Flicker mitigation and voltage sag ride through of a wind turbine using an STATCOM

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I. Summary

Wind farms are becoming more and more important as distributed renewable energy resources. That is why quality issues (such as flicker emission and voltage sag ride through) are being taken into account by grid codes. Wind farms employing fixed speed induction generators may require dynamic compensation devices, for instance, STATCOM units to fulfill the network requirements.

In this paper, the installation of a STATCOM device in parallel with the wind turbines is examined. Different configurations are analyzed through simulation with the aim of determining the STATCOM size and designing its control. Measurement data obtained in a wind park have been used in order to simulate the real working conditions of wind turbines.

II. Introduction

In recent years, there has been a rapid increase in the use of renewable energies throughout the world, in response to environmental concerns and the threat of an energy crisis. Among all the renewable energies, wind energy has grown the fastest, and is still growing [1]. This increased use implies a number of issues; one of the most worrying is the integration of wind energy in distribution and transmission networks. The behaviour of the wind parks is important not only under normal working conditions but also when voltage sags do occur. In some countries, especially those where there are large wind energy installations, Transmission System Operators (TSO) and Distribution System Operators (DSO) are particularly concerned about this problem, consequently their Grid Codes are continuously revised.

Some noteworthy examples of specific grid codes for wind energy are Germany [2], United Kingdom [3] and Spain [4], whose grid codes take into account particular features of wind energy [5]. For wind parks, the following main topics are therefore of interest:

- Frequency dependent active power supply (frequency control)
- Voltage dependent reactive power injection/absorption, steady state and dynamic
- Voltage control, steady state and dynamic
- Fault ride-through
- Flicker emission

Voltage sags are becoming an increasing concern due to the sensitivity shown by the wind generation, caused by the adjustment of protective devices, especially in wind turbines that use power electronics (DFIG). For example, Spanish TSO (REE) reported on the 1st of August 2005 a disconnection of 33.4% of wind energy (1,150 MW). This event was provoked by voltage sag related to a fault in a 400/220kV autotransformer (see Fig. 1).

As a result, many grid codes establish immunity levels against voltage sag.

Another problem here analyzed is the flicker emission, which is closely related to the variation in the power delivered by a wind turbine; mainly due to random mature of wind.

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Added to the random variations, periodic fluctuations of power can appear in the delivered wind turbine power [6,7]. This phenomenon is very important in isolated and weak networks, where high level of flicker can show up.

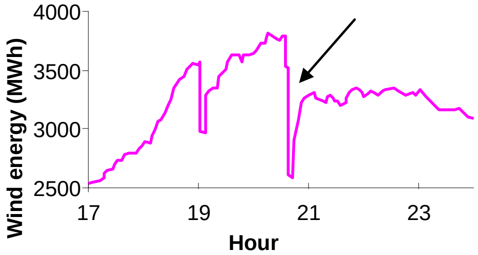

Fig. 1. Wind energy lost in the Spanish network

In this study, the use of a STATCOM device to increase the voltage sag immunity in a wind turbine and to decrease the flicker emission is analyzed. STATCOM and Wind turbines are modelled; and a flicker meter to estimate flicker emission [8,9] has been modeled as well.

III. Grid Code

1. Grid codes and wind energy

As mentioned before, the TSOs have introduced a number of requirements in their grid codes to be fulfilled by the wind farms, with the aim of guaranteeing the stability of the electric network.

In the majority of grid codes, certain level of voltage sag immunity for wind turbines is specified [2,3,4,11,12]. Such requirements are known as Low Voltage Ride Through (LVRT), and it denotes the minimum required immunity of the wind turbine or wind farm (see Fig. 2). After the system voltage returns to normal operation levels, the LVRT requirements also include fast active and reactive power restoration to the pre-fault values. Furthermore, some codes impose limits to reactive and active power generation or consumption during the disturbance.

For this paper, a wind turbine installed in the Sotavento Experimental Wind Park (www.sotaventogalicia.com) has been chosen. This park will only have to fulfill LVRT requirements related to balanced faults [4,13,14].

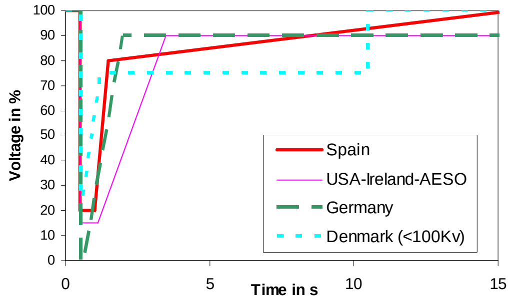

Fig. 2. LVRT requirements

2. Spanish Grid Code

Spanish grid code requirements for the immunity against balanced voltage sag are summarized in Fig. 3 and Fig. 4. The worst voltage that a wind farm must withstand is shown in Fig. 3. During the voltage sag, the wind farm must have a capacitive behaviour as shown in the Fig. 4.

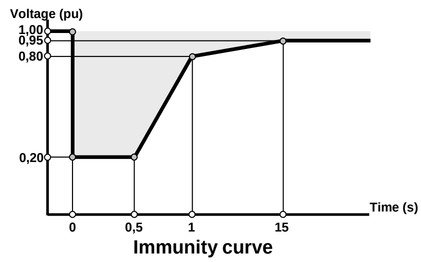

Fig. 3. Voltage sag immunity curve in the Spanish grid code

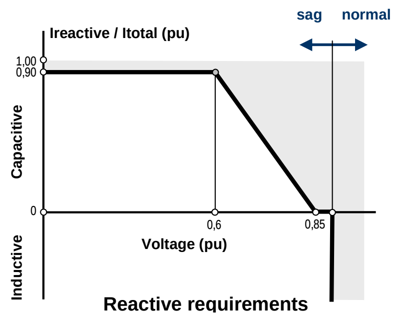

Fig. 4. Reactive current requirement (shaded area) required during a voltage sag.

The different zones of a voltage sag are shown in Fig. 5. These zones are:

- Zone A starts just after the fault that provokes the voltage sag and it lasts 150 ms.
- Zone B is during the voltage sag, between Zone A and C.
- Zone C starts when the fault is cleared and the voltage begins to recover its pre-fault value.

Certain active and reactive power

consumptions are allowed, as shown in Table 1 and in Fig. 5, especially in Zone A and C. The values shown in Table 1 are referred to:

- Wind park or wind turbine nominal power (P_n)
- Nominal current (I_n) of wind turbine or wind park.
- Total current injected (I_{tot}) by wind turbine or wind park.

All values have to be measured in 20 ms periods (IEC 61400-21 [15]), except the I_r/I_{tot} value which is the average value in Zone B.

Table 1. Active and reactive consumption limits during a voltage sag

Spanish Grid Code Limits	Power and reactive consumption		
	Three-phase fault		
	Zone A	**Zone B**	**Zone C**
Active Power (P)	No limit	< -10% × P_n	No limit
Reactive Power (Q)	< -60 % × P_n	< 0 % × P_{nom}	No limit
Reactive Energy (E_r)	No limit	No limit	<-60 % × P_{nom} × 150 ms or < -90ms p.u.
Reactive Current (I_r)	No limit	I_r/I_{tot} > 0.9 (average)	< -150 % × I_{nom}

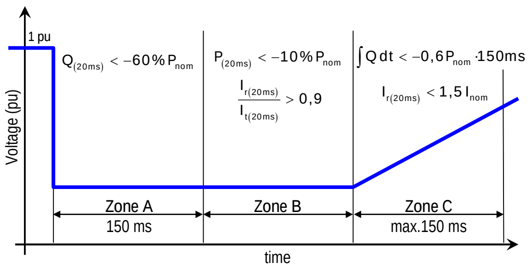

Fig. 5. Voltage sag zones and active and reactive limits.

IV. *STATCOM* DEVICES IN WIND PARKS

STATCOM devices have been used from years to compensate fluctuating loads, e.g. arc furnaces, in order to avoid flicker emission. The power generated by wind turbines, especially by those with fixed speed asynchronous generators, is characterized by rapid variations closely related to the random nature of wind speed. Hence, STATCOM devices can be employed for reactive compensation or voltage control, which allows the reduction of flicker emission in wind farms [10]. Additionally, STATCOM can be used to fulfill the reactive LVRT requirements in fixed speed wind turbines.

STATCOM is able to keep inductive or capacitive reactive current in its maximum value at any voltage. Usually STATCOM devices are connected in the transmission or the distribution network. However, in a wind farm, they can be connected in the low voltage (LV) side of wind turbines, as shown in Fig. 6. For this option, in the last years many commercial devices have appeared in the Spanish market. Their main advantage is their lower cost, because they are installed in low voltage.

In this paper, the installation and capabilities of an STATCOM connected in the LV side of a wind turbine is studied.

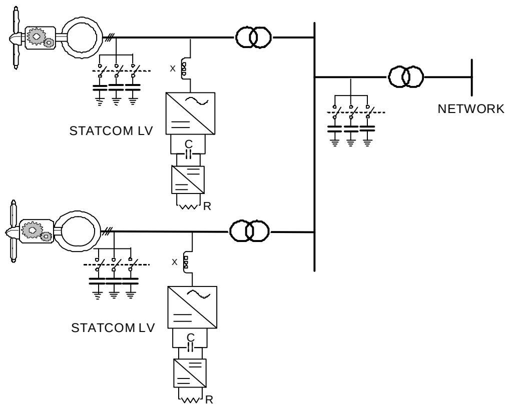

Fig. 6. STATCOM in LV side of wind turbines

V. MODELING AND SIMULATION

The capability of STATCOM devices to reduce flicker emission and to increase voltage sag immunity is analyzed by means of simulation. Wind turbine and STATCOM models are implemented in PSCAD/EMTDC. The control scheme for STATCOM can be seen in Fig. 7 [17].

Real conditions of wind speed, voltage, power, etc (previously measured in a wind park), together with the model of different fixed speed wind turbines have been used during the simulation. Measurements have taken place in the Sotavento Experimental Wind Park [18].

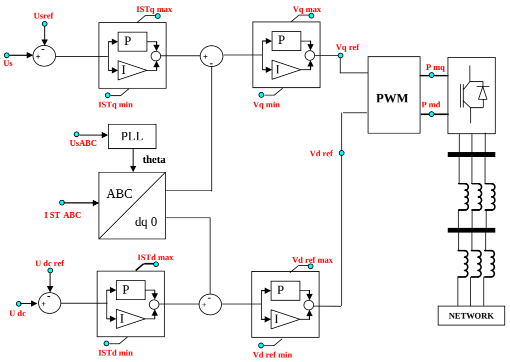

Fig. 7. STATCOM control scheme

In order to study flicker emission, the network has been represented by means of a Thevenin Equivalent. Whereas for the study of voltage sag behaviour, the network has been modeled according to the standard used to certificate WTG immunity [14]. In Fig. 8, network to be modeled in PSCAD is shown, and the curve presented in Fig. 9 is an example of a simulated voltage sag.

VI. RESULTS

The wind turbine is simulated at different working conditions. The obtained results of the analysis show: the sizing of *STATCOM,* the design of the control to achieve the voltage sag ride through, and the amount of the reduction of flicker emission [16].

In this work, a wind turbine with a nominal power of 1.32 MW has been modeled. The study has been carried out to check the influence of a STATCOM device installed in parallel in the LV side during a voltage sag, and also to see how STATCOM influences flicker emission. In order to examine the behaviour of the STATCOM in the wind turbine, the fulfillment of the Spanish Grid Code requirements is analyzed (see paragraph III).

Results from simulation are summarized in Table 2. In green and red are the values that fulfill or not fulfill, respectively, the grid code requirements.

As shown in Table 2, the wind turbine only fulfills the Spanish Grid Code requirements when the STATCOM is connected.

The STATCOM nominal power (approx. 1,630 kVA) in order to withstand voltage sags has been calculated using the simulation results.

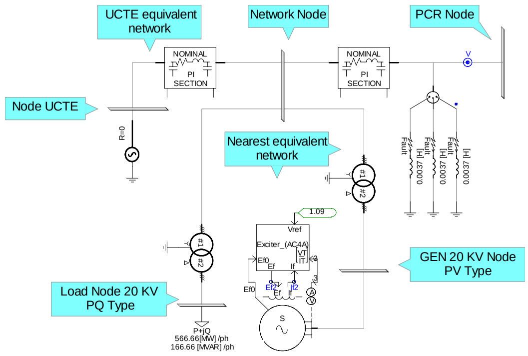

Fig. 8. Network model for voltage sag simulation

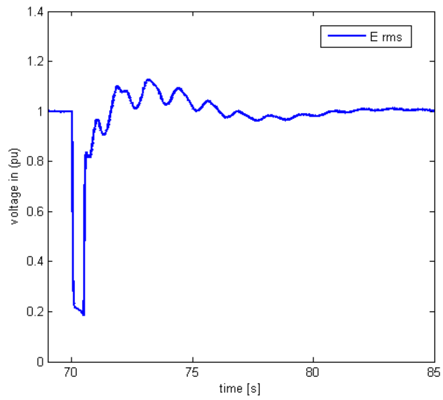

Fig. 9. Voltage sag simulation

Table 2. Simulation results related to Spanish Grid Code (Black: required value; Green: fulfill req.; Red: not fulfill reg.)

SPANISH GRID CODE REQUIREMENTS (W= MEASURED)		Without STATCOM	With STATCOM
Zone A			
Q< 60%×P_n	-0,6 p.u.	-0,033	0,217
Zone B			
P<10%×P_n	-0,1 p.u.	0,012	-0,009
I_r/I_{tot} average	0,9 p.u.	-0,467	0,999
Zone C			
E_r<60%×P_n×150ms	-0,6	-0,626	0,022
I_r<1,5×I_n	-1,5 p.u.	-2,770	-0,836

Voltage, reactive power and active power during voltage sag are shown in Fig. 10. Without STATCOM, a big amount of reactive is consumed after fault clearing (Zone C) due to the re-magnetization of asynchronous generator. This reactive is compensated by STATCOM when it is installed (see Q STATCOM). Injected active power has only slightly changed due to the installation of STATCOM.

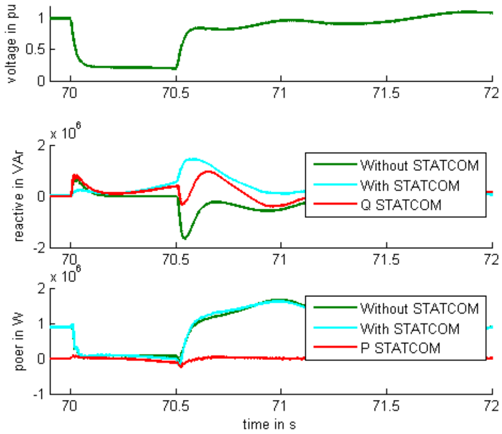

Fig. 10. Voltage, reactive and active power during voltage sag.

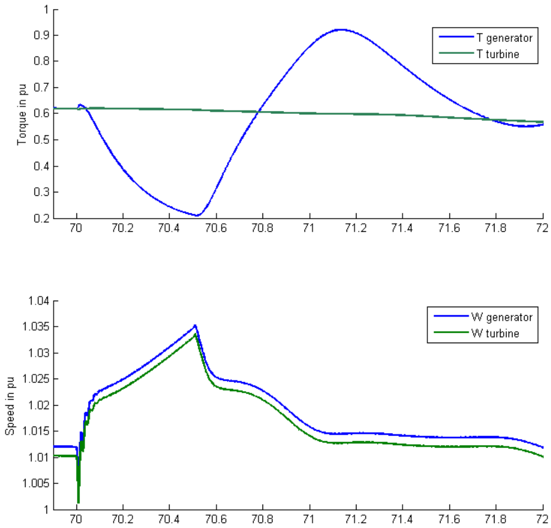

Fig. 11. Torque (T) and speed (W) in the low speed shaft (turbine) and in the high speed shaft (generator) of transmission train.

As can be observed in Fig. 11, the wind turbine and generator accelerate during the voltage sag; which may cause a destabilization in the system. As a result, the system may not reach pre-fault state following a voltage sag.

Furthermore, important torque variations have been detected in the generator shaft, which can provoke failures in the transmission train.

In parallel with the study of the system behaviour during a voltage sag, the flicker emission is also analyzed. To carry out the flicker calculation, a flicker meter has been modeled to standard IEC 61000-4-15 [9].

In Fig. 12, the evolution of wind speed, active power, RMS voltage and reactive power are shown. As can be seen, STATCOM strongly reduces voltage variation in the MV side of wind turbine by injecting the necessary reactive power. Flicker severity level (P_{st}) values are summarized in Table 3, where the flicker emission reduction can be appreciated.

Table 3. Flicker severity level (P_{st}) results.

	Without STATCOM	**With STATCOM**
Flicker level in the MV voltage side	0,1351	0,0063
Flicker level in the LV voltage side	0,1425	0,1167

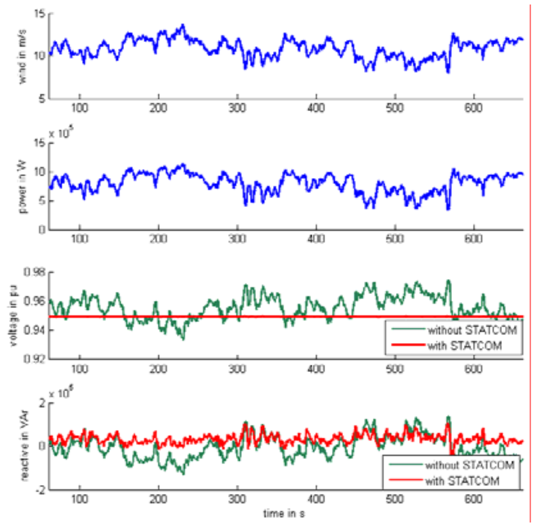

Fig. 12. Wind speed, active power, voltage and reactive power curves.

VII. Conclusions

In this paper a model to simulate a wind turbine with a STATCOM connected in its voltage side has been developed. With this model, the response against a voltage side can be studied and the flicker emission can be estimated.

The capability of a STATCOM (connected to the LV side of a wind turbine) to fulfill the Spanish Grid requirements has been demonstrated by means of simulation. The improved behaviour related to flicker emission has been analyzed as well.

Speed and torque variations during voltage sags are only slightly affected by the STATCOM presence. Therefore, wind turbine protections and transmission train must be designed to withstand working conditions during voltage sag.

VIII. ACKNOWLEDGMENT

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