

Improved Dynamic Performance in Grid Connected Wind Energy System Using Dynamic Voltage Restorer



Preeti Rani, Ved Parkash Arora, and Naveen Kumar Sharma

Abstract Wind system is one of the mostly utilized distribution generation resources due to its positive impacts compared to traditional generation sources. But, its intermittent nature cause power fluctuation and due to this behavior most of distribution generation sources are connected to grid to regulate the supply for utility appliances. Integrated wind energy system (WES) with grid to analyze the stability during various three-phase faults presented in this work. This proposed system consists of wind turbine, permanent magnet synchronous generator (PMSG), filter, and some switching devices. PMSG has many advantages compared with other available alternators to generate electricity such as its high efficiency and required less maintenance due to utilization of permanent magnet in the alternator. But, due to intermittent nature of WES, it leads to power quality (PQ) issues through various three-phase fault scenarios. To mitigate these issues, dynamic voltage restorer (DVR) a custom power device is used in series with grid network. To check the effectiveness of proposed DVR this paper presents proposed system in MATLAB/Simulink environments. Simulation results represent investigates the performance of DVR with specific controller for the stability of proposed system during various three-phase fault conditions.

Keywords DVR · PWM · WECS · PQ · PMSG

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1 Introduction

Non-renewable energy sources such as natural gas and coal are replaced with distribution generation resources due to its ecofriendly nature and easy availability of these resources all over the world. Distribution generation resources can also be refer to renewable energy sources such as solar energy, wind energy, and hydro energy. In these days, utilization of WES is widely used to extract the power from wind especially in large-scale industries [1]. Due to high potential and number of positive impacts of WECS, in future definitely it will become first choice of electricity market [2].

Basically in wind energy, electricity produced with help of converting the kinetic energy of wind into mechanical energy and that mechanical energy is fed to generator for producing electricity. Wind flows due to the uneven of atmosphere by variation of temperature, by rotation of earth so on [3]. Wind turbine is main part of wind farm that is used for to converting the kinetic energy of wind into mechanical energy. Wind turbine is two types, first is horizontal type wind turbine, and another is vertical wind turbine. The length of blades is main factor of wind farm which describes the amount electricity produces by wind turbine. Mostly horizontal type wind turbine prefers for installation of wind farm [4].

Due to intermittent nature of WES some PQ issues occur in network which may trip grid connected sensitive loads. Some of PQ issues are sag, swell, harmonics etc. Out of these sag is one of common PQ issue that generally occurs in the distribution network due to presence of high inductive load at the end users utility side [5]. PMSG may disconnect from the grid connected WES due to unbalance operation. Due to occurrence of tripping and disconnection consequently grid will lose its stability [6]. Thus to avoid this situation many of countries have designed their fault ride through capability codes to enhance the stability during PQ issues [7]. There are devices used at utility side to protect the appliances from PQ issues namely Custom Power Devices (CPD). This paper proposed DVR to mitigate PQ issues by injecting controlled voltage during fault period [8].

Most of industries utilized advanced switching converters and utility devices those are sensitive to unbalance operation [9]. The main reason for unbalance operation is changes in voltage magnitude and non-sinusoidal wave shape of measured signals. Self-operating system of commercial applications subjected to one of the most common PQ issue, namely, voltage sag because some of control devices well performed at the time of voltage sag [10]. As per European standard at each bus of power system network voltage sag limits to 4%. It has been found that distribution network exposed to unbalance operation of grid system due to power fluctuation in some particular frequency range 0.01 to 0.1 Hz [11].

Another most occurrence PQ issue is harmonics. In integrated wind energy system inverter and other switching converts are main reason to generate harmonics in measured signals because they are operated at high-frequency signals and penetrate high current harmonics with active power signals [12]. Harmonics affects the stability

of grid system and cause overheating of utility equipments, tripping of switchgear devices of system.

In future, it is not acceptable that high integration of distribution generation sources will decrease the PQ without any penetration of PQ improvement topologies. It is also find that PQ issue caused by three phase fault at distribution network will make the difficult task to integrate WES with grid network. As per study it is found that there are number of power quality improvement topologies to mitigate the PQ issues cause by WES [13].

The main objective of this paper to present analysis of three-phase fault issues in distribution network with PMGH based WES and also presented the PQ improvement topology by investing the performance of DVR with SRF controller in order to enhance the reliability of proposed system. To verify the assessment of proposed DVR, the proposed system is modeled in MATLAB/Simulink environment. In Sect. 2, WES modeling is presented. Analysis on PQ presented in Sect. 3. DVR structure describe in Sect. 4. Control scheme of DVR topology is presented in Sect. 5. Section 6 represented simulation results and analysis. At the end, Sect. 7 represented conclusion.

2 WES Modeling

In WES, mechanical energy is extract from blowing air by employing wind turbine, then it is converted into electrical energy by using PMSG. Due to its stability and its less cost, this work proposed PMSG to deliver active power to grid.

Due to variant temperature intensity on earth, it creates variable pressure which is the reason to blow air from high pressure to low pressure. The speed of wind can be measured from the following equation [14, 15].

$$V_a = V_{10} \left(\frac{z}{10} \right)^\alpha \quad (1)$$

V_a Velocity of wind at some height (a meter) above ground (m/s).

V_{10} Velocity of wind 10 m above the ground (m/s) (Meteorological Center usually uses 10 m height fir reporting of wind speed).

α Power law exponent or index.

Wind input power can be calculated from following equation [16]

$$P_{wind} = \left(\frac{1}{2} \right) (\rho S V^3) \quad (2)$$

P_{wind} Power in wind (W).

ρ Density of air (kg/m^3).

S Swept area of turbine (m^2).

V Velocity of wind (m/s).

3 Power Quality

PQ can be defined as to sustain the voltage magnitude in specific range for the normal operation of utility appliances. There are number of reasons to generate PQ issues, but today main reason is advanced power electronic devices. Power electronic devices used as switching converters which is the main cause for nonsinusoidal wave shape and it is called as harmonics. There are some other PQ issues are sag, swell, interruptions, overvoltage, under voltage, etc. These issues generally occur due to utility appliance or due to three-phase faults in distribution network [17, 18].

As per literature survey, the percentage of occurrence of above mentioned various issues is different. Such that the percentage of occurrence of sag, swell, interruptions is 55% and harmonic occurrence is only 5% in European countries. In American countries occurrence of harmonic is 22% of total PQ issues. It means a common method cannot be applied to measure PQ issues for each country [19].

4 DVR Structure

DVR is a CPD employed in network in series through series transformer to inject control voltage in series with network. DVR with main components represented in Fig. 1. DVR consists of a battery as storage device to supply DC voltage to voltage source inverter (VSI) [20]. VSI is an insulated gate bipolar Transistor (IGBT) switch which is employed to convert DC supply in to ac but output is a controlled signal on the basis of voltage magnitude and time period to regulate the grid voltage. Controller is a main part of DVR to provide pulse width modulation (PWM) refers to gate pulse of VSI [21]. The utilization of DVR in grid connected WES is to inject three-phase ac voltage in series with network at DVR bus through series transformer. Three-phase voltage has controlled voltage magnitude and phase angle to regulate the grid voltage during abnormal condition of grid [22].

5 Control Scheme of DVR

There are number of control scheme to inject control voltage in series through transformer. This paper proposed synchronous reference frame (SRF) controller to prove the effectiveness of DVR during three-phase fault conditions. SRF controller operation depends on Clarks and Parks transformation as represented in Fig. 2. By

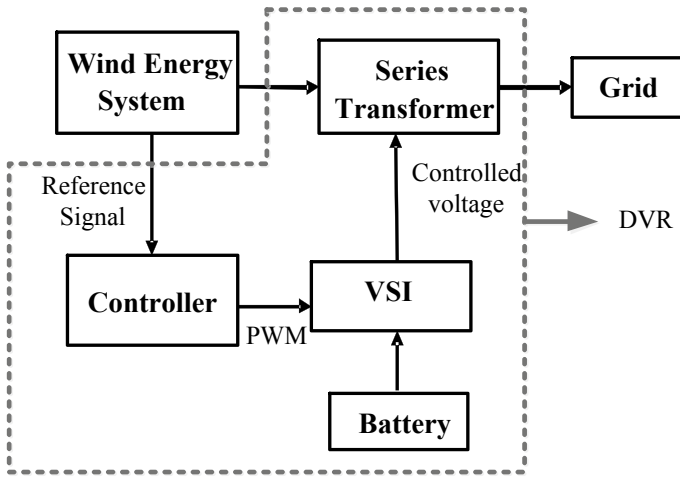
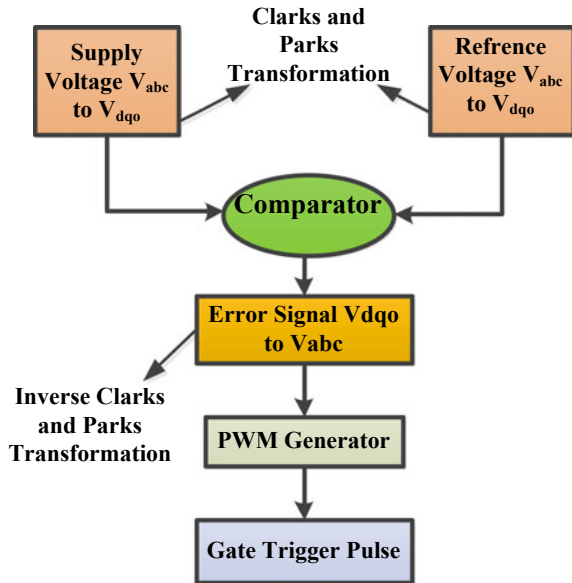


Fig. 1 Schematic diagram of DVR connected to grid connected WES

employing this transformation control scheme converts three-phase SRF (abc) to two phase rotating reference frame (dq0). In same manner, this transformation applied on reference voltage for getting reference voltage in two phase rotating reference frame (dq0) [23].

In this controller, a comparator is used to compare two phase rotating reference frame of grid connected WES supply voltage with reference voltage to provide error

Fig. 2 Flow chart of operation of SRF control of DVR



signal in the form of pulse width modulation. The reference signal consists of voltage amplitude, frequency and phase angle. Phase locked loop (PLL) is utilized to match phase angle of rotating dq0 reference frame with supply voltage phase angle. The output of controller provided to inverter in the form of gate trigger pulse to control the injected voltage of DVR [24].

6 Simulation and Result Analysis

To investigate the performance of DVR, the proposed system is modeled in MATLAB/Simulink environment shown in Fig. 3. In this work grid connected WES consists of PMSG to deliver active power to grid. When three-phase fault occur in the grid connected system, system voltage regulated with SRF control with DVR. The proposed scheme utilized to enhance the stability of grid during various three-phase faults. The important parameters of proposed system depicted in Table 1.

6.1 Case 1: Short-Circuit Fault: Three-Phase Line to Ground Fault (3L-G)

In the first case, the performance of WES DVR with proposed control techniques is evaluated under three-phase line to ground fault condition. Real-time three-phase supply voltages are 1 p.u., and fundamental frequency is 50 Hz. In this DVR is required to maintain supply voltage at 1 p.u. across grid connected sensitive loads. Figure 4a represents three-phase load voltage in p.u. without DVR under sag period 0.2–0.3 s, DVR injection sag compensation voltage in volts by SRF controller is

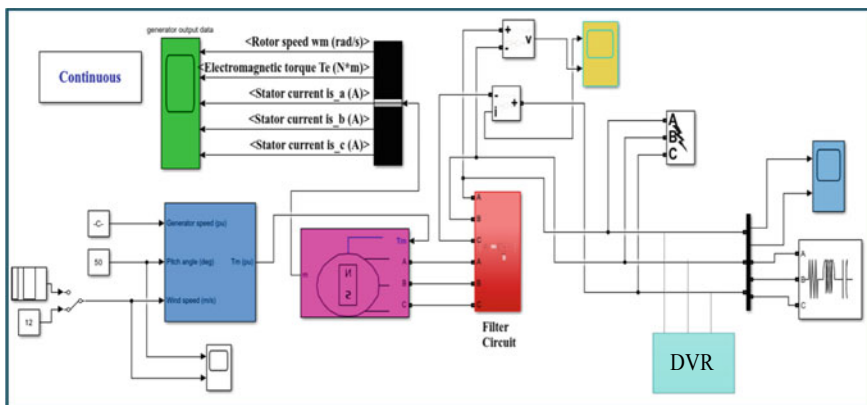


Fig. 3 Simulink model of grid connected WES

Table 1 Grid connected WES

Simulation parameters	Values
Base wind speed	8 m/s
Stator resistance	0.001 p.u
Flux linkage	0.09 p.u
Armature inductance	0.01 H
Rated voltage and frequency	562 V/50 Hz
Base rotational speed	1.0 p.u
Max. power at base wind speed	0.69 p.u
Series RLC branch	1 Ω, 0.001H, 0.0001C
Parallel RC branch	0.1 Ω, 0.0001C

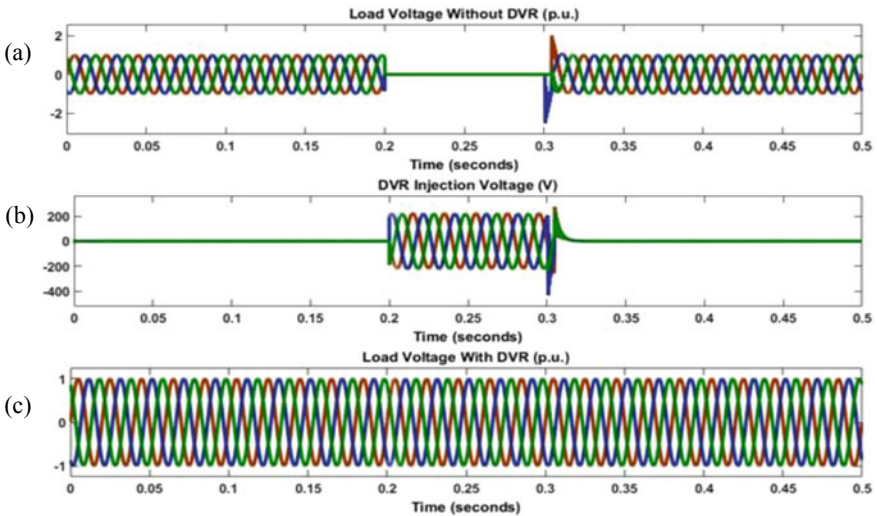


Fig. 4 a Load voltage with three-phase (3L-G) fault in p.u., b DVR injected voltage in volts, c Load voltage in p.u.

shown in Fig. 4b, three-phase sag compensation load voltage in p.u. utilizing SRF controller as depicted in Fig. 4c.

6.2 Case 2: Unbalanced Sag: Two Phase Line to Ground Fault (2L-G)

In the second case, the performance of WES DVR with proposed control techniques is evaluated under two phase line to ground fault condition. Real-time three-phase supply voltages are 1 p.u. and fundamental frequency is 50 Hz. In this, DVR is

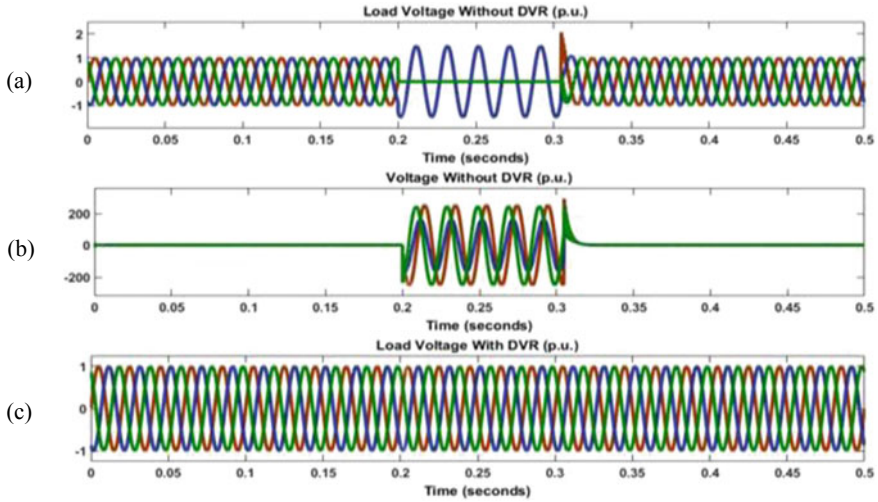


Fig. 5 **a** Load voltage with three-phase (2L-G) fault in p.u., **b** DVR injected voltage in volts, **c** Load voltage in p.u.

required to maintain supply voltage at 1 p.u. across grid connected sensitive load. Figure 5a represents three-phase load voltage in p.u. without DVR under sag period 0.2 to 0.3 s, DVR injection sag compensation voltage in volts using SRF controller in Fig. 5b and three-phase sag compensation load voltages in p.u. using SRF controller DVR as shown in Fig. 5c.

6.3 Case 3: Total Harmonic Distortion Analysis

By employing switching converters in proposed system with DVR cause distortion of voltage waveforms and in this work the Total Harmonic distortion (THD) in percentage measured at three buses with fast-Fourier transform (FFT) analysis in MATLAB software. Using SRF Control, the THD percent of DVR drops to 2.31%, compared to 7.65% without it. Figure 6 shows harmonic spectrum of proposed system with SRF control DVR.

7 Conclusion

A DVR-based control scheme to mitigate PQ issues in grid connected WES is presented. The execution of DVR with SRF controller to enhance the stability of grid connected WES with PMSG during various three-phase conditions, namely, short-circuit fault and unbalanced sag is also presented. The proposed control scheme

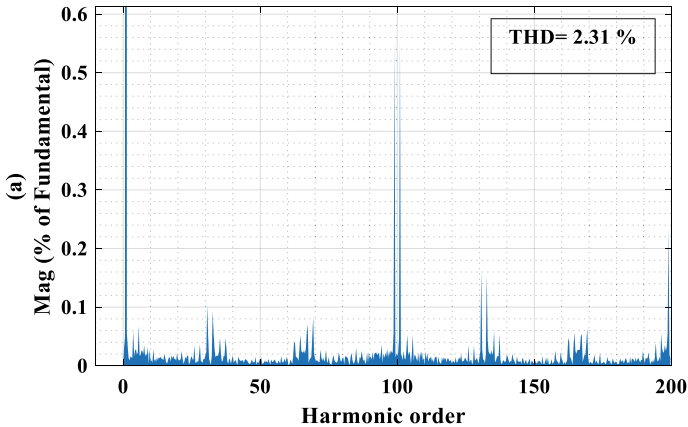


Fig. 6 Harmonic spectrum of grid connected WES with SRF control DVR

utilized for DVR is modeled in MATLAB/SIMULINK software to improve the dynamic of PMSG-based WES. Series compensation-based DVR prove its effective behavior with grid voltage regulation capability, THD control and reactive power control proficiency. Due to SRF controller simplicity, it utilized with DVR to inject controlled voltage in terms of magnitude and time period through series transformer. The simulation is carried out to represent better functioning of DVR with SRF controller with compensation of various three-phase fault scenarios for improving dynamic performance of grid connected WES.

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