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# LVRT Enhancement in Grid Connected DFIG Based Wind Turbine Using PSO Optimized DVR

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## Abstract

This paper suggest a control strategy to enhance the LVRT capability of doubly fed induction generator (DFIG) based wind turbine system using dynamic voltage restorer (DVR). Wind turbine generator should support the grid during the fault time. The method used here is series compensation method at the point of common coupling on the occurrence of fault to maintain the stator voltage constant. LVRT performance is improved by optimization of PI parameters using particle swarm optimization as compare to conventional DVR. This PI controller is used to regulate the IGBT pulses of the inverter fed by DC source. To validate the improved LVRT performance, a 9 MW grid integrated DFIG based wind plant is considered. The result shows that the voltage compensation of sag is greatly improved with PSO optimized DVR.

**Keywords:** DFIG, DVR, LVRT, PSO.

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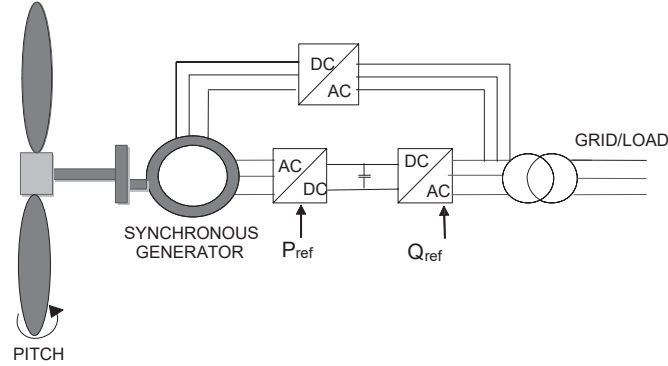
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## 1 Introduction

The growth in wind energy generation led to wind generators to great share of power sector. For renewable energy developers, it is a remarkable time of growth in energy market. As the wind energy cannot be predicted so grid operators set some grid codes for grid integration with the renewable energy sources. Out of them low voltage ride through capability during fault conditions for variable speed wind turbine is one of the required condition. According to which wind power plants are not allowed to disconnect during fault occurrence and supposed to connect with grid supplying reactive power.

DFIG based WT are most proffered among available generators due to inherent capability of active and reactive power regulation yet they are very prone to stator faults or grid voltage disturbances. When a fault appears the voltage level falls to zero and active generation reduces which causes abrupt rise in rotor current for the compensation of active power in the rotor side of converter. By this rotor voltage rises due to converter action and crowbar circuits are used to protect the power electronics converter initially. During this period DFIG initiates absorbing reactive power in spite of producing reactive power support to the grid. To limit the over current SDBR, STATCOM, crowbar circuits and much more new methods are available. DSTATCOM as a shunt compensation device is connected to the point of common coupling (PCC) to provide LVRT capability. Some times DSTATCOM may be connected with fault current limiters like SDBR. The use of dynamic voltage restorer (DVR) is much better application as their is no need of auxiliary fault protecting circuit. Figure 1 shows the configuration of DVR connected to the power grid. The effectiveness to overcome the fault may be determined by control strategy implemented. The control structure of DVR consist of fault detection, reference signal generation, pulse width modulation, ac generation by VSI according to switching pulses.

This article utilizes the voltage based control algorithm on PI controller. LVRT capability discussed here for the three phase balanced fault condition. Section 2 consist of description regarding modelling of a dfig with DVR, Section 3 describe the control structure of the VDR with detailed explanation of Fault detection, Section 4 explains the particle swarm optimization algorithm utilized in this article to optimize the PI parameter and Section 5 depicts the results an Section 6 ends with conclusion.



**Figure 1** Schematic diagram of DFIG based wind turbine.

## 2 System Description and Modelling of DFIG Wind Turbine

There are many limitation associated with wind power generation. Out of which some are related to operational issue and some are regarding dynamic operation. Like sub-synchronous resonance and LVRT. Here dynamic issues LVRT is take care off. The scope of this article is to analyze the LVRT performance and prove the effectiveness voltage sag compensation process.

The mechanical power produced by the WT is given by

$$P_m = 0.5\rho C_p A U^3 \quad (1)$$

Where  $\rho$  is the density of air,  $A$  is the swept area by wind turbine,  $C_p$  represents the power coefficient,  $U$  is the wind speed.

Value of  $C_p$  i.e. power coefficient is given by

$$C_p(\lambda, \beta) = C_1 \left( \frac{c_2}{\lambda_2} - C_3\beta - c_4 \right) e^{\frac{-c_5}{\lambda_i}} + C_6\lambda \quad (2)$$

And  $\lambda_i$  is expressed as

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.35}{\beta^3 + 1} \quad (3)$$

Here  $\beta$  denotes the pitch angle of the blade,  $\lambda$  stands for tip speed ratio. Where tip speed ratio is defined as the ratio of tip speed to wind speed.

$$\lambda = \frac{\omega R}{U} \quad (4)$$

In above expression  $\omega$  is the rotational speed of rotor in rad/sec and  $R$  is the radius of the rotor in meters.

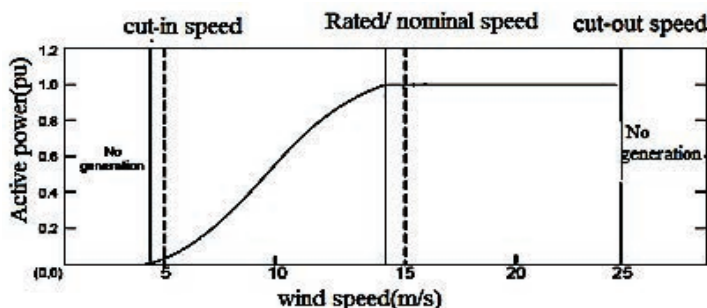


Figure 2 Characteristics of wind turbine.

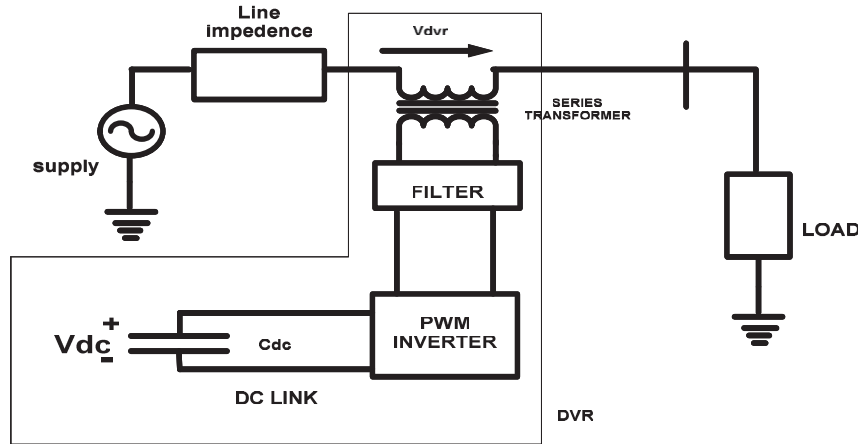
The Figure 2 shows different power curves at various wind speeds. If the operating point is along the maximum power locus, then the wind energy conversion system will be highly efficient.

From the modelling of wind variations [9] the following speeds are defined which is as shown in Figure 3: In the Figure 3 cut-in speed around 5 m/s is shown which is the velocity at which turbine starts to rotate. Another point depicts the rated wind velocity at which power output reaches the limit where generator is capable of these velocities (10 m/s–17 m/s). Next range of wind velocity of rotor at which their is risk of damage and breaking start initiating to standstill the rotor (17 m/s–30 m/s).

### 3 Dynamic Voltage Restorer (DVR)

DVR is an electronic solid state custom power device that inject necessary reactive power in the system in order to improve the voltage profile of the non-linear load. As compare to other solid state devices it is more cost effective. DVR mainly consist of DC power source, an IGBT converter, and an injected transformer which is connected in series with the load. Here the system voltage is detected by control scheme used in DVR which produce the triggering pulses for VSI. Passive filters are used to make the injected voltage harmonic free. DVR injects the filtered output voltage in the load or distribution power line through injection transformer.

The amount of voltage sag/swell compensated by DVR depends upon the rating of injection transformer and inverter. Due to this rating and design of voltage injected transformer is of very much important for the proper operation of DVR. This harmonics must be removed. For this purpose an L-C, hybrid filter is used. In designing of LC filter the value of inductor should



**Figure 3** Schematic and control diagram of DVR.

be choose very carefully, as change in inductance has more impact on the cost of filter as compare to the change in conductance. Inverter unit is connected between energy storage unit and transformer through a passive filter. As storage unit store fixed supply (DC) and series transformer require variable supply (AC). This conversion of fixed supply to variable supply is take place in DVR through VSI. Output voltage of VSI is of low value. In case of voltage swell the extra amount of voltage is stored in this unit. It may be batteries (Lead-Acid battery), Superconducting Magnetic Energy Storage (SMES), Super capacitors and flywheels. Out of all the four energy devices the first three device store energy in the electrical form whereas Flywheel is a rotating mechanical energy storage device which is used to store rotational energy that can be used instantaneously. It generate an error (compensating) signal by comparing the supply voltage to reference signal. This compensating signal is feed to VSI to compensate the voltage sag. PI controller is used to control the parameters of PWM (Pulse Width Modulation) block. Apart of this SPWM technique another methods like hysteresis cycle control and space vector method for switching of VSI may used.

#### 4 Particle Swarm Optimization

PSO is a computational population based stochastic optimization technique. In this algorithm iteration process is used to deal with a problem. In this method, solution of a group of particles called swarm is taken into account

and these particles are moving in their search space. Concept of this optimization technique is based on behaviour of some biological species like birds.

Millonas suggested following some basic principle to elaborate the technique of PSO by combining the evolutionary algorithm with the artificial life theory. The group of bird should be capable to carry out simple space and time computations. Group of bird which are used in the computation technique should have the property to sense the changes occurred in the quality of their environment and should response according to that changes. The group of bird should not limit their way to get the resources in a tapered range. They should always have an open or wide range of scope to search new way of resources. Birds should have stable mode of behavior. Behavior of the particles should not swing with the change in environmental conditions. Bird should be able to adopt worst changes. It means particle should change their behavior whenever there is a worst or a big change in their environmental conditions.

From the above discussed points it is concluded that PSO is a searching algorithm in which each individual is known as particle. To understand the procedure of PSO whole process is described in steps in the form of flowchart given in figure. In this chart at first each individual is defined as particle which don't have any mass and move in the D-dimensional search space to find the optimized solution of given problem. Secondly, position and velocity vector of each particle is described. In each new generation, information of particle get combined to update the velocity of each new dimension in the further iteration and that updated velocity is used to find new position of the particle. In this way, state of the particle gets updated constantly in the multi dimension search space until the particle reach at optimal state.

To illustrate the technique of PSO in a mathematical form, various vectors may be described as: Let's suppose there are N number of particle take place in the process. Each particle has the position vector

$$X_i = (X_{i_1}, X_{i_2}, \dots, X_{i_d}, \dots, X_{i_D}) \quad (5)$$

moved in D-dimensional space. Their Velocity vector may be defines as

$$V_i = (V_{i_1}, V_{i_2}, \dots, V_{i_d}, \dots, V_{i_D}) \quad (6)$$

and their position vector is

$$P_i = (P_{i_1}, P_{i_2}, \dots, P_{i_d}, \dots, P_{i_D}). \quad (7)$$

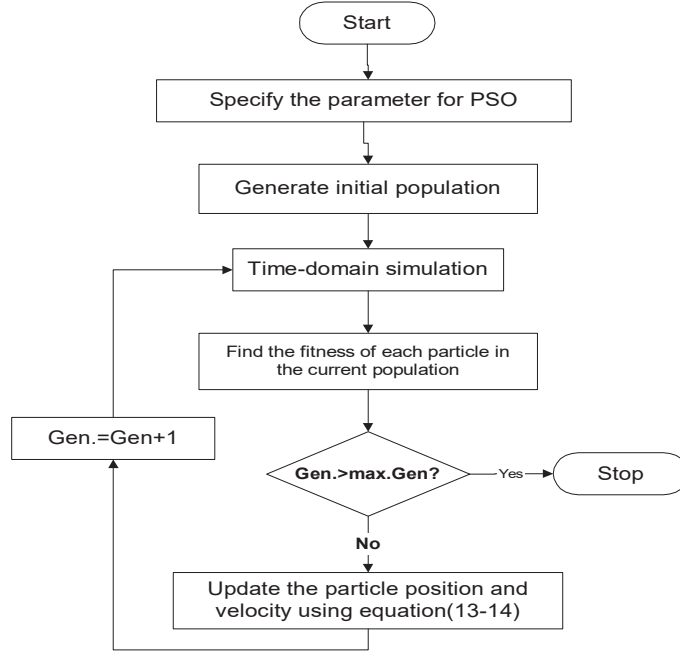


Figure 4 Flow chart of PSO algorithm.

The swarm’s optimal position vector is denoted as  $P_g = (P_{g1}, P_{g2}, \dots, P_{gd}, \dots, P_{gD})$  then the update formula of individual’s optimal position is

$$p_{i,t+1}^d = \begin{cases} x_{i,t+1}^d, & \text{if } f(X_{i,t+1}) < f(P_{i,t}) \\ p_{i,t}^d, & \text{otherwise} \end{cases} \quad (8)$$

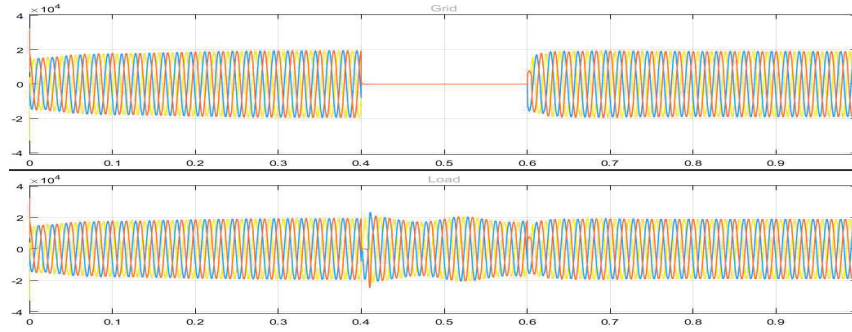
The swarm’s optimal position is that of all the individual’s optimal position updated formula of velocity and position is as follows, respectively:

$$v_{i,t+1}^d = v_{i,t}^d + c_1 * rand * (p_{i,t}^d - x_{i,t}^d) + c_2 * rand * (p_{g,t}^d - x_{i,t}^d) \quad (9)$$

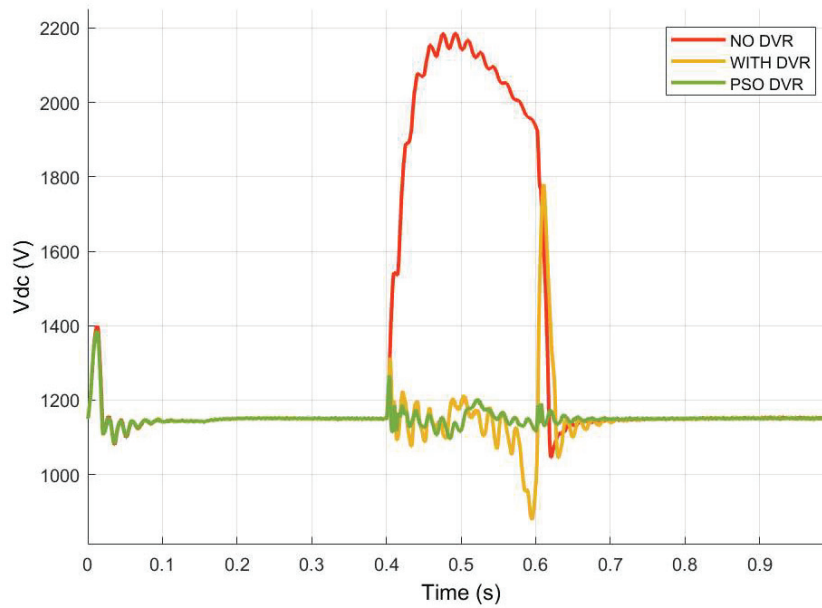
$$x_{i,t+1}^d = x_{i,t}^d + v_{i,t+1}^d \quad (10)$$

### 5 Simulation Results

In this section simulation results for the balanced fault condition of DFIG based WT using DVR is discussed. The test system under consideration is

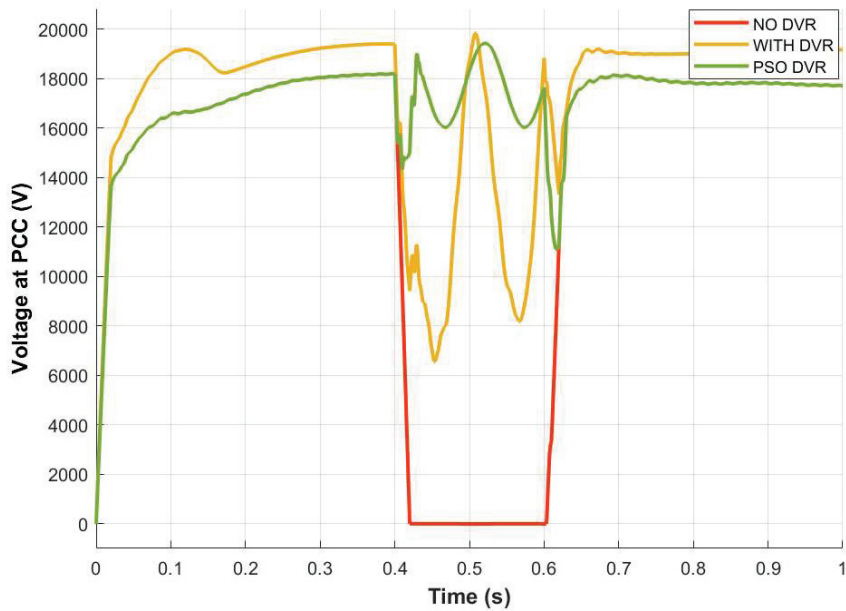


**Figure 5** Voltage at the PCC before and after compensation.

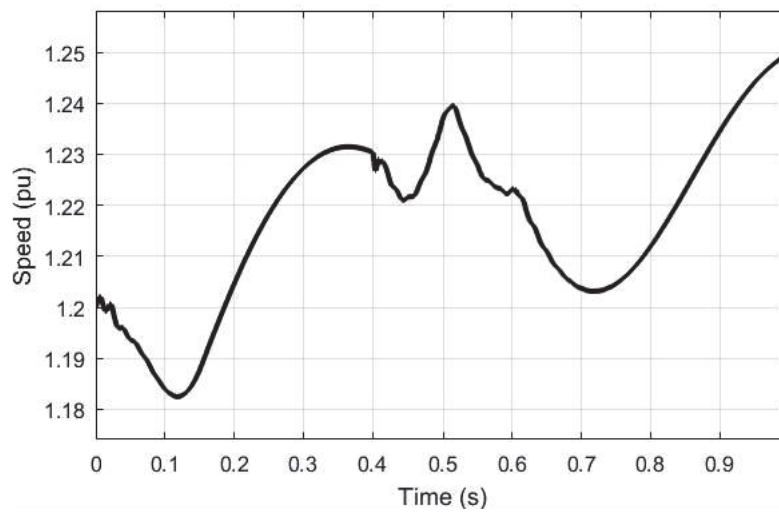


**Figure 6** Voltage at the DC link by different control action.

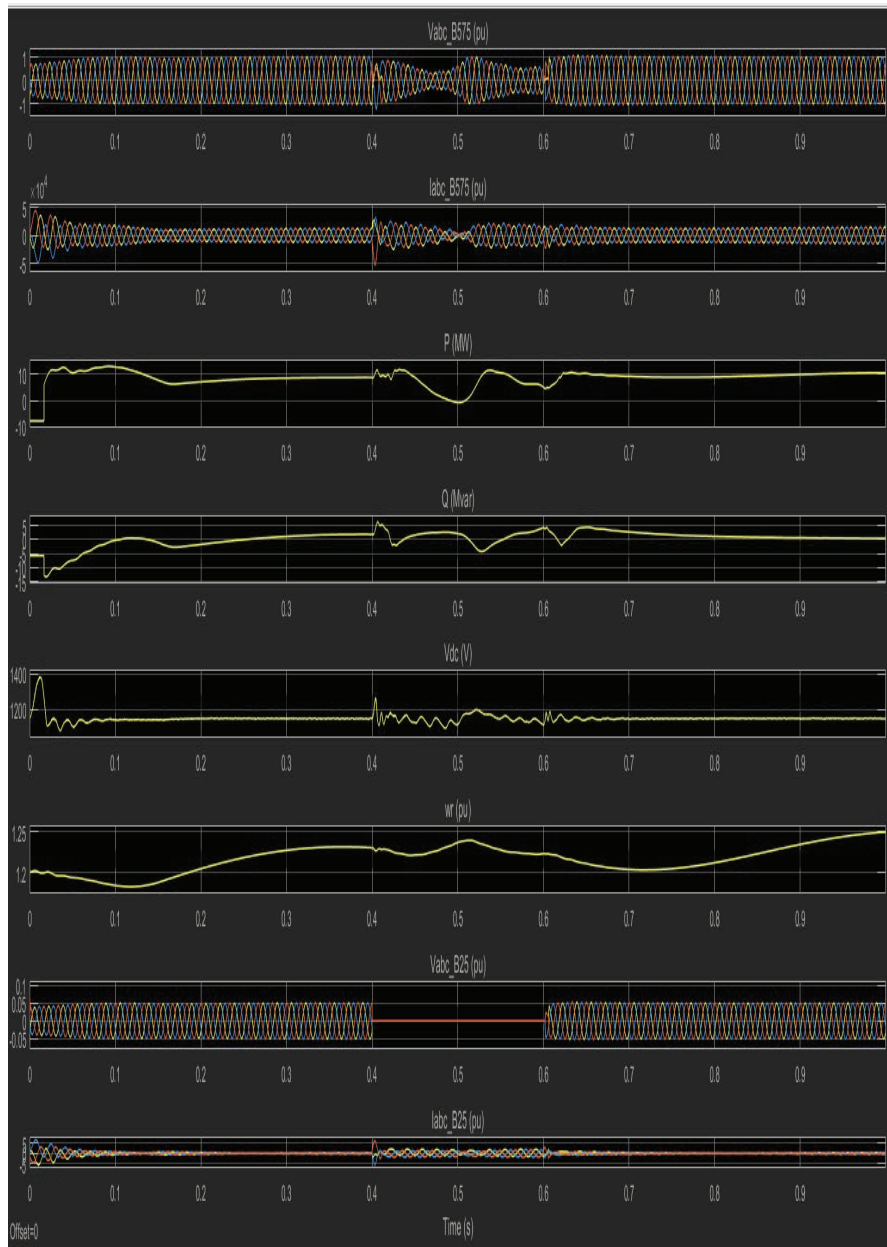
9MW WT integrated with grid in MATLAB/Simulink platform. The LVRT performance is analyzed for the balanced voltage sag between 0.4 s to 0.6 s. Grid connected DFIG network system is simulated using MATLAB Simulation for voltage sag problem. The DVR is integrated at the point of common coupling with a three phase non-linear load.



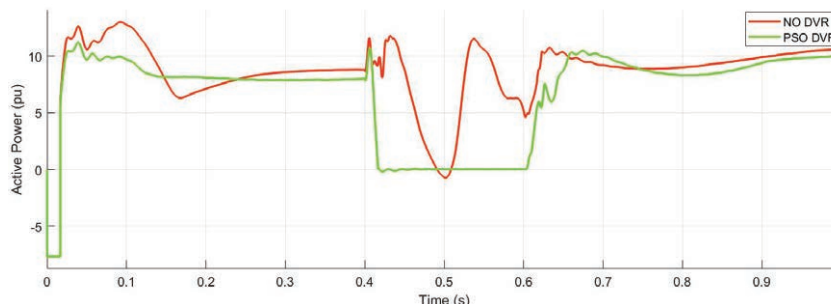
**Figure 7** Voltage level at PCC by different compensation methods.



**Figure 8** Speed variation of DFIG WT at pre fault, during fault and post fault condition.



**Figure 9** Stator and rotor side characteristics of DFIG wind turbine.



**Figure 10** Active power variations with and without DVR.

Figure 5 shows the three phase voltage at the PCC in case of fault and the after the compensation. During the fault, voltage has been reduced to zero due to three phase symmetrical short circuit has occurred. The simulation has been executed with DVR which is not employed in connected and not connected case. It is shown in Figure 5 that the DVR has effectively compensated the voltage by implementing the control strategy. It is also depicted that when DVR is not employed a voltage dip appeared. As the fault initiates it is sensed by the PI controller and compared with the reference signal. This generates the signal which is given to PWM circuit which is proportional to the error at the input. VSI connected with DC source is used to generate the AC signal to the during the fault time.

Figure 6 Shows the DC link voltage wave form on the occurrence of the fault. It is clearly demonstrated that when no DVR is connected the DC link voltage rises up to 2192 V during the 0.4 s to 0.6 s. Such high rise in DC link voltage is highly undesirable. When we connect DVR with the PCC the rise in DC link effectively reduced to 1220 V during the three phase fault. Further it is presented that PSO optimized DVR reduce the DC link voltage up to 1200 V effectively.

Figure 7 demonstrated the voltage level at PCC in case of fault and compensation response by different cases. It is clearly presented that when fault occurs and no DVR is connected voltage droops to zero level. But when we employed the DVR voltage level rises up to 6834 V. Further when we apply PSO tuned DVR at PCC voltage level raises to 11200 V which better than previous result and with less oscillation too.

WT speed variation is shown in the Figure 8.

Active and reactive power of DFIG based WT is shown in Figure 9. Also stator and rotor side voltage and current are presented.

## 6 Conclusion

This article analyze the voltage sag mitigation process and impact on DFIG based wind energy conversion system. Dynamic voltage restorer is employed for this purpose which sense the voltage sag from initial point generate compensating voltage from DC source in proportional to the sag magnitude. Particle swarm optimization method is utilized to tune the PI parameters of DVR. With optimum value of  $K_P$  and  $K_I$  efficient sag mitigation can be done. Extensive simulation results shows that PSO based DVR is effective in LVRT condition for DFIG based wind turbine.

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## Biographies



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