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PROSPECTS AND CHALLENGES OF WIND ENERGY: A COMPREHENSIVE ANATOMY

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ABSTRACT
Wind is packed with kinetic energy – molecules in motion that can be used to make other molecules move such as commonly seen windmill water pumps, or used to compress gas and converted into electricity - when it blows. In this line, wind generation, in particular, has placed new challenges on system operation and planning, because of the ‘undispatchable’ nature of wind, the difficulty of forecasting and the impossibility of storing. Several challenges are associated with wind power use in terms of technical, environmental, financial, political as well as social challenges before considering wind as a major source of energy in the world. This paper attempts to identify major technical, financial and environmental challenges associated with wind energy utilization from feasibility study to generate electricity for regular consumption, based on secondary sources. Finally, the paper addresses emerging important issues to be considered for installing wind power farms and distribution systems.

Keywords: Wind Energy, Distribution, Challenges.

1. INTRODUCTION
The wind is packed with kinetic energy – molecules in motion that can be used to make other molecules move such as commonly seen windmill water pumps, or used to compress gas and converted into electricity - when it blows. When the wind is becalmed, there isn’t any energy other than the latent heat [1]. In this line, wind generation, in particular, has placed new challenges on system operation and planning, because of the ‘undispatchable’ nature of wind, the difficulty of forecasting and the impossibility of storing. In this regard, several challenges are associated with wind power use in terms of technical, environmental, financial, political as well as social challenges before considering the wind as a major source of energy in the world nowadays. The last few months have seen more evidence that climate change is happening at a far faster rate and in a greater variety of ways, than had previously been predicted. To tackle this situation, scientists are working hard to rely more on renewable energy sources instead of using fossil fuel and natural gas. However, all the associated and underlying challenges are not studied properly before installing the windmills and before introducing the multi-million dollar projects across the world. This paper attempts to identify major technical, financial and environmental challenges associated with wind energy utilization from feasibility study to generate electricity for regular consumption based on secondary sources of information. The environmental challenges considers landscape and land use changes, possible impacts on climate change issues, sound pollution, birds and biodiversity losses and including endangered species, as well as visual effects. Technical challenges includes issues of wind power sources, mapping the wind velocity in different areas, electricity distribution system to the grids, assessing capacity of wind power, fluctuation of wind energy in different time period, as well as construction of windmills. Financial challenges highlights the issues of investment of money, sources of investment and ability of the nation/municipality or other governing bodies, cost-benefit analysis of the money invested already in wind power with case studies and experiences from Canada as well as economic feasibility of such huge projects. The traditional tools at many levels, used to assist engineers and decision makers in planning and operation became obsolete, at least while they could not cope with the new problems. This paper attempts to emphasis those challenges in three major areas such as: technical, environmental and financial (considers both traditional and modern techniques) issues and emphasizes the best practices around the world for better understanding the myth of engineering and decision making solutions. Finally, the paper addresses the emerging important issues to be considered for installing wind power farms and distribution systems for the engineers, professionals and decision makers across the world.

2. OBJECTIVES
This paper has some specific objectives, such as:

a) To know the emerging challenges of wind energy's prospects that include technical, environmental, financial aspects and
b) To highlight options for decision makers why wind energy is suitable or not considering the challenges in hand

3. METHOD

This research is conducted based on secondary sources of information. Reliable sources of information and conceptual frameworks have been collected from well renowned international journals. Besides, short talks with professionals in relevant fields have been carried out to support the lessons learned from secondary sources. The research is continuing to explore every criterion in detail as an extension of this foundation work.

4. WIND: A NEW PLAYER IN ENERGY SECTOR

Wind industry has seen explosive growth in the last eight years, due to favorable tax conditions, renewed public interest, and maturing turbine technologies [2]. It is common for wind turbines to be collected into groups, called wind farms. The largest wind farm in the world is the Horse Hollow wind ranch in northwest Texas, boasting 421 wind turbines that are rated between 1.5 and 2.3 megawatts (MW) each. The farm stretches over 47,000 acres, and totals 736.5 MW of installed capacity. Installed capacity refers to the maximum amount of energy produced by the farm if winds are strong enough to run all turbines at full output. When averaged throughout the year, most wind farms produce 25 – 35% of their installed capacity [3]. For comparison, many traditional thermal power plants are on the order of 200 – 300 MW, with the largest coal and nuclear power plants rated at 2,000 to 3,000 MW.

Fig. 1 shows that Asia is now the leading investor of depending on wind energy especially in China and Taiwan. It seems, the energy is getting popular even in the middle income countries. However, there are plenty of possibilities in Latin America and in the Middle East but still it is not as much popular in compare to other parts of the world. It also shows that Europe has a lot more consistency from the beginning of 2003 to end of 2010 to depend on wind energy over time according to the need. China, one of the leading economies in the world is also depending heavily on wind farms to generate its growing power demand, especially in its industrial dependencies.

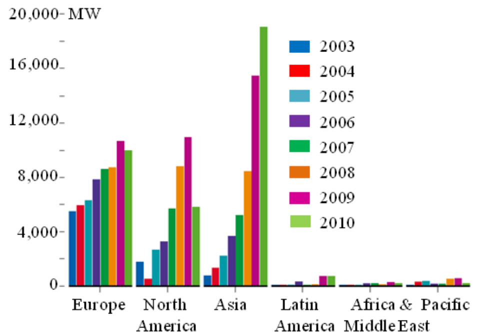

Fig 1. Annual installed capacity of wind energy by region 2003 – 2010 (Source: [4]).

5. CHALLENGES POSE FOR WIND ENERGY

Wind is among the fastest growing power source in the world, the technology is being developed rapidly and wind power is supplying significant shares of the energy in large regions as seen from Fig. 1. However, the challenges of generating the wind power and supplying in the grid system are not an easy task. Several challenges are always posing from generating the consumption of the energy such as: technical, environmental, financial and so on (see Fig. 2 for more detail information).

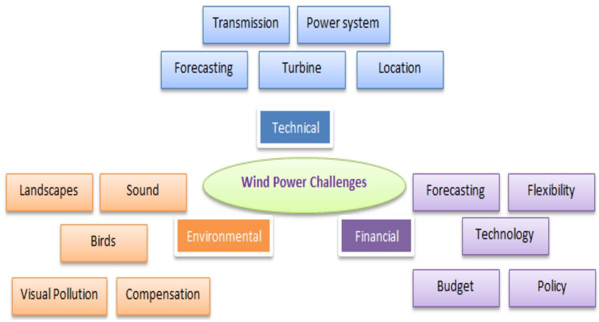

Fig 2. Major challenges imposed on wind power energy.

Besides the above mentioned major challenges, there are many other challenges to take advantages of the wind energy, such as: political will, investment possibilities, emerging technical supports as well as research and innovation strategies around the world.

5.1 Technical Challenges

There are no technical limits to the integration of wind power. However, as wind capacity increases, measures have to be taken to ensure that wind power variations do not reduce the reliability of power systems. There will be an increasing economic impact on the operation of a power system if wind power penetration exceeds 10% [5]. General technical challenges have been identified by Lin, et.al. [6] once they conduct a comprehensive study in Taiwan as:

a) Load minus wind variability;
b) Wind power generation reserves;
c) System reliability;
d) System operating cost impacts of wind's variability;
e) Wind farms capacity credit;
f) Roles and value of wind forecasting;
g) Wind penetration; and
h) System operating strategies

5.1.1 Transmission planning

Transmission system planning is one of the major technical challenges followed by the engineers, planners and economists to minimize costs and improve the efficiencies. In order to plan to power system in the most efficient and effective manner, system planners have to treat the system as a whole rather than focusing only on individual components. In Taiwan, the impact study has found some criteria once they studied the major challenges in transmission planning. They have identified that the system must meet the following major criteria for thermal, voltage and stability limits which are some of the major challenges for transmission planners and system engineers:

a) Overloading for 345 –kV, 161 – kV and 69 – kV transmission lines: the transmission lines cannot be violated the capacity limitation in the existing overhead transmission lines underground cables.
b) Voltage stability: if there is an N – 1 contingency, 5% of the voltage stability margin shall be remained. If there is an N – 2 contingency, 2.5% of the voltage stability margin shall be remained.
c) Small signal stability: At the normal condition, the damping ratio has to be larger than 3% and the damping ratio shall be larger than 0% if there is an N – 2 contingency at the 345 – kV transmission lines.
d) Transient stability: if there is a three-phase short circuit fault, the critical clearing time shall be above 5.5 cycles at the fault location along with 4 cycles at the remote end in the 345 – kV system and the critical clearing time for 161 – kV system shall be above 12 cycles at the fault location along with 7 cycles at the remote end.
e) Maximum short circuit current limitation: the limitations for different transmission system are 63 – kA for 345 – kV, 50 – kA for 161 – kV, and 40 – kA for 69 – kV.

From the above points, it is clearly depicted that the challenges are difficult to meet at some points to explore possible system connections for offshore wind farms.

5.1.2 Power system

The voltage variation, flicker, harmonics causes the malfunction of equipment's namely microprocessor based control system, programmable logic controller; adjustable speed drives, flickering of light and screen all are important in the total power system and it poses a big challenge for the engineers. It may leads to tripping of contractors, tripping of protection devices, stoppage of sensitive equipment's like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipment's. Thus it degrades the power quality in the grid and at the end, the primary objective of the wind power generation comes under threat.

The limited predictability and high inter-temporal variations of wind power cause a full spectrum of problems, ranging from shorter term frequency deviations to longer term balancing problems. Fig. 3 provides a summary of likely problems and possible solutions in power system operations related to high wind penetration. The sections are organized based on the operating practices, which imply temporal separation.

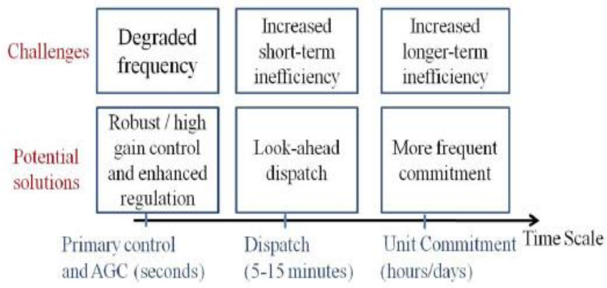

Fig 3. Operational challenges and potential solutions of power system (after [7]).

5.1.3 wind Forecasting

Using physics-based forecasting models, real time wind and energy data from the wind plants, and computational learning systems such as artificial neural networks or support vector machines, it is possible to provide forecasts of wind energy delivery that are significantly better than simplistic forecasts based on climatology (historic values) or persistence (assuming that what is currently happening will continue without change). The accuracy of forecast results depends on the specific challenges of the wind plant location, the surrounding terrain, and the local climatology [5]. Because wind plants are internationally located at sites that tend to amplify wind effects when compared with the surrounding space, it is often worthwhile to run customized fine-scale forecasting models and local wind flow models to simulate the enhanced local effects. These results may be combined with other regional forecasts, using computational learning systems to detect complex relationships and optimize the wind energy forecast. While results are site-specific, a reasonable expectation at most locations is that the accuracy of the next day hour-by-hour power forecasts using current state-of-the-art methods will have a mean absolute error (MAE) of perhaps 10 – 15% of the rated (nameplate) capacity of the wind park.

5.1.4 Turbines

Wind power works by harnessing the breeze that passes over the rotor blades of a wind turbine and rotates a hub. The hub is connected to a gearbox via low-speed and high-speed shafts that drive a generator contained within a nacelle. A generator converts the energy into electricity and then transmits it to a power grid. The typical wind turbine is a slender structure that consists of a three-bladed rotor that extends up to 300 feet in diameter attached to the top of tall towers that soar hundreds of feet into the air. A yaw mechanism uses electrical motors to turn the nacelle with the rotor against the wind. An electronic controller senses the wind direction using a wind vane. The average wind turbine **contains up to 8,000 parts** that must be assembled. Towers and rotors are the largest and most basic components. In this regard, there are varieties of challenges of wind turbines from its manufacturing to placement. Besides, specific areas need specific types of wind turbines so selection of a specific one is one of the major challenges for the decision makers and engineers. The technology is offering varieties of wind turbines nowadays that can produce electricity at different scales. In this regard, the paper considers selection of the types of wind turbines as a major challenge posed for the planners, engineers and decision makers around the world. Besides, aerodynamics is another important aspect to design the specific turbines. Fig. 4 shows the tree structure of aerodynamics which are posing continuous challenges to design specific wind turbines.

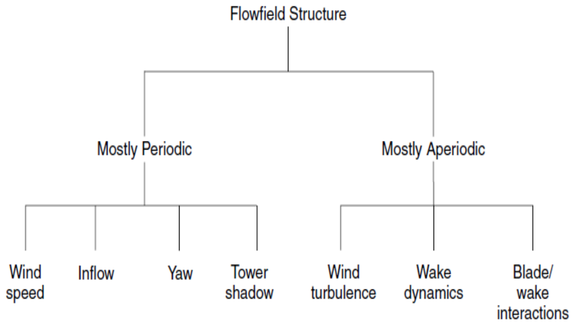

Fig 4. various aerodynamic sources that contribute to air loads on a wind turbine (after [8]).

5.1.5 Locations

First of all, it is important to know if we are going to place the wind turbines either on-shore or off-shore. Depending on the site selection processes, the decision comes at the end where to install or to know about the suitability of the wind energy either on or off shore. Onshore wind energy has grown enormously over the last decade to the point where it generates more than 10% of all electricity in certain regions (such as Denmark, Schleswig-Holstein in Germany and Gotland in Sweden). However, this expansion has not been without problems. The resistance by some members of the public and planning procedures to wind farm developments experienced in Britain since the mid-1990s is now present in several other countries. One solution to this problem is to move the developments offshore, where land use disputes are avoided and noise and visual impacts greatly reduced. There are also a number of other advantages [9]:

a) Availability of large continuous areas suitable for major projects;
b) Higher wind speeds, which generally increase with distance from the shore (Britain is an exception to this, as the speed-up factor over hills means that the best wind resources are where the turbines are also most visible);
c) Less turbulence, which allows the turbines to harvest the available energy more effectively and reduces the fatigue loads on the turbine;
d) Lower wind shear (i.e. the boundary layer of slower moving wind close to the surface is thinner), thus allowing the use of shorter towers.

However, specific challenges are also important considering access to the farms and availability of the wind to avoid the financial losses. In this regard, the following locational aspects should be considered as a major challenge to install the wind farm:

a) Distance to main urban centers
b) Distance to secondary urban centers
c) Saturation level
d) Distance to roads
e) Distance to coast line and
f) Terrain slope

5.2 Environmental Challenges

Wind power offers enormous benefits to the global environment, but it must also tread softly on the earth it is helping to protect. According to the most recent (Third Assessment, 2001) report on scientific evidence from the Intergovernmental Panel of Climate Change (IPCC), the average surface temperature of the world is projected to increase by 1.4 to 5.8 degrees centigrade over the period 1990 to 2100 and Sea level Rise (SLR) will rise by 0.1 to 0.9 metres. This is happening because of using fossil fuel and putting more greenhouse gases (GHG) in the atmosphere. If Carbon di Oxide is the main greenhouse gas resulting from the electricity production, what contribute to its reduction will the expected increase in wind power generation make at European level? There are different ways of assessing the CO2 emissions that will be avoided by electricity generation from the wind. It, however depends on the assumptions made about the fuel which will be displaced by introducing wind into the energy mix, a mix which clearly varies across the World. In this circumstance, wind plays important role to ensure safe and sustainable environment. But there are other challenges associated with the wind energy production on environment. Some of the important ones are being considered in this paper.

5.2.1 Landscape

Wind turbines are tall structures which ideally need to operate in an exposed site where they can make best use of the prevailing wind. This means they are likely to be visible over a relatively wide area. Once constructed, the actual turbines in a wind farm occupy only about 1% of the land area taken by the whole development. However, it may threat the local landscape as well as it can change the landuse in the adjacent areas. European Wind Energy Agency (EWEA) estimates that the land area taken up by the 150 GW of wind power projected to be installed on shore in Europe by 2030 would amount to only a few hundreds square kilometers – and the space between the turbines can still be used for other purposes which people did not feel interest to use because of such changed landscapes.

5.2.2 Sound

Sound emission of wind turbines can be subdivided into mechanical and aerodynamic sound. Better design and better insulation have made more recent wind turbine models much quieter than their predecessors. Mechanical noise from the gearbox and generator has been virtually eliminated, leaving the turning blades as the main sound source. Changes in blade design and operation can reduce this. Compared to road traffic, trains, construction activities and many other sources of industrial noise, however, the sound generated by wind turbines in operation is low. A wind farm of 350 m brings 35 – 45 dB (A) sound in compare to 105 dB (A) of jet aircraft and 65 dB (A) of a running truck (48 kph) (Wind Power in the

UK, 2009). In this regard, people's negative attitude sometime brings the most important challenge of installing a wind turbine either on or off shore.

5.2.3 Birds

Birds can be affected by wind energy development through loss of habitat, disturbances to their breeding and foraging areas and by collisions caused by the rotating turbine blades. Compared to other causes of mortality among birds, however the effect of wind power development is negligible (i.e., less than 0.01%) [10].

5.2.4 Visual Pollution

The visual effect on the unfettered and infinite horizon of the sea is something which is emotionally very strong, claimed by some residents in Amsterdam. A related issue was about the visibility of the turbines at night, when they have to be identified by lights as a warning to passing ships too. It creates problem for the adjacent residents sometime. Some people also complained that the natural landscape is completely changed and it is monotonous to see the monster wind turbines all the time even during the relax time. Besides, some people claimed they would not feel good to go for hiking because of the visual pollution of the wind turbines in southern Spain. So it may affect the tourism industry as well. Considering this as one of the major challenges, the researchers and the decision makers should make decisions to combat the visual pollution at its lowest possible form.

5.2.5 Compensation

As well as complying with environmental legislation, the wind farm developers have been required to carry out a compensation plan to compensate for the project's potential disruptive impacts on the local environment of the local community. Sometime, the local community does not get the direct benefit of the wind farms but they need to pay their landscape, visual and environmental costs. These costs should be compensated. In financial mechanisms, there are several ways to compensate the negative impacts. However, the engineers and decision makers should use the appropriate design of wind turbines that can minimize the compensation costs. Sometime, because of the installment of large scale wind turbines, a zone is completely dedicated as an exclusion zone. In this regard, some people need to be resettled in another place. This kind of compensation plans should be a big challenge posing by wind farms too.

5.3 Financial Challenges

Wind energy projects require initially higher investments than onshore owing to turbine support structures and grid connection. The cost of grid connection to the shore is typically around 25% (of the initial capital investment; see Fig. 5), a much higher fraction than for connection of onshore projects. Other sources of additional cost include foundations (up to 30% of the initial capital investment), operation and maintenance (with expected lower availability) and marinization of turbines.

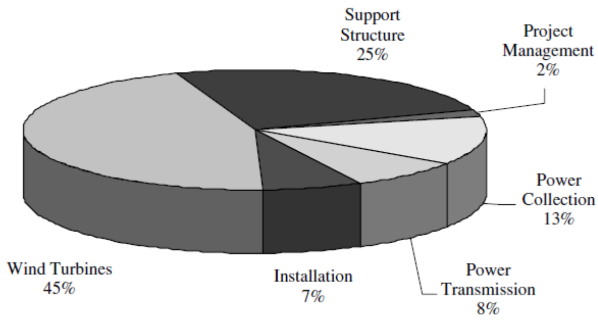

Fig 5. Example break down of initial capital costs of and wind farm (after [9]).

To install a wind farm is a big challenge based on the financial plan and budgets. Some countries are still trying to aware people with the forthcoming benefits out of it but people are not well convinced as they need to put lots of support in such a huge project. Considering these aspects, this study points some challenges as:

5.3.1 Forecasting

Financial forecasting is the main important issues to see if the government or the wind farm put a big amount of money and do not find any outcome in quick succession. In this regard, economic forecast is important to see the break even point when the farm or the developer can start getting benefits out of it. Some projects ended up with no break even points in Mexico and in the Netherlands in 2001. However, the governments are optimist to invest money in this green project because of environmental concerns and to maintain the Kyoto Protocol of carbon neutral society. The Internal Rate of Return (IRR) is also important challenge to investigate before heading towards such a huge project.

5.3.2 Flexibility

Financial allocations are always very much rigid in terms of government allocation or from the private farm allocation. However, considering the time it takes to install wind turbines, the budget should be flexible. It has been observed in some European countries that the allocated budget was not enough after completing 75% of the project in 3 years. In this point, the new government would not even allocate new budget and at the end the project may fail. It may happen mostly in the developing countries where the political instability and economic prioritizations is not the same in each year to prepare and allocate money in its budget.

5.3.3 Technology

Each and every day, the technology is changing. Wind energy related technology is changing very faster speed too especially the dynamics of wind turbine design and the power distribution system. It affects the financial institutions directly to take quicker decision for which technology the farm should react. Once financing the wind energy project, the investors and financing companies should consider the substitute technologies and possibilities in short term to replace the existing one. Sometime a significant amount of budget is needed to buy the new technology but the stability of that specific technology should be taken under consideration as a first step before injecting the money.

5.3.4 Budget

Financial budget is a significant component of financial management in wind power generating projects. Budget considers manpower, time, import and export components, sources of finance and incentives as well as the right technology at the right time. If the farm fails to consider the allocated budget at a proper time, the whole project may be ruined. Budgeting should be done in different level and in different options. Otherwise, it may impose threat to the whole project at the end. Devaluation of currencies and replacement of technology is another component which is considered in budget. The compensation plans and environmental impacts should be focused in the budget too. Public-private partnership is a very common system of financing new development projects anywhere in the world. This partnership options should be clear in the financial budget so that the organizations can see the responsibilities in detail.

5.3.5 Policy

The U.S. department of Energy released a report in the spring 2008 titled, "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to US electricity Supply." This report shows the policy outcome of the government. Many investors and public organizations started to build their partnership to attain such policy in the US. As a matter of fact, California is one of the World Leader in installed wind plant capacity recently. However, Europe has taken the lead to install even more wind turbines to depend more on wind energy. It means, the government policies are focusing mostly on wind energy nowadays. To take these policies into reality is certainly a big challenge. Sometime, the political will work very well to bring new policies. Taxing fossil fuels or their use to reflect their environmental damages also makes sense nowadays to bring more green energy sources as wind energy.

6. CONCLUSION

In summary, we would argue that the world is in the midst of an epochal transition from an unsustainable energy path. There is a tremendous amount of inertia in the system, and the change will not come easily or quickly. But we are on the road to change and we have little choice but to follow the road and to see where it leads. We should consider the emerging challenges of wind energy that are coming almost every day and should act according to the present need for a green environment. We have come across some future research possibilities to know the challenges in more quantitative forms considering:

a) Varying amounts of wind generation
b) Market structure and imbalance energy pricing
c) Correlation of load and wind forecasting errors
d) Varying generation portfolio and fuel cost mix
e) Simplified models and methods
f) Wind penetration definition and
g) Transmission congestion

If we consider the challenges well in advance, the success of wind power energy will certainly benefit the local, regional, national and international level as a blessing of technology in the 21st century.

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