Choosing the Best Approach to Wind Energy Utilities

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Abstract – **In this paper are discussed different options for wind turbines (design, control strategies and location) and choices among them. Also, development from the point of view of business is mentioned.**

Keywords – **wind turbine, wind farm, control strategy, design,business.**

I. Introduction

Wind energy can be transformed into electrical energywith different approaches to design, control and allocation.Once a choice is made, it should be close to optimum. Windenergy is renewable and clean and such is its role – toprovide renewable and clean energy with an eco-friendlyapproach. It means that the chosen approach to business andtechnology must take into account society and theenvironment as a whole. Once a direction is chosen andglobalized, it is difficult to change it. There is no time for toomany mistakes. This challenge is discussed in this paper.

II. Current Situation

Wind energy technology and its implementation aredeveloping relatively fast lately, but, because its role is notjust to produce electrical energy but also to replace existingnon-renewable and harmful energy sources, thisimplementation should be as fast as possible.

Wind energy (wind mills) was actually used before theappearance of fossil fuel fired engines. The reason for thistechnology being replaced in the first place was itsinconsistency as a power source [1]. There is a hugedifference between steam engines and electricity generation,but the problem of inconsistency of wind energy and the challenge how tooverride it is similar.

“Classical” energy, compared to wind energy technology, is relatively simple for modeling and controllersare standardized. Dynamical aspects of wind turbines havevery non-linear characteristics. Wind cannot be controlledand turbines produce energy from noise (air fluctuations with veryunpredictable behaviour). Electrical grid systems demand relatively stable energy production and wind as an energy source is variable on different time scales (variable speed, seasons of the year) [1].

Hence, this technology faces withtwo big challenges: how to produce a significant amount ofelectrical energy (compared to non-renewable energysources) and how to integrate wind power into a grid systemand keep it stable.

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III. Performances and Location

The cost of generation of electrical energy from windturbines is falling because they are increasingly morepowerful and cheaper. A wind turbine converts mechanicalenergy of the wind into mechanical energy and then convertsit into electrical energy. The degree of power produced bydifferent turbines varies from a few hundred kilowatts tomegawatts.

Onshore wind farms are constructed inland in regionsrich with wind energy in order to maximize their efficiency. Offshorewind farms are located in the sea relatively far from thenearest coast. There are generally higher wind speeds. Also,if one wanted to achieve a significant penetration of windenergy percentage-wise compared to non-renewable andnon-ecological energy sources, a significant number of wind farmsshould be planned to be constructed offshore as soon as possible [2]. Their costis higher in comparison to onshore wind farms.

It is worthy to mention here the possibility of oil priceshock as a way to provoke the urge for wind energy usage. Agood historical example is the crisis during the 1970s. Thiswas a period when the era of modern wind turbines began. Itis highly uncertain when exactly will the problems related topeak oil happen (it depends on national economies and the data about oil reserves are secret), but they will happen soon.

A significant number of offshore wind farms shouldalready be working before it happens because in that casenew wind farms would be a continuation of somethingalready existing and expected social and economicalpost-peak-oil complications (or even chaos) would affectbuilding new wind turbines to a lesser extent. Also, the needfor offshore wind farms in deep waters would be a lesserchallenge because of experience, already existing companiesand hopefully lower prices.

IV. Design

The majority of commercially available wind turbines arewith the horizontal axis of rotation (compared to vertical-axisturbines) [1]. One may assume that vertical-axis windturbines are more practical because they are independent ofwind direction (horizontal-axis turbines need the yawmechanism to face the wind) and gearboxes and generatorscan be placed on the ground. This is not the case becausethey have problems during the rotation into and away fromthe wind and with high speed of the wind.

Horizontal-axis wind turbines are made of bladesadjoined at a hub connected with a nacelle. The nacellecontains components for energy transmission (mechanical(drive-train) and electrical) and control and it is placed on atower. They usually have three blades. Concerning energy capture efficiency, stability and material used, it is generally accepted that the optimal number of blades for a wind turbine is three. There are turbines with other numbers of blades, but the majority is made with three blades. A turbine with one or two blades has problems with too fast rotation and those with more than three blades need to be thinner, use extra material (cost more without significant improvements in energy capture) and cause more turbulence (disrupt the incoming wind in a non-productive way).

V. Wind Power

The equation for the power of the wind (Eq. (1))can be written from the fact that it depends on kinetic energy ($mv^2/2$) and that the mass flow rate of air flowing through an area A isρAv (ρ is the density of air and v is the wind speed). It is:

$$P = \frac{1}{2} \cdot (\rho \cdot A \cdot \nu)^2 = \frac{1}{2} \cdot \rho \cdot A^3 \qquad (1)$$

The power extracted from the wind is C_p P. C_p is the power coefficient. It is a function of λ (= ω_m R/ν – ω_m is the angular velocity and R the radius of the rotor) and β (the blade pitch angle).

Because of the fact that this is a cube function of the wind speed, it is important for wind turbines to be designed the way they support higher wind loads (protection from damage) [1]. Above wind speeds that provide the highest efficiency of a wind turbine (higher wind speeds are rare and as such have a lower power density), the power output must be controlled to reduce the load.

VI. Modelling and Control

Two different approaches to identification of a wind energy conversion system exist: the procedure based on collected data (totally independent on dynamics and structure, "black box") and the identification that relies on its structure and dynamics (modeled drive-train and components) [3]. Deterministic components of wind fluctuations on the turbine are wind shear (when blades rotating change their heights) and tower shadow (effects of the tower on the airflow). There is also a stochastic component related to turbulence.

Control is focused on four subsystems [3]: the aerodynamic subsystem (wind energy into mechanical energy), the mechanical subsystem (the drive-train transferring the torque from the rotor to the electric generator and the support of the rotor and other devices in height), the electrical subsystem (conversion of mechanical power into electricity) and the pitch servo subsystem (the device that rotates the blades and modifies the pitch angle). Modeling and control is based on collective behaviour of these interconnected components.

A wind turbine behaves nonlinearly. Still, experiences with linear modeling with deviations from the nominal optimal point are relatively satisfying.

Passive stall control doesn't depend on moving of adjustable parts. It is based only on the design (aerodynamics) of the blades which provide losing of power when the wind speed is too high. This method has low efficiency at low wind speeds and, as a type of control with a constant speed turbine, has lower energy efficiency than turbines with the variable speed. Active control, besides of its complexity and need for design of control mechanisms, is preferred, especially for large wind turbines.

There are three regions of operation:

1) The wind speed is too low for energy production.

2) The wind speed is high enough for energyproduction and lower than the critical value. Energycapture is important in this region.

3) The wind speed is beyond the critical value. Theobjective of the controller is protection from fatigueload.

Control strategies can theoretically be with fixed and variable speed and with fixed and variable pitch. The variable speed strategies are more common lately. Variable speed wind turbines, compared to those previously used with constant speed, adapt the blades velocity to fluctuations of the wind speed and this way operate at optimum energyefficiency (maintain C_p at the maximum value-the parameterλ mentioned earlier depends on the generator torque). In thecase of variable pitch control, the pitch angle of a bladechanges according to the wind speed when it is beyond itscritical value. The advanced control approach is dividedbetween optimal energy capture in the region 2 and loadmitigation in the region 3.

The majority of control algorithms depend on measurements from turbine structure and drive train [4]. This approach has a delayed response to the current situation and the wind speed can be very variable. This can especially be a problem at high wind speeds when loads need to be mitigated at the moment they appear. Samples of the wind speed measured upwind can be used for a preview controller which expects changes from upwind measurements. These expectations differ from the real wind speed at the location of the turbine, so they can be used only as an approximation.The challenge for this and new wind turbine technologies in general is how to develop sensors and actuators that provide local control of aerodynamic effects and that are effective, reliable and don't add extra costs.

Different approaches todesign of controllers have been proposed, such as for example gain scheduling [3],parametric controller [1], fuzzy logic [5], and neural networks [6]. Also, pitch angles of the blades can be controlled collectively or individually. In order to produce and distribute enough electrical energy, there must be taken into account which approach is the best. Once a certain approach to control and design (and business) is globally applied, it must be very close to the best possible. There is a paradox that wind turbines are supposed to be a more sustainable option to energy production, but they still use energy and natural resources. Technological improvements of wind energy utilities and replacements of outdated ones should be observed in this context. If wind farms really significantly penetrate into electrical energy production, it will be achieved through the collaboration of people, companies and technological solutions.

Because wind farms are often connected to the powergrid without anything in between, it is preferred for wind turbines in farms to have, besides of control strategies mentioned above, power electronic technology [1]. There are different configurations of wind farms: centralized and decentralized. An obvious disadvantage of the centralized approach is that individual wind turbines don't always operate at their optimum, but an advantage is its robustness to failures of the grid. In the decentralized control case individual wind turbines operate at their optimum. A highvoltageDC link can also be used for wind farms. In this case there are two connected power converters, one on the side of the wind farm and another one on the side of the grid. On the side of power distribution, there are also specific requirements for keeping a balance between produced and needed power. The active power control approach means that the power demand is predicted and wind farms are adjusted to this prediction. The imbalance between production and consumption is visible if the frequency in the system moves farther from 50 Hz (or 60 Hz used in some countries). The frequency control is used to keep the balance. Voltage regulators are used to keep the voltage within the required limits. Also, tap-changing transformers are used to maintain voltage levels. Wind farms should be protected from faults in the network and external control (from people) is mostly provided.

Researches on smart grids [7], focused on improved efficiency, stability, and flexibility will also be important for implementation of wind farms and renewable energy in general. The intent is to improve the redistribution of produced electrical energy and to maximize local usage of electrical energy from renewable sources.

With the growth of share of the wind power in the system, the frequency fluctuations will increase [8]. There is a need for an additional frequency control of such an interconnected system.

VII. BUSINESS

Strong competition between wind turbine manufacturers results with the lack of widely available data. Science and business ("business as usual" historically inherited from previous industrial revolutions – the one that has caused problems in the first place) can observe the same problem with different intents. Companies try to keep their technology secret and remain competitive and scientists will maybe keep their results and ideas secret only by the moment of publishing of their scientific paper. What will at the end really matter for society and the environment as a whole is how will wind energy technology with other renewable energy sources deal with environmental problems.Motivations and expected results are not aligned.

For a company the best way to remain competitive is to protect its knowledge and ideas from "leaking". Employers in a company are not all the time with the best ideas and opportunities to find solutions. The market and competition are strong motivators for further achievements, but the results and their reflections on society, energy production and nature will be the only relevant thing when our current challenges will be observed by future generations.

New technologies and products develop like they are isolated from companies' environment. The way a new product is being made, distributed and sold does not take into account (or it does very superficially) its influence on the environment (production, existence and its further fate after it's not being used). It is difficult (if not impossible) to observe all environmental, societal and economic aspects of a technology from the point of view of competition.

Here is worthy to mention the complexity (interactions between competing ever-changing and as such highly unpredictable forces) of the world in which wind energy technologies are being developed and implemented [9]. Local communities should be independent as much as possible from the national and international energy supply. On the other hand, offshore wind turbines should be built as soon as possible because of available areas and strength and behaviour of offshore winds. Tighter local communities make sustainability or a lack of it more visible and planning of wiser spending of energy would have more chances in this case. Economic growth has its obvious advantages, but this planet is limited by its size and natural resources. This would be more obvious within relatively independent local communities. There is a paradox that at the moment the "best" way to start thinking differently about collectivity is to let the old approach fail working properly. Instead of working on real strategies, people still focus on short-term decisions and politics insisting on economic growth (and growth of energy and resources demand) and competition.

VIII. CONCLUSION

In this paper different options for wind turbines and utilities are observed, such as location, design, control strategy and connection to the grid. There are some that are more widely accepted and implemented than others. Companies and the way they work on new types of wind turbines are also considered. The urgency of the situation (environmental problems, peak oil) demands for the best technological and business solutions from the point of view of all of us and not only companies. The ways communities and long-term strategies fit in the big picture are also important.

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