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Comparative Analysis of Voltage Stability of DFIG Wind Turbine by Using DVR

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ABSTRACT
In this paper problems related to the voltage stability may be cleared by the use of custom power devices. These devices provide the customized ability to control the power in the circuits. One such reliable customer power device used to recover the problems related to the voltage is the Dynamic Voltage Restorer (DVR The main function of the DVR is to monitor the load voltage waveform constantly and if any sag or swell occurs, the balance voltage is injected to the load voltage. To achieve the above functionality a reference voltage waveform has to be created which is similar in magnitude and phase angle to that of the supply voltage. The DVR is applied to DFIG for maintaining the voltage output constant. The model is developed in MATLAB Simulink. This allows the DFIG system to ride through the voltage sag produced due to system faults. The DVR compensates the faulty line voltage, during that the DFIG wind turbine continues its nominal operation as demanded in actual grid codes.

Keywords: Wind Turbine, DVR, DFIG, PWM MATLAB.

INTRODUCTION
We know the development in the power system has been increased the practice of power electronic components.

The industrialized devices are typically based on power electronic devices like programmable logical controllers & electronic drives. These devices essentially need supply of an un-interruptible power with healthier quality during the production process. The goal for demanding high quality power is fundamentally the modern manufacturing & process equipment, which functions at high efficiency & requires great quality power supply for their fruitful operation. Numerous machine modules are designed to be very sensitive for the power supply differences. Variable frequency drives, automation devices, power electronic components are patterns for such equipment. Disappointment to provide the required quality power output leads to complete shutdown of the industries resulting into major monetary loss.

1. Voltage dip is defined as the decrease in rms value of the voltage to a value between 0.1pu to 0.9 pu& lasting for the period between 0.5 cycles to 1 minute, Fig. 1.1. System faults are the core reasons of the voltage sags & contingent up on the fault clearing time; it may last for the 3 cycles to 30 cycles as the voltage regulation devices comes in action after the 60 seconds of voltage dip.

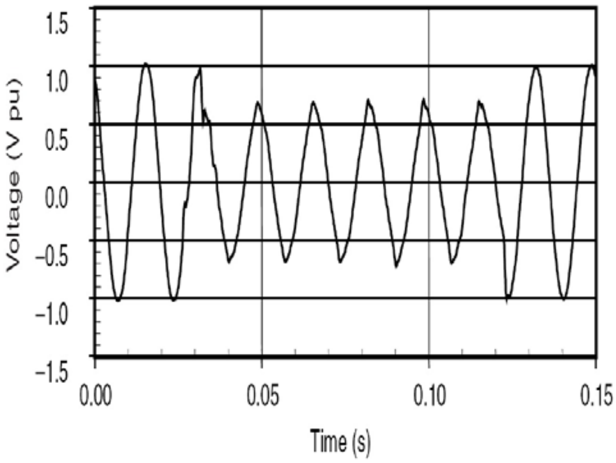

Fig. 1.1 Voltage Sag Waveform

2. Voltage swell is defined as the upswing in rms voltage that is between 1.1pu to 1.8pu for the time period of 0.5 cycles to 1 minute, Fig. 1.2. Single Line to Ground fault may give upswing to the voltage swell in the healthy phases. Switching of large capacitor bank is too the reason of voltage swell production.

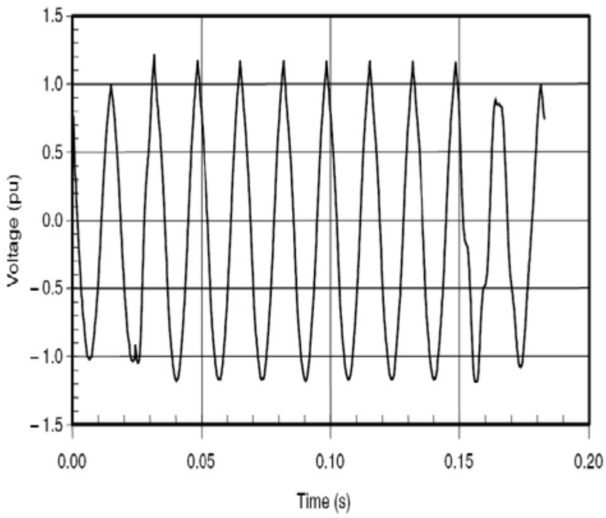

Fig. 1.2 Voltage Swell Waveform

3. Interruptions are nothing but the reduction in supply voltage or load current below 0.1pu for time not more than 1 minute, fig. 1.3. The origin of interruption is either by system fault, equipment failure or by control miscarriage.

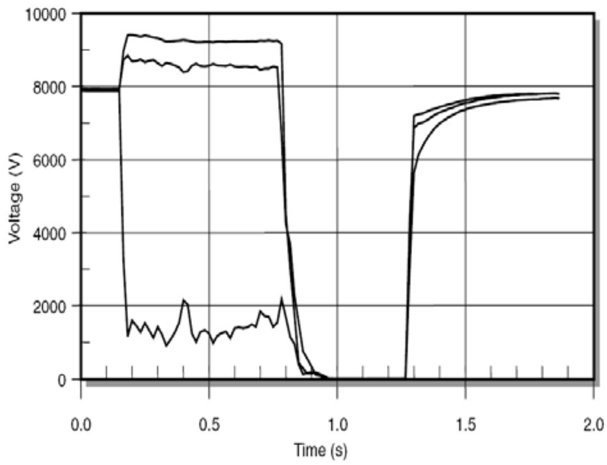

Fig. 1.3 Voltage Interruption Waveform

4. Transientsare momentary undesirable voltages that appear on the system. Transients are high over-voltage disturbances that last for a very tiny time duration, Fig. 1.4. The transient happens due to Lighting loads, capacitor switching, nonlinear loads etc.

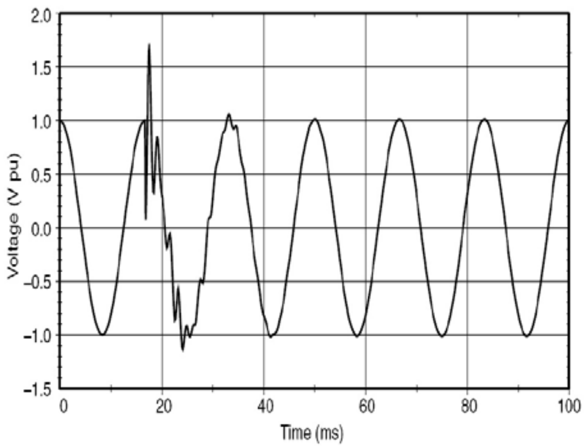

Fig. 1.4 Oscillatory Transient Waveform

5. Harmonics are the effect on the fundamental frequency of supply which produces multiples of the fundamental frequency, Fig. 1.5. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency.

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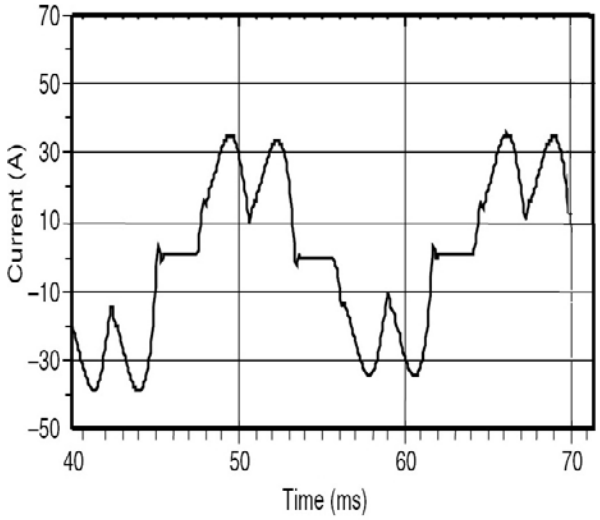


Fig. 1.5 Waveform with Current Harmonics

As an outcome of above power quality defect, the engineering may get affected out of failure of motors, loss of data on volatile memories, redundant downtime, increased maintenance costs etc. Among those abnormalities voltage sags & swells or simply the voltage variations are considered to be one of the most regular types of abnormality. Motor start up, lightning strokes, fault clearing & power factor switching are considered as the causes for fluctuating voltage conditions in the system.

Mechanically switched shunt capacitors in the primary of the distribution transformer are mounted. The mechanical switching might be controlled from Supervisory Control & Data Acquisition System (SCADA) scheme, at several particular timing schedules or by no switching at all. It has drawback that, high speed transients cannot be recompensed with this practice. Sometimes transformer taps can be used, but tap changing under load is costlier to fix. Alternative power electronic solution to the voltage regulation is the usage of a DVR. It pays a series of voltage boost technology using solid state switches for compensation of voltage sags or swells. The DVR presentations are mainly for sensitive loads that are affected by fluctuations in system voltage.

III. SYSTEM DEVELOPMENT

We will discuss about the mathematical models that are necessary to develop the system of DFIG wind turbine & DVR. The mathematical models are prepared first & then that formulations are used for the design of the Simulink model. The fig. 3.1 shows complete overview of the system model to be developed.

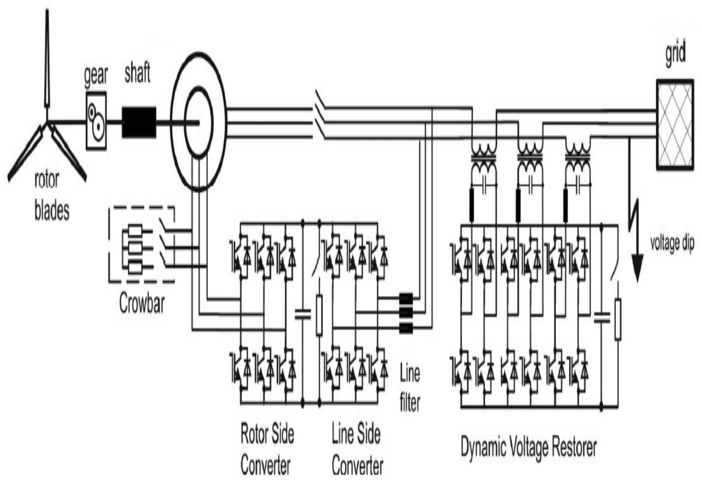


Fig. 3.1 Complete System Overview

3.1 Mathematical Modeling of DFIG wind Turbine System

The investigated wind turbine system, as shown in fig. 3.1, consists of the basic components like the turbine, a gear (in most systems), a DFIG, and a back-to-back voltage source converter with a dc link. A dc chopper to limit the dc voltage across the dc capacitor and a crowbar are included. The back-to-back converter consists of a RSC and a LSC, connected to the grid by a line filter to reduce the harmonics caused by the converter. A DVR is included to protect the wind turbine from voltage disturbances. Due to the short period of time of voltage disturbances, the dynamics of the mechanical part of the turbine will be neglected and the mechanical torque brought in by the wind is assumed to be constant.

3.2 Modeling of Induced Rotor Voltages

A precise knowledge about amplitude and frequency of the rotor voltage is necessary to design and control the RSC. Therefore, equations for the rotor voltage in normal operation & under symmetrical stator voltage dip are derived. Afterwards, the rotor converter rating is taken into account.

From the per-phase equivalent circuit of the DFIG in a static stator- oriented reference frame, the following stator & rotor voltage and flux equations can be derived as follows.

$$v_s = R_s i_s + \frac{d\phi_s}{dt} \tag{3.1}$$

$$v_r = R_r i_r + \frac{d\phi_r}{dt} - jf\phi_r \tag{3.2}$$

$$\phi_s = L_s i_s + L_h i_r \tag{3.3}$$

$$\phi_r = L_r i_r + L_h i_s \tag{3.4}$$

Where ϕ, v,i represent the flux, voltage & current respectively. Subscript s&r denote the stator & rotor respectively. $L_s = L_{s\sigma} + L_h$&$L_r = L_{r\sigma} + L_h$represent stator & rotor inductances R_s&R_r are the stator & rotor resistances &f is the electrical rotor frequency.

3.4 Modeling of Crowbar System

To protect the RSC from tripping due to overcurrent in the rotor circuit or overvoltage in the dc link during grid voltage dips, a crowbar is installed in conventional DFIG wind turbines, which is a resistive network that is connected to the rotor windings of the DFIG. The crowbar limits the voltages and provides a safe route for the currents by bypassing the rotor by a set of resistors. When the crowbar is activated, the RSCs pulses are disabled and the machine behaves like a squirrel cage induction machine directly coupled to the grid. The magnetization of the machine that was provided by the RSC in nominal condition is lost and the machine absorbs a large amount of reactive power from the stator, & thus, which can further reduce the voltage level & is not allowed in actual grid codes.

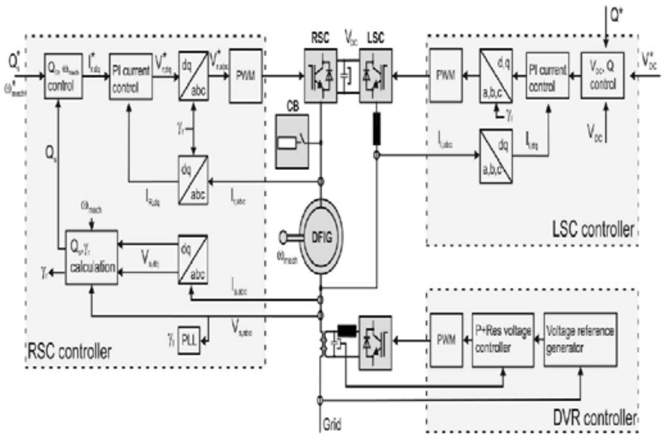


Fig. 3.2 Control System of DFIG & DVR

3.4 **Rotor Side Converter Modeling**

This rotor side converter unit acts as controller to control the amount of active & reactive power flow from the stator. The system is so designed to have stator voltage oriented control, for that purpose, the decomposition in *d&q* components is done. i.e. (V_{sq}=0) Neglecting the stator voltage drop, the stator output active & reactive powers can be expressed as,

$$P_s \approx \frac{3L_h}{2L_s} V_{sd} I_{rd} \tag{6.20}$$

$$Q_s \approx -\frac{3V_{sd}}{2L_s}\left(\frac{V_{sd}}{\omega_s} + L_h I_{rq}\right) \tag{6.21}$$

Thus the active & reactive power flow can be controlled with the control on *d&q* components of the rotor.

IV SIMULATION RESULTS & ANALYSIS

4.1 General

Sequentially, moving towards results of this proposed work, the simulation is now completed with MATLAB Simulink software. The simulation is carried out by different types of faults on the power system that is designed. The system is subjected to the faults & then the ride through capability of the wind turbine is verified. The flow of the simulation is as follows.

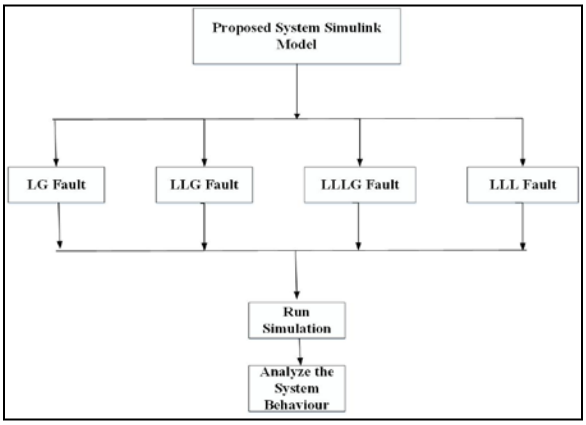


Fig. 4.1 Flow of Simulation

The simulation is carried out on the Simulink model with different types of the faults on the system. Then the system undergoes run command & after completion of the system run, the system behavior is analyzed from the waveforms.

4.2 Analysis of the Proposed System model

The system that is designed in this modeling undergoes all the types of possible faults in the system. For the analysis of the system there are mainly two constrains to be taken in considerations. The system with active crowbar protection & system with active DVR protection is analyzed.

4.2.1 Analysis of System with Crowbar Protection

The conventional DFIG system was using the Crowbar protection from the fault. The protection was needed to secure the RSC & LSC circuits. These circuits were equipped with IGBTs i.e. power electronic devices which are very sensitive to the fluctuations in the loads. When fault occurs on the system these crowbars are switched ON simultaneously cutting the Back-to-Back Converter OFF. This was necessary to protect the system from overshoot of the system current during faults. The excess flow of current passing through the power electronic converting devices may damage the system.

When the crowbars are switched ON, at that time the rotor winding is short circuited with the help of that crowbar resistance, it is switched from the wound rotor configuration to squirrel cage rotor configuration. The system model for active crowbars protection is in fig. 4.2.

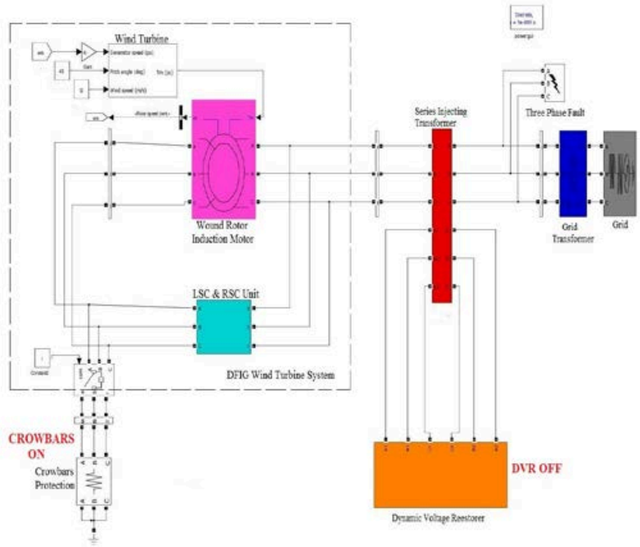
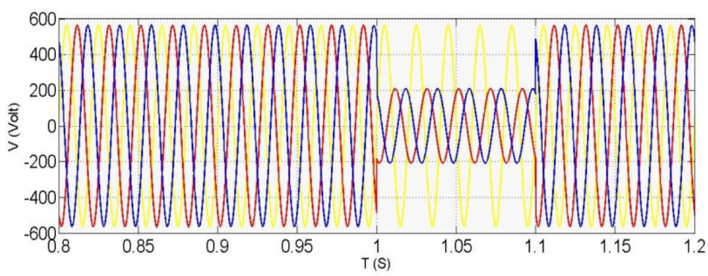


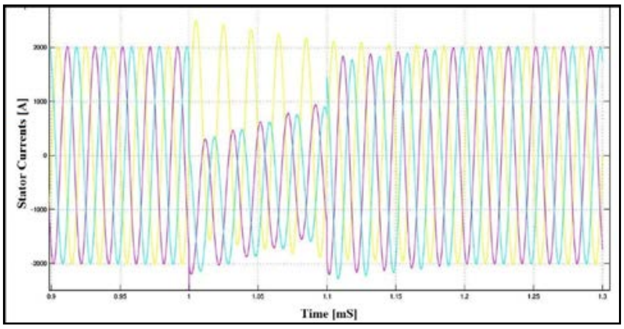
Fig. 4.2 Simulation Model with Crowbars ON

4.2.1.1 Simulation Results with Crowbars Protection

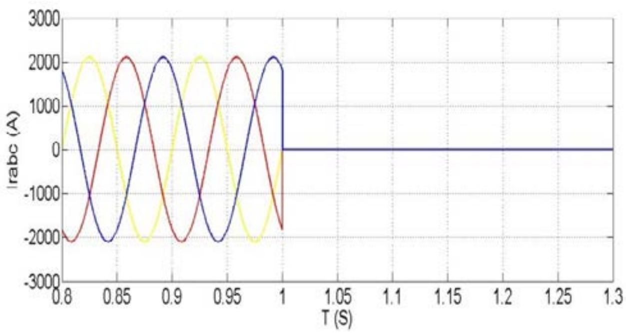
When the simulation undergone run command, the system is subjected to LLG fault for the duration of 1 to 1.1 sec, the results are as follows.



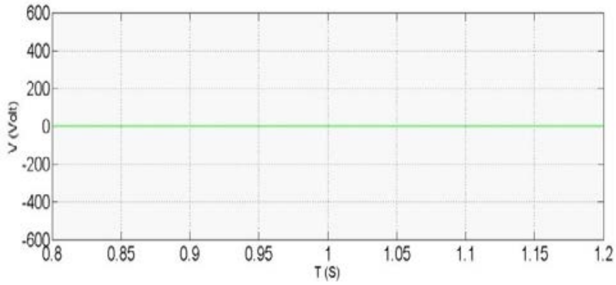
(a) Line Voltage



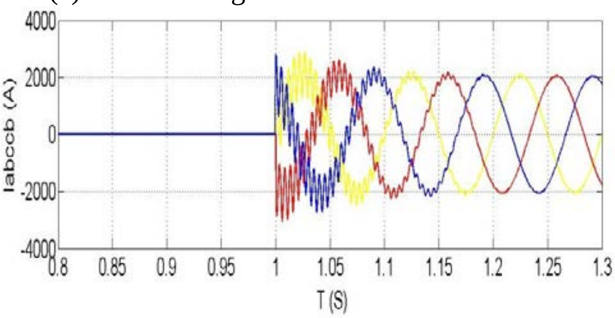
(b) Stator Currents



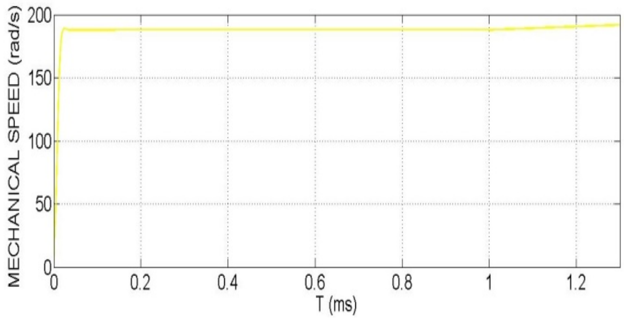
(c) RSC Currents



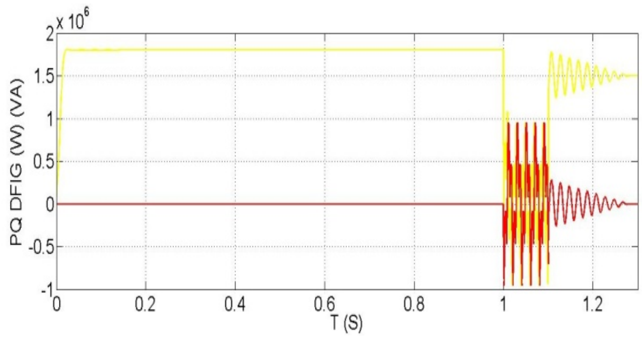
(c) DVR Voltage



(d) Crowbar Currents



(f) Mechanical Speed of DFIG

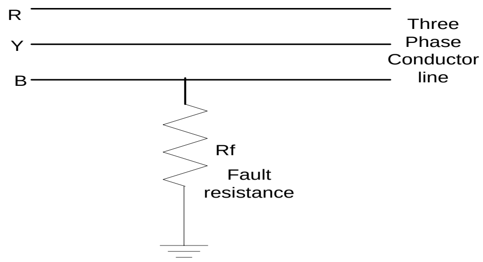


(g) Active & Reactive Power supplied by DFIG

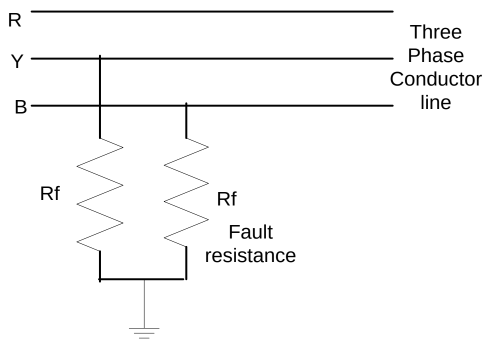
Fig. 4.3 Simulation Results for the system under fault with crowbar protection

4.2.2 Analysis of the system with DVR Protection

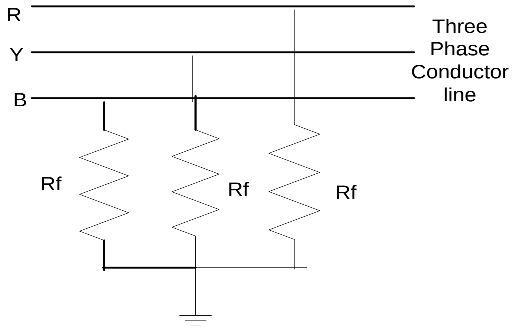
When the system is protected with DVR, the crowbars do not focus. When fault occurs on the system, DVR switches to the injection mode. DVR injects the required amount of voltage so as to meet the grid code requirements still in the faulty condition.



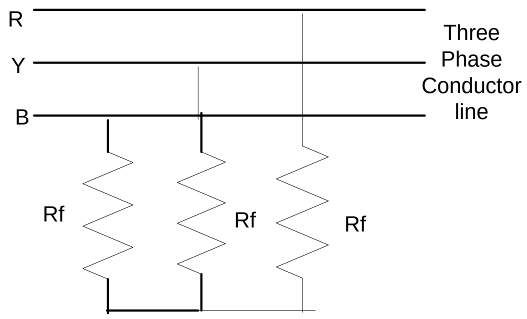
(a) Single Phase to Ground Fault (L-G)



(b) Two Phase to Ground Fault (L-L-G)



(c) Three Phase to Ground Fault (L-L-L-G)



(d) Symmetrical Three Phase Fault (L-L-L)

Fig. 4.4 Types of Faults for which system is subjected

The system with the active DVR protection is subjected to all above faults as shown in the fig. 8.4. The system model with active DVR protection is shown in the fig 8.5. For this case the crowbars are maintained OFF & DVR is switched ON.

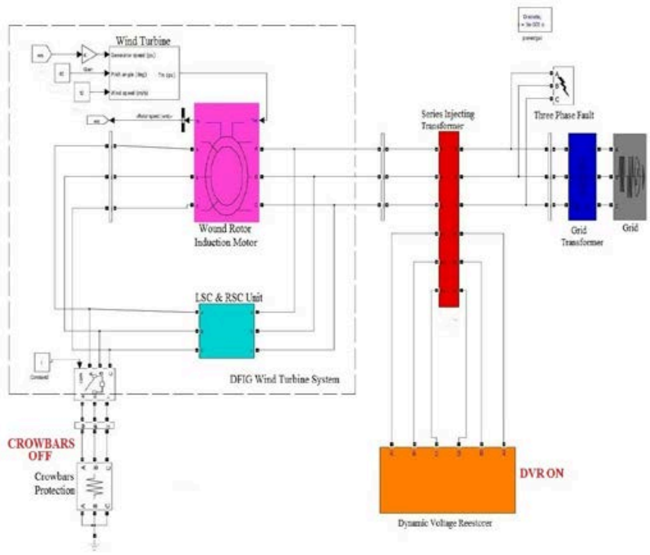
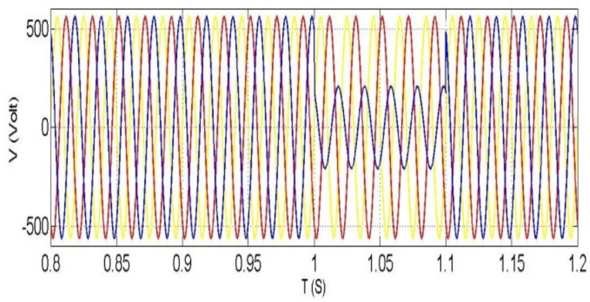


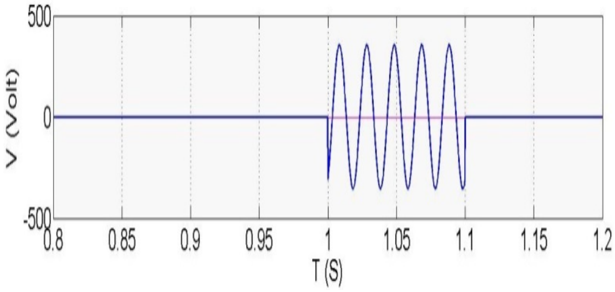
Fig. 4.5 Simulation Model with DVR ON

4.2.2.1 DVR for LG Faults

When the system developed is subjected to the Single Phase fault i.e. L-G Fault, the results obtained as shown in the fig. 4.6.



(a) Stator Voltage



(b) DVR Voltage

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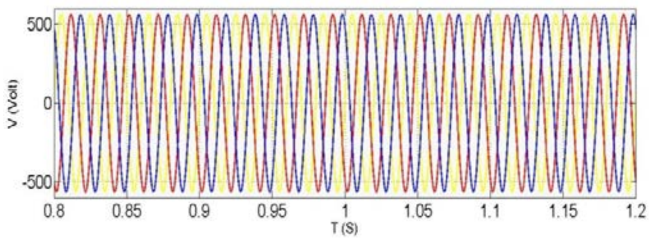
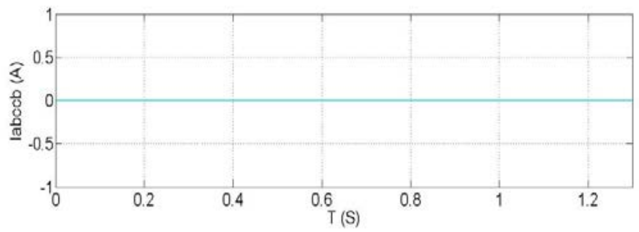
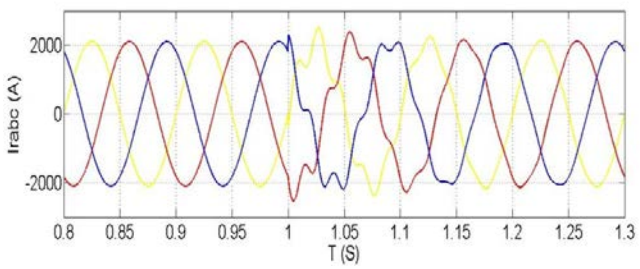


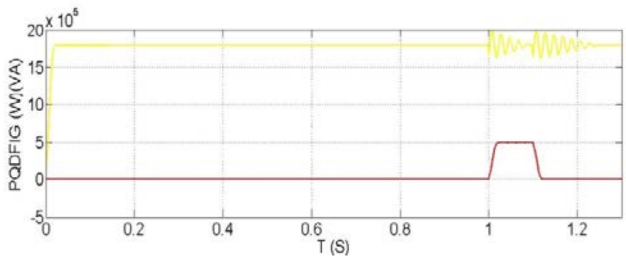
(c) Line Voltage



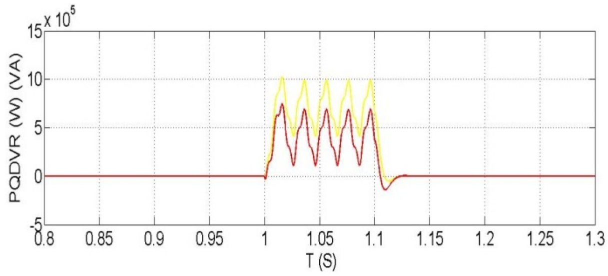
(d) Crowbar Current



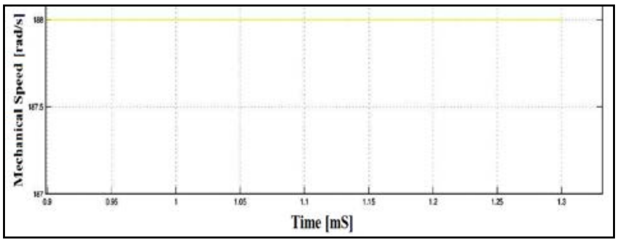
(e) RSC Currents



(f) Active & Reactive Power supplied by DFIG



(g) Active & Reactive Power supplied by DVR

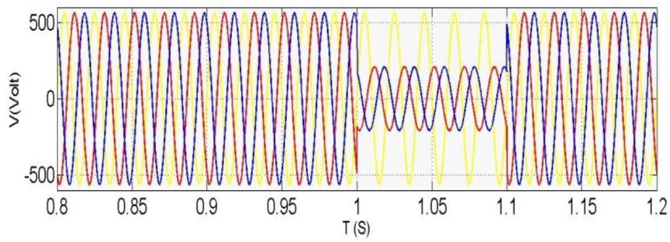


(h) Mechanical Speed of the DFIG

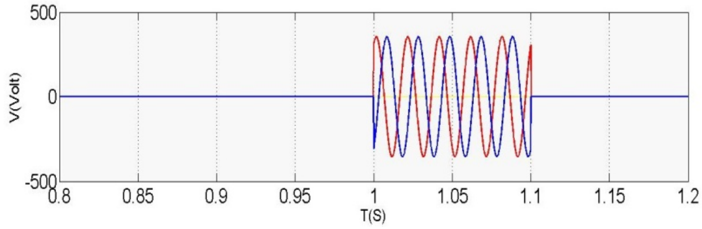
Fig. 4.6 Simulation Results for the system under L-G fault with DVR protection

4.2.2.2 DVR for LLG Faults

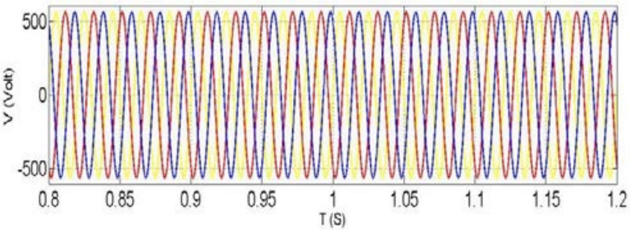
When the system developed is subjected to the Two Phase fault i.e. L-L-G Fault, the results obtained as shown in the fig. 4.7.



(a) Stator Voltage



(b) DVR Voltage

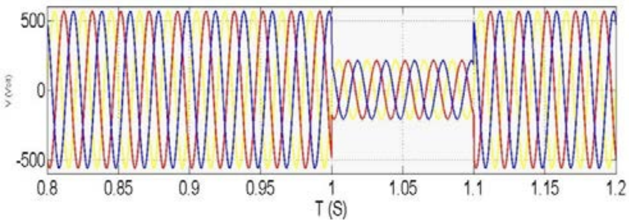


(b) Line Voltage

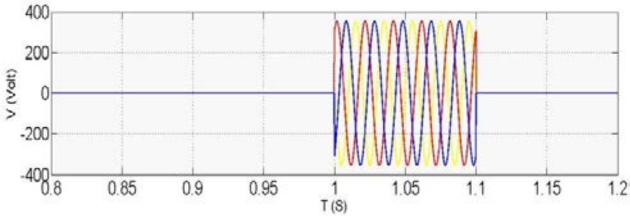
Fig. 4.7 Simulation Results for the system under L-L-G fault with DVR protection

4.2.2.3 DVR for LLLG Fault

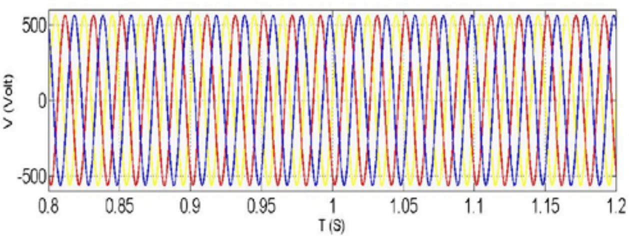
When the system developed is subjected to the Two Phase fault i.e. L-L-L-G Fault, the results obtained as shown in the fig. 8.8.



(a) Stator Voltage



(b) DVR Voltage



(c) Line Voltage

Fig. 4.8 Simulation Results for the system under L-L-L-G fault with DVR protection.

IV. Conclusion

In this chapter, the system analysis for which the work is carried out is done. The results are obtained for the DFIG wind turbine system when subjected to the faults. The comparison of the systems is done with two topologies. First when the system is subjected to the fault & the protection of the system is done with the help of crowbars. It is found that, with crowbars, the converter circuit is cut off thus the magnetization shifts to stator & due to non-supply of reactive power required, the system does not satisfy grid codes. When the system is employed with DVR protection scheme, it is observed that for any kind of the fault on the system, the DVR successfully satisfies the requirements of the grid codes. It allows DFIG wind turbine to successfully ride through the fault.

V. Future Scope

There are many aspects that are not yet studied & evaluated for the operation of DVR. The future scope of this power electronic device is wide & it includes following areas.

1. Verification of the HV-DVR performance at a location with different types of voltage dips originated from faults at the transmission level & distribution level.

2. Investigation of DVR topologies including the direct connected DVR.

3. Testing a number of different loads, such as thyristor loads, motor loads, active rectifier loads to verify the robustness of the loads to protect from voltage dips.

4. Designing of the line-filter, to have an optimum damping of the switching harmonics generated by the VSC & to avoid the oscillations at non-linear load.

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