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FRT Capability in DFIG based Wind Turbines using DVR with Combined Feed-Forward and Feed-Back Control

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Abstract

In this paper, Dynamic Voltage Restorer (DVR) based series compensation of the voltage to provide Fault Ride Through (FRT) and reactive power support is discussed. The control of DVR is crucial in order to improve the FRT capability in Doubly Fed Induction Generator (DFIG) based wind turbines. This is observed in terms of voltage sag mitigation capability, active and reactive power support without tripping and fault current control. To achieve a flexible control solution for balanced and unbalanced fault conditions, a combination of Feed-forward and Feed-back control is discussed in this paper. The advantage of utilizing this combined control is verified through MATLAB/Simulink based simulation results of a 1.5 MW grid connected DFIG based wind turbine. The results show good transient and steady-state response and good reactive power support during various fault scenarios. The results are verified for the recent updated grid code standards.

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Keywords: Fault Ride Through (FRT); Doubly Fed Induction Generator (DFIG); Dynamic Voltage Restorer (DVR); Reactive power support; Wind Turbines.

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1. Introduction

Fault Ride Through (FRT) capability in wind turbines is a popular topic of interest due to the growing penetration of wind energy into the grid [1]. Therefore, stringent grid codes have been established for grid integration of wind power to maintain the power system stability in terms of transient stability, power quality and system reliability [2]. Doubly Fed Induction Generators (DFIG) are most popular among the wind turbines for their capability of decoupled active and reactive power control, partially scaled converters and variable speed operation [3]. Even though DFIG based wind turbines are the most dominant type of wind turbines, they are very sensitive to grid voltage disturbances. Therefore, FRT capability improvement of DFIG is given much importance.

Conventionally crowbars were installed to prevent the converters from the over-current and over-voltage damages during fault conditions. When crowbar is initiated, the Rotor Side Converter of DFIG is disabled and the system starts to operate as an induction generator and starts absorbing reactive power [4]. The present grid codes require continuous operation without tripping and reactive power to support the grid recovery from fault. Therefore, several new methods are still being proposed to improve the FRT capability in DFIG based wind turbines [5]. Static Synchronous Compensator (STATCOM) proposed to assist uninterrupted operation of DFIG during grid faults, is a shunt compensation connected at the Point of Common Coupling (PCC). But STATCOM cannot protect the Rotor Side Converter (RSC) of DFIG and therefore require the operation of crowbar [6]. The application of a Dynamic Voltage Restorer (DVR) is a good solution as it does not require any other protective circuit during operation [7]. The control algorithm utilized in the DVR for the FRT capability in DFIG determines the effectiveness of the solution to overcome most of the faults in the grid.

In this paper, the combined Feed-Forward and Feed-Back control of DVR is utilized for the effective mitigation of voltage sags during unbalanced fault conditions. The ride through of unbalanced faults is essential for an effective FRT capability of DFIG based wind turbines. The remaining paper is structured as follows: Section 2 includes the control of DVR which explains the voltage sag detection, Load voltage reference generation and the operation of combined Feed-Forward and Feed-Back control. Section 3 includes the simulation results and discussion and Section 4 ends with conclusion.

Nomenclature

FRT	Fault Ride Through
DFIG	Doubly Fed Induction Generators
DVR	Dynamic Voltage Restorer
RSC	Rotor Side Converter
STATOM	Static Synchronous Compensator
PCC	Point of Common Coupling
PLL	Phase Locked Loop

2. Control of the DVR

The important role of the DVR control includes the detection of the start and end of the fault event, reference generation, transient and steady-state control of the injected voltage and the system protection [8]. The Feed-Forward control includes the pre-sag voltage on the grid side before DVR to detect the voltage sag during fault. The Feed-Back control monitors the voltage mitigation on the DFIG side after DVR. The DC-link voltage is monitored for converter protection [9], [10]. The general schematic of the DFIG with DVR is shown in Fig.1.

2.1. Voltage Sag Detection and load reference generation

Voltage sag detection is an important part of the control which requires fast detection of voltage sag during fault conditions. The balanced and unbalanced sag is determined along with the phase jump. The load voltage references are generated by Phase Locked Loop (PLL) to create sinusoidal load voltage references. These references are utilized for the dq co-ordinates of the controller. The PLL response is expected to be slow in order to avoid sudden changes in the phase angle.

2.2. Combined Feed-Forward/Feed-Back Controller

Combine Feed-Forward and Feed-Back control is a combination of electrical grid and load voltage respectively. Transient response based on the DC-link voltage is carried out by the Feed-Forward control to calculate the sag depth. But since Feed-Forward does not take into account the drop across the filters and series injection transformer, the Feed-Back control is utilized for closed loop load voltage Feed-Back to avoid steady-state errors. The control diagram of the combined Feed-Forward and Feed-Back control is shown in Fig.2.

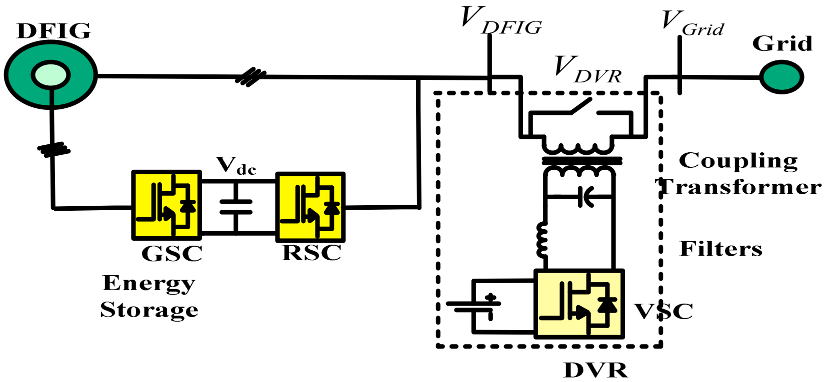

Fig. 1. Schematic Diagram of DVR with DFIG

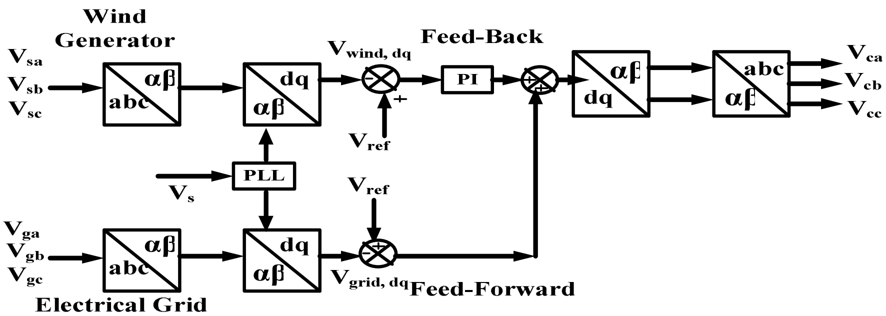

Fig. 2. Control Scheme of DVR using combined Feed-Forward and Feed-Back control

3. Simulation Results and Discussion

This section discusses the simulation results of series compensation of voltage sags during balanced and unbalanced fault conditions using DVR with DFIG. The test system is simulated for DFIG of 1.5 MW wind turbine connected to electrical grid. The simulation parameters of the DFIG and DVR are given in Table.1. The FRT performance is evaluated for balanced and unbalanced fault conditions. The performance of DVR for improving FRT capability is analyzed in response to the grid fault during balanced and unbalanced fault conditions at PCC. A sag of 0.35 pu which lasts for 6 cycles between 0.7 s to 0.8 s. Fig.3 (a) to 3 (d) shows the DC-link voltage, rotor speed, stator current and stator voltage respectively after series compensation during balanced fault condition. Fig.4

(a) to 4 (d) shows the DC-link voltage, rotor speed, stator current and stator voltage respectively after series compensation during un-balanced fault condition respectively.

The active power injected into the grid during the fault by DFIG, without series compensation, is almost zero, therefore, the mechanical power cannot be converted into electrical power leading to very high stresses on the mechanical system and increasing the generator rotor speed. By employing DVR, the DFIG wind turbine is able to deliver active power to the grid and keep the generator in an equilibrium condition, as stated in Fig.3 (b) and Fig. 4(b).

The voltages are injected in series to maintain the stator voltage of the DFIG during the fault using the DVR based series compensation. Overvoltage can be observed on the DC-link of DFIG even up to 1.5 pu without employing DVR. The simulation results in Fig.3 (a) and Fig.4 (a) conclude with the effectiveness of the proposed series grid interface scheme to isolate the wind turbine from the grid faults to prevent any transient currents or voltages in the DFIG. The compensation of voltage sag and regulating the current during balanced fault is shown n Fig.3 (c), Fig. 3(d). The compensation of voltage sag and regulating the current during unbalanced fault is shown n Fig.4 (c), Fig. 4(d).

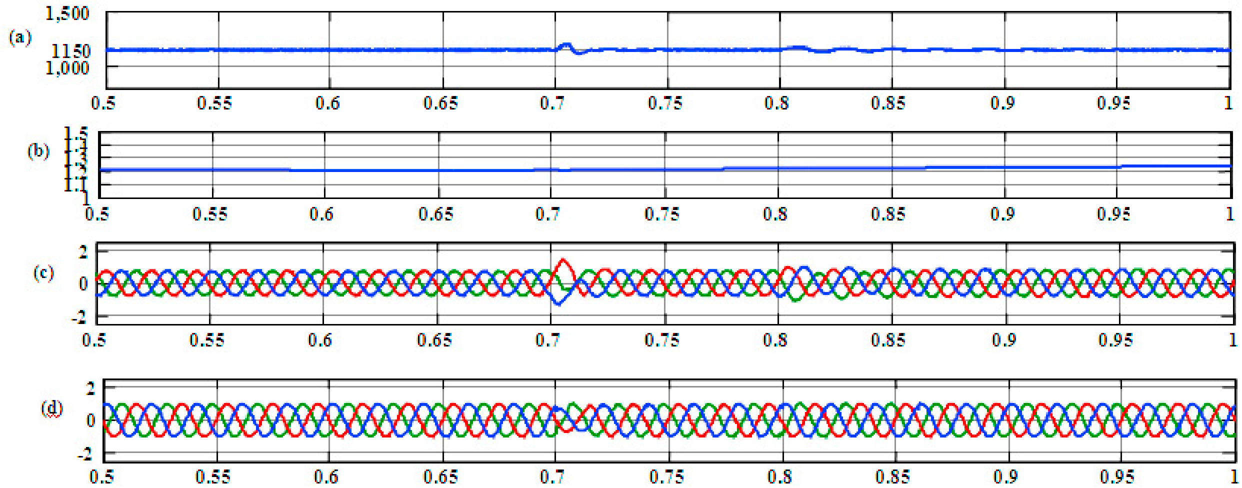

Fig.3. Balanced sag: (a) DC link voltage in Volts, (b). Rotor speed in pu, (c). Stator current in pu, (d). Stator voltage in pu.

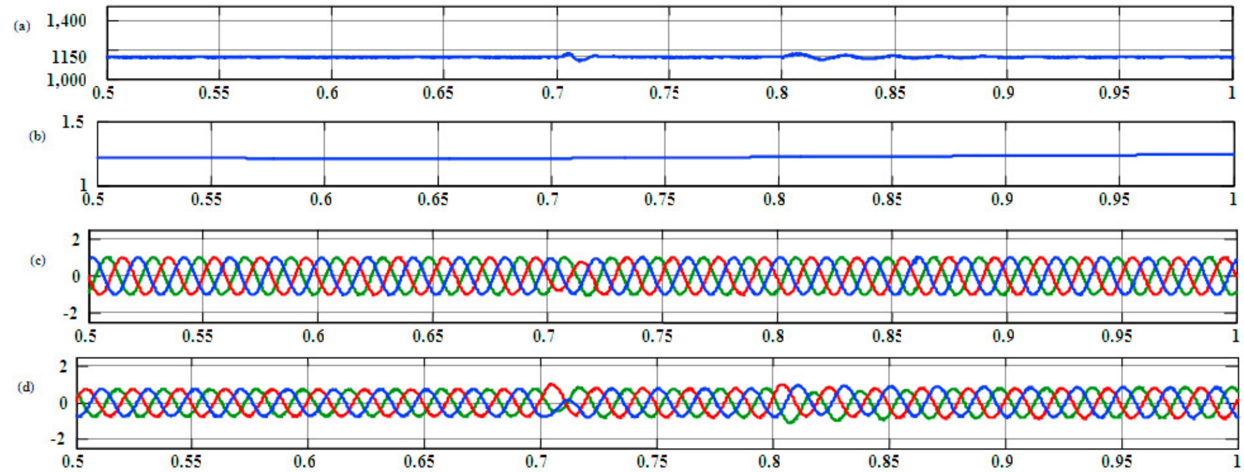

Fig.4 Unbalanced sag: (a) DC link voltage in Volts, (b). Rotor speed in pu, (c). Stator current in pu, (d). Stator voltage in pu.

The simulation results clearly show an effective mitigation of balanced and unbalanced fault condition by utilizing the combined Feed-Forward and Feed-Back control. Since active power injection, rotor speed control, DC link control, stator voltage and current compensation are effectively done, the grid code adherence is effectively done through this method.

Table. I Simulation parameters of DFIG and DVR

Rated power of DFIG	1.5 MW
Cut-in speed, cut-out speed	6 m/s, 30 m/s
Rated wind speed	11 m/s
Stator voltage/frequency	575 V/ 50 Hz
Stator resistance	0.023 pu
Rotor resistance	0.016 pu
Stator leakage inductance	0.18 pu
Rotor leakage inductance	0.16 pu
Generator inertia constant	0.685
Nominal DC bus voltage	1150 V
DVR Capacity	1.5 MVA
DVR Filter inductance	0.1 mH
DVR Filter capacitance	1 µF
DVR Switching frequency	10 kHz
Series transformer ratio	1:1

4. Conclusion

The FRT capability of wind turbines are essential with the growing integration of wind power in the grid and contribute to the reliable grid integration. This paper investigates the performance of DVR with combined Feed-Forward and Feed-Back control for the FRT capability of DFIG based wind turbines. The control performance is proved by the effective series compensation of both balanced and unbalanced fault conditions. The performance comparison suggests that the operation of DVR is suitable for FRT capability as per grid code standards imposed globally. Simulation results performed using a 1.5 MW DFIG based wind turbine connected to electrical grid show better performance of DVR with the combined Feed-Forward and Feed-Back control for improving the FRT capability of DFIG based wind turbines.

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