LOW AND MEDIUM VOLTAGE WIND ENERGY CONVERSION SYSTEMS: GENERATOR OVERVIEW AND GRID CONNECTION REQUIREMENTS

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ABSTRACT

This paper presents a survey of the state of the art and the future techniques in wind energy conversion systems. At first, the most common generation systems in wind turbines are shown (Squirrel Cage and Wound Rotor Asynchronous Generators and Permanent Magnet Synchronous Generator). These turbines can be classified in constant or variable rotor speed systems. Finally, wind farm grid connection requirements are exposed and the capability of the different topologies to verify the new regulations is discussed.

INTRODUCTION

Without doubt, wind energy is one of the generation technologies that is being developed faster, with a worldwide increase of 21.7% in 2005, reaching the 57,837 MW [1]. In the case of Spain, in less than ten years, a hardly testimonial installed wind power becomes in a power potential of 10,027 MW at the end of year 2005, locating second after Germany in installed capacity.
A clear indicator of the relevant development of the sector is that EurObserv' ER 2005 [1] anticipates for the year 2010 an installed total power in Europe of around 72 GW, whereas the European Commission White Book of 1997 had anticipated 40 GW, an objective already reached at the end of 2005 with 40,504 MW installed.
Many factors have helped to the fast development of this technology [2], notably the considerable reduction of the cost of the wind energy, from the 40 cents/kWh in 1979 to the current 3-4.5 cents/kWh.
The many benefits that the wind energy offers are convincing [3]: environmental protection, economic development, diversity of the supply, rapid spread, transference and technological innovation, industrial scale electricity in network and the fact that the wind does not pollute, is abundant, free and unlimited.
Although the defenders of this source are majority, there are detractors that argue that the environmental impact of the wind generators does not compensate the obtained benefits. Another factor to consider is the variability of the source, so wind energy extraction is irregular and the maximum energy demand does not correspond to the maximum power generated. Therefore, the joint use of several power sources is needed, making more expensive and difficult the control system. Energy storage systems can also be used, but are still under development. Currently, numerous studies and models of wind prediction are being developed in order to estimate the energy obtained by the wind generators.
Considering the previously mentioned factors, wind generation and grid connection at Medium Voltage is an option to study. This work explores the possibilities of Medium Voltage generation and grid connection, and is the initial stage of this research project.

GENERATION SYSTEMS IN WIND TURBINES

In the state-of-the-art, several wind generation systems are documented [4] [5]. They have been divided into the constant rotor speed systems and the variable speed ones.
The constant speed systems are simpler and cheaper, but they present some drawbacks. The requirements and the cost-benefit balance determine the decision to use them.
Its greater drawback is that it is not possible to fit the rotor speed in order to compensate the torque variations caused by the variability of the wind. The wind energy extraction is not optimal and the power transmitted from the rotor varies, resulting in current fluctuations that can create flicker in the grid, since the frequency of the grid, and therefore the generator turn speed, is and must be constant.
In comparison to variable speed systems, constant speed systems produce greater acoustic pollution, since rotor speed is the same with smooth and strong winds.
These systems have integration difficulties in weak grid areas since neither the voltage nor the power factor can be regulated. As a partial solution, capacitor banks are used to improve the power factor. The voltage is determined by the grid and the generated power determines the current.

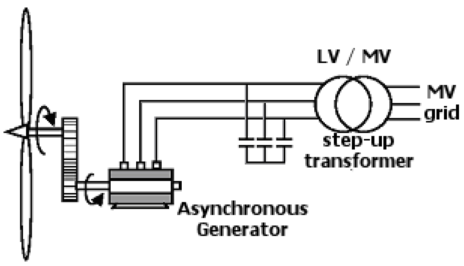

Fig 1. Grid Connected Squirrel Cage Asynchronous Generator.

The topology used in constant speed systems is the squirrel cage asynchronous generator connected to the grid. The sliding is usually limited to 2% so the rotor speed is almost constant. A popular option is the use of a double stator winding, one with a low number of poles to use at high wind speeds and another one with a greater number to be able to work at smaller wind speeds.

This system is used in some of their models by companies like NEG Mikon, Bonus and Nordex, among others. The typical working voltage is 690V, and the power of the commercial generators does not exceed 2.3 MW.

In variable speed systems, the variability is obtained uncoupling the grid frequency and the rotor mechanical frequency by means of AC-DC-AC converters and advanced control systems.

Variable speed systems contribute with abundant and important improvements: High performance in the wind energy capture, minor grid fluctuation [6], minor mechanical stress, smaller rotor noise in low wind speed conditions. But in spite of this, given the increase of the price that supposes the inclusion of power electronics, this systems has not yet reached all the market quota they would have to have given their qualities.

The topologies exposed below make possible the control of voltage and power factor of the wind farm [7]. This last one can be crucial in the presence of a weak grid.

Fig 2 shows the most used configuration of the squirrel cage asynchronous generators. This configuration allows to extract the maximum power from the wind at every moment and to inject it to the grid. It has a set of converters that form an AC/DC/AC conversion structure, commonly denominated Back-to-Back. In this configuration all the generated power is managed by the power electronics.

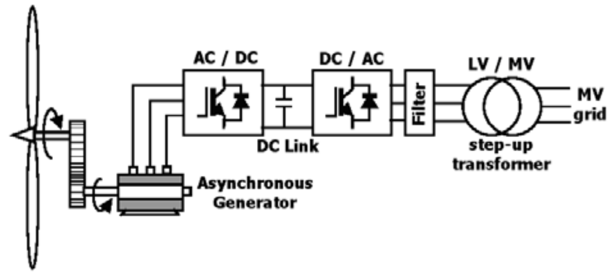

Fig 2 Grid Connected Squirrel Cage Asynchronous Generator in full converter topology.

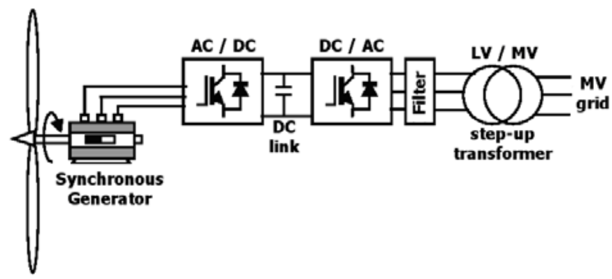

Fig 3 Grid Connected Permanent Magnets Synchronous Generator in full converter topology.

In the system shown in Fig 3, the wind generator axis is directly connected to the synchronous generator. In this configuration the mechanical connection (gearbox) is eliminated, maintaining the structure of the Back-to-Back converter. In search of a trade-off between benefits and costs, reduced speed variation systems have been developed. Despite of not having a 100 % speed variation rank, the cost is not excessive with a partial rank of speeds. The wounded rotor asynchronous generators adapt very well to the applications of variable speed with restricted speed ranks. These systems reduce the mechanical torque oscillations transmitted to the electrical system regulating the sliding of the generator by means of the electronic variation of the rotor resistance.

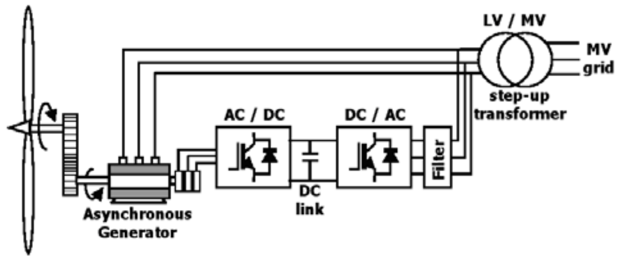

Fig 4 Doubly Fed Wounded Rotor Asynchronous Generator.

In this configuration (Fig 4) the stator of the asynchronous machine is connected directly to the grid whereas the rotor is connected by means of a Back-to-Back converter. This converter works with a fraction of the generated power (approx 30%). This way is able to implement a system with energy absorption and return capacity through the rotor.

Wind generation tends to variable speed topologies forehead to those of constant speed, but this tendency is braked by the cost that supposes the introduction of the electronics of power and different motor topologies.

Currently, among variable speed systems, the most used topology is the doubly fed induction generator. Although some studies affirm that this topology is the most efficient [8], the future tendency seems to be the use of topologies that allow a 100% speed variation range, obtaining greater aerodynamic efficiency. By its robustness, the synchronous permanent magnet machine can have significant prevailing possibilities in this field.

In spite of the present tendency, the development of these topologies will depend on the development of the power electronics, increasing its yield and reducing its cost.

In this scene, the small and medium power (<600 kW) wind generator technologies present robust and high performance solutions, being abundant their use in the wind farms. Nevertheless, in the last years greater unitary power wind generators have been installed with a tendency towards 3MW, or even 5MW [9] [10]. This is due to the bigger the generator the greater is the efficiency. However, with the present voltage levels, the increase of the power means to increase the value of the current at no desirable levels.

A possible solution consists of increasing the working voltage, which could take to even remove the step-up transformer in each wind generator.

GRID INTEGRATION REQUERIMENTS

In recent years, the increasing number of wind farms connected to the grid has motivated the power systems operators to introduce new connection requirements for wind farms. These new requirements impel the wind farms to contribute, as a conventional synchronous generator, to the operation of the electrical system, in order to guarantee the quality and continuity of the power system. Therefore many conventional solutions are not valid in this new scene. Nevertheless, the converters versatility enables to reproduce and even improve the behaviour of the synchronous generators before different grid disturbances.

The different characteristics from the different grids in each country cause that the behaviour of the wind farm has greater or smaller influence in the stability of the system. For that reason the demanded requirements vary from one country to other and there are international organisms that work on surrounding of requirements that include the different exigencies [11].

The new requirements are focused in the following aspects: voltage ride-through, reactive power exchange, voltage control, frequency control and power limitation [12] - [15].

A voltage sag is a more or less pronounced fall of voltage (depending on the existing impedance) produced by a short circuit in the neighborhoods. Fig 5 shows a surrounding of the more restrictive international requirements. The wind generator does not have to disconnect during any voltage sag that is over the surrounding. During the sag, the wind generator must limit the consumptions of active and reactive power. Sometimes a reactive power contribution is requested, greater whichever greater is the magnitude of the sag. After the sag, a, more or less fast, active power recovery is required.

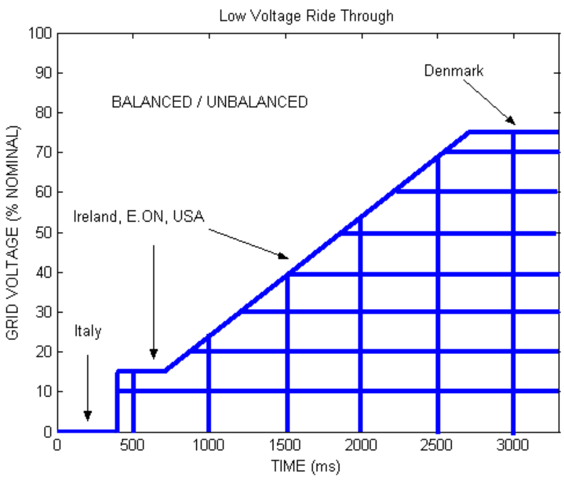

Fig 5 International Voltage Ride Through Requirements.

In order to assure the voltage stability in the different grid nodes, it is necessary to balance the reactive power generation and consumption. The grid operators demand to the Wind farms to participate in active form in that task.

Traditionally, the wind farms have worked with unitary power factor, the new norms demand to work in a much more demanding reactive rank. In most of the cases, in order to be able to contribute the demanded power factors, the generator has to work with reduced power factors (capacitive or inductive) or requires the contribution of auxiliary elements at substation level (solutions like STATCOM, DVR or capacitor banks).

In many standards the requirement of implement a voltage control in the wind farm is included. This implies the development of a control strategy that varies the point of operation of the generator (generally the reactive power) based on the connection point voltage value. Other requirements imply the possibility of limiting the variation of the active power.

The frequency is the magnitude that reflects the existing imbalances between generation and demand. The loss of a generator originates a frequency fall and the abrupt diminution of the demand causes a frequency rise. The standards demand that the wind generators must be able to regulate the torque input in the turbine in function of the frequency and thus to control the generated active power. Some standards demand a total frequency control, i.e., the possibility of responding to frequency rises and falls. This implies that the generator works below its maximum power production point, to have margin to generate more power in case that the frequency falls. Other standards only demand a control limited to the frequency rises, reducing the generation when the frequency increases and eliminating the limited power continuous operation and its related production losses.

This type of applications requires a bidirectional communication between the wind farm and the grid operator through the control system of the farm.

The constant speed wind generators, whose active power is controlled pitching the blades or disconnecting the turbine, can not contribute by themselves to grid stability as will be required. Energy storage may be an option, but at the present such technologies are expensive. Power electronic solutions play a key role in complying with the requirements.

The squirrel cage induction generator of the constant speed systems always consumes reactive power. The consumption depends on the voltage and generated active power. In most of the cases this consumption is compensated by capacitors. By adding capacitors the impact of the wind generator is reduced. However, controllable reactive power sources are needed to fulfil the requirements, such as switched capacitor banks, STATCON and SVC.

In doubly fed induction generators the reactive power generation can be controlled by the rotor currents.

In full converter topologies the generator is fully decoupled from the grid. The power exchange is not determined by the properties of the generator but by the characteristics of the grid side converter. The generator and the grid side power factors can be controlled independently.

The conclusion is that variable speed wind turbines can face the control requirements. Unfortunately, this has a cost. The achievement of the voltage control capabilities requires power electronic converters with a rating that is higher than the rating for operation at unity power factor. The relative increase of the converter size is larger in the case of the doubly fed generators, but the full converter topology converters are larger, and thus more expensive. So, although the relative increase in converter size will be smaller in the case of full converter topologies, the absolute cost increase may be substantially higher.

IMPACT OF MV CONCEPT

The Medium Voltage technology can be effectively applied to the electrical energy conversion in a wind energy system. Since the generators are more and more powerful, it is interesting to process the power increase, enlarging the voltage and thus reducing the current (or keeping it at reasonable levels). The benefits of this concept are: cupper loss reduction in all components of the system (generator, converters, wiring), eventual suppression of the LV/MV transformer. The main drawback is that MV technology requires an increase of the safety issues in installation and maintenance.

The Medium Voltage technology can be effectively implemented using the multilevel technology [16]. Multilevel converters can be used in back-to-back topologies, as the ones shown in Figs. 2-4. Multilevel technology adds additional benefits to the MV concept: harmonic reduction (so smaller and cheaper filters), switching loss reduction, slightly faster dynamic response (providing a way to fulfil grid connection standards) [9]. The drawbacks of the multilevel technology are an increase in the hardware complexity (more power diodes, more power drivers) and the complexity of the clamping voltage stabilisation.

CONCLUSIONS

This paper has presented the most important current wind generator concepts and the new grid connection requirements. It has concluded that the constant speed systems will need external power electronic solutions to comply with the requirements whereas the variable speed systems can fulfil them using an appropriate control strategy. However, in practice, this possibility is often not used. Finally, multilevel technology can be effectively used to introduce the benefits of MV technology in wind energy systems.

ACKNOWLEDGMENTS

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