21, rue d'Artois, F-75008 PARIS
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Improvement of Technical Requirements for Connecting Wind and Solar Plants in the Brazilian Interconnected Power System

S. SARDINHA, S. CISNEIROS, M. BOTELHO, P. GOMES, D. BRASIL, F. MEDEIROS, A. BIANCO, A. MEDEIROS, P. QUINTÃO, A. BARBOSA, F. SOBRAL, R. NUNES, T. MUNDSTOCK
Operador Nacional do Sistema Elétrico (ONS)
Brazil

SUMMARY

The growing trend in renewable generation development which most of them have intermittent nature, has presented new challenges for the electricity markets and system operators. These challenges include: planning resource adequacy for long and short terms, providing adequate transmission facilities to incorporate these sources, mitigating transmission constraints due to the rapid loss of a large amount of such generation, managing increased system reserve and ancillary service requirements, and ensuring acceptable performance by these generators. Thus, the connection requirements of this generation source should ensure control of the frequency and voltage of the whole system as well as the capacity of wind generators to withstand impacts that may occur in the network within the standard limits.

The main objective of this paper is to present the results obtained by the Brazilian System Operator (ONS) about minimum technical requirements related to the connection of wind and solar power plants into the transmission system in order to guarantee power system security. This paper presents the improvements that ONS has done on the technical requirements for the integration of wind and solar power plants into the Brazilian transmission system in order to guarantee power system security and performance according to the grid code. Finally, conclusions and remarks are presented regarding the integration of wind and solar power plants, keeping the power system security and performance.

KEYWORDS

Wind generation, solar generation, power system impacts, criteria, technical requirements, security, grid codes.

sardinha@ons.org.br

1. INTRODUCTION

Brazil has increased the installed capacity of wind power plants due to its the great wind potential existent, especially in Northeast and South regions, as well due to the decrease of energy final price, motivated by improvements in the technologies of wind turbine generators and plants, and the generation expansion model based on energy auctions. Brazil reached the top ten countries in 2014, and the installed capacity reached 8 GW in 2015 and it will be around 20 GW by 2020. Although the PV power plant is in a very beginning stage of implementation into the Brazilian grid, ONS has also established the first version of technical requirements for the connection of these plants.

The first version of the technical requirements for connection of wind turbines was stablished in 2004 according to the degree of insertion predicted for this source, when there was not yet a realistic expectation of its growth. With the increasing penetration of wind power in the Brazilian power system and the consequent greater impact from this source on system performance, a revised version of the Grid Code was developed in 2015, improving the original requirements.

The main aspects of this new version are presented in this article. This version take into account the perspective of massive installation of wind generation in the Northeast and South regions, and considers innovations offered by manufacturers in modern wind turbine designs and the growing evolution of the requirements set by System Operators worldwide towards ensuring systemic security.

2. IMPROVEMENT OF TECHNICAL REQUIREMENTS FOR THE INTEGRATION OF WIND GENERATORS

The proposed improvements on the minimum technical requirements for integrating wind turbines into the Brazilian Interconnected Power System (BIPS) in order to ensure its safe and reliable operation were developed based on the international experience and considering the features of the BIPS. They covered the following aspects:

- Operation out of nominal frequency (60 Hz);
- Operation out of nominal voltage;
- Reactive power capability at the POC;
- Reactive power generation and absorption capability on off-nominal voltage conditions;
- Control Modes of operation at the POC;
- Low and High Voltage Ride Through Fault Capability;
- Injection of additional reactive current during short circuits;
- Active power output during disturbances;
- Inertial response capability - Synthetic Inertia.

2.1. Operation out of nominal frequency (60 Hz)

This is one of the most important requirements to be met by wind turbines, particularly in an electrical system with the characteristics of the BIPS, where the exchange of large blocks of power between subsystems is usually practiced, aiming the optimal exploitation of the complementarity of its hydro plants placed in several river basins. The ability of generating units to withstand large variations in frequency that occur at the opening of an interconnection link until the actions promoted by load shedding schemes are completed (in case of underfrequency) or generation dropping is performed (in case of overfrequency), is of vital importance to the survival of the islanded area. The purpose of this requirement is to ensure that the settings of frequency protections of wind turbines do not lead to its premature disconnection, which can result in system collapse. Thus, it was defined as a minimum requirement for operation on off-nominal frequency conditions, the following references:

- Instantaneous disconnection allowed for operation below 56 Hz;
- Operation below 58.5 Hz for a minimum time of 20 seconds;
- Operation between 58.5 and 62.5 Hz for an unlimited time;
- Operation above 62.5 Hz for a minimum time of 10 seconds;
- Instantaneous disconnection allowed for operation above 63 Hz.

2.2. Operation out of nominal voltage

Wind generators should operate in the following ranges of the nominal voltage at the connection point:

- Continuous operation between 0.90 and 1.10 pu;
- Between 0.85 and 0.90 pu during 5 seconds;
- Between 1.10 and 1.20 pu during 2.5 seconds.

2.3. Reactive Power Capability at the Point of Connection (POC)

The following minimum requirement was defined for generation and absorption of reactive power based on the international experience and considering the features of the BIPS. Wind generators must have resources to operate at the POC with inductive or capacitive power factor between the minimums of 0.95 capacitive and 0.95 inductive, as shown in Figure 1. In conditions when the turbines are not producing active power, the wind power park should have control features to generate and absorb reactive power, to provide zero injection and absorption at the POC.

In order to contribute with system operation, the wind power park should provide at POC the resources, like shunt capacitors, reactors and SVC, to operate with leading or lagging power factor at any point in the area shown in this figure. It is included also the minimum requirement to provide zero injection in its connection, even on condition that wind speed is below of cut in or above of cut out.

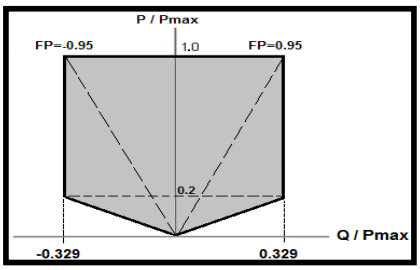

Figure 1 - Reactive Power Capability at the POC

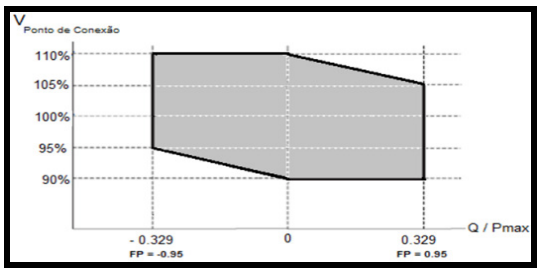

Figure 2 - Reactive power generation and absorption capability on off-nominal voltage conditions

2.4. Reactive power generation and absorption capability on off-nominal voltage conditions

The following minimum requirement was defined for reactive power generation and absorption capability on off-nominal voltage at the POC based on the international experience and considering the characteristics of the BIPS, as shown in Figure 2.

2.5. Control Modes of Operation at POC

Wind Power Parks should be able to operate in steady state in three different distinct modes of operation: voltage control, reactive power control and power factor control. The normal control mode is the voltage control mode in the POC of the wind power park, and has the objective of contributing to the the system voltage profile within acceptable ranges in normal or emergency conditions. When operating in voltage control mode, the wind power park should be able to provide a continuous control voltage at its connection point with an adjustable reference voltage between 95% and 105% of rated voltage and droop adjustable in a range between 2% and 7% with a resolution of 0.5%. Depending on system needs, the wind power park may be requested to operate in reactive power control mode or power factor control mode in the connection point in any of the above mentioned points, as shown in Figure 3.

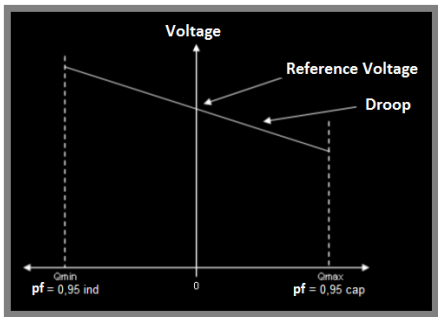

Figure 3 – Voltage Control Droop Characteristic

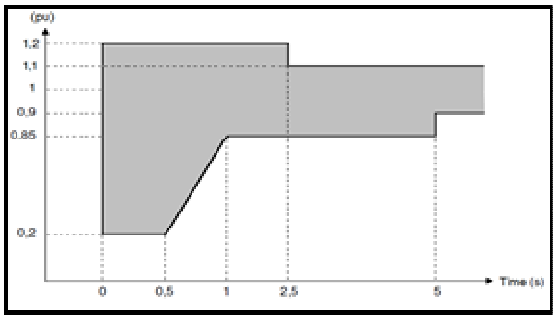

Figure 4 - Voltage at terminal of the wind generator (low and high voltage ride through fault capability)

2.6. Low and High Voltage Ride Through Fault Capability

The following minimum requirements were defined for low and high voltage ride-through fault capability based on the international experience and considering the characteristics of the BIPS. These requirements are associated with wind generation performance during under voltages caused by short circuits in the power system, named as Low Voltage Ride Through Fault Capability, as shown in Figure 4. The wind generator should continue operating when the voltage at this terminal is above this curve. On the other hand, it is important to guarantee the full operation in case of overvoltages, named as High Voltage Ride Through Fault Capability, as shown in the same Figure 4.

2.7. Injection of additional reactive current during short circuits

Currently, in addition to the requirement of withstanding low and high voltages during faults (fault ride-through) without disconnecting from the network, the wind generators are requested to contribute to the injection of reactive current for improved voltage recovery, taking advantage of power electronics ability. The following minimum requirement was defined for the injection of reactive current during faults based on the international experience and considering the characteristics of the BIPS. When subjected to transient voltage variations, in addition to meeting the requirement to stay connected for the period described on the fault ride-through characteristic, the wind generators must be able to provide voltage support to the grid through additional reactive current injection for voltages below 85%, and additional absorption of reactive current for voltages above 110%. The installation must be able to start the reactive power supply within no more than 30ms after fault detection. The System Operator is responsible for defining the operation of this resource, including setting the value of K (slope) to be used considering the power system features. This requirement is shown in Figure 5.

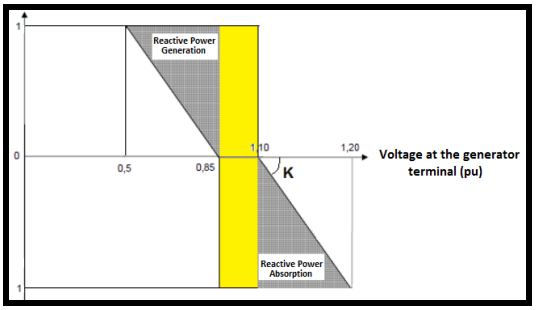

Figure 5 - Requirement for the injection of reactive current during faults

2.8. Active power output during disturbances

Wind power plants have a limited capability to participate in the frequency control. However, most of the Grid Codes include requirements for frequency control capability. The following minimum

requirements were defined for power output during disturbances based on the international experience and considering the characteristics of the BIPS:

a) The output power of the wind generator should recover to 85% of pre-fault value within no more than 4 seconds after the voltage recovery to 85% of rated voltage.
b) It is ONS's responsibility to define the power recovery ramp depending on the characteristics of the system where the wind generator is inserted.
c) No reduction in the output power in the frequency range between 58.5 and 60.0 Hz is admitted for voltages in the corresponding connection point of the restricted facilities of the wind generating plant between 0.90 and 1.10 pu.
d) Reduction in output power up to 10% for frequencies in the range between 57 and 58.5 Hz is permitted.

2.9. Inertial response capability - Synthetic Inertia

The following requirement was defined for the inertial response capability (Synthetic Inertia) of new wind turbines to be integrated into the BIPS with the objective of controlling the output active power in the conditions described below. The generators of wind power parks should be equipped with frequency sensitive controllers so as to emulate inertia (Synthetic Inertia) through the transient modulation of its output power, contributing with at least 10% of its nominal power for a minimum period of 5 seconds for frequency offsets greater than 0.15s. Synthetic Inertia provision should be enabled whenever the active power of the wind turbine is at least

3. TECHNICAL REQUIREMENTS FOR THE INTEGRATION OF PV - SOLAR GENERATORS

The expansion of the solar photovoltaic (PV) generation is very promising in Brazil, although there are major challenges for the grid integration of intermittent sources with daytime feature and fast deployment. Since October 2014, three public energy purchase auctions were carried out resulting in the total capacity of 2.7 GW on PV plants hired to start operation until 2018, and the Brazilian Government estimates that this amount may reach 8.3 GW by 2024.

The Brazilian Grid Codes in force do not include technical requirements for PV plants, however the recent experience gained with the wind technology and the common characteristics of the network interface encouraged the adoption of similar solutions. In essence, taking into account that the inverters adopted in the network interface of modern PV sites are comparable with the full-converter arrangement employed by Type IV wind generators, some of the depicted above technical requirements applied to wind plants were spread to be applied also in the connection of PV plants in the power system. They consist of operation out of nominal frequency and voltage, reactive power capability at the POC, reactive power generation and absorption capability on off-nominal voltage conditions, control modes of operation at the POC, low and high voltage ride through fault capability and injection of additional reactive current during short circuits. Regardless of not being part of the approved Grid Codes, these requirements are already mandatory to most of the hired PV projects, given that they are explicit in the public notices for the energy auctions carried out since 2015.

4. CONCLUSIONS

The main conclusions and remarks on the Brazilian interconnected power system, including results obtained, improvements in the Grid Code requirements, and perspectives referred to the integration of wind and solar power plants, in order to keep the power system security and performance are presented below.

a) The impacts of wind generation on system security must be evaluated considering the effects in time and space. In the temporal context, the consequences of imbalances of load and generation in the operating scale (minutes to hours) should be considered. In the space dimension, local and systemic consequences should be evaluated.

b) The significant increase in the penetration of wind generation in the Brazilian Interconnected Power System that will take place in the coming years is a major challenge for its operation. The connection requirements for this generation source should ensure control of frequency and voltage of the entire system as well as the ability of wind turbines to withstand the impacts provoked on the network, within the established standards and limits. To meet this goal, the Grid Code should be kept under constant review, updating and complementation.

c) The proposed improvements on the minimum technical requirements for integrating wind turbines into the Brazilian Interconnected Power System in order to ensure its safe and reliable operation were developed considering the following aspects:
   - Operation out of nominal frequency (60 Hz);
   - Operation out of nominal voltage;
   - Reactive power capability at the POC;
   - Reactive power generation and absorption capability on off-nominal voltage conditions;
   - Control Modes of operation at the POC;
   - Low and High Voltage Ride Through Fault Capability;
   - Injection of additional reactive current during short circuits;
   - Active power output during disturbances;
   - Inertial response capability - Synthetic Inertia.

d) The experience adquired with the operation of wind plants especially regarding the improvements made in the technical requirements is an important background to be applied for connection of PV solar plants in the power system.

e) However, it is important to consider the specific features of PV Solar plants, as mentioned below:
   - The PV - Solar generation depends on effectivelly of the solar radiation;
   - For that, there is not generation during the night and during the day the amount of generation depends on the Global Horizontal Irradiation (GHI), presence of clouds and occurrence of solar eclipse;
   - Definitely, the PV Solar generation is more provisional and has less variability than wind generation.

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