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Research Article

Modeling of Wind Turbine PMSG System Using DVR Based Fuzzy Logic Controller for Voltage Sag and Swell Compensation

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Abstract

Nowadays, many industries are using non-conventional energy sources to generate a huge amount of power/electricity, as these are non-pollutant. But connecting wind turbine to the power system or grid may lead to power quality issues such as voltage sag/swell, flicker, and harmonic and inter-harmonics.DVR is one of the CP devices used to mitigate voltage drop/raise .Sag is a more critical issue than swell. In this paper, sag and harmonic problems have been addressed. It demonstrates that how DVR injects voltage to compensate sags and reduces harmonics during fault. Here, the performance of DVR with PI controller, fuzzy controller, and hybrid fuzzy logic controller has been compared. The demonstration is done in MATLAB/Simulink.

Keywords

Custom power (CP) Dynamic voltage restorer (DVR) Wind energy system (WES), Permanent magnet synchronous generator (PMSG) ,Fuzzy logic controller (FLC), Hybrid fuzzy logic controller (HFLC) ,MATLAB/Simulink

1 Introduction

In modern days, power quality problems have become more critical issues not only for industries also for commercial people. So, maintaining a good quality of the power without any disturbance is very important. If any failure occurs in the system, it effects on the whole system; hence, it is essential to clear all failures and disturbances. In the proposed system, WES is connected to the grid, which is based on PMSG. There are many types of wind turbine. Voltage dip leads to an increase in the current beyond the inverter limitation. Due to this, DC capacitor voltage increases vulnerably. Hence, the fast removal of voltage sag is important [2].

There are many alternative ways to mitigate voltage sag, such as STATCOM, DVR, UPQC. In [3], the dynamics of wind energy system is analyzed with and without DVR and STATCOM. The modeling and construction of PMSG have been explained in the literature [3]. This PMSG is very efficient than induction generator, as it is excited without any energy supply. Because of connecting wind turbine harmonics will be generated in the system, DVR is used to mitigate harmonics and voltage dip. DVR injects the constant voltage and helps to enhance power quality in the network. Here, DVR is connected with fuzzy logic controller, as it can able to check the error of 0.1–0.9.

2 DVR

DVR is one of the CP devices which are used to inject voltage to compensate load terminal voltage. It is designed to connect in series to the distribution system via injection transformer. It injects constant voltage to the load terminal for mitigating sag/swell. Sag is a more critical issue than swell.

2.1 Main Components of DVR

1. Injection transformer
2. Harmonic filter
3. Storages devices/control system
4. VSC/VSI.

Voltage injection from the DVR can be written in equation form [4] as, $V_{DVR} = V_{load} + (Z_{line} \times I_{load}) - V_{source}$ (1)

where

V_{load} Load voltage
Z_{line} Impedance of line
I_{load} Load current
V_{source} Source voltage at fault condition
V_{DVR} DVR injected voltage (Fig. 1).

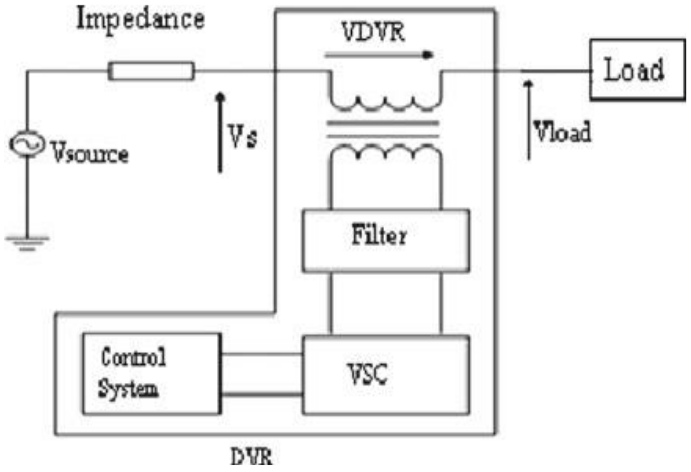

Fig. 1 Schematic diagram of DVR

2.1.1 Injection Transformer

Injection transformer is used for the purpose of boost V_{ac}, supplied by voltage source converter to the required voltage levels.

2.1.2 Harmonic Filter

Harmonic filter eliminates the harmonic components which generated by the VSI. Filter can be connected either high voltage side or converter side of the injection transformer.

2.1.3 Storage Devices/Control System

DVR is used for compensation purpose. For compensation, DVR requires real power during voltage disturbances. Hence, storage devices are used to supply real power to DVR. In this system, controllers used are PI Controller, FLC, and HFLC.

2.1.4 VSC/VSI

VSC converts the DC voltage into AC voltage. Firing pulses to VSC is given from PWM generator.

3 Proposed Control Scheme

In the proposed method, WES is integrated into the grid. In this method, PMSG-based WES is connected to the source side. WES is used as an external source. Here, wind speed is maintained at 12 m/s. Mitigation of sag and harmonics during fault condition is very important. To mitigate these problems, DVR is designed and proposed control strategy using HFLC. It has been shown that HFLC has more advantages than PI. FLC analyzes analog input value in terms of logical variables which may be any real numbers between 0 and 1.

3.1 Mathematical Equation for Conversion of Energy in WES

The KE of wind is written as

$$E_c = \frac{1}{2}mv^2 \quad (2)$$

$$m = \rho v S \quad (3)$$

m = air mass; v = speed of the wind
q = density of air; S = surface area of turbine.

Power in the wind is expressed as $$P_W = E_c \frac{1}{2} \times m \times v^2 \frac{1}{2} \times \rho \times S \times v^3 \quad (4)$$

The above equation can be modified as $$P_w = \frac{1}{2} \times \rho \times A \times v^3 \times C_p \quad (5)$$

$$C_p = 0.5\left[\gamma - 0.022\beta^2 - 5.6\right]e^{-0.17\gamma} \quad (6)$$

where

C_p Rotor power coefficient

β Blade pitch angle.

4 Test System

A 3Φ, 415 V, and 50 Hz programmable voltage source is connected to three winding transformers which feeding two transmission lines. DVR is connected in series between the point of common coupling and load through an injection transformer. Voltage sag is created using three-phase faults. DC link is supplying DC voltage to inverter to get AC voltage. Discrete PWM generator is used to produce firing pulses to inverter (Table 1).

Table 1 Test system parameter

Parameter	Rating
Supply voltage	Three-phase, 50 Hz, 415 V
DC voltage	120 V
Line resistance	0.001 Ω
Line inductance	0.005 H
Stator phase resistance	0.425 Ω

Vital role of dynamic voltage restorer is to inject voltage at load terminal during fault condition. Simulation is carried out for duration of 0.1–0.2 s. DVR with HFLC scheme [5].

5 Simulation and Results

Simulation is done for DVR with PI controller, fuzzy logic controller, hybrid fuzzy logic controller for voltage sag from 0.1 to 0.2 s. Nominal voltage taken here is 415 V, 50 Hz. It is observed that DVR has injected the required voltage for

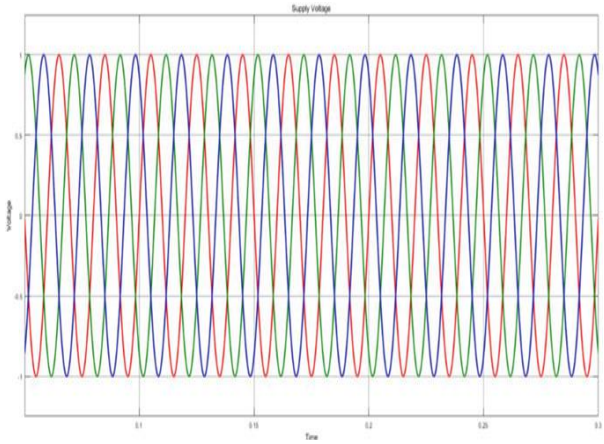

Fig. 2 Supply voltage of the proposed system

compensation in all three phases during sag condition. Discrete PWM generator has been used for pulse generation (Figs. 2 and 3).

Case 1: Compensated System for PI Controlled DVR

Case 2: Compensated System of DVR with Fuzzy Logic Controller

Case 3: Compensated system of DVR with Hybrid Fuzzy Logic Controller

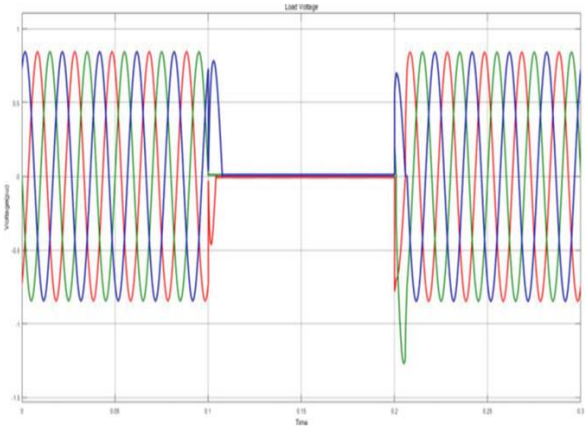

Fig. 3 Uncompensated system with three-phase faults

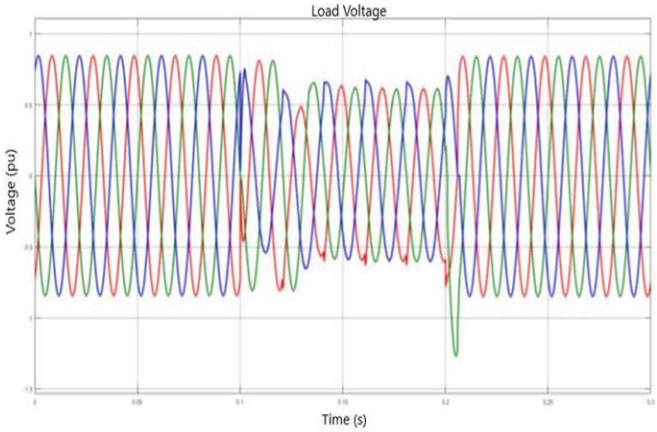

Fig. 4 Injected load voltage for DVR with PI controller

6 Conclusion

In this proposed system, simulation is carried out for DVR with PI, FLC, and hybrid fuzzy logic controller for mitigating voltage dip and harmonics. Three-phase 415 V, 50 Hz generation system has been developed with wind turbine, and PWM

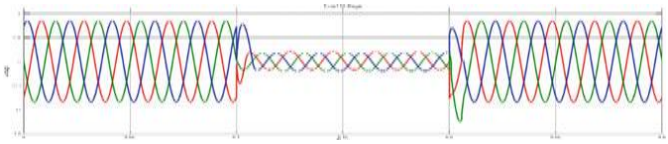

Fig. 5 Injected load voltage for DVR with fuzzy logic controller

generator is used for pulse generation. From the simulation result, it is shown that DVR with hybrid fuzzy logic controller has effectively compensated voltage sag at the load side and reduces harmonic distortion that compared simulated outputs with PI controller and FLC. This system can be implemented further by using SVPWM for better results.

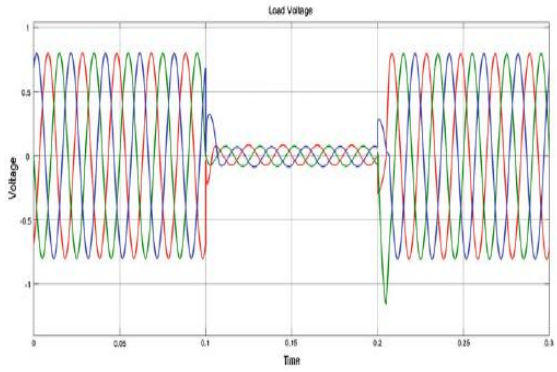

Fig. 6 Injected load voltage for DVR with hybrid fuzzy logic controller

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