# FAULT RIDE THROUGH TECHNIQUE OF DFIG UNDER FAULTS BY USING DVR

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***Abstract:*** Power quality can be affected both due to utility side as well as the customer side abnormalities. The increasing gap of generation and demand has raised many options for the power generation. The use of renewable energy sources is increasing. One of the major researches in the area of wind turbine generator is Doubly Fed Induction Generator (DFIG). The DFIG is variable speed wind turbine facilitating the constant generation throughout the changing wind velocities. When these types of wind farms are connected to the microgrid, then it is difficult to predict their time of uninterrupted operation. Because, when wind farms are connected to grid, the grid codes are to be satisfied. One of the important requirements is the fault ride through ability of the wind farm. Faults in the power system affect the magnitude of current and voltage of the system. These fluctuations in the parameters create disturbance in the operation of the generators. The fluctuations bring generators into instability which may in turn result into loss of synchronism. The problems related to the voltage stability may be cleared by the use of custom power devices having 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). It is a series connected custom power device, which is considered to be a reliable alternative when compared with other commercially available voltage sag/swell compensation devices. 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 function a reference waveform of voltage has to be generated which is similar in magnitude as well as phase angle to that of the supply voltage. Thereby during any abnormality of the voltage waveform it can be detected by comparing the reference and the actual voltage waveforms. The DVR is applied to DFIG for maintaining the voltage output constant. The DVR compensates the faulty line voltage, during that the DFIG wind turbine continues its nominal operation as demanded in actual grid codes. So the reliability is improved with the use of DVR, and the DFIG is available for the production of electricity continuously. Simulation results for a 2 MW wind turbine are presented, for symmetrical and unsymmetrical grid faults.

***IndexTerms*** **- Doubly Fed Induction Generator (DFIG), Dynamic Voltage Restorer (DVR), Low Voltage Ride Through (LVRT), MATLAB/Simulink.**

## I. INTRODUCTION

The development in power system has led to the increased use of power electronic components. The important factor deciding the efficiency of the power system is power quality. The power quality gets affected with the use of nonlinear components in the network as well as the faults on the system. Faults affect the system by manipulating the parameters of the transmission line such as voltage. Voltage stability of the system decides the healthy behavior of the system and life of the components in the network, as the components are rated depending up on voltage of the system. The modern manufacturing and 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. Among those abnormalities voltage sags and swells or simply the voltage variations are considered to be one of the most regular types of abnormality.

The power system has increased the use of renewable energy sources day by day. Among all the renewable energy sources, wind energy is extensively utilized. One of the useful technologies of power generation using wind energy is DFIG turbines. Most national grid codes and standards didn't involve wind turbines to support the power system during a disturbance. For an instance, wind turbines trips off the system during a grid fault or frequency deviation. This can cause major power system stability issue. An emphasis in this requirement is drawn to both the fault ride through and the grid support capability. Fault ride through capability tackles mainly the design of the wind turbine controller in such a way that the wind turbine is able to remain connected to the network during grid faults. Grid support capability signifies the wind turbine capability to support the power system by supplying reactive power, in order to recover grid voltage during and just after the clearance of faults. Due to the power converter, wind turbines based on the DFIG are very susceptible to grid disturbances, especially to voltage dips during grid faults.

DVR is FACTS device that injects / absorbs the reactive power to maintain voltage profile of the system. The basic operation principle of DVR is measuring the missing voltage by using control unit and injecting the dynamically controlled missing voltage in series to the line and providing the load voltage unchanged during sag. The phase angle and amplitude of the injected voltage are variable during sag. This will allow the control of active and reactive power exchange between the DVR and the distribution system. Generally, the operation of the DVR can be categorized into three operation modes: protection mode, standby mode (during steady state) and injection mode (during sag).

## II. DOUBLY FED INDUCTION GENERATOR (DFIG)

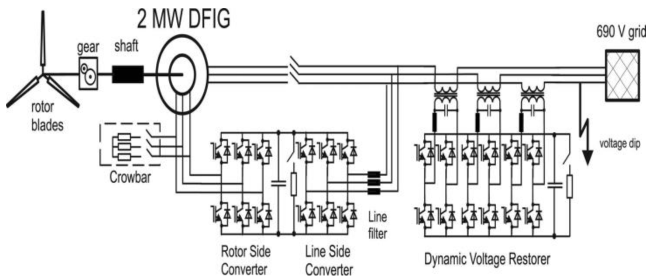



Figure 2.1: DFIG wind turbine with DVR and crowbar (Wessels, C. et al, 2011)

Fig. 2.1 shows the wind turbine system, consisting of basic components such as the turbine, a DFIG, a gear, and a dc link with back-to-back Voltage Source Converter (VSC). A dc chopper has an application of limiting the dc voltage of capacitor and a crowbar and DVR is also shown. Rotor Side Converter (RSC) and a Line Side Converter (LSC) as a part of the back-to-back converter are connected to the power grid and harmonics (due to converter) reduction is done by the line filter. To protect the wind turbine from voltage variations a DVR is used. Due to the short term voltage disturbances, the mechanical part dynamics of the turbine are neglected and the constant mechanical torque exerted by the wind is assumed. Decoupled control of stator active and reactive power is provided by RSC. DC voltage $V_{dc}$ is controlled by LSC and also supplies reactive power. A crowbar is used in DFIG wind turbines to avoid tripping of RSC because of rotor circuit over-currents or dc link overvoltage. Crowbar is a resistive network that is connected to the DFIG rotor windings. It limits the voltages and provides bypass for the currents through resistors instead of passing through the rotor circuit.

## III. DYNAMIC VOLTAGE RESTORER (DVR)

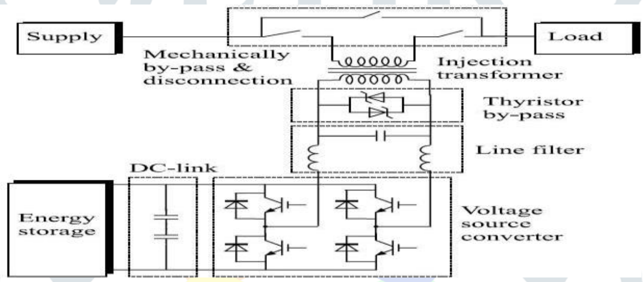



Figure 3.1: Schematic arrangement of DVR

The DVR is made up of electronic switching devices, energy storage unit, voltage injection transformer and filter devices. The components are shown in Fig. 3.1. The DVR functions by injecting three single phase AC voltages in series with the three phase grid during disturbance. It compensates for the difference between faulty and nominal voltages. All three phases of the injected voltages are of controllable amplitude and phase. Three Pulse Width Modulated (PWM)-Voltage Source Inverter (VSI) fed from a dc link supply the active and reactive power. During normal condition, the DVR functions in a low loss standby mode. In the normal operating mode the low voltage side of the booster transformer is shorted either by solid state bypass switch or by switching one of the inverter legs and it works as a short-circuited current transformer. Since no VSI switching takes place, the DVR produces conduction losses only. These losses are maintained as low as possible so as to reduce steady state power loss. The required energy during sags has to be delivered by an energy source. The essential amount of energy that must be supplied by the energy source depends on load MVA requirement, control strategy, deepest amplitude of sag to be protected. In case of fault or over current exceeding the rating of DVR on the load side, solid state bypass switches or electromechanical bypass switches must be added as a measure to protect DVR from getting damaged.

## IV. SIMULATION MODEL

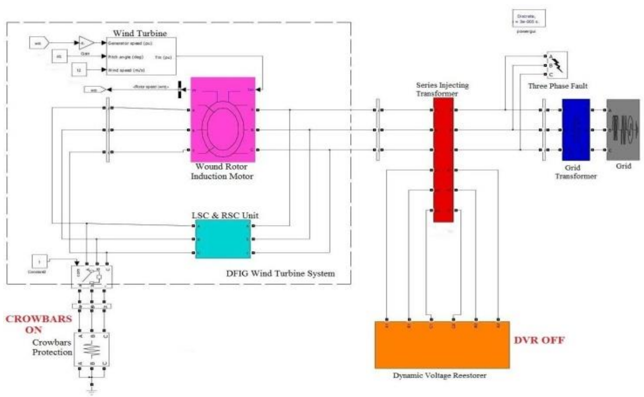



Figure 4.1: Proposed system model in MATLAB/Simulink

The complete system model is prepared with MATLAB/ Simulink software. The proposed system comprises of DFIG wind turbine with crowbar protection, DVR connected on the same grid just after the DFIG system, transformer and the grid. The proposed system is shown in Fig. 4.1.

Table 4.1: Simulation parameters

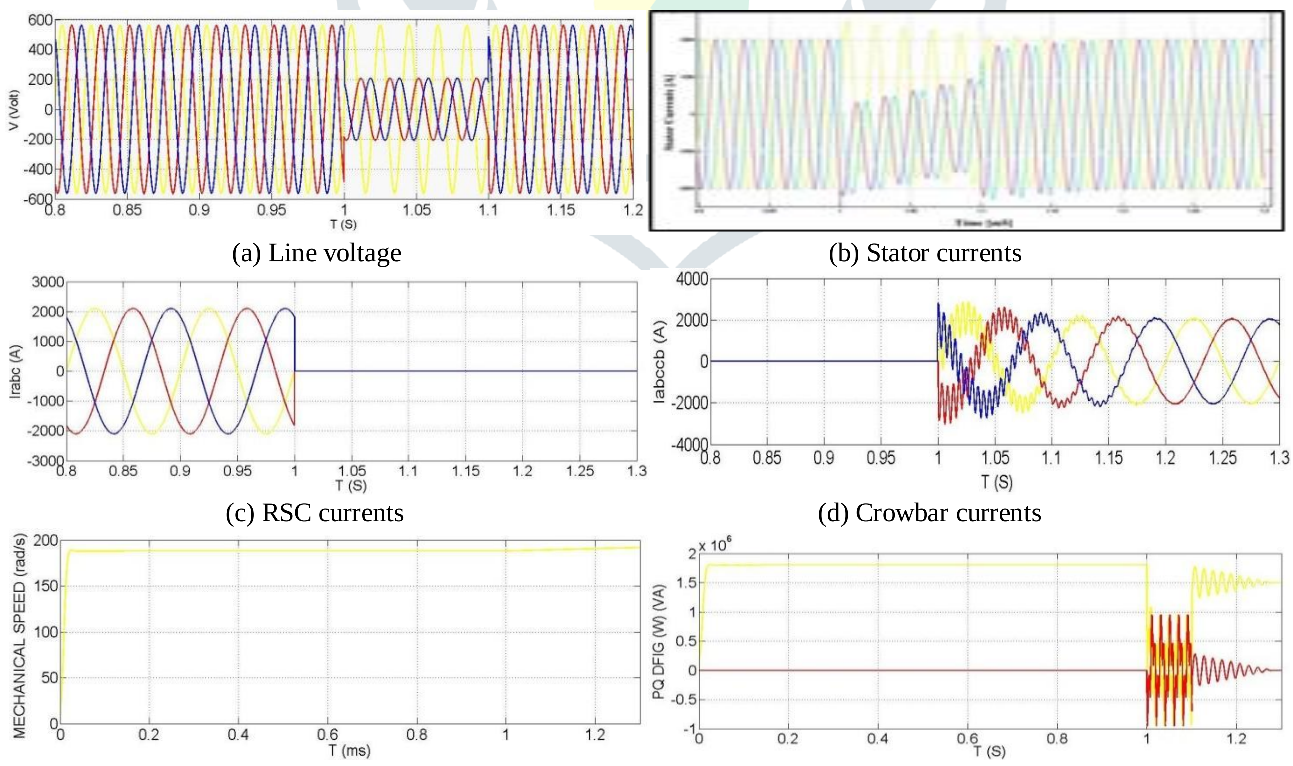
| Component | Parameter | Rating |
|---|---|---|
| DVR Module | Injecting Transformer | 100 MVA 480/690 V |
| | DC link voltage | 560 V |
| | DC link capacitance | 7.5 mF |
| DFIG wind turbine | Rated Power Output | 2 MW |
| | Stator to rotor transmission ratio | 1 |
| | Rated mechanical speed | 1800 rpm |
| | Mutual inductance | 3.7 mH |
| | Stator resistance | 10 mΩ |
| | Crowbar resistance | 0.3 Ω |
| Line | Line voltage | 690 V |
| | Line angular frequency | 2π50 Hz |

## V. RESULTS AND DISCUSSION

Simulation is carried out with MATLAB/Simulink software for different types of faults on the power system that is designed. The system is subjected to the faults and then the ride through capability of the wind turbine is verified. For the analysis of the system there are mainly two constrains to be taken in considerations. The system with active crowbar protection and system with active DVR protection is analyzed.

### 5.1 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 and LSC circuits. These circuits were equipped with Insulated Gate Bipolar Transistors (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 is 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. When the simulation undergoes 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 (d) Crowbar currents

(e) Mechanical speed of DFIG (f) Active and reactive power supplied by DFIG

Figure 5.1: Results under fault with crowbar protection.

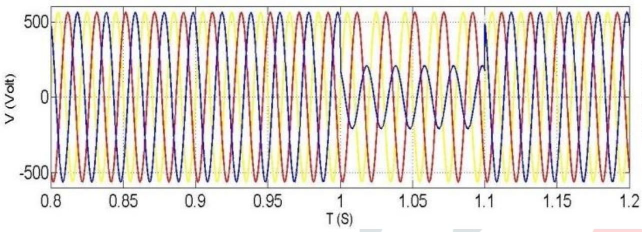
Fig. 5.1(a) shows line voltage of the DFIG system during faults. The voltage at that time period is decreased due to increase in the current flowing through the system. When the fault occurs on the system, the currents increase drastically. Thus affects the system voltage output. Fig. 5.1(b) shows the DFIG stator currents. The LLG fault reduces the magnitudes of faulty phases while the phase that is unaffected the current increases beyond the limit. The Fig. 5.1(c) shows RSC currents. When fault occurs on the system, the crowbars are activated. This activation simultaneously cuts the RSC OFF. The waveform shows the RSC current reduced to zero at fault instant. The DVR is not activated hence the voltage across DVR remains zero. The Fig. 5.1(d) shows the crowbars currents. When the rotor currents exceed the limit, the crowbar is activated and the converter unit of the DFIG is isolated. It shows the flow of currents through the crowbars from the fault initialization instant. The current shows distortion at the beginning and then with the time it decays. Fig. 5.1(e) shows the mechanical speed of the DFIG. When the RSC is in operation, the machine magnetization is provided by the rotor, but when the crowbar is triggered, the RSC is disabled and the machine excitation is shifted to the stator. Thus, reactive power control cannot be provided during the voltage dip, which is not acceptable when considering the grid codes. Thus, machine cannot generate enough torque so that the rotor accelerates, which can lead to disconnection of the turbine due to over speed. Fig. 5.1(f) shows the active and reactive power supplied by the DFIG during fault. In normal condition, the system feeds active power at the rated capacity while the reactive power supplied is zero. But, when the fault occurs, the system active power output is reduced and ultimately it affects the frequency as there exist cross coupling in the active power output and frequency. Thus from the above results, it is clear that if DFIG is subjected to fault and the crowbars protection is activated , then the output of the generation is so affected that, the parameters of the system deviates, leading to failure for the satisfaction of grid codes.

### 5.2 Analysis of system with DVR Protection

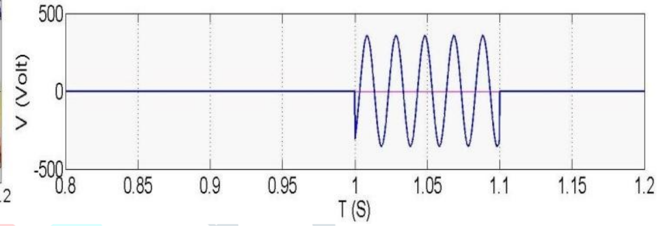
For this case the crowbars are maintained OFF and DVR is switched ON.

#### 5.2.1 DVR for LG Faults

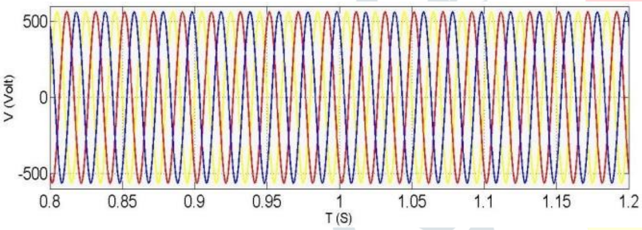
When the system is subjected to the single phase fault (L-G) fault, the results obtained as shown in the Fig. 5.2.



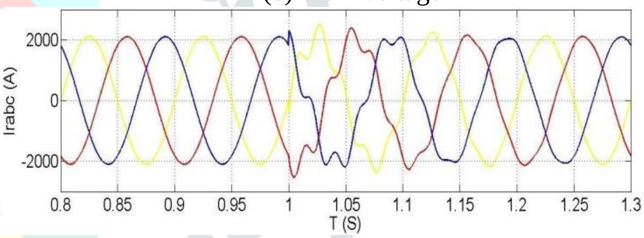

(a) Stator voltage



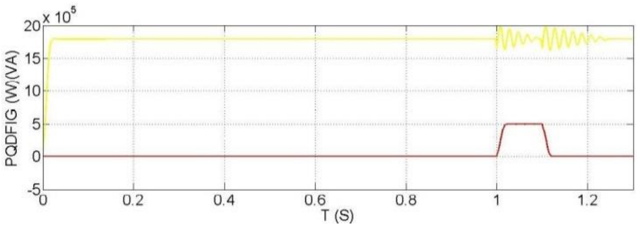

(b) DVR voltage



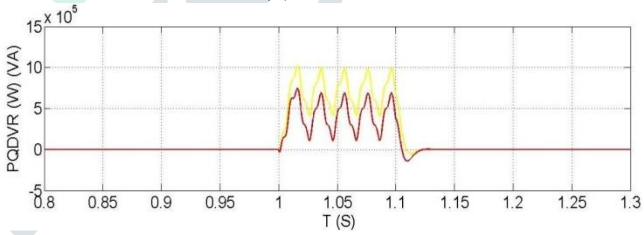

(c) Line voltage




(d) RSC current




(e) Active and reactive power supplied by DFIG



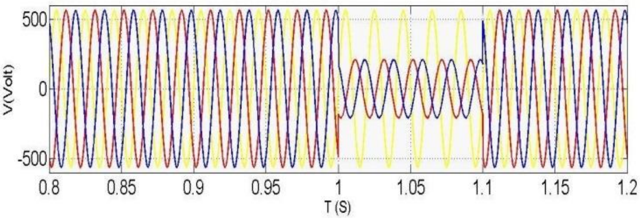

(f) Active and reactive power supplied by DVR

Figure 5.2: Results under L-G fault with DVR protection

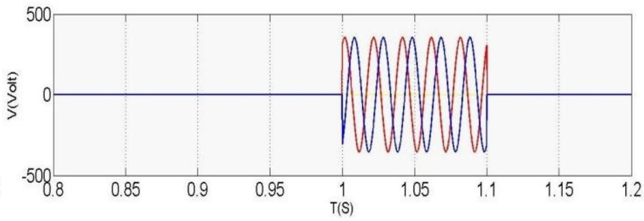
Fig. 5.2(a) shows stator voltage of the DFIG system during faults. The fault occurred for the duration 1 to 1.1 sec i.e. 100 msec. The voltage at that time period is decreased due to increase in the current flowing through the system. When the fault occurs on the system, the currents increase drastically. Thus affects the system line voltage. Fig. 5.2(b) shows the DVR Voltage. The DVR has succeeded to compensate the faulty line voltage. As soon as the voltage sag sensed by the DVR, the voltage is injected in the faulty line only so as to maintain the voltage of the line constant as shown in the Fig. 5.2(c). The Fig. 5.2(d) shows the RSC currents. Though the stator voltage dip is well compensated, a slight distortion in the stator currents (dc components), and thus, disturbed rotor currents can be observed. With this protection scheme RSC remains in operation and can control stator active and reactive power independently as shown in Fig. 5.2(e) and (f). A reactive power (Qs = 0.5 MVAR) during grid fault was supplied as demanded in grid codes. Thus from the results, it is clear that if DFIG is subjected to fault and the DVR protection is activated, the output of the generation is still maintained at the required grid codes. Thus the require amount of active and reactive power demand is fulfilled by the use of DVR. This maintains the grid codes during the fault. The testing of DVR is done with different types of faults. Hence, the results for the active and reactive Power supplied by DFIG and DVR, rotor currents, mechanical speed of the rotor etc. remain constant. So, for further analysis, only line voltage, DVR voltage and stator voltages are shown.

### 5.2.2 DVR for LLG Faults

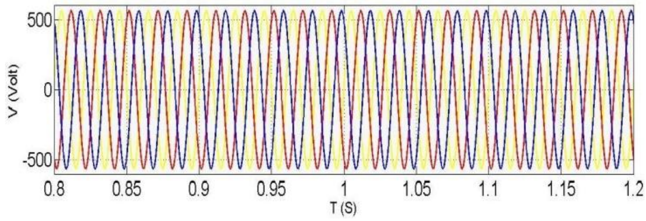
When the system is subjected to the two phase to ground fault (L-L-G Fault), the results obtained are shown in Fig. 5.3.




(a) Stator voltage




(b) DVR voltage



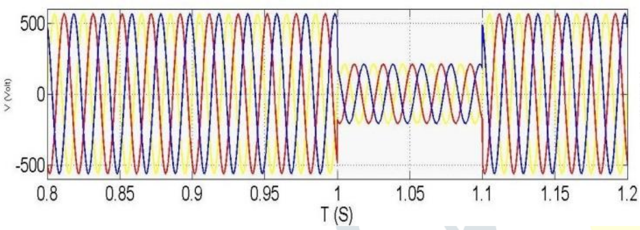

(c) Line voltage

Figure 5.3: Results under L-L-G fault with DVR protection

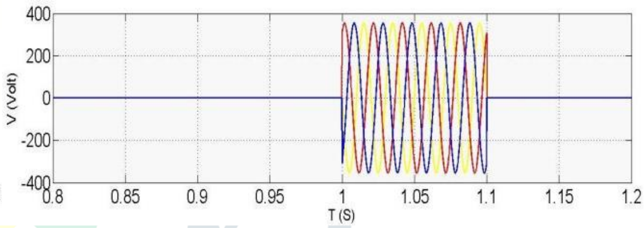
Fig. 5.3(a) shows stator voltage of the DFIG system during faults. The voltage at that time period is decreased due to increase in the current flowing through the system. When the fault occurs on the system, the currents increase drastically. Thus affects the system line voltage. Fig. 5.3(b) shows the DVR Voltage. The DVR has succeeded to compensate the faulty line voltage. As soon as the voltage sag sensed by the DVR, the voltage is injected in the faulty line only so as to maintain the voltage of the line constant as shown in the Fig. 5.3(c).

### 5.2.3 DVR for LLLG Fault

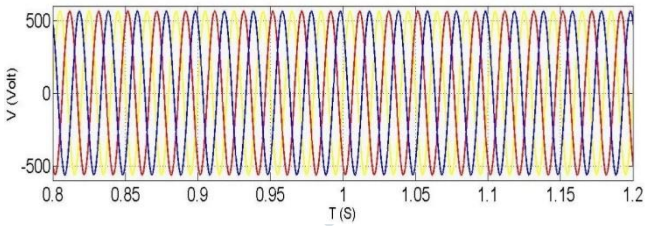
When the system is subjected to the three phase to ground fault (LLL-G) fault, the results obtained are shown in Fig. 5.4.




(a) Stator voltage




(b) DVR voltage

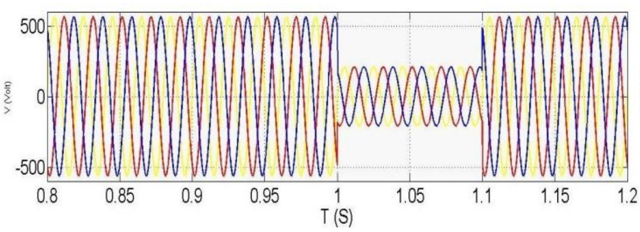



(c) Line voltage

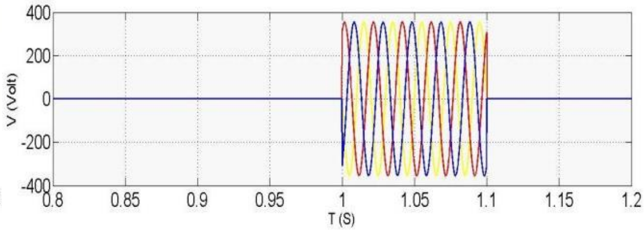
Figure 5.4: Results funder L-L-L-G fault with DVR protection

### 5.2.4 DVR for LLL Fault

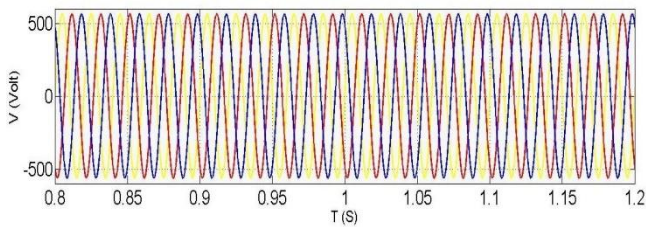
When the system is subjected to the three phase fault (L-L-L) fault, the results obtained as shown in the Fig. 5.5.




(a) Stator voltage




(b) DVR voltage




(c) Line voltage

Figure 5.5: Results under L-L-L fault with DVR protection

## VI. CONCLUSION

In this paper, DFIG wind turbine system with DVR is designed, simulated and analyzed to overcome the problem of voltage stability. The proposed system with DVR has shown the ability to compensate the voltage sags during the fault on the system. The comparative analysis of the obtained results of active crowbars and active DVR is done. The results have verified the efficiency, flexibility and fast response capability of the developed system. The designed DVR has supplied a regulated and sinusoidal voltage to maintain the stator voltage of the DFIG during the fault. The DVR can compensate the faulty line voltage, while the DFIG wind turbine continues its nominal operation and ultimately fulfills grid code requirement without the need for additional protection methods. Wind turbines which are already installed but are having insufficient fault ride through capacity can be protected by DVR. Simulation results with wind turbine under various fault conditions show the effectiveness of the proposed technique using DVR with sufficient reactive power compensation in comparison to the LVRT of the DFIG with a crowbar.

## VII. ACKNOWLEDGEMENT

I am greatly indebted forever to my Guide, to my HOD and all teaching and no-teaching staff those who supported directly and indirectly to complete my work. I sincerely thank to my Principal Dr. S. K. Biradar for continuous encouragement and active interest in my progress throughout the work. I am grateful being a M.E. Electrical Power System student of Matshyodhari Shikshan Sanstha's College of Engineering and Technology, Jalna, Maharashtra.

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