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Improved Low Voltage Ride through Capability of a Fixed Speed Wind Generator using Dynamic Voltage Restorer

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Abstract

Wind energy is one of the fastest growing renewable energy technologies in world. The new grid code proposes that the wind turbine should remain connected to the grid during voltage disturbances. Three phase voltage sags and faults cause reduction in voltage at the point of interconnection to the grid when fixed speed wind turbines connected to squirrel cage induction generators are employed resulting in disconnection of wind turbine from the grid. Dynamic voltage restorer is a series connected custom power device used for voltage compensation during sags and swells. In this paper, the Low voltage ride through capability of a fixed speed wind turbine is improved using dynamic voltage restorer. Simulation studies are done to determine the transient stability of a fixed speed wind turbine with squirrel cage induction generator using Matlab Simulink.

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Keywords: Low voltage ride through capability;Dynamic voltage restorer;fixed speed wind turbine

1. Introduction

Conventional energy sources like oil, gas and coal has several disadvantages like rapidly decreasing supply and high emission of CO2 into the atmosphere. Wind energy is one of the fastest growing renewable energy technologies in the world. There is a huge potential available for wind power generation but the extent to which the wind electric generation can be integrated into the power system without affecting the overall stable operation depends on the technology available to mitigate the power quality problems. Fixed speed wind turbines utilizing squirrel cage induction generators (SCIG) are widely used because they are robust, economical and simple in design. During electrical faults this reactive power consumption is increasing leading to over speeding of generators. This

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causes low voltage and rotor speed instability leading to disconnection of wind energy generator (WEG) from the grid. To avoid this, new grid codes requires power generating units to remain connected and continuously operated even if the voltage dips reaches very low values [1, 2]. It is known as low voltage ride through capability (LVRT).

Limitations of using fixed capacitors for reactive power compensation include damage to gearbox and inability to provide fast control of reactive power .Dynamic voltage restorer (DVR) is a series connected custom power device used for voltage compensation of sensitive loads during voltage dips due to faults [3]. Both normal and fault condition operation of wind farms can be optimized by using power electronic compensation devices, especially DVR. Its operation principle is based on insertion in series with the line of a voltage equal to sag depth and with same phase as network. Compared with a STATCOM, the use of a DVR is a relatively simpler solution, with a smaller current injection [4]. In this paper the behavior of a fixed speed wind turbine using a squirrel cage induction generator connected to grid is simulated and studied under balanced fault and sag conditions using Matlab/Simulink software.

Nomenclature

Pm	Mechanical power captured from the turbine
Cp	Power coefficient of wind turbine
ρ	Air density
B	Pitch angle
V	Wind speed
R	Length of the turbine blade
φ_{ds}	Stator d axis flux
φ_{qs}	Stator q axis flux
V_{ds}	Stator d axis voltage
V_{qs}	Stator q axis voltage
i_{ds}	Stator d axis current
i_{qs}	Stator q axis current
Rs	Stator resistance
Lls	Leakage inductance
R'r	Rotor resistance
L'lr	Leakage inductance

2. Modeling of wind turbine with SCIG

2.1 Modeling of wind turbine

The mechanical power developed by a wind turbine is given by

$$P_m = 0.5C_p(\lambda,\beta)\rho AV^3 \tag{1}$$

It is seen that the mechanical power varies as the cube of wind speed [5].

$$\lambda = \frac{2\pi RN}{V} \tag{2}$$

2.2 Squirrel Cage Induction generator Model

Fig. 1 shows the d axis and q axis model of electric equivalent circuit of squirrel cage induction generator [6].

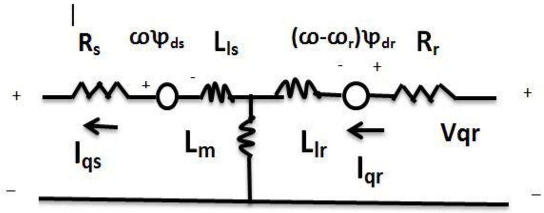

Fig. 1. Electric equivalent circuit of induction generator

$$. \ V_{qs} = R_s i_{qs} + \frac{d}{dt}\varphi_{qs} + \omega\varphi_{ds} \tag{3}$$

$$V_{ds} = R_s i_{ds} + \frac{d}{dt}\varphi_{ds} - \omega\varphi_{qs} \tag{4}$$

$$V'_{dr} = R'_r i'_{dr} + \frac{d}{dt}\varphi'_{dr} - (\omega - \omega_r)\varphi'_{qr} \tag{5}$$

3. Dynamic Voltage Restorer

The components of DVR include an injection transformer, filters, pulse width modulated inverter and energy storage device as shown in Fig. 2. The inverter generates the missing voltage to be supplied by the DVR which is injected into the grid through the injection transformer. The basic function of the injection transformer is to increase the voltage supplied by the filtered VSI output to the desired level while isolating the DVR circuit from the distribution network [7].

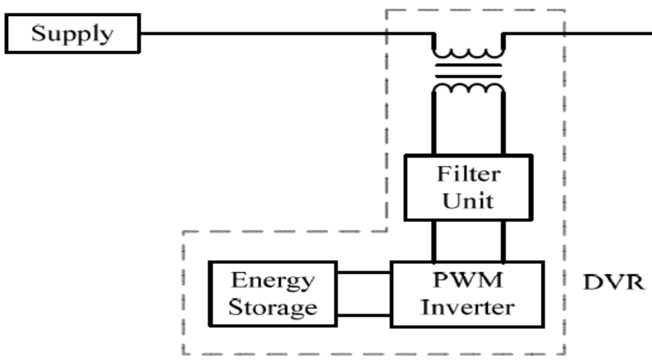

Fig. 2. Components of DVR

4. Dynamic Voltage Restorer Controller

The voltage sag is detected by measuring the error between the dq-voltage and the reference values. The d-reference is set to rated voltage whilst q reference is set to zero. The dq components of load voltage are compared with the reference values and the error signal is then entering to PI controller [8].The Kp value is set to 0.4 and Ki value is set to 500. The outputs of PI controller are then transformed back to Vabc before forwarding to PWM generator. The block diagram of the control part of DVR is shown in Fig. 3.

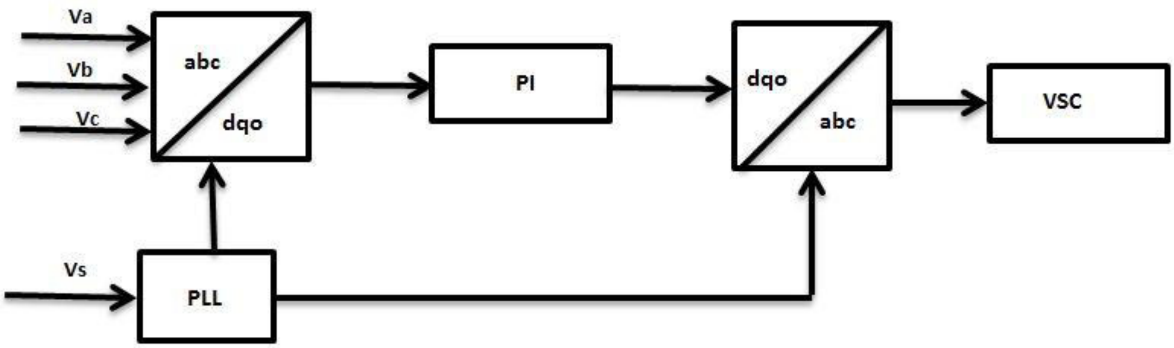

Fig. 3. Block diagram of DVR controller

5. Case study

Single line diagram of a fixed speed wind turbine using a squirrel cage induction generator connected to the grid is shown in Fig. 4. A simulation diagram of a 250 kW squirrel cage induction generator coupled to a wind turbine is developed using sim power system toolbox. The model of SCIG is adopted from Power System Block set in MATLAB Simulink .The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. The induction generator is connected to the grid through a gear box of gear ratio 40. The wind turbine is connected to an 11 kV grid through a small transmission line of X/R ratio 1.6. A local R load is connected at the point of common coupling [9] .The cut in speed of the wind turbine is assumed to be 3.5 m/s and cutout speed to be 24 m/s. The parameters of squirrel cage induction generator to be simulated are given in table 1.The simulation block diagram of the system under study is shown in Fig. 5.

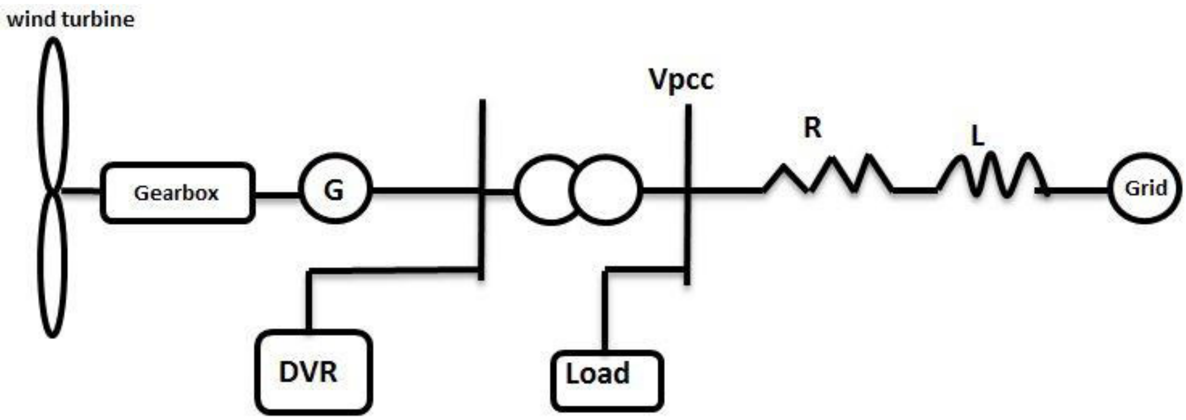

Fig. 4. Single Line Diagram of the system under study

Table 1. Parameters of squirrel cage induction generator.

Squirrel Cage Induction Generator Parameters	Values
Rated Power(kW)	250
Voltage (V)	415
Stator resistance(ohm)	0.01379
Stator Inductance(mH)	0.152
Rotor Resistance(ohm)	0.007728
Rotor Inductance(mH)	0.152
Mutual Inductance(mH)	7.69

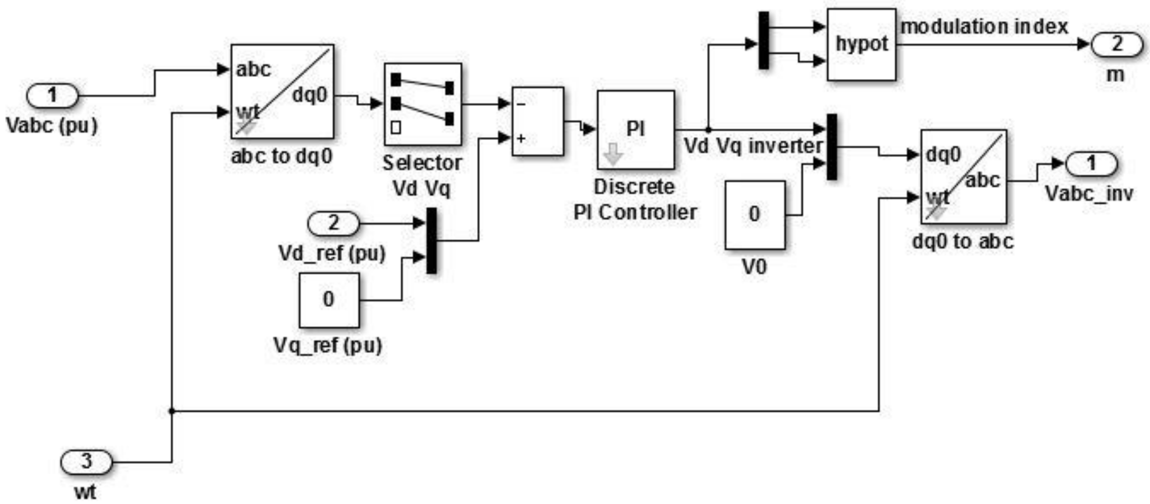

Fig. 5. Simulink model of the system under study

6. Results and Discussions

The transient behavior of the system under study with and without using DVR are simulated and studied under balanced three phase fault for duration of 150 milliseconds at the point of common coupling (PCC). Fig. 6(a) and 6(b) shows the rotor speed before and after DVR compensation. Before DVR is connected, the speed increases to a very large value and hence the wind turbine is disconnected from the grid. But when DVR is connected, the rotor speed is brought back to normal value before critical clearing angle is reached and hence wind turbine remains connected to the grid even after the fault. Fig. 7. to Fig. 9. show the voltage at PCC without connecting DVR, DVR injected voltage and voltage at PCC with DVR.It is seen that when a three phase fault occurs, the DVR injects the required voltage in series and hence compensates the voltage at the generator terminals. Fig. 10. to Fig. 12. shows the voltage at PCC without connecting DVR, DVR injected voltage and voltage at PCC with DVR when three phase sag is occurring at the point of common coupling for duration of 150 milliseconds.

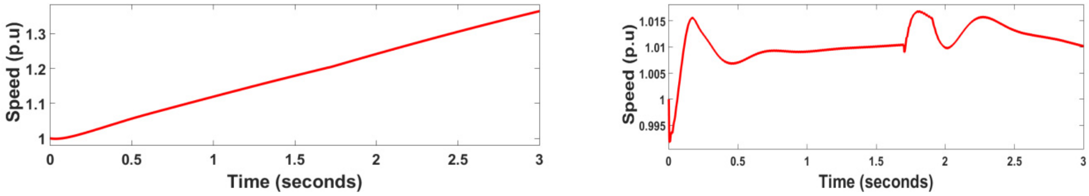

Fig. 6. (a) Rotor speed before DVR compensation; (b) Rotor speed after DVR compensation

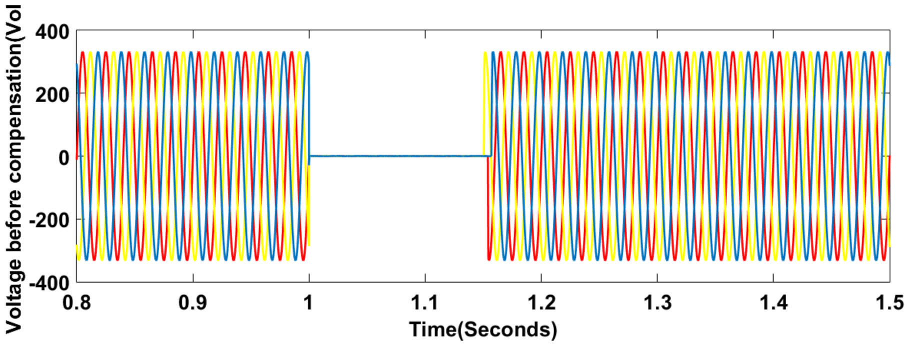

Fig. 7. Voltage at PCC without DVR during three phase fault

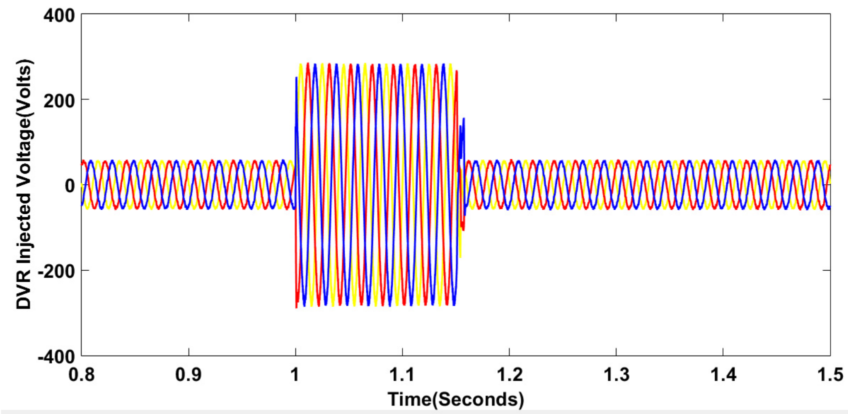

Fig. 8. DVR injected voltage during three phase fault

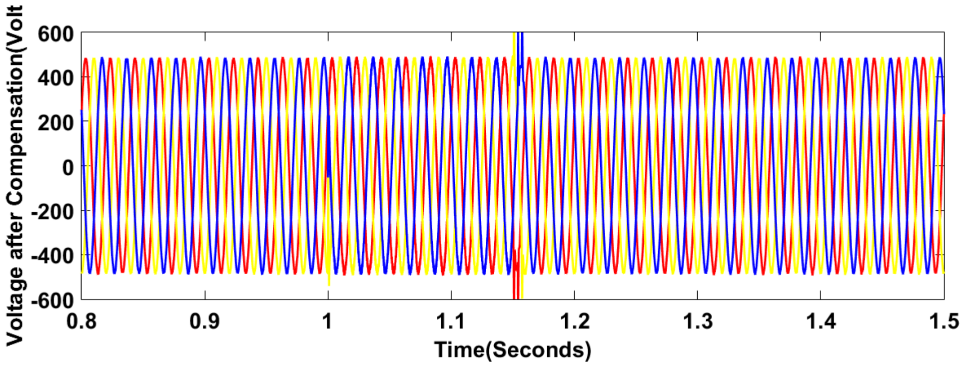

Fig. 9. Voltage at PCC with DVR compensation during three phase fault

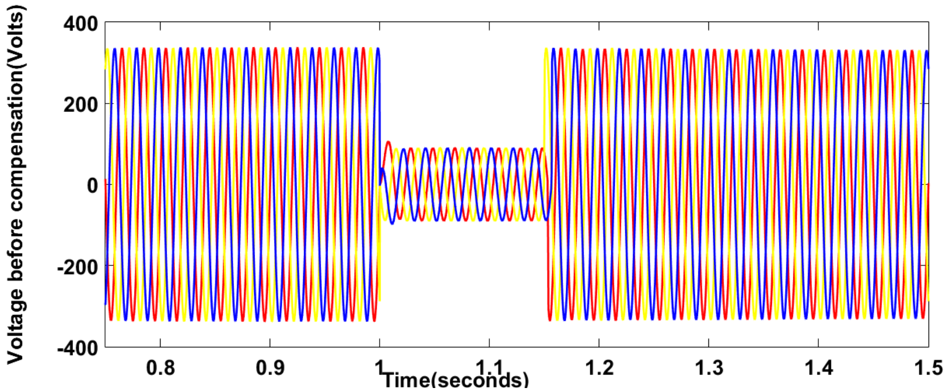

Fig. 10.Voltage at PCC without DVR during three phase voltage sag

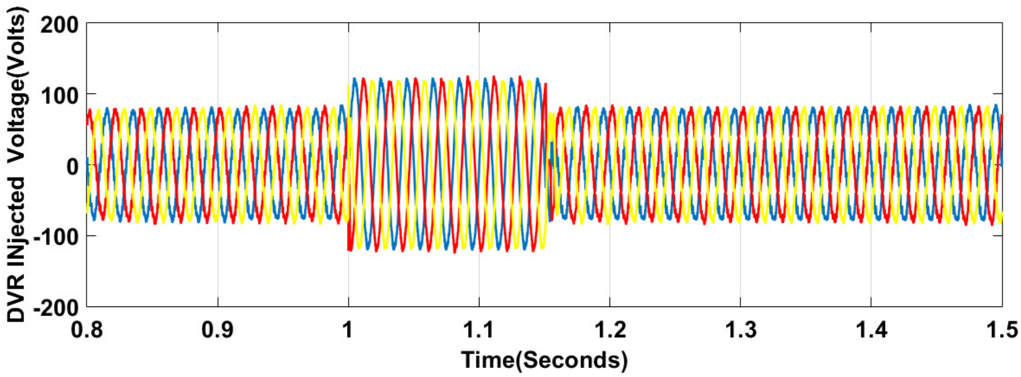

Fig. 11. DVR injected voltage at PCC during three phase voltage sag

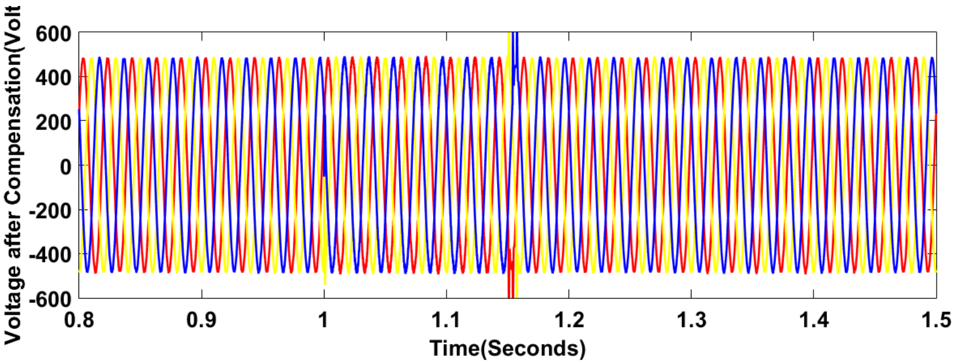

Fig. 12. Voltage at PCC with DVR compensation during three phase voltage sag

Table 2 shows a comparison of total harmonic distortion of voltage at PCC with and without DVR compensation.

Table 2. Performance Parameters with and without DVR.

Performance Parameters	Balanced fault	Balanced sag
THD without DVR(%)	29.15	14.22
THD with DVR(%)	4.22	8.9

7. Conclusion

Voltage sags and faults affect the normal operation of fixed speed wind turbines. The transient behavior of a fixed speed wind turbine using a squirrel cage induction generator connected to grid is analyzed by simulating voltage sags and faults at the point of common coupling for a period of 150 milliseconds. The performance of the system with and without using DVR is studied and compared. It is seen that the use of DVR prevents rotor speed instability and provide the compensation of balanced voltage sags and faults and also decreases the total harmonic distortion.

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