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PROBLEMS RELATED TO THE ELECTRIC POWER SYSTEM OF WIND FARMS AND NEW TENDENCIES IN THEM

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Abstract: Wind farms supply real power variations into the upstream grid, and at the same time, in some types of wind generation systems, the reactive power consumption is related to the real power production. These power variations cause voltage variations with consequences for the electrical power system and the customers. On the other hand, the increasing use of power electronics in wind generation systems introduces voltages and current harmonics into the power system. As wind energy is a non–controllable energy source, it can cause problems with voltage stability and transient stability. The first part of the paper presents the problems of electricity production using wind farms. In the second part of the paper, new tendencies in the realization of wind farms are given. Power systems are complex systems that evolve over years in response to economic growth and continuously increasing power demand. In order to make energy economically available with reduced carbon emission using renewable energy sources, the structure of the modern power system has become highly complex.
Keywords: Wind farms, power systems, connecting wind farms

INTRODUCTION

The annual energy production of a wind farm is not equal to the sum of the generator nameplate ratings multiplied by the total hours in a year since the wind speed is variable. The capacity factor of a wind farm is the ratio of actual productivity in a year to the theoretical maximum. The range of the capacity factor is between 20 and 40%, with values at the upper end of the range in particularly favorable sites.

The rapid development of the wind turbine industry is going in two key directions – increasing power, through increasing the diameter of the rotor, or through increasing the coverage of kinetic wind energy, and increasing efficiency conversions through the improvement of converter circuits, ie active speed regulation and setting at the point of maximum power [1]. Electricity generated from wind power can be highly variable at several different timescales: hourly, daily, or seasonally.

However, wind is always in constant supply somewhere, making it a dependable source of energy because it will never expire or become extinct. Annual variation also exists, but is not so significant. Like other electricity sources, wind energy must be scheduled. Wind power forecasting methods are used, but predictability of wind plant output remains low for short–term operation. Because instantaneous electrical generation and consumption must remain in balance to maintain grid stability, this variability can present substantial challenges to incorporating large amounts of wind power into a grid system [2], [3].

POWER SYSTEM CONNECTION ISSUES OF WIND FARMS

Unlike classical sources of energy, wind farms supply real power variations into the upstream grid, and at the same time, in some types of wind generation systems, the reactive power consumption is related to the real power production. These power variations cause voltage variations with consequences for the electrical power system and the customers. On the other hand, the increasing use of power electronics in wind generation systems introduces voltages and current harmonics into the power system. As wind energy is a non–controllable energy source, it can cause problems with voltage stability and transient stability. Due to the rapid increase in the number of wind farms connected to the grid, the increasing rate of power of single wind farm and the weakness of the upstream power grid, where the wind farm connects, the importance and necessity of the study of wind farms connected to power systems is clear [3].

The connection of wind farm to electrical power systems influences the system operation point, the load flow of real and reactive power, nodal voltages and power losses [4].

The impact of wind farm on the power system depends on the location of wind power plants relative to the load, and the correlation between wind power production and load consumption. Wind power, like any load or generation, affects the power flow in the network and may even change the power flow direction in parts of the network. The changes in the use of the power lines can bring about power losses or benefits.

Increasing wind power production can affect bottleneck situations. Depending on its location, wind power may, at its best, reduce bottlenecks, but at another location result in more frequent bottlenecks. Grid extensions are commonly needed if new generation is installed in weak grids far from load centers to make full use of the wind power. The issue is generally the same for modern wind power plants or any other power plants.

The cost of grid reinforcements, due to wind power, is therefore very dependent on where the wind power plants are located relative to the load and grid infrastructure, and one must expect numbers to vary from country to country.

With current technology, wind power plants can be designed to meet industry expectations such as riding through voltage dips, supplying reactive power to the system, controlling terminal voltage, and participating in SCADA (supervision control and data acquisition) system operation with output and ramp rate control [4, 5].

DIFFERENT WIND TURBINE TECHNOLOGIES

There are many different generator types for wind power applications in use today. The main distinction can be made between fixed speed and variable speed wind generator types. Previous solutions with asynchronous machines of cage or sliding type with constant or partially regulated operating speeds are not sufficiently energy efficient and can hardly meet the increasingly complex network requirements given in the "Rules for the operation of power systems" [5]. Also, the issues of reliability and reduction of maintenance costs, especially for offshore wind farms, are becoming increasingly important, so new solutions are being sought for more efficient use of wind energy through the growing role of power electronic converters as interfaces between generators and grid, and operation without mechanical speed multipliers. The rapid development of the wind turbine industry is going in two key directions – increasing power, through increasing the diameter of the rotor, or through increasing the coverage of kinetic wind energy, and increasing efficiency conversions through the improvement of converter circuits, ie active speed regulation and setting at the point of maximum power [1], [5].

Wind turbines started as small generator units of several tens of kW and with a symbolic role in the power system. However, they developed very quickly and in the previous decade, units of several MW became commonplace. Power generators are currently appearing on the market 6–8 MW, with the planned development of 10 MW units with a vision to increase to as much as 20 MW [6].

In a continuous effort to reduce costs, increase the reliability and efficiency of wind energy conversion systems, various solutions have been developed. In general, wind turbines can be classified as fixed and regulated speed turbines [1], [8]. Fixed speed wind turbines use a cage asynchronous generator connected directly to the grid. To start, thyristor energy converters are used in the "soft start" configuration, which are in nominal mode short–circuited. This method forces the electric machine to operate at a constant frequency and therefore at an approximately constant speed. Wind power pulsations are transmitted directly to the grid and there is no control of active and reactive power, which are typically important parameters for frequency and voltage regulation. Network connection and difficulties in complying with the "Power System Rules" are additional problems. On the other hand, these solutions are simple, robust and use existing, already developed technology, so they are affordable. An improved solution with a synchronous generator with permanent magnets and a converter circuit connected in an open stator hub, enables active damping with relatively low converter power (20% of the nominal power of the generator) [1], [8]. However, that solution remained at the level of an academic proposal and outside the interests of the industry. Fixed speed wind turbines were mainly used in the first days of using wind energy and are characterized by low power. Greater interest in the application of wind generators and stronger investment cycles, have led to the search for solutions to remove the above limitations, ie to the development of the application of structures with regulated speed. Speed–regulated turbines provide better power utilization and are easier to adapt to network needs.

Synchronous generators and asynchronous cage generators connected to the energy conversion system are used in practical embodiments of these wind turbines. In addition, sliding–reel machines, such as double–powered asynchronous generators with reduced converter power or asynchronous generators with external controlled rotor resistance, have practical applications [1], [7].

Due to the variability of wind speed, it is highly desirable that the turbine drive be of variable speed. Also, with the increase of turbine power, control parameters become more and more important, so it is necessary to implement power electronics as an interface between the wind turbine and the network. The turbine is with variable speed it improves the dynamic behavior of the turbine and enables propulsion with maximum power at a certain wind speed and control of the flow of active and reactive power. Other benefits are reduced mechanical stress, less torque and power pulsations, improved voltage quality and less noise at low wind speeds [1], [5]. Based on the use of the transmission mechanism, they can be divided into turbines with direct or indirect drive. Both solutions of a synchronous generator with a wound rotor or with permanent magnets are acceptable for direct drive, for which a full energy converter system is required. Asynchronous cage generators can also be used, also with the use of a back–to–back converter system. This system serves as an interface between the generator and the network and consists of a diode or active rectifier, a DC link and a network inverter. The generator speed is adjusted turbine speed and thus the transmission mechanism is of minor importance and can be eliminated. In wind turbine systems with multi–pole (eg 72–pole) or multi–phase configurations (for example phase 6) synchronous generators a mechanical multiplier can be eliminated [1]. This is especially true when the generator is running at low speed, ie. has a large number of poles. Such a turbine without a mechanical multiplier (transmission mechanism) is attractive due to lower cost, weight and significantly lower maintenance costs. Multiphase or multi–winding generators are interesting for research also because such a topology increases the reliability of the whole system, and with the appropriate design of switching schemes, the influence of harmonics on the network can be significantly reduced [1]. Indirect–driven turbines require a transmission mechanism to synchronize low–speed turbines with high–speed generators. Another possible classification reflects the application of converter systems based on energy electronic converters. There are wind generator systems with partially regulated speeds and full speed regulation.

In the early stage of wind power development, most wind farms were equipped with fixed speed wind turbines and induction generators. A fixed speed wind generator is usually equipped with a squirrel cage induction generator whose speed variations are limited. Power can only be controlled through pitch angle variations. Because the efficiency of wind turbines depends on the tip–speed ratio, the power of a fixed speed wind generator varies directly with the wind speed. Since induction machines have no reactive power control capabilities, fixed or variable power factor correction systems are usually required for compensating the reactive power demand of the generator. Figure 1 shows the schematic diagram of the fixed speed induction machine [3].

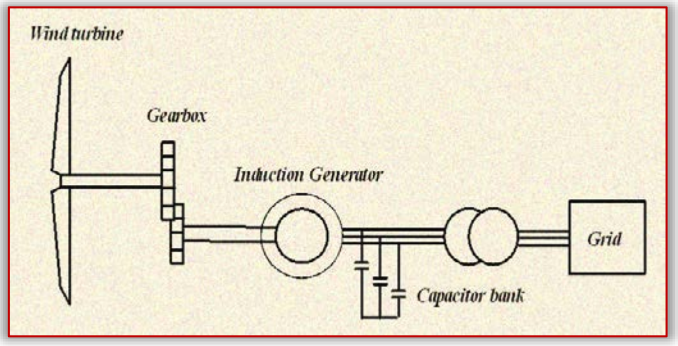

Figure 1. Fixed speed induction generator [3]

Variable speed concepts allow operating the wind turbine at the optimum tip–speed ratio and hence at the optimum power coefficient for a wide wind speed range. The two most widely used variable speed wind generator concepts are the DFIG and the converter driven synchronous generator. Due to advantages such as high energy efficiency and controllability, the variable speed wind turbine using DFIG is getting more attention. DFIG is basically a standard, wound rotor induction generator with a voltage source converter connected to the slip–rings of the rotor. The stator winding is coupled directly to the grid and the rotor winding is connected to power converter as shown in Figure 2.

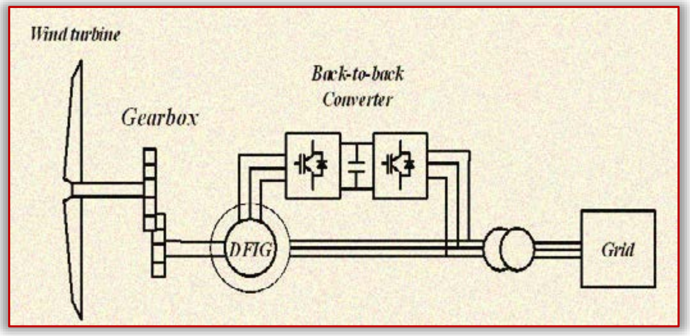

Figure 2. Double fed induction generator [3]

The converter system enables two way transfer of power. The grid side converter provides a dc supply to the rotor side converter that produces a variable frequency three phase supply to generator rotor via slip rings. The variable voltage into the rotor at slip frequency enables variable speed operation. Manipulation of the rotor voltage permits the control of the generator operating conditions. In case of low wind speeds, the drop in rotor speed may lead the generator into a sub synchronous operating mode. During this mode, DFIG rotor absorbs power from the grid [3].

This category of wind turbines uses a synchronous generator that can either be an electrically excited synchronous generator or a permanent magnet machine. To enable variable–speed operation, the synchronous generator is connected to the network through a variable frequency converter, which completely decouples the generator from the network. The electrical frequency of the generator may vary as the wind speed changes, while the network frequency remains unchanged. The rating of the power converter in this wind turbine corresponds to the rated power of the generator plus losses. The schematic diagram of the converter driven synchronous generator is as shown in Figure 3.

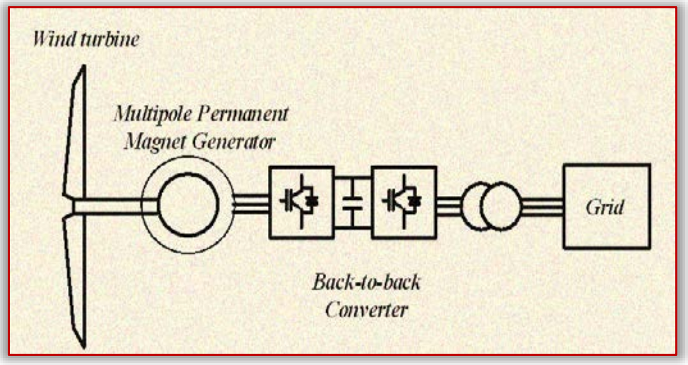

Figure 3. Converter–driven generator

A wind generator with a synchronous generator (SG) has a number of possible configurations, because SGs can produce rotor flux independently. Instead of an active rectifier on the generator side, a cheaper diode rectifier with a voltage boost converter can be used in the DC link (Figure 4). However, for higher power the voltage booster must be composed of several intertwined units or in some other way.

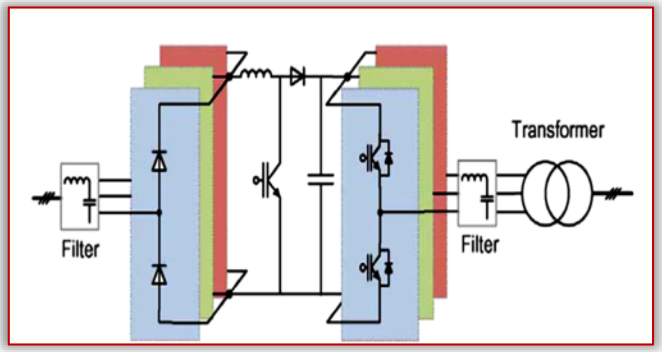

Figure 4. Converter assembly with diode rectifier, boost voltage converter and voltage rectifier [1]

Medium voltage electric generators and adequate converters are used for higher power wind generators (10 MW). The problem is the high voltage stress of the electronic switching components, however components must bind to the row.

New solutions for higher power converters include the use of multilevel converters. 3–level, 5–level inverter variants are possible, as well as combinations of these solutions in a half–bridge or bridge configuration. Figure 5 shows a solution with a 3–level rectifier and a 5–level inverter in a half–bridge configuration. In addition to the problem with the voltage fluctuation of the midpoint, which is on the way to a solution, a serious drawback is the uneven distribution of losses in the branches of the converter.

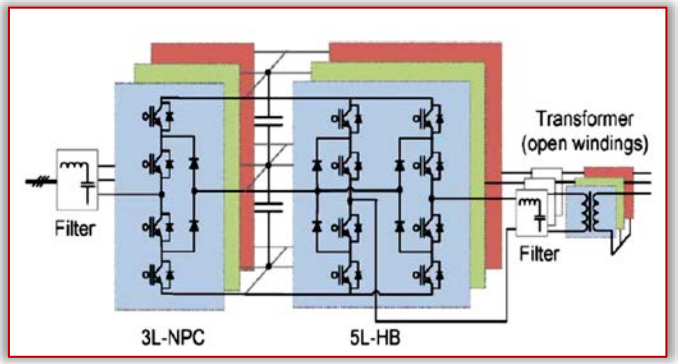

Figure 5. Dual converter with 3–level rectifier and 5–level inverter [1]

For wind generators, it is possible to use converters with several connected smaller units, which is more convenient considering the voltage levels of the switching electronic components themselves. Unlike variants with double converters, solutions with indirect or direct AC / AC converters are proposed here.

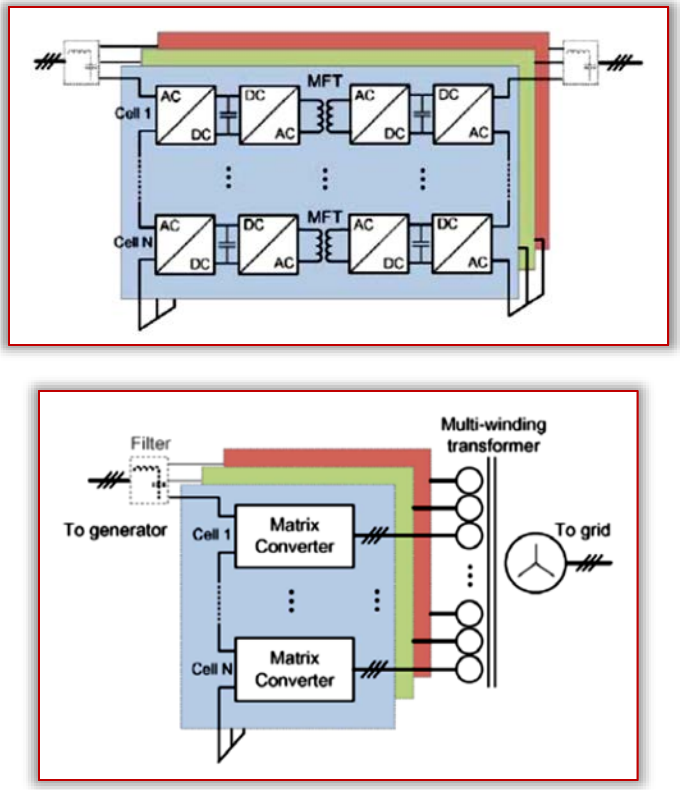

Figure 6. Indirect and direct AC / AC converters for wind turbines [1]

Figure 6 shows two possibilities: an indirect converter and a direct (matrix) converter. An indirect converter is a combination of AC / DC, DC / AC, AC / AC, AC / DC and DC / AC series–connected converters, with the AC / AC converter being in fact an isolating transformer, operating at medium frequencies. A matrix converter is a complex unit, which requires an isolating transformer with a larger number of primary windings. Other solutions are possible, which include a large number of differently parallel or series–connected converters with a large number of switches. However, due to the many components, the issue of system reliability comes to the fore, so complex analyzes of possible outages and maintenance methods are needed [1].

IMPACT OF WIND INTERMITTENT AND VARIABILITY

Uncertainty and variability are characteristics that exist in wind power, aggregate electric demand and supply resources and have always posed challenges for power system operators. Future expansion of the loads cannot be predicted accurately, generator outputs and loads fluctuate strongly in different time frames, and it can also lose energy system equipment at any time and without prior warning. Different amounts and types of operating reserves are secured by power system operators to compensate for uncertainty and variability for load reliable service and to keep the system frequency stable. There are many different terms, definitions, and rules concerning what operating reserves entail.

The real power capability that can be given or taken in the operating timeframe to assist in generation and load balance and frequency control is defined as the operating reserves. To provide voltage support systems also require reactive power reserve as well, and require certain targets for installed capacity that is often referred to as planning reserve [3].

The type of event the operating reserves respond to, the timescale of the response and the direction (upward or downward) of the response can differentiate the types of operating reserves. Unpredictable imbalances between load and generation caused by sudden outages of generating units, errors in load forecasting or unexpected deviations by generating units from their production schedules can be compensated by spinning reserve (SR).

It becomes more difficult to predict accurately the total amount of power injected by all generators into the power system, as the proportion of power produced by wind farms increases. This added uncertainty must be taken into account when setting the requirement for SR. The uncertainty on the wind power generation increases the uncertainty on the net demand that must be met by traditional forms of generation if wind power generation is considered as a negative load. Spinning reserve is intended to protect the system against unforeseen events such as generation outages, sudden load changes or a combination of both by taking the increased uncertainty into account when determining the requirements for SR [3].

CONNECTION OF THE WIND POWER PLANT TO THE NETWORK

Each power system operates in accordance with certain rules that define the obligations of existing and future users to operate and connect to the power grid [1,4]. These requirements must be met by electricity producers, consumers connected to the electricity grid and grid management companies. These rules are known as the "Rules of Procedure power system" (Grid Code).

Similar to transmission networks, the distribution network determines the requirements for connection of its users in the "Rules of operation of the Distribution Network" (Distribution Code) [1]. Compared to transmission network users, distribution network users have less power and less impact on the operation of the network, so that the requirements of the Rules of Operation of the Distribution Network are significantly easier compared to transmission. The fact is that the requirements of the "Rules of operation of the power system" are constantly adapted to the development of technology. These include fault issues, active power regulation, frequency, reactive power regulation, voltage regulation and production planning.

Wind farms are connected to the electricity grid, depending on the power: for installed power over 15 MW, farms are connected mainly to the transmission network, while for power below 15 MW they are connected to the distribution network. Since wind farms can have a significant impact on the quality of electricity and the stability of the power system, their installation, activation and operation are a significant problem. In that sense, technical ones are prescribed rules for connection of wind farms in the Rules for the operation of power systems (Grid Code). Wind turbine technology is evolving rapidly and has a lot of special functionalities compared to conventional power plants. For this reason, in many countries the requirements for joining farms wind generators have a special treatment in the form of special rules (Wind Code) [1].

CONCLUSION

The changing nature of a power system has considerable effect on its dynamic behaviors resulting in power swings, dynamic interactions between different power system devices and less synchronized coupling.

The general requirements of most of the leading Rules on the operation of the system (Grid Code) in the part of connecting wind farm farms, include the problem of failures, regulation of active power, frequencies, regulation reactive power and voltage, which are analyzed in this paper.

On the other hand, modern constructions of wind generators enable cost reductions and increased reliability. In future high–power units, quality and reliable solutions of power electronics converters will play a key role in the electrical part. Further progress and significant improvements are expected in this area.

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