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# DYNAMIC VOLTAGE RESTORER USING PI CONTROLLER FOR VOLTAGE SAG SWELL MITIGATION USING MATLAB

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**Abstract: -** *Power quality has been a issue that is increasing now a day in industry and commercial application. Modern industries employ sensitive and sophisticated equipment to increase energy efficiency and productivity. Voltage disturbance in the form of voltage sag and swell can cause several processes in industry and result is economical loss. To resolve these issues many custom power devices are used. One of the device is Dynamic voltage restorer (DVR) .which is most efficient and reliable custom power device. DVR normally connected in series between the source voltage and sensitive load. The main function of DVR is quickly mitigating the voltage sags in the system and restores the load voltage to the pre-fault value. In this project present modelling and controlling of DVR using Proportional and integral (PI) controller for voltage sag swell mitigation when induction motor load in connected in the system. The simulation is performed using matlab/simulink simpower system*

***Keywords: -****DVR, Power Quality, Voltage Sag, Voltage swell. PI Controller, Pulse width modulation, MATLAB/SIMULINK.*

## I. INTRODUCTION

Now a day, power quality and reliability in distribution system have been increasing interest in modern times and have becomes an area of concern for modern industries and commercial application. Modern industrial devices are mostly depends on electronics devices like industrial drives, programmable logic controller, and precision electronics instruments are demand greater quality of power quality of power supply in distribution network. This electronics device are very sensitive to voltage disturbance and less tolerance to disturbance like voltage sags, swells harmonic distortions, flickers, and transients. Due to this kind of disturbance problems plant shut down and loss of production or manufacturing process happen. Voltage sags/swells can occur more frequently than other power quality problem.

Voltage Sag or Voltage Dip is defined by the IEEE 1159 as the decrease in the rms voltage level to 10%-90% of nominal, at the power frequency for durations of ½ cycles to one minute. The IEC (International Electro-technical Commission) terminology for voltage sag is dip. The IEC defines voltage dip as a sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period, from ½ a cycle to a few seconds. Voltage sags are usually related with system faults but it also generated by energization of large loads or at the time of starting up large motors which can draw 6 to 10 times its full load current during starting.

Voltage Swell is defined by IEEE 1159 as the increase in the rms voltage level to 110%-180% of nominal, at the power frequency for durations of ½ cycles to one minute. Swells may also be a result of switching off a large load or energizing a large capacitor bank and are identified by their magnitude (rms value) and duration.

In industry quality of power is strictly related to the economic result associated with the equipment. So the need for solution of this kind of disturbance fast response of voltage regulation is required. Further it required separate the characteristics of voltage sags/swells and phase angle. Voltage sags/swells are also accompanied by change in phase angle called phase angle jump.

To calculate the voltage sag/swell magnitude at the Point of Common Coupling (PCC) in radial systems (which is the most prevailing one in industrial distribution networks), it is common to use the voltage divider model, shown in Fig 2, where the voltage magnitude at the PCC is given by:

$$Vsag = Z_f / Z_f + Z_s$$

Where:

Zs = the source impedance including the transformer impedance.

$Z_f$ =the impedance between the PCC and the fault including fault and line impedances.

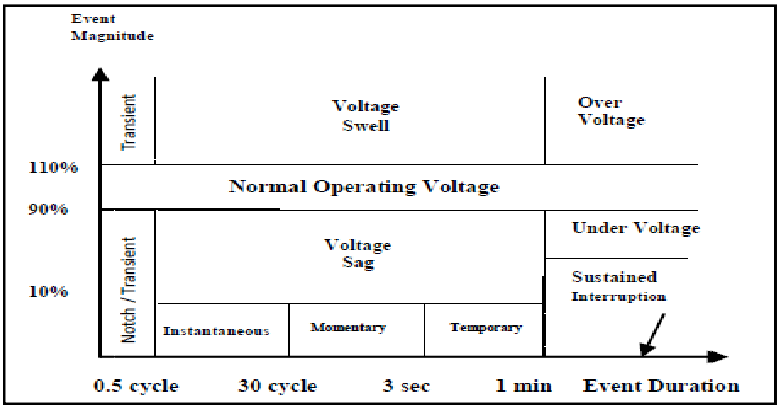


***Figure 1. Voltage Reduction Standard of IEEE 1159-1995***

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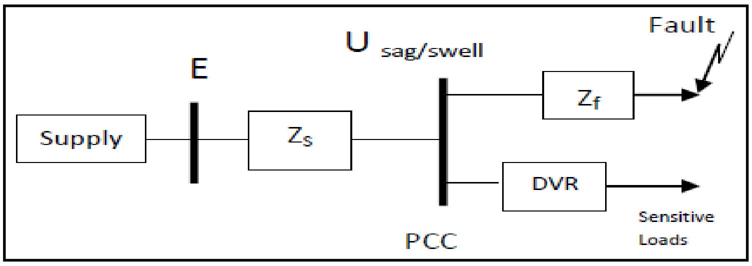


***Figure 2. Faults on Parallel Feeders Causing Voltage Sag***

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To overcome this type of disturbance custom power devices are used which capable of injecting minimum energy so as to regulate load voltage to its previous value. Dynamic voltage restorer (DVR) is one of the custom power device which will provide effective solution of compensate the voltage sags/swells by establishing load voltage to the prefault voltage. The major advantage of DVR is the keep the high quality constant voltage and continuity of production.

In this paper dynamic voltage restorer with proportional integral (PI) controller is used to compensation power quality problem related with voltage sags/swells and maintaining required level of supply voltage at load terminal. The simulation of DVR is accomplished using MATLAB/simulink and the performance of DVR at different voltage disturbance is tested.

## II. DYNAMIC VOLTAGE RESTORER

Dynamic Voltage Restorer (DVR) is one of the most efficient custom power devices which used in distribution networks. DVR is a series connected solid state device that injects voltage into the system in order to regulate the load side voltage or restore the load side voltage in to pre-fault voltage. It is normally installed in between the supply and the critical load feeder at the point of common coupling (PCC) in distribution system.

### 2.1 Basic Configuration of DVR

The basic configuration of the DVR consists of injection transformer, storage device, voltage source converter/inverter, harmonic filter, and control/protection system.

#### 2.1.1 Injection transformer:

The Injection transformer is a three phase transformer or three single phase transformer which specially designed transformer that reduce the coupling of noise and transient energy from the primary side to the secondary side. It is installed in distribution network. It also knows as static series compensator. . It is a series custom power device intended to protect the sensitive loads at the point of common coupling (PCC) from various power quality problems in distribution network. Its two main task, It isolates the load from rest of the system and It connects the DVR to the distribution network via high voltage winding and injecting compensating voltage generated by the VSC to the incoming supply voltage. Proper integration of the injection transformer into the DVR, the MVA rating, the primary winding voltage and current ratings, the turn-ratio and the short-circuit impedance values of transformers are required.

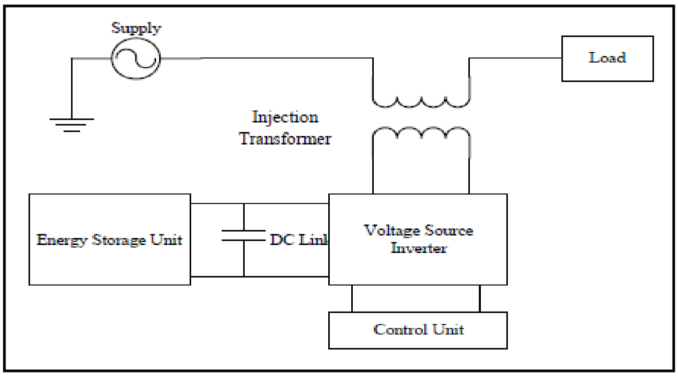


***Figure 3. Schematic Diagram of Dynamic voltage restorer***

### 2.1.2 Storage device:

The main purpose of energy storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. They fulfil the active power requirement of the load. Superconductive magnetic energy storage Batteries and capacitors used as a energy storage devices.

### 2.1.3 Voltage Source Converter/Inverter:

Voltage source converter can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. It consists of storage devices and switching devices. There are mainly four types of storage devices: MOSFET, GTO, IGBT and IGCT. Highly sophisticated converter design with IGBT's are used which allows the DVR to compensate voltage sag/swell. A VSC is used to produce when voltage missing when disturbance occur in system. The most popular three phase inverter topology is a two level inverter. Generally Pulse-Width Modulated Voltage Source Inverter (PWMVSI) is used. In the previous section we saw that an energy storage device generates a DC voltage. To convert this DC voltage into an AC voltage a Voltage Source Inverter is used. For generation of required injected voltages storage device supply energy to the VSC via a dc link. Superconductive magnetic energy storage (SMES), batteries and capacitor are different energy storage devices.

### 2.1.4 Harmonic Filter:

Due to the nonlinear nature of the semiconductor devices Voltage waveform distortion associated with the high frequency harmonics at the output of the inverter circuit is a common phenomenon. Harmonics filter or passive filter mainly consist of inductor and capacitor. Generally it used at output of inverter to keep the harmonic contain generated by VSC to permissible limit to improve the quality of generated voltage.

### 2.1.5 Control and Protection System

The control system determines the control the compensating voltage generation by controlling the PWM pulses to the gates of semiconductor switches of the VSC. The protection unit of DVR generally consists of Bypass switches, breakers, measuring and protection relays etc. Depending upon the operating conditions, the control and protection unit maximizes the system performance and minimizes the losses associated with the operation of DVR.

## 2.2 OPERATION MODE OF DVR

The operation of DVR mainly categories in three mode protection mode, standby mode, and injection mode.

In protection mode If the over current on the load side exceeds a permissible limit due to the short circuit on the load or large inrush current flow on load side and it exceeds a permissible limit over, the DVR will be isolated from the systems by using the bypass switches and supplying another path for current. Generally DVR operates in standby mode in normal steady state conditions. In this mode of operation, the DVR may either be bypassed or inject small voltage to compensate the voltage drop on transformer reactance or losses. DVR is generally bypassed because the small voltage drops do not disturb the load requirements if the distribution circuit is not too weak. In the Injection mode the DVR is injecting a compensating voltage through the injection transformer due to the detection of a disturbance in the supply voltage. DVR injects a three phase compensating voltage with each of the three phases having independently controlled magnitude and phase to meet the requirements on that particular phase.

### 2.3 COMPENSATION METHOD

Voltage compensation methods in DVR depend upon the limiting factors such as DVR power ratings, various conditions of load, and different types of voltage sags and swells. Some loads are sensitive towards phase angle jump and some are sensitive towards change in magnitude and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics. There are three different methods of DVR voltage compensation which are as follows:

#### 2.3.1 Pre sag compensation method

If any disturbance occur in the system and voltage goes down then it will inject the difference voltage between sag and pcc to pre-fault voltage, and load voltage get restore to pre-fault voltage. In this method DVR compensate for both magnitude and phase angle. If any sensitive load which tolerance to phase angle jump then this method is best suited for compensates both magnitude and phase angle jump. The main drawback of this method is it required higher capacity energy storage device. Fig 4 shows the vector diagram for the pre-sag control strategy for voltage sag disturbance.

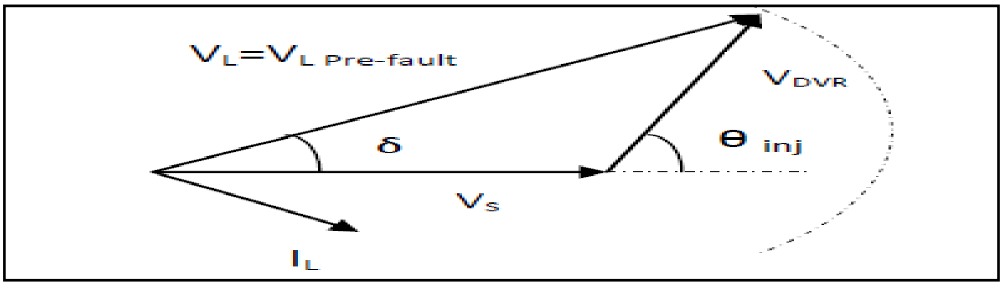


***Figure 4. Compensation to pre-fault conditions for a voltage sag event (magnitude and phase)***

In this diagram, $V_{pre\text{-}fault}$ and $V_{Sag}$ are voltage at the point of common coupling (PCC), before and during the sag. In this case $V_{DVR}$ is the voltage injected by the DVR, which can be obtained as:

$$V_{DVR} = \sqrt{V_L{}^2 + V_S{}^2 - 2V_L V_S \cos\delta}$$

And the required angle of injection θ in j is calculated as:

$$\theta_{inj} = \tan^{-1}\frac{V_S \sin\delta}{V_S \cos\delta - V_L}$$

A closer look at Fig 4a shows that, in normal conditions (pre fault), the system or supply voltage is equal to the load voltage $V_L$, both are equal to 1 p.u. with zero angle. During sag, the system voltage decreases to a value Vs less than 1 p.u., this reduction in voltage is associated with a phase angle jump δ. The DVR reacts to the sag event and injects a compensating voltage $V_{DVR}$ to restore the voltage at the load to pre-fault conditions of both magnitude and angle. The method gives nearly undisturbed load voltage.

#### 2.3.2 In-phase compensation method

This method also called straight forward method. In phase method compensate only magnitude. In this method the injected voltage is in phase with the supply side voltage irrespective of the load current and pre-fault voltage. This method compensates only magnitude so any load which is not sensitive to the phase angle jump this method best suited.

 

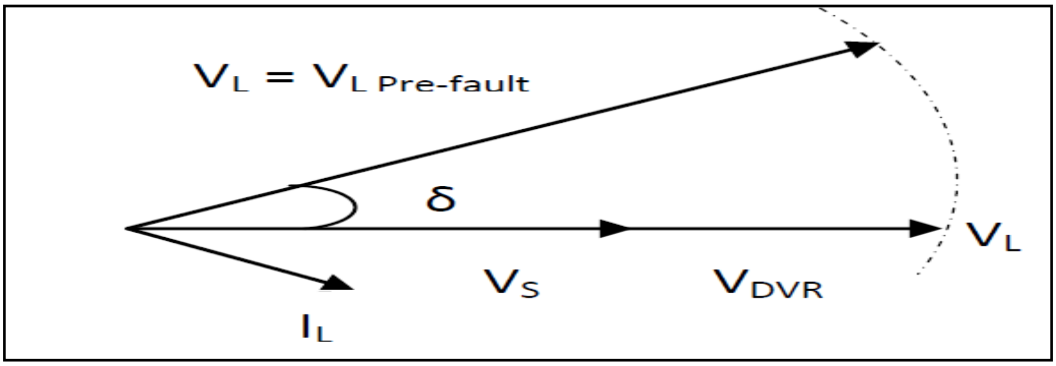


***Fig 5: In Phase Compensation to pre-fault conditions for Voltage sag event (magnitude only)***

The vector diagram corresponding to In Phase Compensation method is shown in Fig 5. Here, the pre-fault voltage is 1 p.u. with zero angles and during sag, the system voltage decreases to $V_S$ with a phase angle δ. The DVR injects a compensating voltage $V_{DVR}$ in phase with the system voltage $V_S$, to boost the voltage magnitude up to the pre-fault voltage magnitude $V_L$, with no attention to the angle δ. This method is suitable for loads that can withstand phase angle jumps, which is a typical case for induction motor loads which comprise a large portion of the industrial power system, with no sensitive equipment such as adjustable speed drives or any equipment depending in its operation on phase triggered switches. This method is very simple to implement and very fast in calculating the DVR compensation voltage, which is obviously calculated as:

$$|V_{DVR}| = |V_L| - |V_S|$$

**2.3.3 In-phase advance compensation method**

In this method the real power which is injected by the DVR is reduced by reducing the power angle between the voltage during sag condition and load current. The minimization of injected energy is achieved by making the active power component zero by having the injection voltage phasor perpendicular to the load current phasor. In this technique the values of voltage and load current are fixed in the system so only the phase of the voltage during sag is changed. This technique is only appropriate for a limited range of sag because this technique uses only reactive power and unfortunately, but all the sags cannot be mitigated without real power.

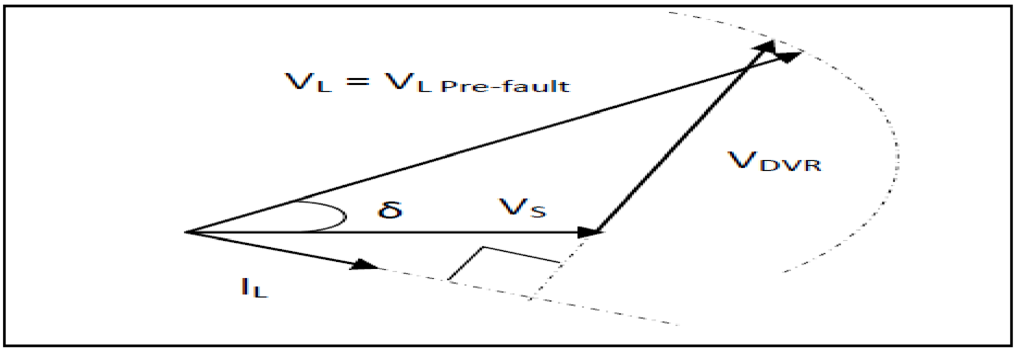


***Figure 6: In Phase Advanced Compensation to pre-fault Conditions for voltage sag event.***

## III. CONTROL METHOD OF DVR

DVR having mainly two control method: Linear control methods employ feedback, the feed-foreword and the combined feed controllers. Non-Linear control methods employ the Artificial Neural Networks (ANN), the Fuzzy Logic (FL) and the Space Vector (SV) controllers. Although feedback controllers are popular, they require load and source tracking, whereas feed foreword controllers are much simpler yet open-looped, there is no feedback from the load voltage or current.

## IV. PI CONTROLLER

 

A proportional-integral (PI) controller shown in figure 8. Drives the system to be controlled with a weighted sum of the error (difference between the actual sensed output and desired set-point) and the integral of that value. An advantage of a proportional plus integral controller is that its integral term causes the steady-state error to be zero for a step input. PI controller input is an actuating signal which is the difference between the Vref and Vin. Output of the controller block is of the form of an angle δ, which introduces additional phase-lag/lead in the three-phase voltages.
The output of error detector is Vref - Vin.
Vref equal to 1 p.u. voltage
Vin voltage in p.u. at the load terminals.
The controller output is compared with PWM signal generator results in the desired firing sequence of the inverter. The sinusoidal voltage Vcontrol is phase-modulated by means of the angle δ or delta as shown in figure and the modulated three-phase voltages are given by

$$VA = Sin(\omega t + \delta)$$
$$VB = Sin(\omega t + \delta - 2\pi/3)$$
$$VC = Sin(\omega t + \delta + 2\pi/3)$$

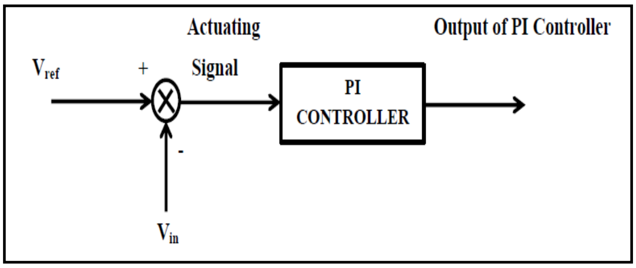


**Figure 7. Basic circuit of PI controller**

The modulated angle is applied in phase to the PWM generators A. The angles for phases B and C are shifted by 120$^o$ and 240$^o$. In this PI controller, only voltage magnitude is taken as a feedback parameter in the control scheme.

## V. MODELING AND SIMULATION

The performance of the DVR was evaluated by using the Matlab/Simulink program as a simulation tool. The DVR is connected in series between a three phase programmable (controllable) voltage source with 11 kV line to line rms voltage, 50 Hz and a linear load of 400v rms phase to phase, 10 MW and 10 KVAR (with installation of power factor correction capacitors). The Simulink model of the proposed DVR is shown in Fig 8.
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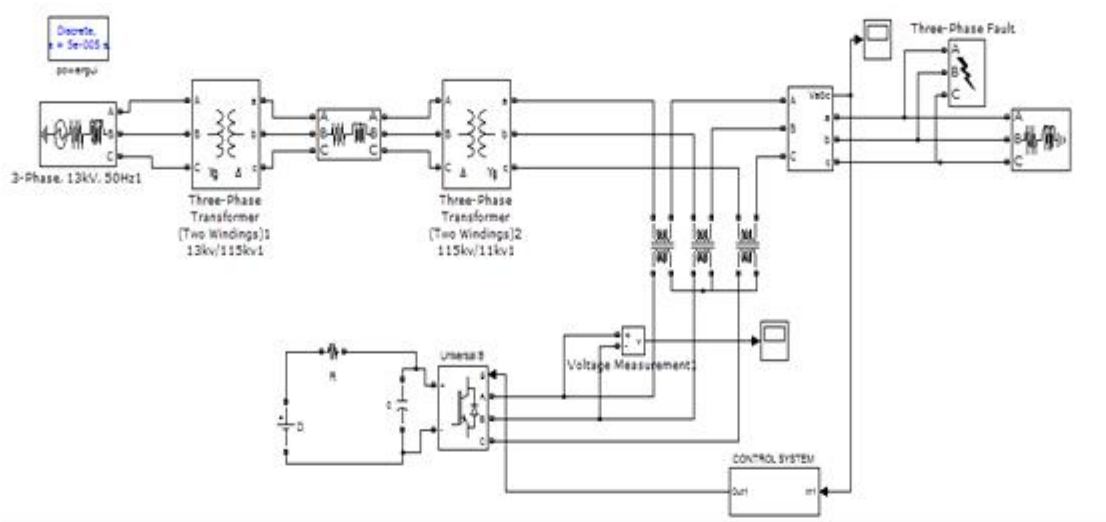


*Figure 8. Simulink Model of the DVR With Linear load*

Voltage sag is created at load terminals via L-L-L fault. Load voltage is sensed and passes through a sequence analyzer. The magnitude is compared with Vref**.** Fault timing is 0.2s to 0.3s. Here the fault resistance is 0.66 ohms and ground resistance is 0.001 ohms.
Control system of DVR shown in figure 9.

 

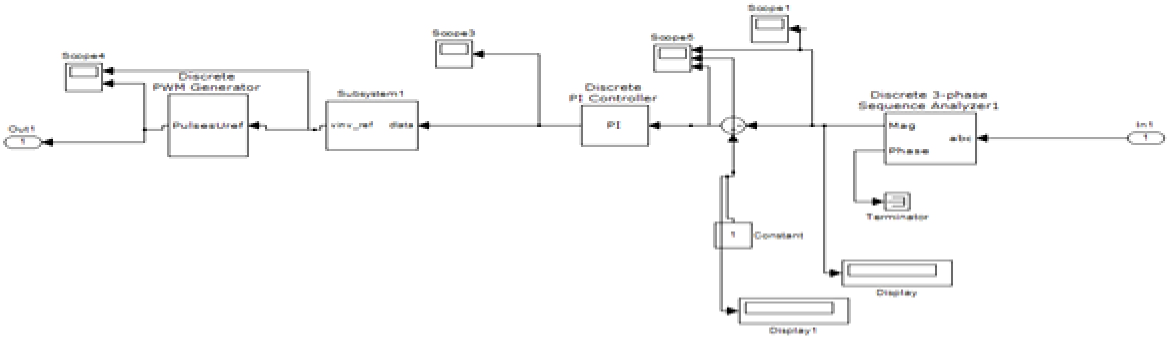


*Figure 9. Control system of DVR*

All the waveform is in R.M.S. voltage in p.u. As shown in the waveform voltage sag can be observed for the duration of 0.1s. Figure 10 shows the voltage waveform at the load side without DVR.

## SIMULATION RESULTS

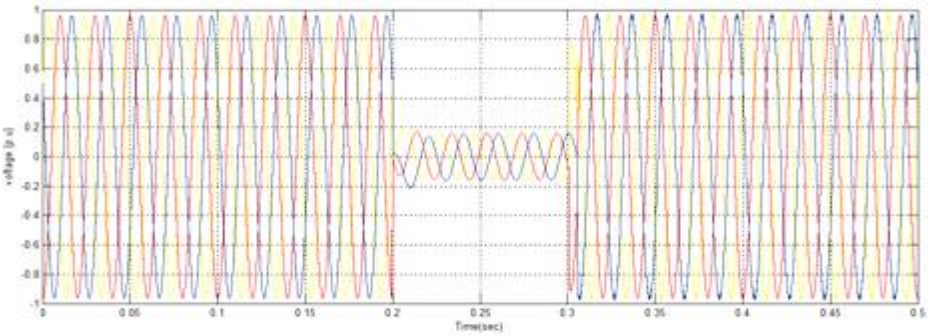

*Figure 10. Load voltage without DVR*

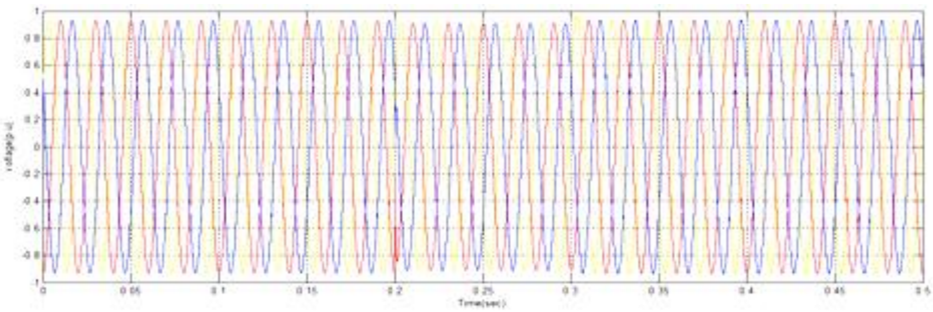

*Figure 11. Load voltage with DVR*

Voltage sag which occur due to L-L-L fault, is mitigated by using DVR. Output waveform of circuit with DVR is shown in fig. 11, in which the mitigation of voltage sag can be observed.

The simulation model for swell with the capacitive load is shown in figure 12. Here swell created by suddenly connecting the capacitive load or we say capacitor bank. Here load is connecting for the duration of 0.2s to 0.3s. As shown in figure 13 voltage swell can be observed for the duration of 0.1s.

Output waveform of circuit with DVR is shown in figure 14, in which the mitigation of voltage swell can be observed.

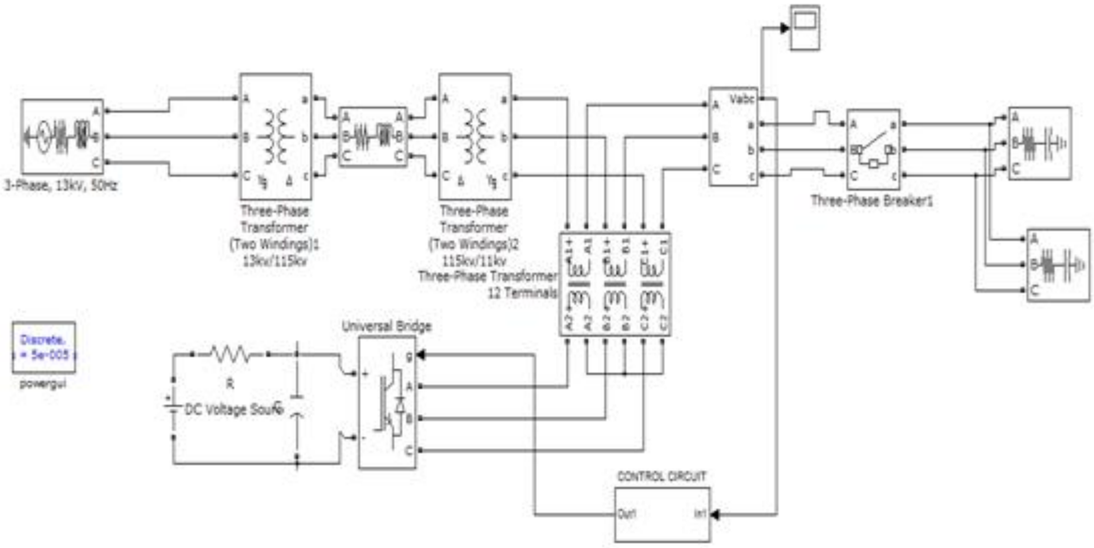


*Figure 12. Simulink Model of the DVR With Capacitive load*

**SIMULATION RESULTS**

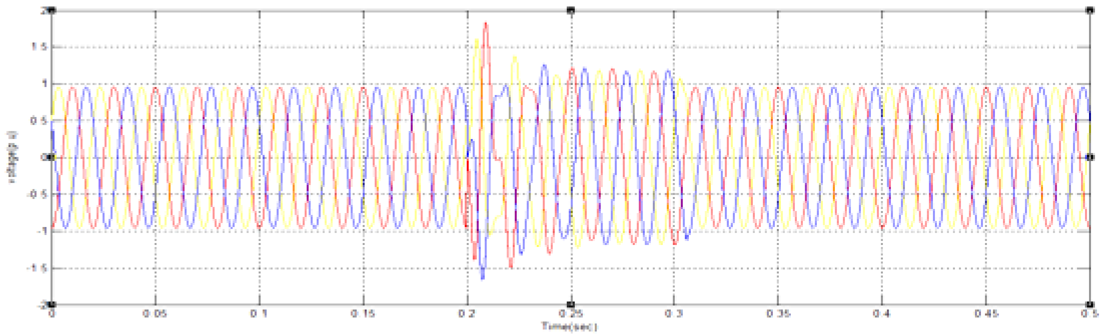

*Figure 13. Load voltage without DVR*

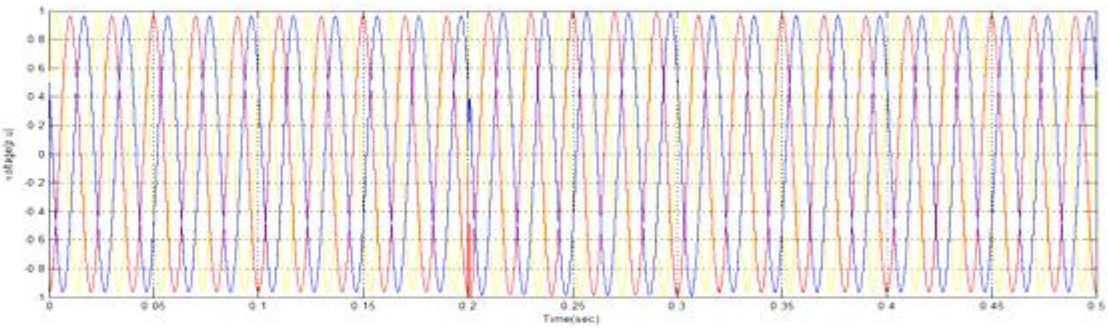

*Figure 14. Load voltage with DVR*

## VI. CONCLUSION AND FUTURE SCOPE

In this dissertation, DVR has been modelled and simulated in MATLAB simulink. The performance of DVR has been analyzed by linear load and induction motor load. Dynamic Voltage Restorer (DVR) is proposed for compensating the problem of voltage sag/swell and other fault conditions in industrial distribution systems, specially consisting of the induction motor load. The effectiveness of DVR by using PI controller is established for both linear and induction motor load and its control is simple.

Hence, it is conclude that DVR reduces voltage disturbance voltage sag and swell from load voltage very effectively and makes it smooth. So we say that DVR is useful device to improve the power quality .

 

## FUTURE SCOPE

By different Controllers like fuzzy controller and adaptive PI fuzzy controller can be used in DVR for compensation of disturbance. And DVR also established for active loads like PV source and Wind turbine

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