Application of UPFC to Improve the Low-Voltage-Ride-Through Capability of DFIG

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Abstract—**In this paper, a new controller approach for unified power flow controller (UPFC) is proposed to improve the low-voltage-ride-through (LVRT) capability of a DFIG-based WECS during voltage sag. The shunt and series converters of the UPFC are controlled using a hysteresis current controller (HCC) and proportional integral controllers (PI), respectively. Detailed simulation is carried out using MATLAB/SIMULINK software to highlight the impact of UPFC in improving the overall system performance during grid fault.**

Index Terms— **wind energy conversion system, doubly fed induction generator, low-voltage-ride-through and unified power flow controller.**

I. INTRODUCTION

RENEWABLE energy sources have been given more concern due to the harmful effects of conventional energy resources on the environment and utilization of renewable energy sources has been accelerated by proposing a carbon tax in some countries [1]. Wind energy is one of the most promising renewable energy sources that has been significantly increased from generating about 93 GW at the end of the year 2003 to 318 GW by the end of the year 2013[2]. The future estimation of the global wind market is very promising as it is expected to grow by more than 13% to reach 536 GW by the year 2017[2] and by the year 2020 wind power is expected to supply at least 10% of the global electricity demands [3]. Doubly fed induction generator (DFIG) based wind energy conversion system (WECS) is dominating the market of wind turbines due to its superior advantages over other wind turbine technologies [4]. In DFIG-based WECS, as shown in Fig. 1, the generator stator winding is directly connected to the grid at a point of common coupling (PCC) through a coupling transformer whereas rotor winding is connected to the PCC via the coupling transformer and a back-to-back partial-scale voltage source converter (VSC) that facilitates variable speed operation of the DFIG [5],[6]. During the initial stage of introducing WECS to the electrical energy market, wind turbine generators (WTGs) were allowed to be disconnecting from the grid during fault events in the grid side to avoid any possible damages to wind turbines [7]. Currently, the developed grid codes require

WTGs to ride-through intermittent fault conditions to remain connected and support the grid under such events. This will assure sustainable power delivery to the grid during faults and abnormal operating situations [8]. Improving DFIG fault ride through (FRT) capability can be achieved by implementing new control schemes for WECS to make them complying with various grid codes established by transmission system operators as presented in the literature [9]-[13] which is effective for new WECS installation. A cost effective approach to improve the FRT capability of the existing WECS is by connecting flexible ac transmission system (FACTS) device to the PCC [14],[15].
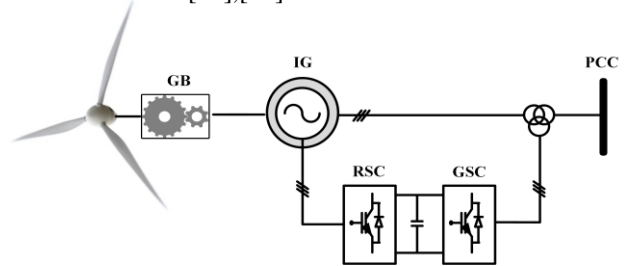

Fig.1.Typical configuration of DFIG.

A proper FACTS controller can also aid in overcoming some of the drawbacks of DFIG that include its high sensitivity to grid faults. If not attended, these faults may lead to voltage drop at the DFIG terminal, high current within DFIG converter switches and high voltage across the converters dc link capacitor.

Unified power flow controller (UPFC) concept was introduced in 1991[16]. Since then, UPFC has attracted many researchers to study its potential applications in power systems [17]-[20]. However, there are limited papers in the literature investigating the application of UPFC to WECS. Moreover, most of these studies have only focused on the use of UPFC to smooth the output power of fixed speed WECS during wind speed fluctuation to avoid system instability [21].

This paper presents a new application of the UPFC to improve the low-voltage-ride-through capability of DFIG-based WECS during fault event at the grid side. A new control approach for UPFC based on hysteresis current control (HCC) in conjunction with proportional integral control (PI) is proposed. Simulation is carried out using Simulink/Matlab software and results are analyzed to highlight the performance of WECS with and without the connection of UPFC.

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II. Unified power flow controller

A UPFC is a complex power electronic device developed to control and to optimize the power flow in electrical power transmission systems [17]. As shown in Fig. 2, a UPFC is mainly a combination of a static compensator (STATCOM) and static synchronous series compensator (SSSC) coupled through a common dc link. The shunt and series converters of the UPFC can control both active and reactive power of the system at the PCC smoothly, rapidly and independently in four quadrant operation [16], [17].
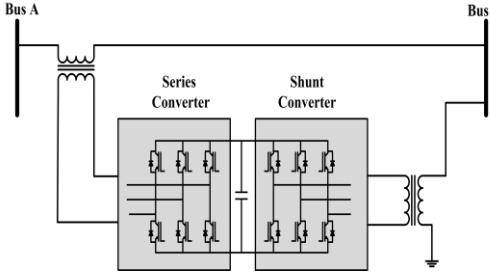

Fig. 2. Typical schematic diagram of a UPFC.

III. System Under Study

Fig. 3 shows the system under study, it consists of six- 1.5 MW DFIGs integrated to the ac grid at a point of common coupling (PCC). The DFIG consists of an induction generator with the rotor winding connected to a bidirectional back to back voltage source converter while the stator winding is connected directly to the grid through a Y/Δ step up transformer. The wind turbines are connected via 30 km transmission line and Δ/Y step up transformer to the ac grid which is represented by an ideal three-phase voltage source of constant frequency. Under normal operating conditions the reactive power produced by the DFIG is controlled at zero MVar level to maintain unity power factor. For an average wind speed of 15 m/s, the generator speed is 1.2 pu and the output power is 1.0 pu. To improve the performance of the DFIG, UPFC is connected to the PCC bus.
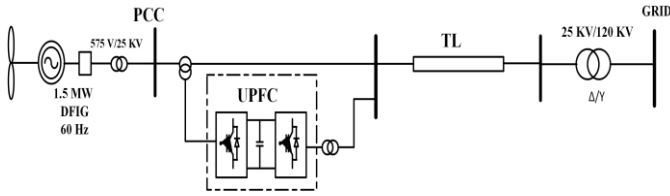

Fig.3. System under study

IV. UPFC Control Approaches

IGBTs based converters have been used in the proposed UPFC due to its advantages over GTOs, since IGBT has a higher switching frequency range (2-20 kHz) while GTO switching frequency is up to 1 kHz [6]. The shunt and series converters of the UPFC are controlled using hysteresis current controller (HCC) and proportional Integral controller (PI), respectively as elaborated below.

A. Hysteresis Current Controller (HCC)

The HCC has the advantageous of simplicity, fast dynamic response, insensitivity to load parameters variations and inherent maximum current limiting characteristic [22]. The basic implementation of HCC is based on generating the converter switching signals from the comparison of the actual phase current with a fixed tolerance band around the reference current associated with that phase. However, this type of band control is not only depending on the corresponding phase voltage but is also affected by the voltage of the other two phases [23].
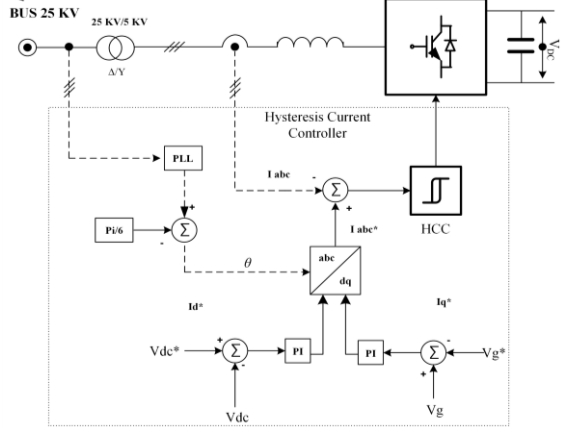

Fig.4.Shunt Converter configuration and the proposed HCC control scheme

As shown in Fig. 4, deriving signals to the UPFC shunt converter switches are generated by comparing the three-phase line currents (I_{abc}) with the reference currents ($I_{abc}*$) which are derived using I_d* and I_q* references. The values of I_d* and I_q* are generated through conventional PI controllers based on the error values of the voltage across the dc-link capacitor (V_{DC}) and the generator terminal voltage (V_g). The value of I_d* and I_q* is converted through the Park transformation ($dq0\text{-}abc$) to produce the reference current ($I_{abc}*$).

B. Proportional Integral controller (PI)

The series inverter is used to control the real and reactive line power flow by inserting a voltage of controllable magnitude and phase in series with the transmission line.
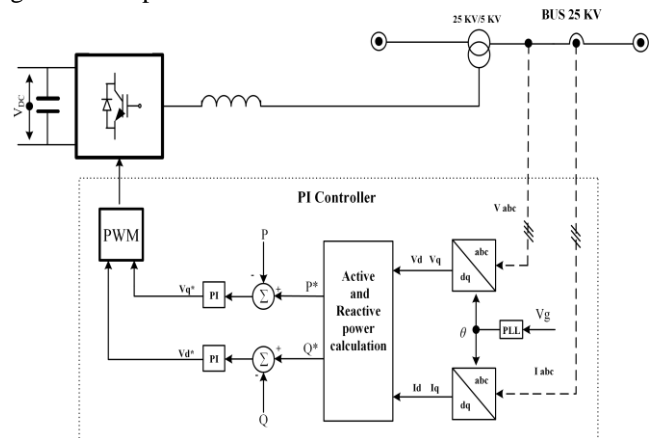

Fig.5. Series Converter configuration and the proposed PI control scheme.

As shown in Fig.5, the differences between the generator active and reactive powers and their pre-set values are used as input signals to the PI controllers which are tuned to generate the reference voltage values in d-q reference frame (V_d^* and V_q^*) required for controlling converter switches using pulse width modulation (PWM).

V. SIMULATION RESULTS AND DISCUSSION

In order to assess the robustness of the proposed UPFC controller in improving the low-voltage-ride-through capability of a DFIG-based WECS under study, voltage sag is simulate and analysed with and without the connection of the proposed UPFC controller
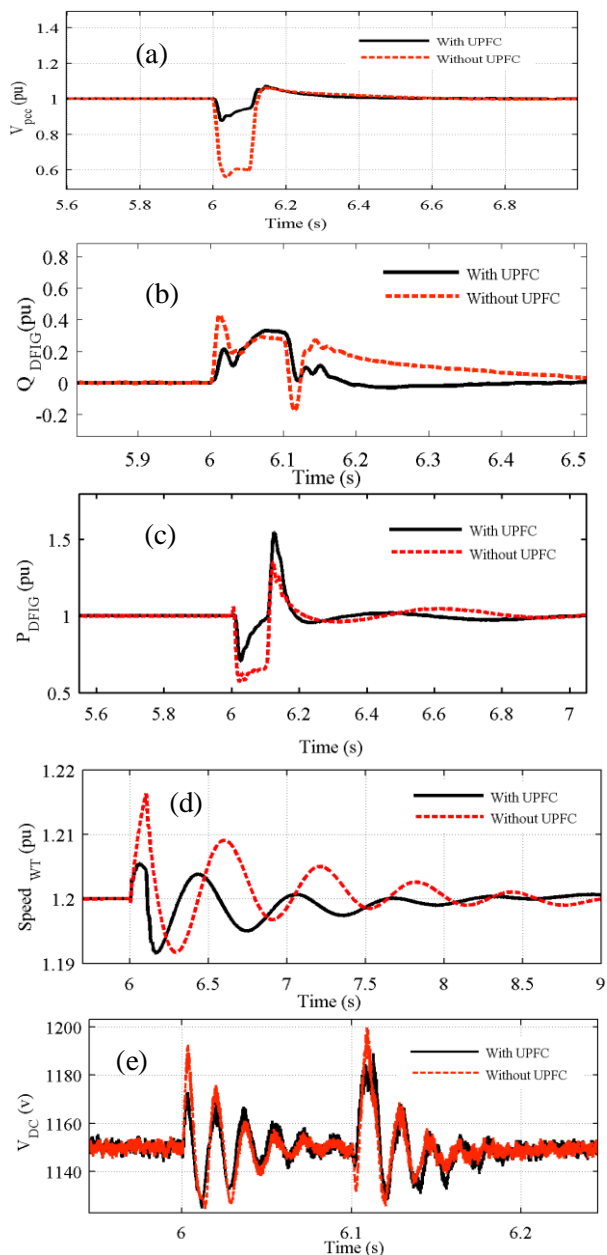

Fig. 6. DFIG performance during voltage sag without/with a UPFC; (a) PCC voltage, (b) reactive power, (c) active power (d) shaft speed, and (e) Voltage at DC link of DFIG.
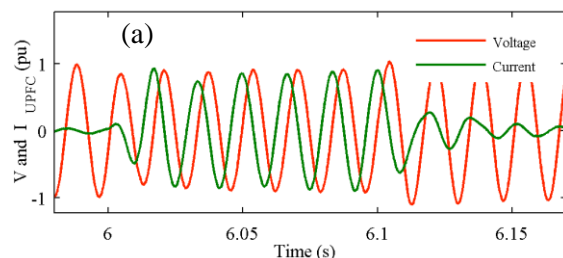
A. Voltage Sag Event

A significant voltage sag of 0.5 pu of the nominal value is assumed to take place at the grid side of the system under study (Fig. 3) at t=6s and is assumed to last for 6 cycles. As shown in Fig.6 (a) the voltage at the PCC will drop to 0.55 pu without the connection of the UPFC. Whereas, this voltage drop is regulated to 0.87 pu by connecting the UPFC to the PCC bus. This voltage drop is assumed as a safety margin by wind turbine manufacturers [24]. Fig.6 (b) shows that during the event of voltage sag and with the presence of UPFC reactive power support by the DFIG to the grid is reduced and the steady state condition is reached faster compared with the system without UPFC. Without the UPFC, the real power produced by the DFIG is significantly decreased during the sag event as shown in Fig. 6(c) while with the connection of the UPFC, DFIG output power is increased. The DFIG power drops cause acceleration to the shaft speed to compensate for the power imbalance as can be observed in Fig. 6(d). However, with the connection of the UPFC, the drop in DFIG generated power is reduced which leads to a reduction in the speed overshooting and settling time. The voltage across the DFIG dc link capacitor (V_{DC}) experiences 60 Hz oscillation during and upon the clearance of the fault as shown in Fig. 6(e). With the connection of the UPFC at the PCC, voltage overshooting across the dc link capacitor is reduced.

B. UPFC Responses

The performance of the UPFC during voltage sag event can be examined through Fig. 7. When voltage sag at the PCC is applied, the UPFC controller acts to instantly exchange reactive power with the AC system to maintain the voltage at the PCC within a safety level that does not violate the limits of transmission line operator codes.

Standby mode takes place during normal operating conditions where there is no power exchange taking place between the UPFC and the grid. During this mode, reactive power generation of the wind turbine is maintained at zero level to achieve unity power factor operation and the voltage across the dc link capacitor of the UPFC configuration is maintained at constant level. This mode of operation is shown in Fig.7 prior and after the occurrence of the fault.

When voltage drop at the PCC occurs at t =6s, the UPFC is functional in capacitive mode where the UPFC terminal current (at bus B of Fig. (2)) will lead the bus voltage as shown in Fig. 7(a). As a result, reactive power is instantly injected by UPFC to support the grid and to regulate the voltage at the PCC as shown in Fig. 7(c).
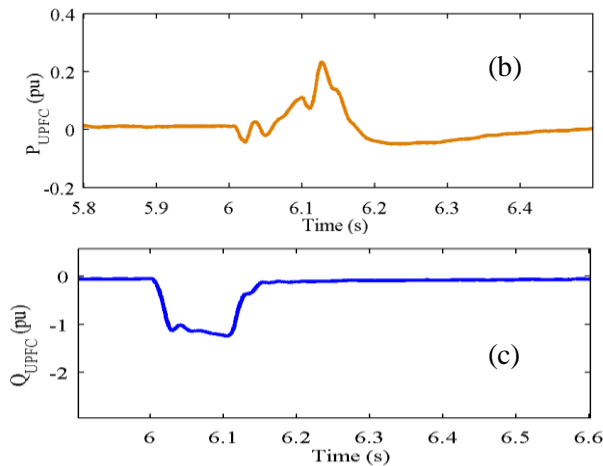
Fig. 7. UPFC transient responses during voltage sag event (a) UPFC terminal voltage and current, (b) UPFC active Power, and (c) UPFC reactive Power.

VI. CONCLUSION

This paper proposes a new application and control approach for the unified power flow controller (UPFC) to improve the (LVRT) capability of a (DFIG)-based wind energy conversion system during voltage sag at the grid side. The proposed controller is based on hysteresis current and proportion integral controllers. Simulation results show that the proposed UPFC controller is effective in improving the dynamic performance of the studied DFIG-based WECS during fault event. The proposed control algorithm is simple, easy to implement and is able to improve the fault ride through of the DFIG. The UPFC, on the other hand is still a costly piece of equipment, however its application in power systems is expected to become viable in the near future due to the rapid development of power electronics.

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