GRID CODE INTERRELATION, WIND GENERATION EVOLUTION AND REACTIVE COMPENSATION. SPECIAL TOPICS INSIDE A GRID CODE

RAFAEL GUERRERO
Arteche – México
rguerrero@arteche.com.mx

ABSTRACT

By all appearances, the evolution of wind generation has been orientated to satisfy the requirements, every time inside narrower limits, imposed by the grid codes, standing out among all the determining ones, the administration of the reactive power. In the age of induction generator's fixed speed, the requirements to access to the network were lax, considering the lack, for any practical, end of the capability´s curves.

The advent of the DFIG's and the electronic switch (IGBT's) evolution, have allowed that a wind farm, in the first instance, can handle the reactive power by means of the availability of a capability curve and comply, this way, with the most restricted codes. The update has been given in very recent date, with a wind farm´s activation of an integrated by DFIG's and full converter generators, whose capability´s curve are similar to that of a conventional plant. Seeing to the future, probably let's be able attend the elimination of the gear's box. Nowadays the wind generators operate better with high speeds and, therefore, they need gear´s box to reduce it. Considering all gear train´s issues: cost, vibrations, noise, fatigue, lubrication and maintenance, eliminating the box would have big advantages.

The recent versions of the grid code, authorizes the operator to treat the wind farm just like a conventional plant, using the capacity of reactive power inside the extended range of the capability curve. This is not just for reducing the limits inside which one must move the tension and the power factor; now the wind farms must satisfy polygon´s critical points of operation, impossible to satisfy with the first generation machines. Under this new operation criterion, the good administration of reactive power is the result from a combination of machines contributions, switched capacitor banks and the reactive dynamic compensation get it using switch electronic devices.

The grid code tacitly, yields the owner of the wind farm, the responsibility of solving extraordinary problems or out of the normal catalogue, like a subsynchronous resonance or torsional effects.

Give an idea of the entail of all these factors is the purpose of this paper.

Key words - wind farm, grid code, point of common coupling (PCC), synchronous generator, reactive control, sub synchronous resonance (SSR).

INTRODUCTION

The utilities think that the power system reliability would be at great risk if the variable wind energy resources continued increasing in the near future. These new concerns will be expressed on the Grid Codes.

As *wind* generation becomes increasingly more important each day, regulations for its interconnection have become more and more demanding. These can be sequentially enlisted as follows.

Grid Code requirements

- Both voltage control and power factor control modes are required, and will be measured at the PCC. Voltage control and power factor control will be functional at least to the power factor limits of lead/lag 0.95 and voltage band 0.95 –1.05 p.u. Either control mode shall be functional to the above limits as long as the wind farm is generating, including up to rated power.
  See especially reference [1], which confirms applicability of this section to all generating facilities, including wind. Section 9.6.1 indicates that power factor lead/lag 0.95 is not automatically applied to wind generating facilities, but many System Impact Studies (SIS) determines the required range. The published SIS indicates power factor lead/lag 0.95 is now an accepted as a general rule.
- Low Voltage Ride Through, LVRT.
- Generation of lagging or leading reactive power as required by the System Dispatcher.
- It's strongly recommended to manage the wind farm as if it were a conventional generation plant, and to abide by the dispatch policies on the real and reactive power of the wind farm, with very few exceptions.
- Strict fulfillment of the polygon of operation conditions (See figure 1) can be interpreted as a full integration of the wind generation as a conventional generation plant without exceptions.
- In order to preserve the system's reliability, the wind farm must operate with spinning reserve.
- The inclusion of more constrictive conditions on the Grid Codes, as specified reference [2]: Long-Term Reliability Assessment (2010). This text suggests the curtailment of the variable or intermittent generation after conventional resources are reduced to the minimum possible outputs.
- Resonance. The Generator Facility(ies) and Generator Interconnection Facility(ies) should be designed to avoid introducing detrimental resonance into the Transmission System or avoid unnecessary outages of the wind farm by disturbances related occurred on the system. The

Generator shall ensure that any issues related to resonance are addressed on the protection and control design schemes of the Generator Facility(ies).

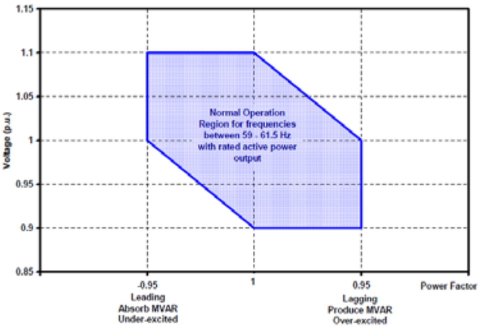

Figure 1. Reactive power requirements.

Some historical background

Wind Energy Conversion Systems (WECS) transform the energy present in the blowing wind into electrical energy. Wind is a highly **variable resource that cannot be stored** and Wind Energy Conversion Systems must be operated accordingly. A short overview of the system is given next. Wind energy is transformed into mechanical energy by means of a wind turbine that has one or several blades (three is the most usual number). Figure 2 shows a wind turbine characteristic for maximum power extraction.
The turbine coupled to the generator by means of a mechanical drive train. It usually includes a gearbox that matches the turbine low speed to the higher speed of the generator.

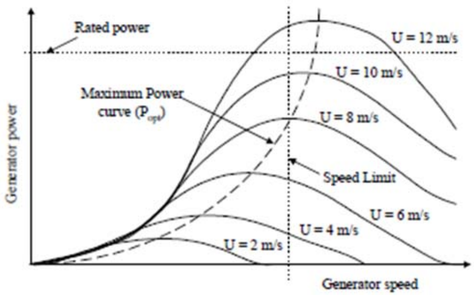

Figure 2. Wind turbine characteristic.

New wind turbine designs use multi-pole, low speed generators, usually synchronous with field winding or permanent magnet excitation, in order to eliminate the gearbox.
Variable speed systems require the presence of a power electronic interface that can adopt very different configurations. The compensating unit may include power factor correction devices (active or passive) and filters.
The switching equipment should be designed to perform a smooth connection, a requirement usual in standards.
Standards also specify some protections that, at least, must be present in the generating unit.
Finally, the control system may have different degrees of complexity.

Energy converter systems

Regarding rotational speed, the wind turbines can be split into two types variable and fixed rotational speed units. In this paper only covers the variable speed wind turbines, by their ability to regulate power.

Variable speed wind turbines

In variable speed machines, the generator is connected to the grid through an electronic inverter system (see figure 3), or the generator excitation windings are fed by an external frequency from an inverter (see figure 4). The rotational speed of the generator and thus of the rotor is decoupled from the frequency of the grid, the rotor can operate with variable speed adjusted to the actual wind speed situation.

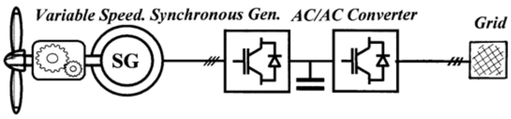

Figure 3. Full converter machine.

All devices may be pitch or stall regulated. The pitch regulation systems rotate the blade about their long axes through a pitch regulation mechanism. With this mechanism, the mechanical power can be reduced, according to the turbine characteristics. Stall regulated turbines do not have such a mechanism, but when the wind exceeds rated levels, they are prevented from taking excessive power from the wind by an aerodynamic effect.

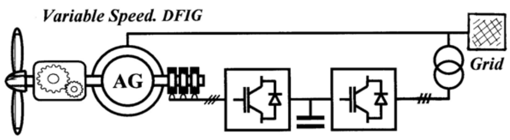

Figure 4. Doubly-Fed Induction Generator (DFIG).

Asynchronous generators must be provided with reactive power control equipment.
Variable speed systems provide more energy production, less mechanical stress on the mechanical parts and a more smooth power production (fewer dependants on wind variations and system oscillations). In some of these systems, the gearbox can be omitted. Some of these devices may require harmonic compensation, due to the presence of electronic converters.

REACTIVE POWER SOURCES – REACTIVE POWER CAPABILITY

Premises

It seems as a general criteria, that in steady state the voltages must remain within 0.95 p.u. and 1.05 p.u. Following a single contingency (single element outage), transmission system steady sate bus voltages must remain within 0.90 p.u. and 1.10 p.u. Many, if not all utilities, expect the reactive compensation to be capable of achieving a PF of ±95% at the PCC at full generation with

voltages ranging from 0.95-1.05 p.u.
The reactive power generation resources defined or restricted by the capability curves are shown next.
If any Load Tap Changer (LTC) has a range of regulation of ±10%.
Some manufacturers use the line side converter in the rotor circuit for supply or consume reactive power. That permits voltage / power factor regulation that exploits the reactive power capability of the individual wind turbines.
The first one uses the power electronics to demarcate the permissible zone (see figure 5). Wind turbines can operate permanently at any point within the zone delimited by the black lines (triangular zone). The line itself is the limit for having power factor of ± 0.95. In fact, the manufacturer's warrantee is effective if the machine operates inside or touching the triangular zone.

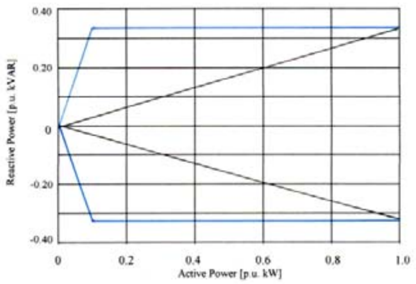

Figure 5. DFIG characteristic curve.

Finally, for the full converter wind generators showed in figure 6, the use of the line power converter for supplying or consuming reactive power results on a family of capability curves, depending on the voltage at generator terminals. The bigger the voltage the lower capability. At 1.1 p.u. voltage, the generated lagging reactive power is almost zero. At any voltage level, the absorbed leading power factor capability is high.

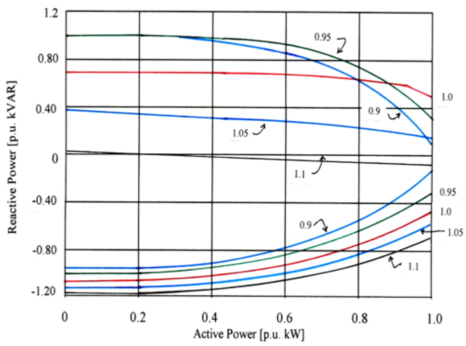

Figure 6. Full converter characteristic curve.

This is the closest approximation to a synchronous generator capability curve, and satisfies by itself the vertices of the polygon of operation conditions.
Actually, the fact of using the line side converter for achieving an extended capability curve can be visualized as having a VAR controller (Dynamic reactive power source) on each wind unit.

More about Grid Code – Obligations

The Generator Facility(ies) and Generator Interconnection Facility(ies) should be designed to avoid introducing detrimental disturbances into the Transmission System or avoid unnecessary outages of the wind farm by disturbances related occurred on the system.
The reactive power capability shall be sufficient to ensure both steady state and transient stability during and after a disturbance.
The INTERCONNECTION STUDIES will determine the appropriate amount of dynamic reactive power on a site by site basis.
The use of mechanically-switched reactors or capacitors, static VAR compensators or similar devices may be acceptable alternatives for providing all or part of the reactive supply and verified by the INTERCONNECTION STUDIES.

FIRST RELATED DOCUMENTED CASE: SUBSYNCHRONOUS RESONANCE (SSR)

The wind farm is connected to the system with a transmission line which is series compensated.
There is the potential risk that the wind farm could be radially fed through the series compensated. The series compensation could have potential SSR interaction with the wind farm generators tied to the main network. The utility is concerned about the interaction of the converter controls and the transmission system. It is also important that the wind farms' owner understand any potential impact of interconnecting to a series compensated transmission line. The wind farm owner is responsible for the analysis and protection of their equipment as well as any damage that can occur on their side of the interconnection. The utility recognizes interconnecting to the transmission system with series compensated line is not a typical interconnection. The following are some of the issues for consideration by wind farm entity in their analysis.
Wind farms´ owner and their selected turbine manufacturer will need to take this into consideration and determine if the turbines are susceptible to any damaging interaction due to the close proximity of the series compensated transmission line. Based on the data provided by wind farm owner and their turbine manufacturer.

The Crowbar

A rotor crowbar circuit is often used to protect the power converter from dangerous overcurrent, in response to faults and to allow safe demagnetization of the machine by connecting the rotor phases together through a resistance. Immediately after the presence of the high current the crowbar is engaged on the rotor circuit, which temporarily closes the rotor circuit through a dc resistance (25 Ω) via a fast-acting Insulated Gate Bipolar Transistor (IGBT).
The crowbar is automatically activated by a specific level of rotor overcurrent (2 p.u). The crowbar diverted current away from the DFIG´s power converter that is

disconnected temporarily.

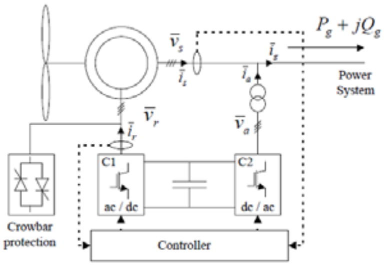

Figure 7. DFIG with crowbar.

The crowbar advantages becomes evident after the next qualitative comparison: a machine configured as singly fed induction generator, with the three phases of the wound rotor physically short-circuited, with some specific set up to generate real power at a steady speed prior to the fault, has a response to a fault on the next terms: The rotor current exhibit more dc than ac, indicating that the rotor transient time constant is longer. The near dc component of the stator currents decay over roughly 25 ms, while near dc on the rotor decays over 40 msec. The peak rotor current is a little below 5 p.u.

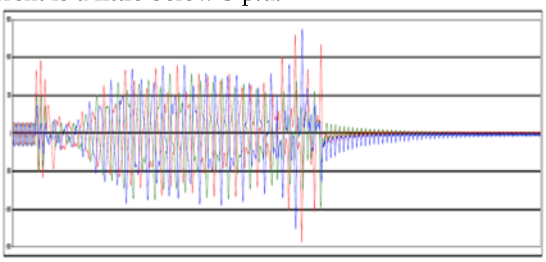

Figure 8. SSR disturbance.

On the other hand, the induction machine is now configured as DFIG, with a crowbar that increases significantly the rotor circuit resistance, leading to a very much shorter rotor time constant (10 msec). We can say that the high rotor resistance caused the rotor flux to decay over only approximately 10 msec. The disturbance in figure 8 was registered after a severe disturbance, in which a wind farm remained solely connected in series with the compensated line. The crowbar's control was not able to decipher the 24-cycles current and hence, it failed (35 of them).

SECOND RELATED DOCUMENTED CASE: REACTIVE POWER

In the figure 9, the reactive power supplied by the capacitor banks (red) reestablishes the 230 kV line's natural power (P_n=135 MW). Without the shunt capacitors' injection, the line needs by itself 53.7 MVAR while transporting 2.2 P_n.

In the figure 10, the reactive power supplied by the capacitor banks flows into the system (blue), but only if the system's voltage in p.u. becomes lower than the voltage of the wind farm (red).

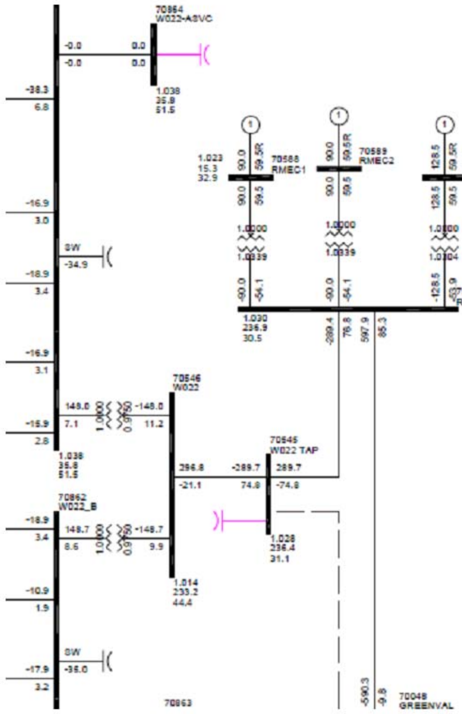

Figure 9. Reactive power compensation (Example 1).

Otherwise, the reactive power is absorbed by each unit of the park, something one would strongly advise against. If the system voltage actually took such low values, one could conclude that the grid must have been severely perturbed; that would also mean that the shunt capacitors would be needed for satisfying only one corner of the operating-conditions polygon. This statement is true for full converter wind generation schemes.

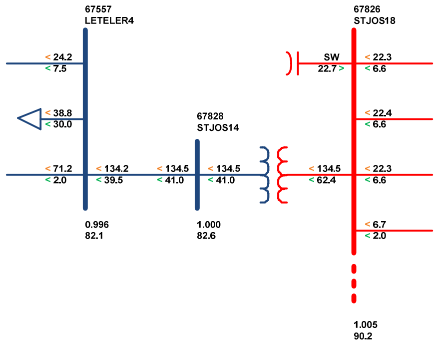

Figure 10. Reactive power compensation (Example 2).

REFERENCES

[1] Federal Energy Regulatory Commission (FERC), USA, 2005. Interconnection for Wind Energy. Order No. 661A Final Rule.

[2] North American Electric Reliability Corporation (NERC), 2010. Long-Term Reliability Assessment.

[3] CIGRE TF38.01.10, 2000 "Modeling New Forms of Generation and Storage".