MITIGATION OF VOLTAGE SAG IN A DFIG BASED WIND TURBINE USING DVR

M Venmathi*, Soumyadeep Chakraborti[1], Soham Ghosh[2], Abhirup Ray[3], Vidhya Nikam[4]

[*] (Senior Lecturer, Dept. of Electrical and Electronics, Dr M.G.R. University, Chennai, Email: venmathi.m.d@gmail.com)
[1] (UG Students, Dept. of Electrical and Electronics, Dr M.G.R. University, Chennai, Email: sdc121190@gmail.com)
[2] (UG Students, Dept. of Electrical and Electronics, Dr M.G.R. University, Chennai, Email: cagpcik@gmail.com)
[3] (UG Students, Dept. of Electrical and Electronics, Dr M.G.R. University, Chennai, Email: rayabhirup@yahoo.co.in)
[4](UG Students, Dept. of Electrical and Electronics, Dr M.G.R. University, Chennai, Email: vidya.nikam.1990@gmail.com)

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Abstract

Energy is one of the most prominent factors in shaping the civilization of today. Under consideration for non- conventional energy source wind energy has turned out to be a leading source of energy. In recent years there has been a significant global commitment to develop a clean and economical alternative sustainable power source especially from wind. In this field of development wound rotor induction generator has seen considerable success. One scheme of wound rotor induction generator is realised when a converter cascade is used between the slip rings terminals and the utility grid to control the rotor power. This configuration is called Doubly Fed Induction Generator (DFIG). In this paper various aspects of a DFIG system is analysed. It also primarily analyses the voltage sag in a grid connected to a DFIG. The paper implements Dynamic Voltage Restorer as a control technique to mitigate the voltage sag generated due to a fault. Finally the paper concludes with an inference of the voltage profile generated by a DFIG and a vivid study of various parameters at varied conditions.

1. INTRODUCTION

Recent growth in industries and energy demand has resulted in a search for non-conventional energy resources. Wind power seems to be a promising alternative with India having a capacity to generate 20,000 MW of power from wind. Wind power projects of aggregate capacity of 8 MW including 7 major wind farm projects of capacity 6.85 MW have been established in different parts of the country. Wind turbines with Doubly Fed Induction Generator (DFIG) as a voltage source has gained attention due to its construction and control ability. Advantages of using DFIG in wind farms lie in the fact that it has a low cut in speed of 15-20 km/hr, a wide range of control and ability to remain connected to grid even in fault conditions. This paper presents an in-depth analysis of different faults in a DFIG based grid and mitigation of the same using a Dynamic Voltage Restorer (DVR).

1.1 DOUBLY FED INDUCTION GENERATOR

The working of DFIG is based on the principle of induction generator. It has multiphase wound rotor and a multiphase slip ring assembly with brushes for accessing rotor winding. The rotor windings are connected to the grid via slip rings and a back to back voltage source converter that controls both the rotor and grid currents (hence acting as a control system). By adjusting the converter's parameters it is possible to control the active and reactive power fed to the grid independently of the generators turning speed, giving it a distinct advantage over other conventional power generators. Fig.1 shows a schematic representation of a DFIG setup :

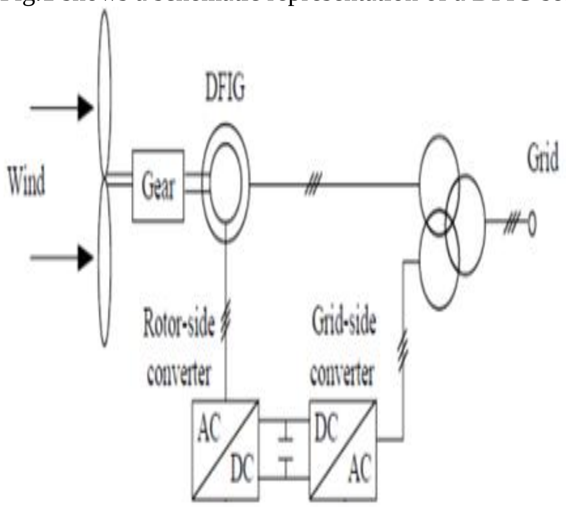

Fig 1.DFIG model

1.2 VOLTAGE SAG

A voltage sag as defined by IEEE Standards 1159-1995,is a decrease in the RMS voltage at the power frequency for duration from .5 cycles to 1 minute. The measurement of the voltage sag is defined as the percentage of the nominal voltage. Example: Voltage sag to 60% is equal to 60% of nominal voltage i.e. 288 volt for a 480 volt system.

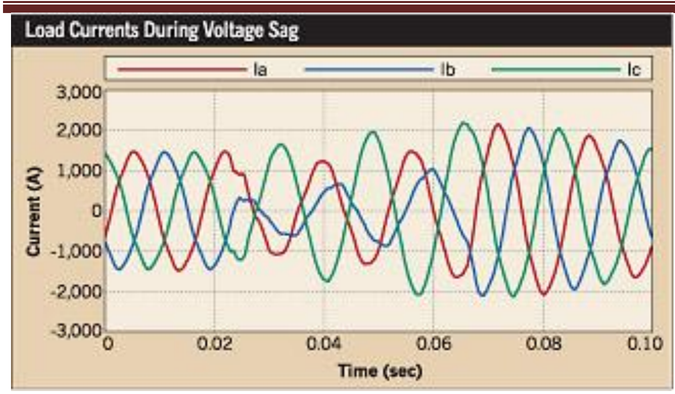

Fig.2 A Voltage sag scenario

2. LITERATURE REVIEW

Power Quality is the ability to provide electric power without interruption. However, in recent years, power quality became an important concern. Major power quality problems such as sag, swell, harmonics, unbalance, transient and flicker may hence impact on customer devices, causing malfunctions by damaging the devices [1].

Sag as defined by IEEE standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, is a "*decrease in RMS voltage or current between 0.1 p.u and 0.9 p.u, at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage*" [2].

There are different control techniques which are prevalent to mitigate the voltage sags.

Dynamic Voltage Restorer [3] is a series connected device designed to maintain a constant RMS voltage value across a sensitive load. The main function of a DVR is the protection of sensitive loads from voltage sags/swells coming from the network. If a fault occurs . DVR inserts series voltage V_{DVR} and compensates load voltage to pre fault value. The DVR has two modes of operation which are: standby mode and boost mode. In standby mode (V_{DVR}=0). In boost mode (V_{DVR}>0), the DVR is injecting a compensation voltage through the booster transformer due to a detection of a supply voltage disturbance.

Active and Reactive Power Set-point technique [4] is also a primary method to remove voltage sag. The reduction of the current peaks during a voltage sag at the point of common coupling(PCC) is based on changing the active power set-point to zero. This control system permits to reduce the stator currents since, in theory, no energy would flow through the stator.
Feedback of the Stator Currents [4] intends to design a control strategy for reducing the currents in the stator/rotor windings when a fault affects the generator. The philosophy of this control, is to feedback the measured stator currents as the set point for the current controller of the rotor side converter when a voltage dip occurs. In this manner the current control system synthesizes rotor currents that generate currents waveforms in the stator windings, with the same shape of the currents generated during the sag but in counter-phase.

The PWM switched autotransformer [5] is a simple and economical method to mitigate voltage sag. In this scheme sinusoidal PWM pulse technique is used. RMS value of the load voltage is calculated and compared with the reference rms voltage. When sag is detected by the voltage controller, the IGBT is switched ON and is regulated by the PWM pulses in such a way that the load voltage profile is maintained.

A hysteresis voltage control technique [5] is a simple mitigating method to remove voltage sag, with no energy storage device. It is a closed loop system where an error signal is used to determine the switching states and to control the load voltage. Error is the difference between the reference voltage and the actual voltage. When the error reaches to the upper limit, the voltage gets forced to decrease and when the error reaches to the lower limit, the voltage gets forced to increase.

3. SYSTEM CONFIGURATION OF DVR

Dynamic Voltage Restorer is a series connected device designed to maintain a constant RMS voltage value across a sensitive load. The DVR considered consists of:

a. an injection / series transformer
b. a harmonic filter,
c. a Voltage Source Converter (VSC)
d. an energy storage and
e. a control system.

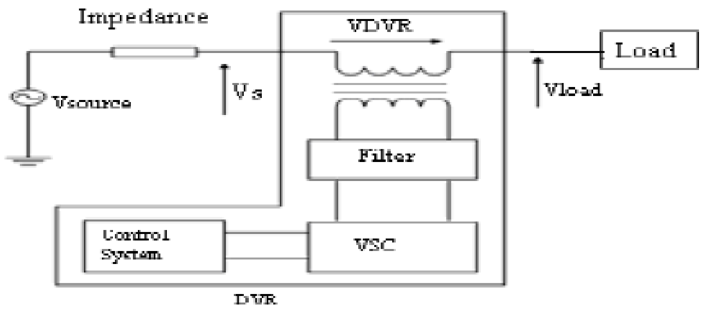

Fig 3: System configuration of DVR

The main function of a DVR is the protection of sensitive loads from voltage sags/swells coming from the network. Therefore as shown in Figure 3, the DVR is located on approach of sensitive loads. If a fault occurs on other lines, DVR inserts series voltage V_{DVR} and compensates load voltage to pre fault value. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage V_L. This means that any differential voltages caused by transient disturbances in the ac feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer.
The DVR works independently of the type of fault or any event that happens in the system, provided that the whole

system remains connected to the supply grid, i.e. the line breaker does not trip. The DVR has two modes of operation which are: standby mode and boost mode. In standby mode (V_{DVR}=0), the booster transformer's low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation, because the individual converter legs are triggered such as to establish a short-circuit path for the transformer connection.
Therefore, only the comparatively low conduction losses of the semiconductors in this current loop contribute to the losses. The DVR will be most of the time in this mode. In boost mode (V_{DVR}>0), the DVR is injecting a compensation voltage through the booster transformer due to a detection of a supply voltage disturbance.

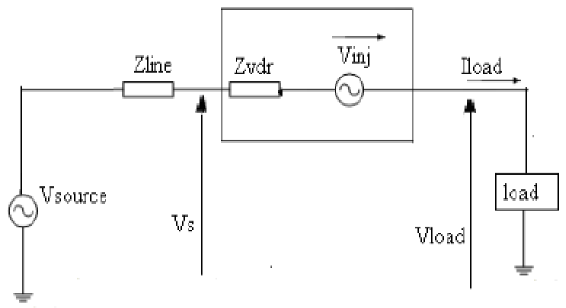

Figure 4: Equivalent Circuit of DVR

Figure 4 shows the equivalent circuit of the DVR, when the source voltage is dropped or increase, the DVR injects a series voltage V_{inj} through injection transformer so that the desired load voltage magnitude V_L can be maintained. The series injected voltage of the DVR can be written as

$$V_{inj} = V_{load} + V_s$$

Where:
V_{Load} is the desired load voltage magnitude
V_s is the source voltage during sags/swells

4. METHODOLOGY AND IMPLEMENTATION

The paper aims to combine a DFIG with a grid supplying 9MW of power as generated by the DFIG. The Dynamic Voltage Restorer(DVR) is incorporated to mitigate the voltage sag caused due to the fault, ahead of a sensitive load.

The DFIG comprises of 6 turbines each of 1.5MW capacity, thereby generating 9MW power in the whole. The wind speed fed to the DFIG is limited to 8m/s. The stator voltage of each generator that is directly transmitted to the grid is fixed at 575V. Along with this the rotor voltage is kept 1975V. This DFIG based wind turbine is connected to a transmission line; here we have taken a π transmission line having very negligible losses.

The DFIG generates a voltage of the order of 5KV at its terminals, which is given to a step down 3 phase transformer 5000/415 V.

This transmission line feeds to sensitive loads parallel connected to the grid. The loads are specified by 'Load1' and 'Load2'. Both the loads have the same power rating, for a comparative study to be made. The loads have a phase to phase voltage of 230V and active power of 10KW.

A fault is introduced ahead of 'Load1' and 'Load2'. However, the DVR injects voltage ahead of 'Load1' so as to keep the voltage constant.

The DVR control system is based on a dqo-transformation technique and is designed in Matlab/Simulink(as a subsystem) to detect any voltage sag ahead of 'Load1'. It measures the voltage across 'Load1' and gives it to the subsystem. The subsystem converts the voltage to dqo domain and then compares it with a reference voltage. The error voltage is fed to a PI-controller to stabilise. The output voltage is then converted back to abc domain which generates the required pulse width modulated signal to trigger the gate of the inverter. The control subsystem is shown in Fig. 7. The dqo algorithm converts is implemented as shown in Fig 5.

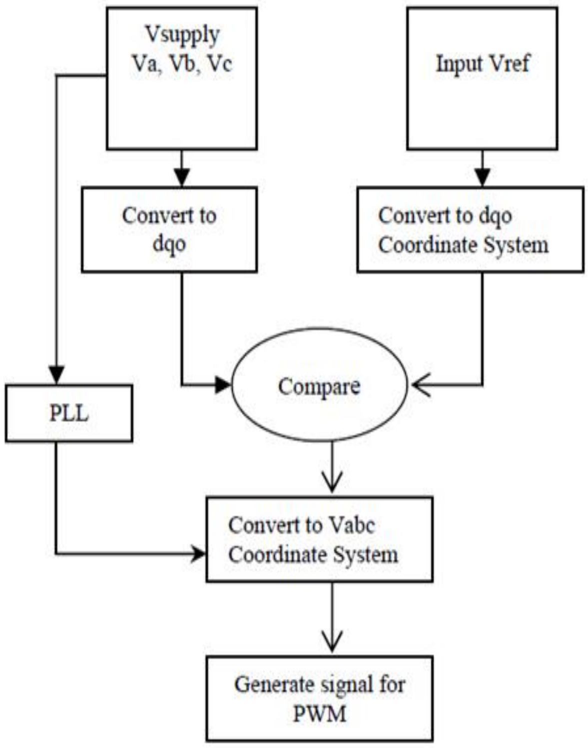

Fig.5 DQO Control Algorithm

The inverter generates the required amount of voltage to be injected at the point of sag. Before injecting it to the transmission line it is passed through a filter to reduce the harmonics, if any.

The MATLAB/SIMULINK model of our configured model is shown below.

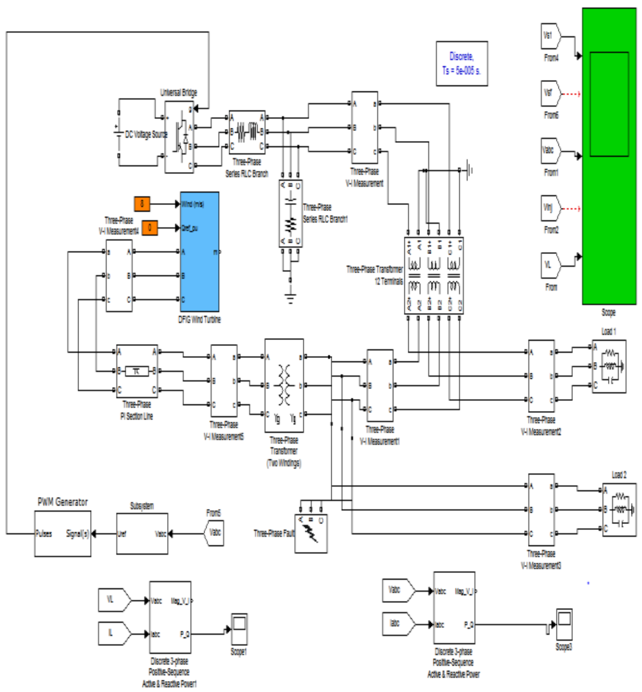

Fig 6. MATLAB/SIMULINK model of our proposed system

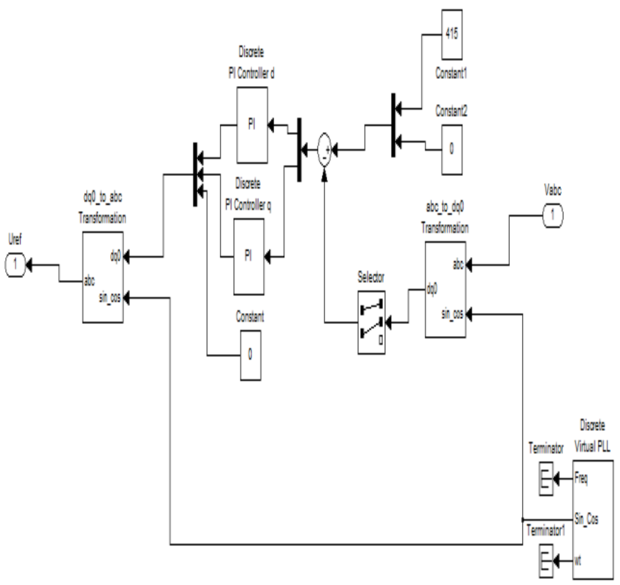

Fig 7. MATLAB/SIMULINK model of the subsystem

4.1 SYSTEM PARAMETERS

The parameters used for the above Matlab/Simulink model are tabulated as:

No. of wind turbines	**6**
Nominal stator voltage of DFIG	**575 V**
DC voltage to universal bridge	**400 V**
PWM generation mode	**3 arm/6 pulse**
Constant multiplier of dqo block	**415**
3 phase transformer voltage	**5000/415**
PI controller gains of d-block	**Kp-40, Ki-154**
PI controller gains of q-block	**Kp-25, Ki-260**

5. RESULTS AND ANALYSIS

A DFIG – grid system was simulated in Matlab/Simulink with the DFIG being fed by a constant wind speed. A DVR based voltage mitigation system was employed to maintain a smooth voltage and power profile at the load end during fault. The model was simulated for 1 second with different fault scenarios from .5 seconds to .9 seconds.

We analysed the following parameters:

- System voltage
- Voltage across sensitive load(Load1) and test load(load2)
- The active power (in MW) and reactive power (in MVAR)

We simulated the system for three phase fault and LLG (line-line ground) faults.

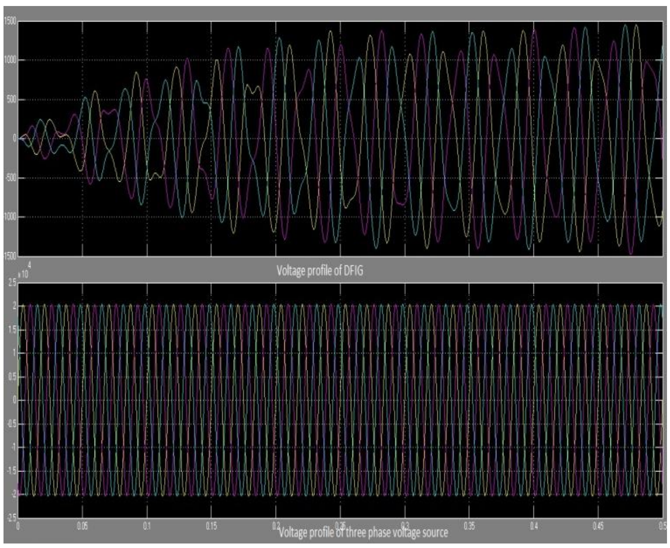

Fig 8. A comparison of voltage profile generated by a) DFIG and b) Three phase voltage source

Prior to all simulations a marked difference was observed between the voltage profile of a three phase voltage source like (synchronous generator or induction generator) and that of a Doubly Fed Induction generator. As DFIG is a wind driven device, it generates a voltage profile that is highly non-uniform by nature itself. Later in the simulations, in Fig.10, it was observed that the DVR injects the voltage at the non uniform sections of the DFIG voltage profile.

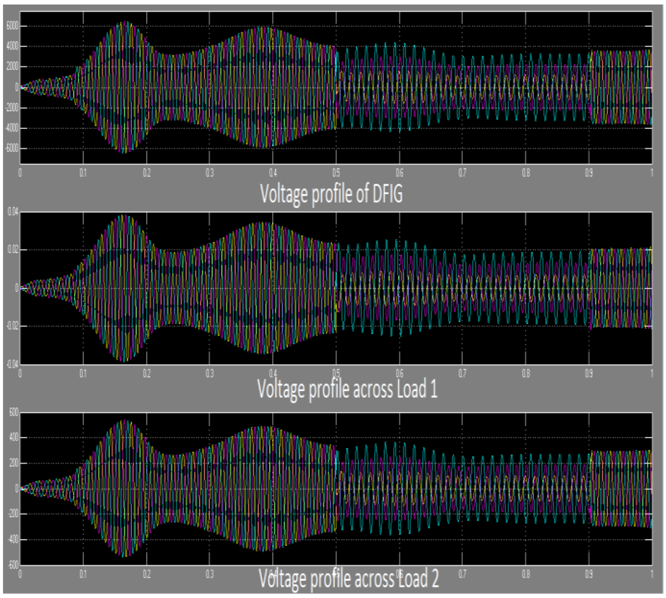

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Fig 9. Voltage profile of a) DFIG b) across Load 1 c) across Load 2 without mitigation by DVR during LLG fault is seen.

The voltage profile generated by the DFIG is highly uneven as seen from Fig.9. It is also seen that it takes an initial time before it starts generating the required voltage. During LLG fault, it can be noted that two phase of the voltages dip due to the fault condition during 0.5 s to 0.9 s.

The case is same for 3 phase faults also. Here a dip will be observed in all the 3 phases of the voltage profile.

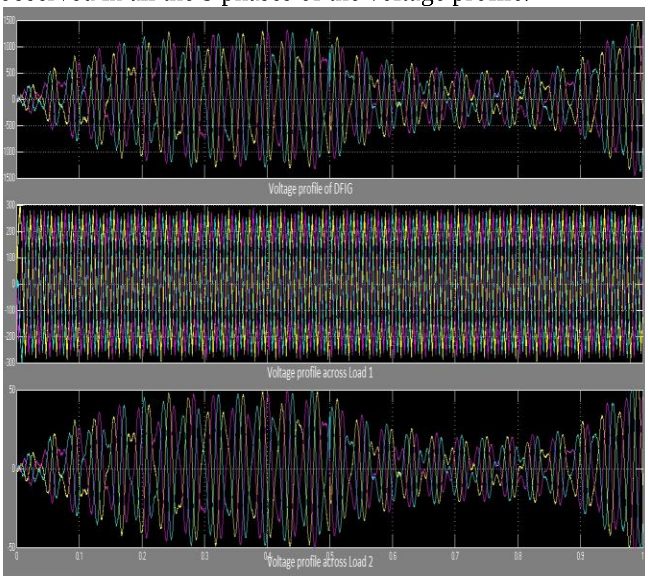

Fig 10. Voltage profile of a) DFIG b) across Load 1 c) across Load 2 with mitigation by DVR during 3phase fault is seen.

Similar to the LLG fault, a balanced 3 phase fault is given during the period 0.5s to 0.9s and the sag is noticed during the period. As 3 phase faults are severe in nature the scale of voltage sag is also drastic.

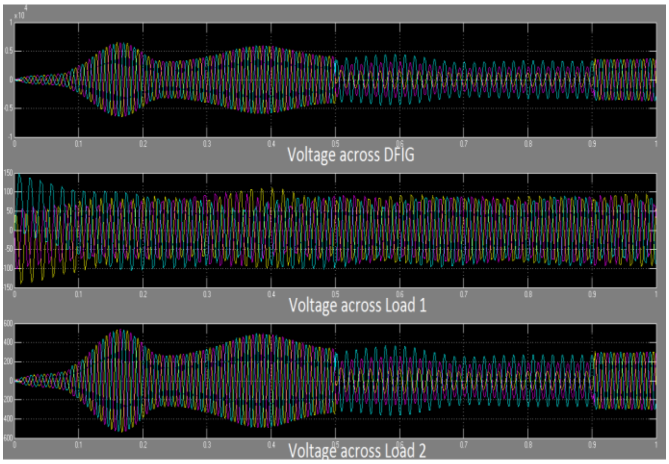

Fig 11. Voltage profile of a) DFIG b) across Load 1 c) across Load 2 with mitigation by DVR during LLG fault is seen.

Voltage mitigation by DVR during LLG fault ahead of Load 1 is depicted in graph shown in fig. 11(b). The desired voltage is obtained across Load 1 by fixing the parameters of the control system. However, it is well inferred that the faulty voltage profile is retained across Load 2, as in fig. 11(c).

The desired voltage across Load 1 is maintained around 150V and it is generated by adjusting the DC voltage source to 400V.

Apart from the voltage sag analysis we analyse the active and reactive power across the two loads Load 1 and Load 2.

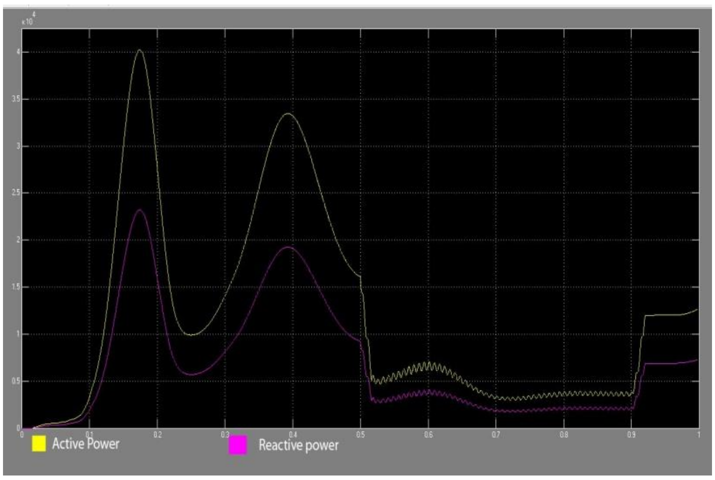

Fig 12. Active and Reactive Power across Load 2, i.e. power transmitted without mitigation

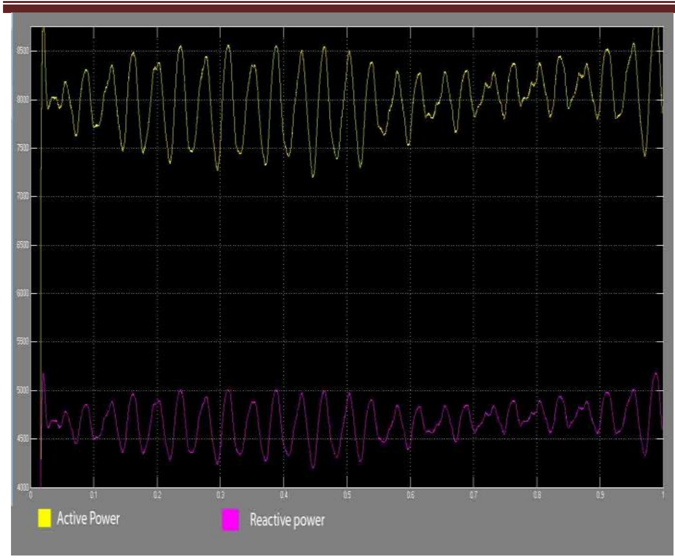

Fig 13. Active and Reactive Power across Load 1, i.e. power transmitted with mitigation

It is observed in Fig.12 that during fault condition the active and reactive power drastically decreases and recovers once the fault condition is cleared after 0.9s. However, it is clear from Fig.13 that the active and reactive power is held at a nominal value according to the load demand at Load 1 as the DVR injects the voltage and mitigates the sag.

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