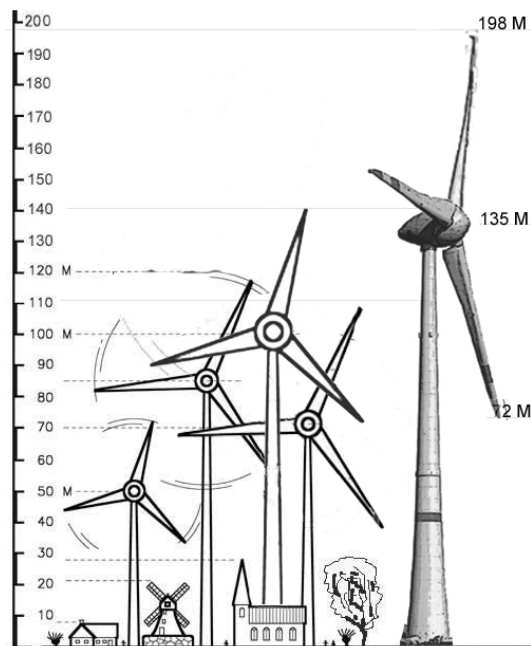


Fig. 6. Types of Onshore wind turbines

V. WIND FARM LAYOUT DESIGN

Rapid growth of the wind energy industry has led to cost reduction challenges. There are various factors that affect the cost of producing wind power (e.g. site selection, site layout design, preventive maintenance, and optimal control system design). Of the various factors, the wind farm layout design is an extremely important component to be considered for ensuring the profitability of a wind farm project [28].

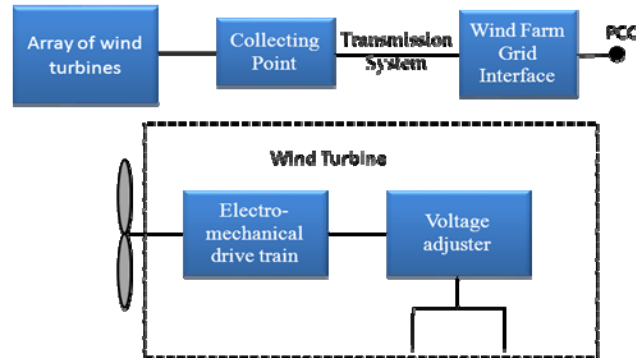


Fig. 7. General wind farm layout

Typically, a wind farm layout can be represented as shown in Fig. 7. A wind farm is a collection of wind turbines in the same site. The wind farm consists of elements like wind turbines, local wind turbine grid, collecting point, transmission system, and wind farm interface to the point of common connection (PCC). The grid connects the wind turbines to the collecting point. The energy from the collecting point is then transferred to the wind farm grid interface through transmission system. The wind farm grid interface modifies the voltage, frequency and power of the transmission system to the level suitable at the PCC. An inadequate wind farm layout design would lead to lower than expected wind power capture, increased maintenance costs, etc. To maximize the energy production, optimization of wind farm radius and turbine distance should be made in such a way that the wake loss is minimized, ideally 8 rotor diameter spacing [29].

Different types of wind farm layouts are: small AC, large AC, AC/DC, small DC, large DC, and series DC [30]. The most common system for wind farms today is AC. Small AC wind farms are best suitable for short distances; AC/DC is the best solution for larger distances, while large AC is preferred for medium distances. For shorter distances, DC systems are preferred because they are cheap and the conversion systems can be avoided. The large DC system is considered a better option than the AC/DC system because of lower losses and low cable cost.

VI. RELIABILITY OF WIND TURBINES

The reliability of a wind turbine is critical to extracting the maximum amount of energy from the wind. Different techniques, methodologies and algorithms have been developed to monitor the performance of wind turbine as well as for early fault detection to prevent catastrophic failures. Implementation of condition monitoring system (CMS) and fault detection system (FDS) is essential for achieving high availability of the system. All wind turbines should be equipped with an integrated condition monitoring system for planned preventive maintenance. This will also reduce the probability of catastrophic failures and consequent damage to components. Two of the more common condition-based maintenance (CBM) techniques are vibration-based monitoring and fluid-based monitoring. Vibration-based monitoring analyzes measured vibration of one or more components to estimate the condition and/or performance of wind turbine components. In a typical vibration-based monitoring system, position transducers are used for low frequency monitoring, velocity sensors are used for middle frequency monitoring, accelerometers are used for high frequency monitoring and spectral emitted energy (SEE) sensors are used for very high frequency monitoring. Thus, a typical-vibration monitoring system includes multiple types of sensors with multiple monitoring algorithms, which can be complex and costly. Fluid-based

monitoring typically involves taking samples of fluids (for example, hydraulic oil or lubrication oil) for analysis to determine whether a component has experienced excessive wear. However, fluid-based monitoring provides only limited information related to the condition of wind turbine components [31].

Fault diagnosis is required for gearbox and bearings, generators, power electronics and electric controls, rotors and blades. Among system failures, gearbox fault is widely viewed as an important issue. As such, detailed stress analysis of gearbox is mandatory for achieving better understanding of the failure mechanism and load distribution, which would lead to improvement of drive train design and sensor allocation [32]. Since a gearbox is a system of shafts, bearings and gears reacting through housing, the system flexibility under high torque needs to be well understood and included in the design process. Misaligned bearings owing to housing-shaft bending can cause premature bearing failure. Vibration measurement and spectrum analyses are typical technologies which are employed in gearbox monitoring and diagnostics [33]. Wind turbine generators have failures in bearings, stators and rotors. Common problems in stators and rotors of induction machines include inter-turn faults in opening or shorting of one or more circuits of a stator or rotor winding, abnormal connection of the stator winding, dynamic eccentricity, broken rotor bars or cracked end-rings (cage rotor), static and dynamic air-gap eccentricities, and so on. It is proven that the current, voltage, power and torque-speed signals are all effective for detecting shorted-coil. Electronic controls account for only about 1% of the cost of a wind turbine, but cause 13% of failures. Therefore, it appears it is especially beneficial to increase the effort on diagnostics of electronic controls. A large proportion of power electronics system failures are caused by the defects and failures of the semiconductor devices in the power electronics circuits. Wind turbine rotor failures can be attributed to creep fatigue and corrosion fatigue, which are reflected as cracks in the composite blades. New technologies like optical fibers are being investigated to detect the cracks in the blades. Another future direction is the use of composite materials in the fabrication of wind blades and other wind turbine components. As larger turbines are built and installed in more difficult environments, there is an overriding requirement to reduce blade weight, putting more emphasis on the need for stronger and lighter materials, improved blade design, and more efficient processing. Consequently, there will be a need for improved properties and/or performance from current and/or alternative materials used [34].

VII. SMARTGRIDS

The electric grid is becoming congested due to lack of expansion and continued growth in electricity consumption [35]. The present electric grid is non-uniform and unintelligent, in which, the demand side cannot communicate with the supply side. Compatibility of the grid with distributed power supplies would bring down costs for connecting wind turbines to the grid. Getting the electricity from the wind farms located in remote areas involves more than just building more power lines. The electric grids should be able to handle greater and faster changes to load flow caused by intermittent generation and should plan for standby reserve capacity to supplement intermittent generation. Effective grid management can be achieved by improving data collection, by using efficient communication protocols, network monitoring systems providing operators with up-to-date information on the status of grid, and incentives for end users,. Such an approach helps identify faults in the grid and deal with them before they become serious [36]. A smart grid applies state-of-the-art technologies and techniques to make the grid

work more efficiently. Smart grid provides advanced energy management techniques and approaches for integrating wind or solar power into the grid. It constantly monitors load and takes particular consumers offline, if that load surges beyond a preset level. The grid's software uses stochastic prediction algorithms for wind power forecasting, and such predictions may be used to switch on/off the loads. Smart grids will integrate weather reports, real-time output monitoring, and grid-load balancing to respond to this variability proactively [37].

The biggest challenge of the wind power is that it does not always blow at the hours of the day when power loads are highest. At one point on 27th August 2009, Spain's wind energy supplied less than 1% of demand, whereas on 14th January this year, 42% of demand was met by wind [22]. As a result, wind energy has to rely upon other expensive technologies like compressed air storage, battery tanks etc. One possible solution is to combine Plug-in Hybrid Electric Vehicles (PHEVs), smart grids and wind power. PHEVs can be considered as a complimentary resource to provide energy storage during the day. As a result of integrating the PHEVs to the smart grid the PHEVs owners benefit by selling the energy to the grid during the day when the demand is more and buying back the energy during the night when the cost is less. The utility thus has a low-cost, low emission power, and can avoid running more expensive power plants and the pollution caused by them. The smartgrid contains advanced technologies that keeps track of the in-flow and out-flow of the loads and communicates with the utility companies. Thus, the wind farms and the PHEVs result in better economic and environmental benefits when used in conjunction.

VIII. WIRELESS SENSORS FOR WIND POWER

Operation of a wind turbine depends upon a number of factors: electrical (*e.g.* generator voltage, current, frequency, etc.), environmental (*e.g.* wind speed, direction, air temperature, etc.), mechanical (*e.g.* shaft speed, vibration in rotor blade and bearings, etc.) [38]. On top of this, for offshore installations, such effects are not well understood. Advanced research is necessary to build cost effective wind turbines. There is also a need to develop models that will serve as a tool to help identify design barriers and quantify the cost and mass impact of design changes on various components of the turbine. Using advanced wireless sensors to collect data on wind installations and performing analysis to further enhance system design can be highly attractive to design engineers and researchers. Advanced sensor technologies have currently focused on improving wind aerodynamics of turbine rotor and increasing the efficiency of the blade design. A wireless sensor network enables the sensors to be placed all over the structure. Such a wireless system could be combined with electrical, mechanical and environmental monitoring sensors and be a part of a remote multi-turbine centralized plant monitoring and control system [39]. The data from the sensors is wirelessly transmitted to a central monitoring station using satellite internet as shown in Fig. 8. At the central monitoring station, data is analyzed and a relationship between various sensed parameters is established for improving the efficiency of the whole system.

Lightning may cause damage to wind turbines in many locations. If the lightning current effects on wind turbine can be measured and quantified, the lightning protection of wind turbine blades can be improved [40]. A lightning measurement and impact detection system, based on fiber optic current sensors, should be used for measuring the current flowing across the turbines, where most impacts are expected to occur.

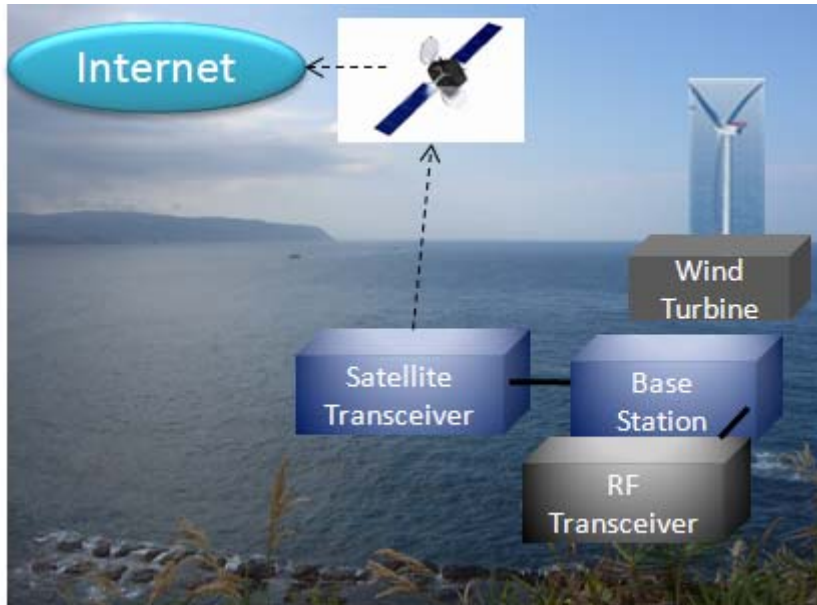


Fig. 8. Wireless communication using satellite internet.

IX. THE COST OF WIND-GENERATED ELECTRICITY

The cost of wind-generated electricity has dropped dramatically since 1980. In the US, wind power was priced as low as \$0.04/kWh in 2008 for a huge number of wind farms representing a combined 8.3 GW. This is half the cost indicated by the IEA, and cheaper than coal, nuclear or natural gas. If we include the production tax credit paid by the government, a full cost of some \$0.055-0.063/kWh is more realistic for the first twenty years of operation, falling to \$0.01-0.02/kWh thereafter, once the wind farm is written off [41].

Table I summarizes different types of costs involved in generating electric energy by major energy sources like nuclear, wind and solar. As can be seen from the table wind has low construction costs and zero fuel costs when compared with nuclear and solar. Thus, wind energy is much more affordable compared to other energies. Table II gives an idea about the cost of electricity per unit kWh in few countries. These costs will reduce over the next period of approximately 7-10 years.

TABLE I: Costs for Generating Technologies [42]

Energy Type	Construction Cost (\$/kWh)	Operations & Maintenance Cost (\$/kWh)	Fuel Cost (\$/MW)
Coal	0.0375	0.01	0.025
Natural Gas	0.02	0.005	0.05
Nuclear	0.075	0.02	0.01
Wind	0.08	0.02	0
Concentrated Solar Power	0.26	0.05	0
Solar – Photovoltaic	0.37	0.02	0

Table II: Startup cost of electricity generated using wind energy [43]

Country	Cost per kWh (US\$)	Year
France	11.152 cent/kWh	2007
Germany	12.512 cent/kWh	2009
India	7.48 cent/kWh	2008
Italy	30 cent/kWh	2008
Spain	9.96 cent/kWh	2008
Turkey	7.48 cent/kWh	2007

X. CHALLENGES OF WIND ENERGY

The high-energy returns on investment (EROI) for wind power do not guarantee that wind will play the major role in the world's power generation system. There are a number of technical, social and environmental challenges surrounding wind energy that requires resolution before that happens [13].

The uncontrolled, intermittent nature of wind poses unique challenges to grid management relative to operator-controlled resources such as coal, gas, or nuclear generation. Much of the wind resource base is located in remote locations, so it will cost to bring the wind-generated electricity from the local point-of-generation to distant load centers. At about 6 or 7 MW per square kilometer of net power potential, wind plants are necessarily spread-out over a significant land area. Thus, wind plants must compete with alternative uses of these land resources. This is especially true when the land is a significant source of aesthetic and/or recreational value [13]. Dramatic cost reductions in the manufacture of new wind turbines that have characterized the past two decades may be slowing due to a variety of economic, financial, and technical reasons. This is particularly true in light of the rising energy and commodity prices, which are slowly escalating turbine costs.

One of the immediate challenges common to all support structure designs is the ability to predict loads and resulting dynamic responses of the wind turbine and support structure when subjected to combined stochastic wave and wind loading. Extreme weather conditions, which in general restrict access for routine maintenance, give rise to the need for more robust turbine parts. This in turn means higher costs, which are not always offset by the higher productivity due to the higher offshore winds. Installation, repair, and maintenance costs are significantly higher for offshore systems than onshore systems simply because of the assembly and access constraints characteristic of working in water. Floating wind turbines will be the only economical way to access the vast area of deep-water sites. But very few floating wind turbines are under research and development in the world today. New foundations, towers, and wind turbine configurations are needed to make floating wind turbines, as well as the offshore market in general, commercially successful.

There has also been a concern for visual impact of wind turbines. In order to minimize such concerns, innovative design techniques should be tried. Better design techniques have made wind turbines much quieter. The noise emitted from wind turbines is less when compared to road traffic, trains, construction activities and many other industrial activities. For offshore wind this is not a major concern since people do not live close to the offshore wind farms.

Wind power forecasting is also one of the most critical aspects in wind power integration and operation. It is needed to estimate the long, medium, and short-term power production. Forecasting approaches are usually based on time-series prediction, neural networks, artificial intelligence, knowledge based systems and fuzzy intelligent system approaches. The forecasts are used as inputs to the operators for switching on/off the turbines.

XI. FUTURE OF WIND ENERGY

Wind energy is the fastest growing energy source in most parts of the world. Wind farms of the size more than 500 MW exist in many countries. The future of wind energy depends more or less on political and technological developments. Political support in terms of incentives to the wind energy will be of great impetus for wind energy advancement. Power production incentives in terms of tax credits will make wind-generated electricity competitive with fossil fuels. Technological progress should be made in terms of managing wind power, energy storage, smart grid integration, and automation. It is also essential that new advancement occur in wind turbine and tower design, rotors, energy loss reduction, smartgrid integration, wireless sensors, real time data analysis and sharing. As space is quickly becoming scarce for the installation of onshore wind turbines, offshore wind energy has become an increasingly attractive option due to the enormous energy potential associated with the vast offshore areas. But the offshore technology will require more extensive development effort because of the added complexity of dynamic floating platforms and other design challenges at the more exposed sites further from shore. Floating structures have already been successfully demonstrated by the marine and offshore oil industries. However, the technical requirements and economics that allowed the deployment of thousands of offshore oilrigs are yet to be demonstrated for floating wind turbine platforms for wind power. The European Wind Energy Association (EWEA) estimates that EU installed wind power capacity will reach 80GW in 2010 and 180GW by 2020. This would cover more than 12% of Europe's electricity demand [44]. Another research claims that wind energy markets are expected to grow at an average rate of 14% per year in terms of new capacity installation in next 5 years alone. This robust growth is expected to drive production of new turbines and consequently impact the demand for composites which is expected to grow to 1,378 million lbs by 2014 at an annual growth rate of 11.8% [29]. The calculations released by Global Wind Energy Council (GWEC) shows that wind energy alone could achieve up to 65 percent of the emissions reductions pledged by industrialized nations [45]. Thus, wind energy has the potential to become a major contributor to the global electricity demand and a critical part of the solution to global warming in the near future.

XII. CONCLUSION

The economics and the benefits of renewable sources of energy and in particular wind power are becoming increasingly convincing across the globe. Wind has the advantages of stable generation costs, low operating costs, renewable, short energy payback, less time-to-market, abundant resource, and environmentally preferable. Offshore wind energy is indeed a very promising field. As transportation and deployment are made at sea, there is virtually no limit on the size of the turbines that can be installed, as opposed to limits imposed by road restrictions onshore. Also, offshore wind parks can be installed close to major urban centers, requiring shorter transmission lines to bring this clean energy to these high cost energy markets. Although, optimal solutions for offshore wind energy are expected to differ from its onshore counterpart yet successful adapted solutions from other offshore activities might result in large cost reductions,

making this form of energy more competitive and its deployment more important in the coming years. As such, offshore wind energy is expected to be the next big step in wind energy development. Of the various factors affecting the cost, the wind farm layout design is an extremely important component to be considered for ensuring the profitability of a wind farm project. Latest technological developments taking place in the area of reliability of wind turbines and improvements in the properties of the materials used will make wind energy more competitive in the next decade. On the other hand, there are a number of technical, social and environmental challenges surrounding wind energy that require to be addressed to make it more competitive even amongst the other renewables. Technological progress in terms of managing wind power, energy storage, real time data analysis, smart grid integration etc. and production incentives in terms of tax credits and other government policies will make wind-generated electricity the first choice across the globe. It seems reasonable to say that the wind energy sector will change the global energy scenario.

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