AN OVERVIEW OF WIND ENERGY, TAKING INTO CONSIDERATION SEVERAL IMPORTANT ISSUES INCLUDING AN ANALYSIS OF REGULATORY REQUIREMENTS FOR THE CONNECTION OF WIND GENERATION INTO THE POWER SYSTEM

UN PANORAMA DE LA ENERGÍA EÓLICA, CONSIDERANDO VARIOS TÓPICOS IMPORTANTES INCLUYENDO UN ANÁLISIS DE REQUERIMIENTOS REGULATORIOS PARA LA CONEXIÓN DE GENERACIÓN EÓLICA EN EL SISTEMA DE POTENCIA

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ABSTRACT: Pollution problems such as the greenhouse effect as well as the high value and volatility of fuel prices have forced and accelerated the development and use of renewable energy sources. In this paper, a revision of wind generation is presented. In the first part, a brief history of wind energy developments is detailed. Next, some commentaries related to the present and future state are made. Then, a revision of the modern structures of wind generation is realized. In fourth place a brief comparison between small and big size turbines is presented. Then, different types of energy storage are mentioned. Finally, some regulatory aspects are discussed.

KEYWORDS: Wind energy, distributed generation, storage, regulation

RESUMEN: Los problemas de contaminación tal como el efecto invernadero, así como el alto valor y la volatilidad de los precios del combustible, han obligado y acelerado el desarrollo y uso de fuentes de energía renovables. En este trabajo se presenta una revisión de la generación eólica. Primero, se detalla una breve historia de la evolución de la energía eólica. A continuación se discuten algunos aspectos relacionados con el estado actual y el futuro. Seguido a esto se realiza una revisión de las estructuras modernas de generación eólica. En cuarto lugar se lleva a cabo una comparación entre turbinas de pequeño y de gran tamaño. A continuación también se mencionan los diferentes tipos de almacenamiento de energía. Por último se discuten algunos aspectos normativos.

PALABRAS CLAVE: Energía eólica, generación distribuida, almacenamiento, normativa

1. INTRODUCTION

Pollution problems, greenhouse effect as well as the high value and volatility of fuel prices, have forced and accelerated the development and use of renewable energy sources. In the three last decades, the level of penetration of renewable energy sources has undergone an important growth in several countries, mainly in the USA and some countries in Europe, where the levels of 20% in power generation, just for wind power, have been reached. Within the great variety of alternative power sources, wind energy has undergone a relatively bigger growth due to the following reasons [1][2]: competitiveness, feasibility, abundance of wind resources, maturity of the technology and shorter construction times. Wind energy has some disadvantages, because is intermittent due to wind discontinuities [3]. Thus, being a primary source of non-dispatchable generation, has a serious impact on the power delivery. Also, the best places to install a wind farm are located in remote areas which require additional infrastructure to transmit the generated power to the load centers. In several countries the regulatory aspect does not follow the fast growth of wind energy, others do not have technical requirements for wind generators, or do not make the necessary operational test before installing a wind farm. Today, Argentina is undergoing an analogous situation with wind energy, having perhaps one of the best sources of such energy around the world. Nowadays there are several operative wind farms and several in the construction and planning stages. In this paper, a revision of wind generation is presented. First, a brief history of wind-energy developments is given. Following that, some comments related to the present and future state are made. Then, a revision of the modern structures of wind generation is carried out. Fourthly, a brief comparison between small and big size turbines is included. Then, different types of energy storage are mentioned. Finally, regulatory aspects are discussed, with regard to the treatment of the technical problems.

2. INTRODUCTION TO WIND ENERGY

2.1. Brief history of wind energy development

For centuries, wind mills and water mills were the only source of power for a number of mechanical applications, some of which are still in use today. The wind turbines that generate electricity today are new and innovative. Developments in the field of aerodynamics, mechanical/electrical engineering, control technology, and electronics provide the technical basis for the wind turbines commonly used today. Since 1980, wind power has been the world's fastest-growing energy source [4],[5]. This growth is shown on Fig. 1 [6],[7].

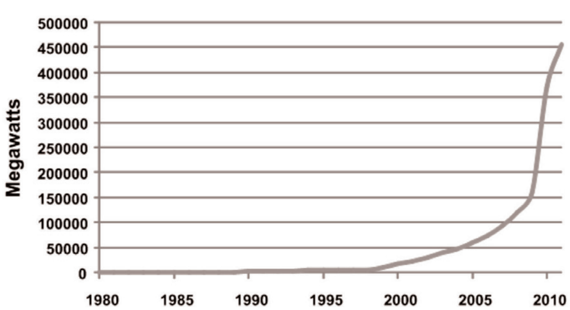

Figure 1. World wind capacity (1980–2011)

2.2. The Theoretical Model

Wind energy is caused by temperature differences at the earth's surface. A theoretical model simply considers two temperatures: a part of the surface is at temperature T1, and a second surface is at temperature T2. The existence of two thermal units at different temperatures makes the exploitation of energy possible. The planet's atmosphere functions as a fluid, which exchanges heat by mechanical energy. Air at places where there is plenty of sunshine intends to heat up and create a cycle that makes the heated air expand and thus become lighter. The lighter air will flow to higher places where it cools down and it has the trend to descend again. Such macroscopic cycles are the reason for the wind. It can be estimated that about 1 to 2 per cent of the energy coming from the sun is converted into wind energy [8], [9]. The wind mechanisms modeled in the previous paragraph are called *thermal tides*. These tides are not the most important element for the production of wind energy. Hadley circulations that are caused by temperature differences located parallel to the Equator are the most important element. Calculations on a surface with an actual power density of 2.4 W/m^2, indicate that can provide 25 mW/m^2, which is enough for humans needs [9].

3. THE STRUCTURE OF THE MODERN WIND TURBINE

3.1. Foundation and Tower

In order to guarantee the stability of a wind turbine, a foundation is used, depending on the consistency of the underlying ground. The foundation anchors the wind turbine to the ground. The tower construction does not only carry the weight of the nacelle and the rotor blades, but must also absorb the huge dynamic loads caused by the varying power of the wind. Generally, a tubular construction of concrete or steel is used. As an alternative to this, there is also the lattice tower form. Examples of tower heights: (a) hub height 40 to 65 m, approximately 600 kW rated power, and rotor diameter of approximately 40 to 65 m; (b) hub height 65 to 114 m, approximately 1.5 to 2 MW rated power, and rotor diameter of approximately 70 m; (c) hub height 120 to 130 m, approximately 4.5 to 6 MW rated power, and rotor diameter of approximately 112 to 126 m.

3.2. Rotor and rotor blades

The rotor is the heart of a wind turbine. It consists of multiple rotor blades attached to a hub. The rotor converts the wind energy into rotation. **Rotor blades:** Rotor blades are a crucial and elementary part of a wind turbine. Various strains are placed on them, and they must withstand very large loads. Rotor blades take the energy out of the wind. They "capture" the wind and convert its kinetic energy into the rotation of the hub. Their profile is similar to that of airplane wings. Rotor blades utilize the same "lift" principle: Below the wing, the stream of air produces an overpressure; above the wing, the stream of air produces a vacuum. These forces make the rotor rotate. Today, most generator rotors have three blades, a horizontal axis, and a diameter of between 40 and 90 meters. In addition to the currently popular three-blade rotor, two-blade rotors are also used, which are common in addition to rotors with many blades, such as the traditional wind mills with 20 to 30 metal blades that pump water in the USA, Argentina, and Australia. Over time, it was found that the three-blade rotor is the most efficient for power generation by large wind turbines. In addition, the use of three rotor blades allows for a better distribution of mass, which makes rotation smoother and also provides for a "calmer" appearance. The rotor blades mainly consist of synthetic materials reinforced with fiberglass and carbon fibers. The layers are usually glued together with epoxy resin. Wood, wood epoxy, and wood-fiber-epoxy compounds are less widely used. One of the main benefits of wooden rotor blades is that they can be recycled. Aluminum and steel alloys are heavier and suffer from material fatigue. These materials are therefore only used for very small wind turbines. Each manufacturer has its own rotor blade concepts and carries out research on innovative designs. In general, though, all rotor blades are constructed similarly to airplane wings. **Hub:** The hub is the center of the rotor to which the rotor blades are attached. Cast iron or cast steel is most often used. The hub directs the energy from the rotor blades on to the generator. If the wind turbines have a gearbox, the hub is connected to the slowly rotating gearbox shaft, converting the energy from the wind into rotation energy. If the turbine has a direct drive, the hub passes the energy directly on to the generator. The rotor blade can be attached to the hub in various ways: either in a fixed position, with an articulation, or as a pendulum. The latter is a special version of the two-blade rotor, which swings as a pendulum anchored to the hub. Most manufacturers nowadays use a fixed hub. It has proven to be sturdy, it reduces the number of movable components that can fail, and is relatively easy to construct. **Power control:** The power that a wind turbine absorbs has to be controlled. If the wind is too strong, power is reduced to prevent damage to the system. The historical progress of power control was as follows: (a) Stall control: Rotor blades with stall control are attached to the hub at a fixed angle. The profile of the rotor blade is designed to cause turbulence behind the rotor blade at a particular wind velocity. At the same time, when the wind is too strong, the asynchronous generator also limits power generation automatically. It restricts the speed of the system to the power grid frequency, so that the rotor cannot turn faster when the wind blows stronger. In this concept, the rotor blades are designed to cause flow separation at a certain wind velocity (stall), the power input is reduced even though the blades are not themselves pitched. In active stall control, the pitch of the rotor blades can also be changed. This control system is used mainly in large wind turbines. When the wind is too strong, the rotor blades are turned into the wind, increasing turbulence. Active stall regulation allows for power to be regulated more accurately than passive stall regulation does. (b) Pitch control: This control concept was developed between years 1990 and 2000. Here, each individual rotor blade can be infinitely turned into or out of the wind. The drive for pitch adjustment is either mechanical for systems with an output below 100 kW, hydraulic starting at 300 kW, or electric, which is the most common one, especially for large turbines (more than 500 kW). (c) Variable speed turbines are the most promising and will progressively replace the others. Because of this, variable speed turbines will be explained in the next section.

3.3. Variable-speed wind turbine

Variable-speed turbine: The incorporation of a variable speed function into a wind turbine has a variety of benefits, including improved efficiency during low wind speed conditions, reduced mechanical load on drive train components, reduced noise, and reduction in tower passing effects. The increased power production during low wind speed conditions is claimed to give an increase of 8% in the total kWh produced by a given turbine. This improvement is very dependent on the wind regime in which the turbine is situated. The improved power production arises by operating the wind turbine at the maximum point of power, even during periods of low wind speed [11]. Fig. 2 shows the system under consideration. The wind turbine is connected to a variable-speed wind generator. The generator output can be controlled to follow the commanded power.

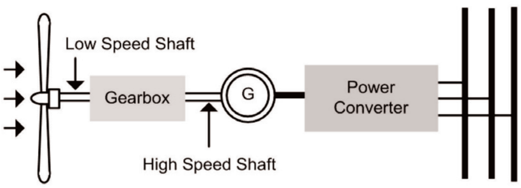

Figure 2. Physical diagram of the system

The wind turbine has a pitch-able blade to control the aerodynamic power. The dashed line indicates the pitch angle control. It is shown that there is a mechanical component, such as a gearbox, between the high-speed and the low-speed shafts. The low-speed shaft is driven by the turbine blades, which generate aerodynamic power. The high-speed shaft is loaded by the generator in the form of an electrical load. The following types are the most common full-variable speed turbines: (a) Double feed induction generator (DFIG). Here, rotor windings are connected to a frequency converter which is connected to the grid that creates the name "double feed". According to the DFIG principle, full control of the generator is possible for both sub-synchronous and over-synchronous operation. This system can control the generator speed and also active power and reactive power. The power through the converter is normally around 10–12% of rated power. This means that converter losses are limited. The remaining 88–90% of the production comes directly from the stator [11]. (b) Full-scale converter. This is where the stator windings are connected to the converter and thereby to the grid. The power through the converter is, as the name says, the full power produced by the turbine and the converter therefore needs to be dimensioned for the rated output, with thereby higher losses compared to the DFIG solution. **Variable speed control:** The wind turbine can be characterized by its CP-TSR curve as shown in Fig. 3 [12]. Where the TSR is the tip-speed ratio, that is the ratio between the linear speeds of the tip of the blade with respect to the wind speed, and CP is the power coefficient. It is shown that the power coefficient CP varies with the tip-speed ratio. It is assumed that the wind turbine is operated at high CP values most of the time. In a fixed frequency application, the rotor speed of the induction generator varies by a few percents (based on the slip) above the synchronous speed while the speed of the wind may vary across a wide range. In Fig. 3, the change of the CP-TSR curve as the pitch angle is adjusted is also shown. In low to medium wind speeds, the pitch angle is controlled to allow the wind turbine to operate at its optimum condition. In the high wind speed region, the pitch angle is increased to shed some of the aerodynamic power. In [12] a strategy for the variable speed turbine is proposed. The main goal is to utilize the information of the curve shape of Fig. 3 as much as possible, following the dashed line in Fig. 4.

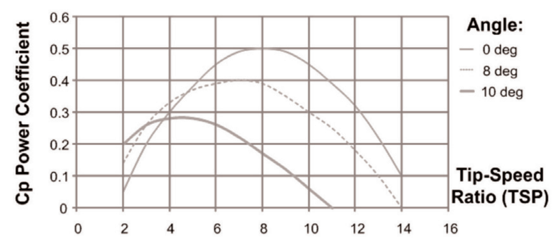

Figure 3. CP-TSP curve

The controller constantly monitors the turbine's power output. If the wind is too strong, the rotor blades are turned out of the wind along their axis, generally only by a fraction of a degree. This reduces the lift, so that the rotor continues to generate power at the rated capacity, even at high wind speeds.

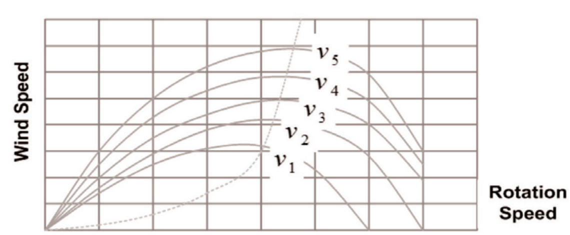

Figure 4. Wind speed vs. rotation speed

3.4. Nacelle with drive train, gearbox, generator, coupling and brake

The nacelle holds all the turbine machinery. Because it must be able to rotate to follow the wind direction, it is connected to the tower via bearings. The build-up of the nacelle shows how the manufacturer has decided to position the drive train components (rotor shaft with bearings, transmission, generator, coupling, and brake) above this machine bearing. The gearbox converts the rotor motion of 18–50 rpm into the approximately 1,500 rpm required by the generator. The gearbox thus takes on the task of matching the rotation speeds of the slow-moving rotor with the fast-moving generator, and generally has several steps to cover for various wind conditions. If a specially-developed multi-pole ring generator is used, the gearbox is no longer required. For high power wind turbines, doubly-fed asynchronous generators are most frequently used. Here, the operating rotation speed can be varied somewhat, unlike when one is using conventional asynchronous generators. Another concept uses synchronous generators. A grid connection for synchronous generators is only possible via converters, due to the fixed rotation behavior. The disadvantage of requiring complicated control systems is countered by the overall efficiency and better grid compatibility. Because of the enormous torque, the coupling between the main shaft and the transmission is a rigid one. The type of brake depends on the blade control mechanism.

3.5. Electronic equipment and other components

The electronic equipment of a wind turbine is composed of the system for the grid in-feed of the electricity and various sensors. The sensors for measuring temperature, wind direction, wind speed, and many other magnitudes can be found in and around the nacelle, and assist in turbine control and monitoring. Also, the wind turbine contains mechanical components for following the wind direction, for cooling, heating and lightning protection, and fire extinguishing equipment.

3.6. Small and big wind turbines

Reasons for choosing large turbines: (a) There is more “economy of scale” in wind turbines; i.e., larger machines are usually able to deliver electricity at a lower cost than smaller machines. (b) Larger machines are particularly well suited for offshore wind power. The cost of foundations does not rise in proportion to the size of the machine, and maintenance costs are largely independent of the size of the machine. (c) In areas where it is difficult to find sites for more than a single turbine, a large turbine with a tall tower uses the existing wind resource more efficiently; and at a higher level, the wind has more potential energy. Reasons for choosing small turbines: (a) The local electrical grid may be too weak to handle the electricity output from a large machine. This may be the case in remote parts of the electrical grid where there is low population density and little electricity consumption in the area. (b) There is less fluctuation in the electricity output from a wind park consisting of a number of smaller machines, since wind fluctuations occur randomly, and therefore tend to cancel each other out. (c) The cost of using large cranes, and building a road strong enough to carry the turbine components may make smaller machines more economical in some areas. (d) Several smaller machines spread the risk in case of temporary machine failure. (f) Aesthetical landscape considerations may sometimes dictate the use of smaller machines.

3.7. Offshore and onshore wind energy

The first offshore wind park was built in 1991 in Denmark with 11 turbines of 450 kW each. From then on, a lot of offshore projects have begun, especially in Europe. The choice between offshore and onshore depends most of the time on economical factors, the availability of wind resources, and political decisions. Advantages of offshore: (a) There are more and bigger areas to place the turbines. (b) Offshore has bigger wind speeds, which generally increase with distance from the shore. This can lead up to 73% more energy with the same turbine [13]. (b) There is less turbulence, which means the turbine can convert the energy more efficiently and has less static fatigue. (c) Water flatness makes it possible to use of shorter towers than the ones used on the earth (d) There is less visual discomfort. Offshore wind farms have to be large to be economical and with the increase of the contribution of wind energy to electric power production, the interaction between the wind farms and the grid will be an important aspect in the planning and operation of the farms [14]. Disadvantages of offshore: (a) The foundations are a lot more expensive because of the great depth and the special ships needed to transport them. A big part of these costs can be recycled because the foundations lasts for 50 years while the towers only last for 20 years. (b) The integration into the grid is a lot harder, and in most occasions more expensive, since in some cases the grid at the shore has to be extended. (c) Installation and access during installation are more expensive and depend more on the weather. (d) Repairs and changes are also more expensive.

3.8. Wind energy all over the world

In the beginning of 2008, the world-wide installed capacity of wind power was 94,211 MW. There was over 20,000 MW of wind power installed in the year 2007, which is an increase of 31% compared with the 2006 market, and represents an overall increase of 27%. The growth of wind energy is following the same rates as nuclear energy in its beginning years of development. The leading countries in the installation of wind power are Germany, China, Spain, and the USA. Germany was the leading country in 2007. The US surpassed Germany as the leader on in wind energy in 2010. It is estimated that Germany has a total potential of 100 GW. The state of North Dakota, in 2011, had a potential of 250 GW or almost 40% of the total demand in the USA. Not all the potential is economically obtainable. The global wind development growth has been exponential, due to the following reasons: (a) Perhaps the most important factor is the cost of wind energy which has declined 90% since the early 1980s (b) The governments plays an important role in the approach towards wind energy. Nowadays more and more countries invest in the future of wind energy. (c) Many customers care about the electric power impact on the environment and prefer the use of clean energies instead of fossil fuels as primary sources. (d) Wind and gas are complementary resources; wind is emerging as the most promising non-gas alternative for electric industry. (e) The support of governments around the world in tax credits gave many people an interest in investing in wind energy.

4. CONVERSION AND COSTS

A rotating wind mill converts the homogeneous wind pattern. A flux tub with a speed v_0 and a section S_0 in front of the wind mill is converted into a speed v_1 on the surface S_1 of the mill, and a speed of v_2 in a section S_2 behind the wind mill. Due to the maintenance of mass and the hypothesis that the density does not change, the M mass flow meets (where μ is the Carnot factor) (Eq. 1):

$$M = \mu v_0 S_0 = \mu v_1 S_1 = \mu v_2 S_2$$ * MERGEFORMAT (1)

Because the speed decreases, the section has to increase. Wind mills make the conversion of mechanical energy of the wind into mechanical energy on the axis, which means that there is no energy conversion and $\mu = 1$. The energy is calculated as the kinetic energy that blows through a section of 1 m^2 (Eq. 2):

$$w = \tfrac{1}{2} m v^2 \quad ; \quad w = \tfrac{1}{2} \mu v^3 S$$ * MERGEFORMAT (2)

The power produced at the axis (Eq. 3), can be described as the difference in energy in front of the wind mill to the energy in the wind behind the wind mill.

$$P = \tfrac{1}{2} v_0^2 v_1 S_1 \left(1 - \left(v_2/v_0\right)^2\right)$$ * MERGEFORMAT (3)

The dimensionless quantity is calculated dividing by 2 the through power that would pass section S_1 of the wind mill when the wind mill is blocked. Considering in Eq. (4) that:

$$v_1 \approx \left(v_0 + v_2\right)^2$$ * MERGEFORMAT (4)

then, Betz's law (Eq. 5):

$$P = 0.5\left(1 + v_2/v_0\right)\left(1 - \left(v_2/v_0\right)^2\right)$$ * MERGEFORMAT (5)

In Fig. 5, Betz's law is plotted, showing that as a maximum, 59% of the energy can be converted to mechanical energy at the shaft.

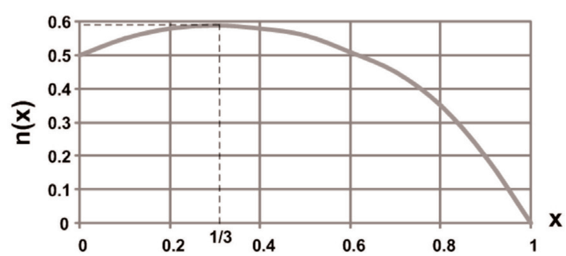

Figure 5. Graphical output of Betz's Law

Wind mills are built for a small interval of wind speed. At $v < v_{ci}$, called the *cut-in* speed, and at $v > v_{co}$, the *cut-off* speed, the wind mill is being shut down. To define the power of a wind mill (Eq. 6), the following data is needed: (a) the operating life of the wind mill, (b) the local wind statistics, (c) the nominal rate of the wind speed v_{nom}, (d) the nominal rate of the wind speed in MV = P_{nom}, this is the power at nominal wind speed. With the power, the costs can be calculated. Eq. (6) shows how these elements can be taken in to account for a wind mill [15]. The purchase price of a wind mill is more or less proportional to the installed power. But the installation costs and maintenance costs are not equally proportional, so that the costs are less than proportional to the power. This makes big projects more attractive than smaller ones.

$$P = lifetime.365,25\frac{days}{year}.24\frac{hours}{day}.P_{nom}\cdot\frac{v^3}{v_{nom}^3}$$

* MERGEFORMAT (6)

4.1. Improvements in technology drive the cost of wind energy down

Wind energy technology has evolved in dramatic ways during past decades. There are five major technology changes that have been translated into reduced energy costs: (1) Increasing wind turbine size, including a substantially larger-rated generating capacity, much larger wind turbine rotor diameters, and increased tower height. Perhaps this is the single most obvious change in the technology over the last few decades, as can be seen in Fig. 6. In 1990, the average turbine size was approximately 100 kW, while today it reaches 5 MW and more; (2) Although wind turbines are much larger than in the past, designers are trying to take some of the weight out of the machines. Reduced wind turbine weight lowers the cost of turbine since it reduces the raw material requirements of the product; (3) A large number of manufacturers, and more and more companies offer wind energy on the market. Competition ensures that prices will go down. (4) Improvements in power electronics and control systems make it so that wind generated electricity can now be more easily integrated into modern electric utility systems. (5) Improvements in blade design, using airfoils especially designed for wind turbine, have resulted in greater energy capture.

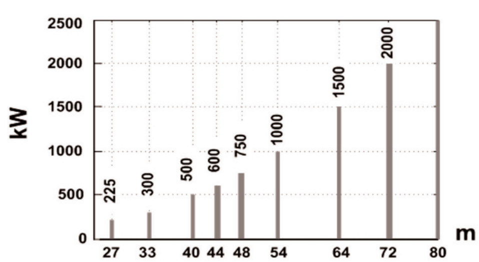

Figure 6. Influence of the size of the rotor

4.2. Optimizing the economics of wind energy

To decrease the cost even more, there are two primary factors that influence the cost of energy from a wind farm: the wind source at the site and the size of the project. The power (P) in the wind is determined using Eq. (7), were e is efficiency, ad is air density, sra is swept rotor area, and ws is wind speed.

$$P = \tfrac{1}{2}e.ad.sra.ws^3$$ * MERGEFORMAT (7)

Because the equation for calculating the power in the wind involves the cubic function of the wind speed, even small variations in wind speed make a major difference in power output. Assuming the same size project, the better the wind source is, the lower the costs will be. The other critical factor regarding the cost of energy from wind projects is the size of the project. There are scale economies from developing large projects [16]. The two projects that are compared in Fig. 7 are 51 MW and 3 MW in size, but both projects will bear many of the same transaction, research, and development costs.

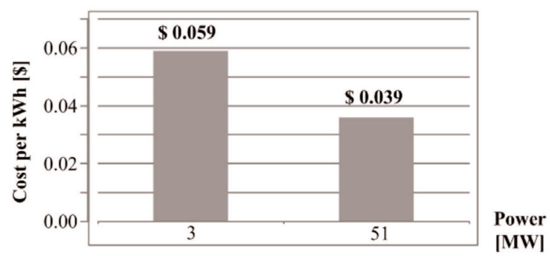

Figure 7. Impact of project size on cost per kWh

5. AN OVERVIEW OF STORAGE OF WIND ENERGY

To reduce the impacts of volatility and fluctuation of the wind, many storage technologies have been researched: flywheels, superconducting magnetic energy stores (SMES) [17], capacitors [18], super capacitors [19], NAS batteries, pump hydro-stations, compressed-air energy storage (CAES) [20], and wind hydrogen energy. Are summarized in Table 1.

Table 1. Storage of wind energy

	Flywheel	Capacitor	SMES	NAS Battery	Pump Hydro Station	CAES	Hydrogen
Storage Capacity	2.5 MWh	Small	3 kWh	several 100 MWh	500MWh 8000MWh	500MWh 2500MWh	several 1000 MWh
Power Capacity	25 MW	Large	10 MW	several 100 MW	100MWh 1000MW	several 100MW	several 100 MW
Energy Density	1000	5	2.8	400	-	-	-
Cycle Life Time	106	106	several 1000	2500	-	-	-

	Flywheel	Capacitor	SMES	NAS Battery	Pump Hydro Station	CAES	Hydrogen
Life Time (years)	20	10	20	15	50	40	-
Access Time	ms	Ms	ms	ms	1-3 minutes	10 minutes	-
Self Discharging	1%-10% /h	10% /h	cooling power	no	no	-	-
Efficiency (%)	90 - 95	90	< 95	90	75	54/70	25
Power Energy	25 MW 5 m 5 MW 30 m	rated power per s several s	high power several s	rated power/h high power/m	rated power long time	rated power long time	rated power long time
Environment Impact	small	Medium	small	medium	high	medium	medium

6. A SHORT REVIEW OF THE REGULATORY ASPECTS

The continuous rise of fuel prices and the commitment to the Kyoto Protocol push the growth of clean generation, specifically, wind energy generation. This situation has caused governments and power markets to develop a system without precedents [21]. At present, no optimal solution for the insertion to the grid is found, and each country is choosing its own procedure according to its own conditions, intentions, and peculiarities. In the world, there can be more or less regulatory demands according to the background of use of wind energy in each country. In the following paragraphs, some regulatory aspects related to wind power in Argentina, Latinamerica, Europe, and the USA are presented.

6.1. Regulatory aspects in Argentina

In Argentina, CAMMESA, *Compañia Administradora del Mercado Mayorista Eléctrico* [22], is in charge of the operation of the power systems. In relation to wind generation, it presents some aspects in Annex No. 40 [23]. Establishes the treatment in the MEM (wholesale electric market) of wind generation, taking care of the singularity of the equipment involved and the nature of the resource (wind). But the wind generation will be considered to be as hydraulic generation unless it was explicitly indicated. This Annex briefly considers 3 aspects: (a) insertion to the grid, (b) voltage control and reactive dispatch, and (c) operation and restrictions. The specifications of the incorporation of wind energy in Argentina are slightly considered, thus urgent legislation in this important subject is necessary. It is necessary to study the impact of insertion of wind energy to the Argentinean power grid in order to extract conclusions that help to write technical regulatory demands on wind energy.

6.2. Regulatory aspects in Europe

Although Europe is subdivided into many independent countries, several overlapping institutions exist. The European Union (EU) has an energy policy with a strong emphasis on renewable energy, but the implementation of this policy has to be carried out by every country independently. From an electrical point of view, the European Union consists of several synchronous areas, interconnected by DC links, and some of the synchronous areas consist of countries which are not members of the EU. Up to now, no specific model has been developed for matters such as wind power access to the grid and balancing of wind power. There are at least as many models as countries in the EU, even some countries have different settings depending on the control area of the active transmission system operators. While in some of the countries, the existing wind grid codes are constantly being updated to take into account the newest technology; other countries still have no grid code for wind power generation. Every country presents different grid access codes. In Belgium, one of the requirements requested from the grid is that the wind farms with a power output higher than the 2% of the short-circuit power at the point of common coupling (PCC) shall have their voltage permanently controlled. Limits are also established for certain output variables of the wind farm, for instance, for the power factor, the flicker coefficient, and the voltage change factor.

6.3. Regulatory aspects in Latinamerica

In Europe, every country has its own power system operator. These system operators act in a coordinated manner, so it could be considered that the power systems between countries operate in a centralized mode. This does not happen In Latin America. Each country operates its own power system independently of each other. Thus, each country of Latin America has its own regulations, and these regulations are quite different for each country. From the point of view of wind generation, there are different regulations, but often they have been written after the wind farm was installed. It is possible to read in the literature about the building of a new wind farm in some country of Latin

America, but regulations are not published.

With regard to Latin America, it is important to consider several aspects. First, due to the long distances between countries, integration between power systems is very low; in some case it may be considered to be an island operation. Second, the primary source (i.e., the wind) varies greatly, not only from country to country, but also from one region to another within each country. Thirdly, there is no integration between countries, as there is in the European Union, which allows for the development of unique connection codes for all of Latin America regarding wind generation. For these reasons it is considered that each of the countries, some more advanced than others, will continue to install wind generation, according to its own policy decisions.

6.4. Regulatory aspects in the USA

In the USA, the AWEA [23] (American Wind Energy Association) is a national trade association representing wind power project developers, suppliers, services providers, parts manufacturers, utilities, researchers, and others involved in the wind industry. In addition, the AWEA represents hundreds of wind energy advocates from around the world. The Association provides up-to-date information, among others, on wind-energy policy developments. The AWEA seeks to improve access to transmission interconnection and delivery service for wind energy; it encourages transmission organizations, policy makers, and market participants to develop new transmission facilities. The AWEA also works with utilities to study the costs and reliability impacts of wind integration, and it promotes the means of reducing those impacts such as wind output forecasting and system operation methods.

7. CONCLUSIONS

From the summarized presentation of wind generation, the following facts can be concluded: The topic is still under development, in spite of the fact that it advances very quickly. Wind generation possesses an immense potential for mitigating the world energy shortage. The turbine-size increase and its cost reduction make it more and more competitive in comparison with other sources. The state subsidies have demonstrated to be an appropriate tool for the development of new energy sources. Wind forecast is fundamental in order to achieve the maximum use of the present and future facilities. Correspondingly, a wide and power-massive development of storage resources is required. The study and the introduction of grid codes in Argentinean regulation is an imperative necessity. The inherent differences between the conventional generation systems and wind generation, such as the impact on the planning, operation, and network connection are suggested for future research and discussion.

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