Application of UPFC to Improve the LVRT Capability of Wind Turbine Generator

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***Abstract*—Variable speed wind turbine generators installation has been significantly increased worldwide in the last few years. Voltage sag at the grid side may call for the disconnection of the wind turbine from the grid as under such faults it may not comply with the recent developed grid codes for wind energy conversion systems (WECS). In this paper, a Unified Power Flow Controller (UPFC) is applied to improve the low voltage ride through (LVRT) capability of doubly fed induction generator (DFIG)-based WECS during voltage sag at the grid side. Simulation is carried out using MATLAB/Simulink software. Results show that UPFC can significantly improve the LVRT capability of DFIG-based WECS and hence maintaining wind turbine connection to the grid during certain levels of voltage sag at the grid side.**

Keywords- LVRT, UPFC, DFIG, voltage sag, grid codes

I. INTRODUCTION

Renewable energy sources have been recently given a significant concern worldwide as they generate electricity from infinite and clean natural resources [1, 2]. Wind energy is one of the most efficient and promising renewable energy resources in the world which is continuously growing with the increase of electrical power demand and the decrease in conventional electricity generation resources [3]. In the year 2010, the growth rate in wind power generation worldwide reached 23.6% and by the year 2015 the global wind power capacity is expected to be 600 GW which is expected to increase to 150 GW by the year 2020 [4]. In the early stages, wind turbine generator (WTG) was disconnected from the grid during grid disturbance events to avoid wind turbine damages. Due to the significant increase in WTGs and the global trend to establish reliable smart grids, the transmission system operators (TSOs) require the connection of WTGs with the grid to be maintained during certain level of faults to provide support to the grid during fault conditions [5].Therefore, grid codes have been established in many countries to specify various technical requirements that WTGs must comply with to maintain its connection to the grid. Since voltage sag is a common power quality problem in power systems, most of studies in the literature focused on the performance of WTGs during voltage sag [6]. Voltage sag is defined as a decrease in voltage level within the range of 0.9 pu to 0.2 pu of the nominal steady state level for a duration of 0.5 cycle to 1 minute [7]. There are many of international codes related to the low voltage ride through (LVRT) and high voltage ride through (HVRT) capability of WTGs. Among these codes, this paper focuses on the LVRT grid codes of Spain and US as shown in Fig. 1.

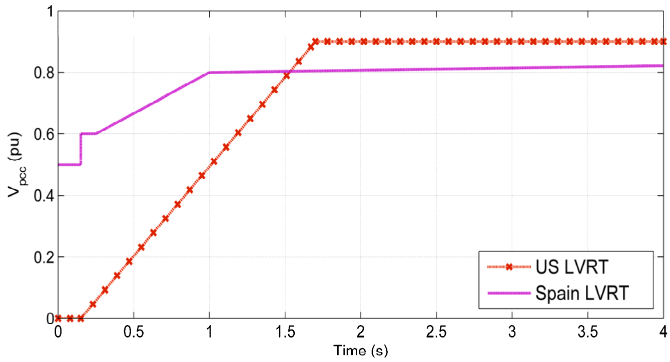

Figure 1. LVRT grid codes of Spain and US

Fig. 1 shows Spain and US grid codes for LVRT capability of wind turbine generators. The allowed voltage sag at the point of common coupling (PCC) of US grid code is 0 pu that lasts for a duration of 0.15s from the occurrence of the fault after which the LVRT profile increases linearly during the following 1.5s to 0.9 pu. Then the voltage level is maintained at 0.9 pu [8]. On the other hand, the minimum voltages sag at the PCC for Spain grid code at the instant of fault occurrence is 0.5 pu which remains for 0.15s after which it increases to 0.6 pu that lasts for 0.1s. Then LVRT profile then ramps to 0.8 pu during the next 0.75s and remains at this level for 3s [8]. WTGs will require to be disconnected from the grid in case of voltage level at the PCC drops to a level lower than the LVRT margins of the US and Spain grid codes.

Flexible AC transmission system (FACTS) devices have been used to maintain the WTGs connection with the electricity grid during fault conditions [9, 10]. This paper investigates the application of UPFC to improve the wind turbine LVRT capability to comply with Spain and US grid

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codes. In this context, the LVRT profile of DFIG-based WECS is investigated under voltage sag at the grid side. Simulation results without and with the connection of UPFC are analyzed and compared as will be elaborated below.

II. System Under Study

Fig. 2 shows the system under study, which consists of six-1.5MW DFIG connected to a grid that is simulated as an ideal 3-phase voltage source of constant voltage and frequency through 25 km transmission line and two transformers. The UPFC is connected to the PCC bus to increase the WTG damping and to provide support to the system during fault conditions.

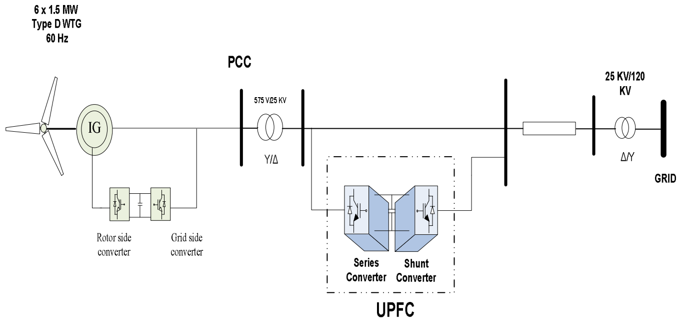

Figure 2. System under study

The DFIG stator windings are connected directly to the grid through a coupling transformer while the rotor is fed two back-to-back voltage source converters linked together by a DC-link capacitor. During normal operation, the reactive power produced by the wind turbines is regulated at 0 Mvar to achieve unity power factor operation. For an average wind speed of 14 m/s which is used in this study, the turbine output active power is 1.0 pu and the generator speed is 1.0 pu. The UPFC is used to improve the LVRT of the WTGs, by controlling the active and reactive powers of the bus that is connected to the UPFC [11].

III. Unified Power Flow Controller Configuration

With the enormous global growth in electrical power demand, there has been a challenge to deliver the required electrical power considering the quality, sustainability and reliability of the delivered power. To achieve this goal, it is essential to control the existing transmission systems for efficient utilization and to avoid new constructions [12]. FACTS technology play an important role in improving the utilization of the existing power system as it can provide technical solutions to improve the power system performance [13]. As a FACTS device, unified power flow controller allows system to be more flexible by using high-speed respond active and reactive power compensations to improve the transmission system's power flow. Thus, installing UPFC at critical points of the transmission system will increase the power dispatch up to the power rating of generators and transformers and the thermal limits of line conductors, by increasing the stability margin. Shunt and series converters of the UPFC can control both active and reactive powers smoothly, rapidly and independently [14]. As shown in Fig. 1, active power and reactive power are produced independently by compensating the current of the shunt converter and the bus voltage. On the other side, real power and reactive power are produced independently by compensating the voltage of the series converter and the controlled transmission line current [14].

IV. The Proposed Controller

Figs. 5 and 6 show the proposed controllers for the UPFC series and shunt converters respectively. Clarke-Park transformation is used to convert the a-b-c quantities for the voltage at the PCC along with the transmission line current to the d-q reference frame. Fig. 5 shows that the active power P and reactive power Q are used to calculate respectively V_{qref} and V_{dref}. The active power flow can be controlled by V_q whereas V_d controls the reactive power flow. It can be seen from Fig. 6 that the reactive power can be controlled by the regulation of the current that is in quadrature with the voltage (I_q) While the current in phase with voltage (I_d) regulates the active power [7]. The active power P and reactive power Q can be calculated as below:

$$P = V_d I_d + V_q I_q \quad (1)$$

$$Q = V_q I_d - V_d I_q \quad (2)$$

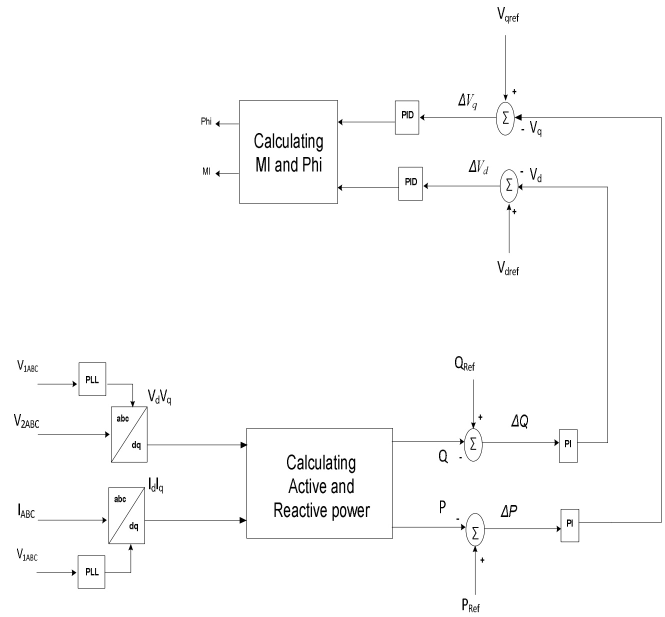

Figure 3. Control system of the series converter

V. Simulation Results

To show the robustness of the proposed UPFC controller, two scenarios are assumed; (i) A voltage sag of 0.6 pu of the nominal value is assumed to take place at the PCC at t= 13s and lasts for a duration of 0.1s, (ii) a voltage sag of 0.75 pu is simulated at the PCC and is assumed to last for a duration of 0.7 s.

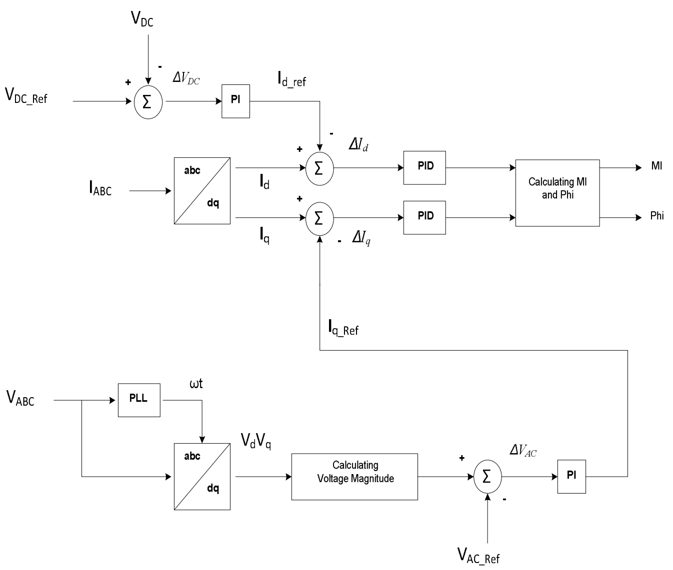

Figure 4. Control system of the shunt converter

The PCC voltage profile for the first scenario is shown in Fig. 5. As can be shown in the figure, the voltage at the PCC violates Spain LVRT level, which calls for the disconnection of the wind turbine from the grid to avoid any possible damages to the WTG. By connecting the UPFC to the PCC bus, the amount of voltage drop at the PCC bus is corrected to reach a safety margin of the Spain's grid requirement as shown in Fig. 6 and therefore maintain the connection of the wind turbine.

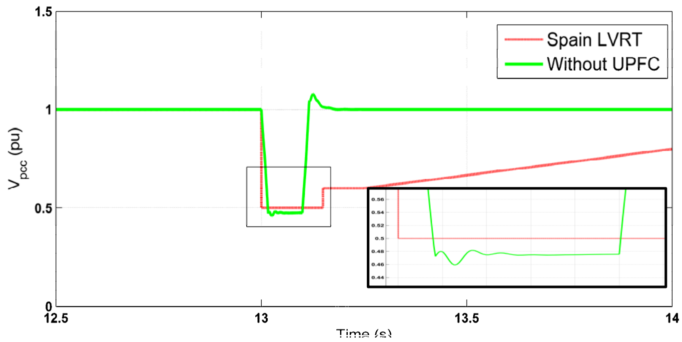

Figure 5. LVRT of the DFIG compliance with Spain's LVRT without UPFC

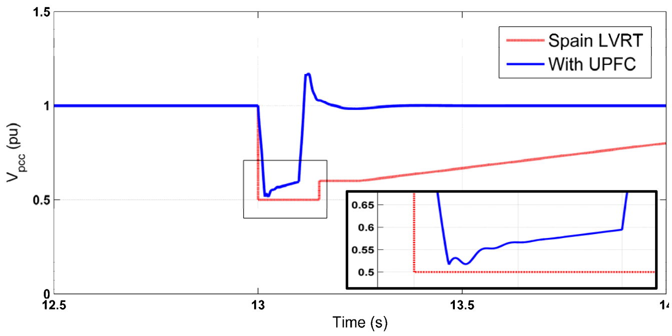

Figure 6. HVRT of the DFIG compliance with Spain's LVRT with UPFC

The second scenario is compared with the US LVRT grid codes as shown in Fig. 1. Without the connection of UPFC, voltage sag at the PCC violates the safety margin of LVRT of the US as shown in Fig. 7. and therefore the WTGs have to be disconnected from the grid. However, when the UPFC is connected to the system, voltage sag can be maintained within the safety margins of the US grid codes as can be shown in Fig. 8 and therefore, the WTGs connection to the grid can be maintained during the fault.

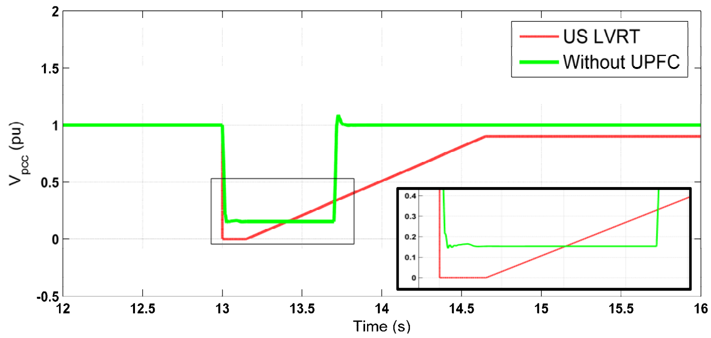

Figure 7. LVRT of the DFIG compliance with US' LVRT without UPFC

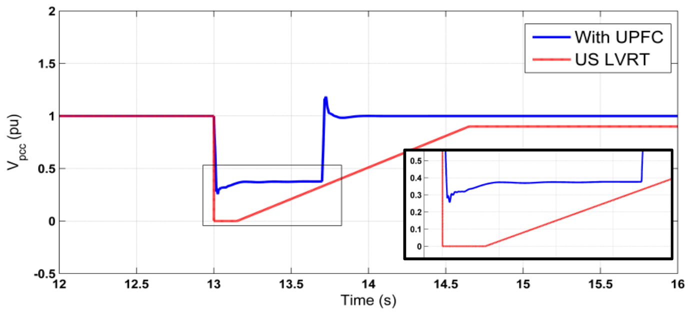

Figure 8. LVRT of the DFIG compliance with US' LVRT with UPFC

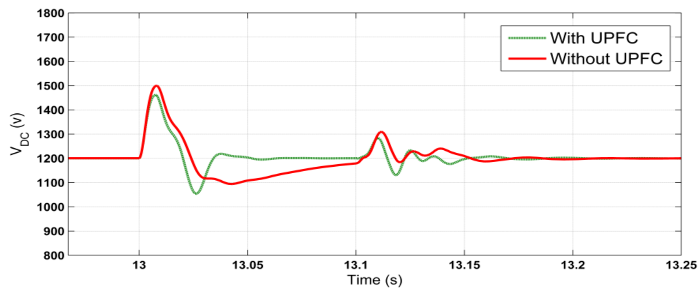

Figure 9. V_{DC} waveform of the DFIG based WTG

Fig. 9 shows the voltage across the DC-link capacitor of the WTG V_{DC} with and without the connection of the UPFC. With the UPFC connected to the system, the overshoot and settling time are reduced compared to the system without the connection of the UPFC.

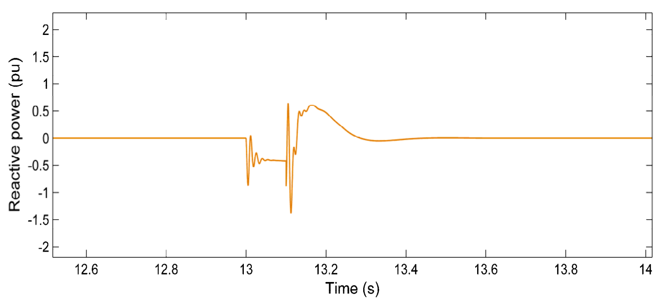

Figure 10. Reactive power response of the UPFC during fault

The performance of the UPFC during fault can be examined in Fig. 10 and Fig. 11 when voltage sag at the PCC is applied at 13 s, the reactive power is instantly injected by the UPFC to the system to maintain the voltage at the PCC stay within the safety level.

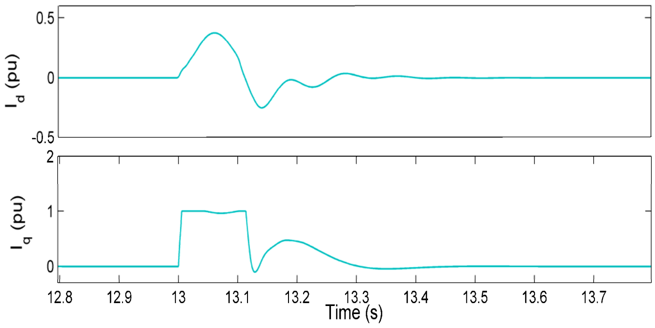

Figure 11. The shunt converter's current components during fault

When the fault is cleared, the UPFC returns to the idle condition and there will be no reactive power exchange between the system and the UPFC as shown in Fig. 10. The direct and quadrature currents response of the UPFC during the fault are shown in Fig. 11. At normal operating conditions both currents are set to zero level and according to (1) and (2), there is no power transfer between the UPFC and the system. Upon fault occurrence at t= 13s, I_d and I_q levels change accordingly to provide reactive and active power support to the system during the fault. After fault clearance, both currents return to zero level.

VI. CONCLUSION

This paper investigates the application of UPFC to enhance the LVRT of wind energy conversion system to comply with the grid codes of Spain and US. Results show that, without UPFC, WTGs must be disconnected from the grid during voltage sag event to avoid the turbines from being damaged, as the voltage at the PCC will violate the safety margin requirements of both studied grid codes. The proposed controller for the UPFC can significantly improve the LVRT capability of the WTGs and hence their connection to the grid can be maintained to support the grid during fault conditions and to guarantee the continuity of power delivery to the grid.

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APPENDIX

PARAMETERS OF DFIG

Rated Power	6-@1.5MW
Stator Voltage	575 V
Frequency	60 Hz
R_S	1.2pu
V_{DC}	1200 V

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