ADVANCED SOLUTIONS FOR ACTUAL POWER QUALITY PROBLEMS DUE TO GROWING DENSITY OF WIND FARMS

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INTRODUCTION

The short-circuit power provided by common wind energy converters (WEC) is extremely low. In case of power system faults this results in severe voltage drops, problems with fault locating and fault evaluation and even in stability problems. This situation becomes even more critical with the growing number of installed wind farms.

The classical synchronous generator doesn't solve the actual power quality problems due to the stiff frequency of the generator while having a variable frequency of the rotor which requires the use of a gear or an AC/AC converter.

The following article describes a solution consisting of a synchronous generator in conjunction with a differential gear.

POTENTIAL EFFECTS ON POWER QUALITY

The appearance of wind power generation has changed dramatically during the last years. In the early years the generation of electrical energy using wind turbines was characterized by single units with limited power feeding into the distribution system, preferably in medium voltage level. Today’s technology is characterized by large wind parks consisting of many units each with a rated power of 1.5 MW or more connected to high-voltage distribution systems or even the transmission system. In the same way effects of wind power generation on power quality have changed.

Due to the use of self-commutated converters instead of current-controlled converters for wind power generation problems of flicker and harmonics are not of major relevance any more, as measurements can prove [1]. Also, the voltage rise at the connection node caused by short-time power variation has lost in relevance, as large wind parks with units distributed over a wide-spread area reduced the influence of local gusts and as the connection to high-voltage systems with a high short-circuit power limited the remaining voltage rise.

On the other hand, new problems arise or gain in significance with the growing density of wind farms and lead to stricter rules for connection of wind power plants to the grid [2] as well as to new concepts for planning and operating the grids [3].

The increasing installed power of wind energy converters (e.g. in Germany a total of 10 GW was reached in summer 2002, see figure 1) in combination with the high variation of power output due to the correlation with the cube of wind velocity requires a high range of quickly available control power [5] and enhanced regional weather forecasts. Also a flexible mix of different dispersed generation sources ("virtual power plant") is discussed to obtain a smoother power production of the dispersed generation in total. However, it is not only the variation of the power output but also the limited short-circuit power which might cause...
problems, when the portion of wind power fed in a system achieves remarkable levels.

Figure 1  Installed wind power in Germany (* estimated) [4]

Effects of Lacking Short-Circuit Power

Fault currents and voltages. In the case of short-circuit faults in the grid a voltage dip shaped like a funnel is formed [6]. Its steepness and also its diameter is depending on the short-circuit power at the nodes of the high-voltage system. Besides, the fault currents in the branches of the afflicted grid are used as the main criterion for fault detection by protection relays.

The power plants connected in the closer surrounding of the fault location will provide the larger portion to the short-circuit power compared to those more distant. Therefore these power plants above all decide about the extension and the depth of the voltage dip in the case of a fault and contribute to the short-circuit currents.

When substituting conventional power plants by wind farms in regions with a high density of wind power without an ability to provide equivalent short-circuit power,

- an extended region will be affected by voltage dips in case of short-circuit faults, and
- a reduction of the resulting short-circuit currents is to be expected.

Figure 2 shows the extension of the voltage dip in the north German E.ON transmission grid, where about 4 GW of installed wind power is connected to the E.ON-grid. The substitution of conventional power plants by wind power plants will therefore result in

- an impairment of the effectiveness of power system protection, if its concept and parameters will not be adjusted and
- an escalation of active power shortage after short-circuit faults increasing the risk of voltage collapse, as undervoltage protective relays are set to disconnect wind turbines from the grid in case of voltage dips. In the revised rules of connection (e.g. [2]), it is required that wind turbines remain connected to the grid for a longer time also in fault conditions.

Both results mentioned above would not occur, if wind power plants would provide a short-circuit power in a way comparable to synchronous generators.

Stability. In systems, which are sensitive regarding the maintenance of static or transient stability, faults will result in a phase shifting between regions with integrated power generation. In general this phase shift will increase with the duration of the fault. This effect appears most likely, if the fault location causes a decoupling of the regions. Oscillations of the rotor angle might result in the loss of transient stability after fault clearing.

If the power output in an area is reduced as a consequence of the fault (e.g. by disconnection of wind power units through undervoltage relays as a consequence of their location inside the area affected by the voltage dip), the voltages after fault clearing will be lower than before. As the synchronizing torques are depending on the voltage, this results in a further reduction of the stability margin.

So, the integration of wind power plants in regions being sensitive to stability does not only require the provision of short-circuit power but also the feed-in of active and reactive power after fault clearing.

Remedial measure. By the connection of wind power plants via converters the maximum available short-circuit power is typically limited to the rated apparent power. The direct connection via synchronous generators could solve the mentioned problems by providing short-circuit power in the same way as a conventional power plant. Due to the fact, that the generator shows the stiff frequency of the system while the rotor frequency is varying with the wind velocity, synchronous generators can be used only in combination with a mechanical gear. Conventional solutions, however, fail because of the extreme mechanical load on the gear caused by gusts.
POSSIBLE SOLUTIONS

To solve the described problems a number of solutions still exist. Some of them will be briefly discussed in the following and complemented with a detailed description of a new approach.

Pole-Changing Generators

Pole-changing generators with different rotational speed values can cope with varying wind velocities. However, they are common only with small power ratings below 1 MW and designed to work with two different speeds only. Furthermore, pole-changing generators need complex and expensive constructions of the generator windings. Their grid compatibility is moderate while undesirable effects like flicker are comparatively high. To be operated properly, a compensation is necessary. In case of short-circuit situations, pole changing generators tend to switch from generator into motor operation leading to problems with grid protection systems. An unresolved problem concerning grid protection is also the limited short-circuit power of these generators.

Gearless Generators

Another solution is based on large heteropolar and speed variable generators. These generators are connected directly to the WEC’s rotor and connected to the grid by using an AC/AC converter system. A special gearbox is not needed which reduces maintenance costs. This solution leads on one hand to comparatively large and heavy generator components. On the other hand, an expensive IGBT converter technology is necessary to reach 100% rated power. Converter and power electronic self protection is problematic towards the grid (e.g. lightning protection). In case of fault situations the reachable short-circuit power is limited to approximately 1.5 x rated power, leading to problems with existing grid protection systems. Also due to the use of an AC/AC converter the supply of capacitive reactive power is only possible if this converter is over-dimensional, which restricts the ability of phase shifting operation.

Double-Fed Asynchronous Generators

Double-fed asynchronous generators compensate speed fluctuation by using an electrical compensation in terms of a rotating field in the rotor. They result in an expensive generator technology, as the polar wheel contains complex windings. To provide the polar wheel with electrical power, slip rings are necessary, which are subject to mechanical and electrical wear.

WEC with Power Plant Properties

The aim of the new approach is to trim the WEC to power plant properties, as requested by large German network operating companies [2]. To reach this aim, the weak points of existing solutions are in focus. A new solution should provide a better short-circuit behaviour, the ability of auto-reclosing and should be able to bear voltage drops or overvoltages as well as increases or decreases of the grid frequency.

Future wind farms will produce high power (up to GW) and therefore will have a strong influence to the grid. To supply the loads with the right power and to operate the grid at its best (overall) efficiency, reactive power has to be provided. Since these wind farms could be far away from the next grid connection point this ability could be used to compensate parts of the cable impedance of the connection as well. To provide reactive power, phase shifting operation is mandatory. This operation should be controllable by remote means.

Another required feature is the supply of power control. Remotely controlled, it can provide a "soft approach" to adjust the power feed into the grid. If wind is present, this feature can also be used to adapt to customer behaviour or to controlled reduction of delivered power before or during storms.

One outstanding feature of conventional power plants is their high availability. To get windmills with a similar reliability and high availability all components like gear box, generator etc. have to be designed in a similar way (different to existing windmill solutions). An additional online condition monitoring systems in conjunction with maintenance management will achieve this target.

New Approach MADynacon

The new approach "MADynacon" consists of a powerful synchronous generator, based on standards and directly coupled to the grid, without an AC/AC-converter link. A complete wind farm of MADynacon WEC's is viewed as a system that can almost be handled like a power plant, as long as wind is present.

In reaction to maintenance clauses from German insurance companies, MADynacon contains an online condition monitoring system with electrical power, slip rings are necessary, which are subject to mechanical and electrical wear.

In addition, this concept allows a sustained short-circuit current limited by the converter design. The peak short-circuit current is strongly limited. In case of short-circuit situations, double-fed generators show the same behaviour as pole-changing generators and tend to switch from generator into motor operation leading to problems with grid protection systems. Phase shifting operation with double fed generators is possible, but restricted.
monitoring system. In combination with an IT System for supervision and planning of maintenance work, the demands can be fulfilled at best.

Figure 3 shows the elementary structure of MADynacon. By integrating a differential gear into the main gear, varying wind speeds, leading to varying tournaments of the rotor, do not affect the generator, but lead to differential tournaments at the auxiliary drive. Thus, gusts of wind do not affect mechanical parts of the generator, which leads to less mechanical stress. The auxiliary drive is a standard asynchronous motor. The needed converter components are robust and well proven. Service and remote supervision is realised via a separate control center.

**Power Quality from WEC**

One of the main advantages of the shown approach is a speed control loop that is not influenced by the grid or vice versa. The use of a "pure" synchronous machine connected directly to the grid provides best possible grid compatibility. Even in case of wind gusts only a small amount of flicker is produced. Gust loads are regulated very fast within the gear. The synchronous machine also guarantees maximum short-circuit power and a very low amount of harmonics. Short-circuit currents up to 14 x rated current are expected. Thus existing grid protection systems can be left unchanged and electrical power can be fed into the grid also during grid voltage drops.

A controlled phase shifting operation is possible. In addition, the adaptation of the generator voltage up to medium voltage level is possible. This leads to simplified constructions of grid-connecting substations.

The used gear provides several details to cope with the special situation in WEC. Wind loads are kept away from the gear steps by special support structures. An automatic load equalisation and reduced load on the gear is achieved by specially designed planetary steps. The gear is constructed modular and easy-to-install.

**CONCLUSION**

Existing wind energy converters show a higher fault rate as expected. The increasing installed power of wind energy converters leads to severe problems with the existing grid. The consequence are stricter rules for the connection of wind power plants to the grid, as already provided by large electric utilities in Germany as well as stricter rules for getting insurance contracts for the wind farms.

The aim of the discussed approach is to solve some of these problems, like limited short-circuit power or the lack of reactive power by a new technical concept, consisting of a synchronous generator with a differential gear, which is directly coupled to the grid and supervised by an online-monitoring system.

However, some of the restrictions cannot be avoided, i.e. the variation of power produced by the stochastic system "wind". The shown approach should therefore be seen as the first step to reach the aim of a WEC with power plant properties.

**LITERATURE**


