International Journal For Technological Research In Engineering
Volume 3, Issue 7, March-2016 *ISSN (Online): 2347 - 4718*

MODELING AND SIMULATION OF DYNAMIC VOLTAGE RESTORER FOR VOLTAGE SAG MITIGATION

Deep S. Thacker[1], Mrs. Barnali H. Keralia[2]
[1]PG Scholar, [2]Assistant Professor,
Electrical Department, HJD Institute of Technical Education and Research, Kera, Gujarat, India

ABSTRACT: Aim of this paper is to represents role of DVR is to compensate the load current and voltage is investigated during the fault condition. The paper proposes enhancement of power quality using DVR during voltage sag and swell conditions. Voltage dips and swells are the most common types of power-quality (PQ) disturbances. They represent a major concern for the industry because they lead to important economical losses and/or distorted quality of industrial products. Voltage dips being the most frequent PQ disturbance, the main research interests are focused on their analysis. The time duration where the dip occurs is determined by segmentation algorithms applied to the three phase voltages, Voltage sags and swells are characterized by their duration, magnitude and phase angle shift. The last two parameters determine their phase relation, which is also called dip/swell type or signature. A PI Controller based control strategy has been used for voltage sag mitigation and power quality improvement in this paper.

I. INTRODUCTION

It had been observed that in modern industrial devices most of devices are based on electronic devices such as programmable logic controllers and electronic drives. The power electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics in the entire problems associated with voltage dips is considered as one of the most severe disturbances to the industrial equipment. Voltage dips and swells are the most common types of power-quality (PQ) disturbances. They represent a major concern for the industry because they lead to important economical losses and/or distorted quality of industrial products. Indeed, equipment used in industrial plants has become more sensitive to such phenomena as a result of technology improvement and increased use of power electronics devices. The problem of poor power quality like voltage sag for sensitive loads can be better dealt or solved by power electronics based Dynamic Voltage Restorer. With the application of DVR, the power system can be operated without voltage sag and the power supply by flexibly changing the distribution configuration after the occurrence of a fault. Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions. Voltage sags can occur at any instant of time, with amplitudes ranging from 10 – 90% and a duration lasting for half a cycle to one minute. Voltage swell, on the other hand, is defined as a swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. typical magnitudes are between 1.1 and 1.8 up. Swell magnitude is also is also described by its remaining voltage, in this case, always greater than 1.0. The Dynamic Voltage Restorer (DVR) has been proposed to protect sensitive loads from such voltage sags. The DVR is connected in series with the sensitive load or distribution feeder and is capable of injecting real and reactive power demanded by the load during voltage sag compensation. The output of the DVR inverter is usually provided with an output LC filter to attenuate the harmonic contents appearing in injected voltage. The filter parameters are designed according to certain design aspects such as depth of the sag to be mitigated and the load voltage. These effects can be very expensive for the customer, ranging from minor quality variations to production downtime and equipment damage. Thus, automatic analysis of voltage dips and swells has become an essential requirement for PQ assessment. Voltage dips being the most frequent PQ disturbance, the main research interests are focused on their analysis. The time duration where the dip occurs is determined by segmentation algorithms applied to the three phase voltages. The dip signature can be identified from measured voltage waveforms, from the comparison between RMS values of phase voltages and phase-to-phase voltages or well from symmetrical components.

The combination of the custom power devices DVR with PI controller is used for the power quality improvement in the distribution system. Here linear load are considered, only when different fault conditions are measured with these loads to analyze the operation of DVR to improve the power quality in distribution system.

II. POWER QUALITY PROBLEMS & SOLUTIONS

2.1DEFINITION OF POWER QUALITY:-

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” As appropriate as this description might seem, the limitation of power quality to “sensitive electronic equipment” might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. The common concerns of power quality are long duration voltage variations (overvoltage, under voltage, and sustained interruptions), short duration voltage variations (interruption, sags (dips), and swells), voltage imbalance, waveform distortion (DC offset, harmonics, inter harmonics, notching and noise), voltage fluctuation (voltage flicker) and power frequency variations. Most reasons of these concerns stems from loads connected to electric supply systems. There are two types of loads, linear and nonlinear. Motors, heaters and incandescent lamps are examples of linear load produce a current proportional to the voltage. The nonlinear load uses high-speed electronic power switching devices to convert the AC supply voltage to a constant DC voltage used by the internal circuits. Producing harmonic currents at the point of common coupling (PCC) cause several adverse effects such as a line voltage distortion at PCC, equipment overheating, overheating, failure of sensitive electronic equipment, interference with telecommunication systems due to harmonic noises, flickering of fluorescent lights, erratic operation of circuit breakers and relays, fuse blowing and electronic equipment shutting down, conductor overheating due to Triplen harmonics in 3-phase 4- wire system, increased RMS current. Personal computers, fax machines, printers, UPS, adjustable speed drives, electronic lighting ballasts, DC motor drives and arcing equipment are examples of nonlinear loads.

2.2 Power Quality Issues and Its Consequences:-

Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or malfunctioning of customer equipment. Power quality is a two-pronged issue, with electronic equipment playing both villain and victim. Most new electronic equipment, consumes electricity differently than traditional mechanical appliances. Power supply quality issues and resulting problems are consequences of the increasing use of solid state switching devices, nonlinear and power electronically switched loads, electronic type loads .the advent and wide spread of high power semiconductor switches at utilization, distribution and transmission leaves have non sinusoidal currents.

2.3 Cost of poor power quality:-

Poor Power Quality can be described as any event related to the electrical network that ultimately results in a financial loss. Possible consequences of poor Power Quality includes as follows:-

Unexpected power supply failures (breakers tripping, fuses blowing).

- Equipment failure or malfunctioning.
- Equipment overheating (transformers, motors) leading to their lifetime reduction.
- Damage to sensitive equipment (PC’s, production line control systems).
- Electronic communication interferences.
- Increase of system losses.
- Need to oversize installations to cope with additional electrical stress with consequential increase of installation and running costs and associated higher carbon footprint.
- Penalties imposed by utilities because the site pollutes the supply network too much.

The following are the main contributors to Low Voltage poor Power Quality can be defined:-

1. Reactive power, as it loads up the supply system unnecessary, Harmonic pollution, as it causes extra stress on the networks and makes installations run less efficiently,
2. Load imbalance, especially in office building applications, as the unbalanced loads may result in excessive voltage imbalance causing stress on other loads connected to the same network, and leading to an increase of neutral current and neutral to earth voltage build-up,
3. Fast voltage variations leading to flicker.

2.4 Compensation in power system:-

Reactive power is either generated or consumed in almost every component of the system, generation, transmission, and distribution and eventually by the loads. The impedance of a branch of a circuit in an AC system consists of two components, resistance and reactance. Reactance can be either inductive or capacitive, which contribute to reactive power in the circuit. Most of the loads are inductive, and must be supplied with lagging reactive power. It is economical to supply this reactive power closer to the load in the distribution system. Reactive power compensation in power systems can be either shunt or series. Therefore, investment is necessary for the studies into the security and stability of the power grid, as well as the improved control schemes of the transmission system.

2.4.1 Necessity of reactive power compensation

“Reactive power (vars) is required to maintain the voltage to deliver active power (watts) through transmission lines. Motor loads and other loads require reactive power to convert the flow of electrons into useful work. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines”. Transformers, transmission lines, and motors require reactive power. Transformers and transmission lines introduce inductance as well as resistance; both oppose the flow of current. It must raise the voltage higher to push the power through the inductance of the lines, unless capacitance has introduced to offset of inductance.

2.5 Voltage Sag

Voltage sags and momentary power interruptions are probably the most important Power Quality problem affecting industrial and large commercial customers. These events are usually associated with a fault at some location in the supplying power system. Interruptions occur when the fault is on the circuit supplying the customer. But voltage sags occur even if the faults happen to be far away from the customer's site. Voltage sags lasting only 4-5 cycles can cause a wide range of sensitive customer equipment to drop out. To industrial customers, voltage sag and a momentary interruption are equivalent if both shut their process down. A typical example of voltage sag is shown in fig.2.1

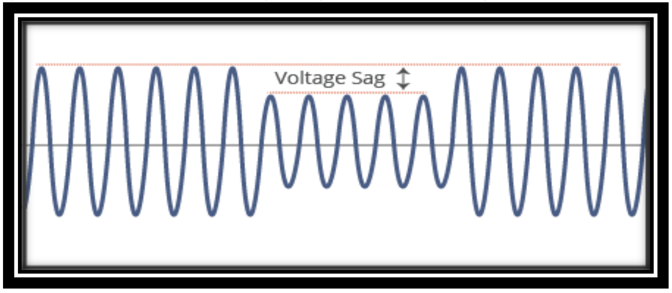

Fig.2.1- Voltage Sag condition

2.5.1 Voltage-Sag Analysis- Methodology

Load Flow:

A load flow representing the existing or modified system is required with an accurate zero- sequence representation. The machine reactance Xd" or Xd ' is also required. The reactance used is dependent upon the post fault time frame of interest. The machine and zero-sequence reactance are not required to calculate the voltage sag magnitude.

Voltage Sag Calculation:

Sliding faults which include line-line, line to ground, line to line- to ground and three phases are applied to all the lines in the load flow. Each line is divided into equal sections and each section is faulted.

Voltage Sag Occurrence Calculation:

Based upon the utilities reliability data (the number of times each line section will experience a fault) and the results of load flow and voltage sag calculations, the number of voltage sags at the customer site due to remote faults can be calculated. Depending upon the equipment connection, the voltage sag occurrence rate may be calculated in terms of either phase or line voltages dependent upon the load connection. For some facilities, both line and phase voltages may be required. The data thus obtained from load flow, Voltage sag calculation, and voltage sag occurrence calculation can be sorted and tabulated by sag magnitude, fault type, location of fault and nominal system voltage at the fault location

Study of Results of Sag- Analysis:

The results can be tabulated and displayed in many different ways to recognize difficult aspects. Area of vulnerability can be plotted on a geographical map or one - line diagram. These plots can be used to target transmission and distribution lines for enhancements in reliability. Further bar charts, and pie-charts showing the total number of voltage sags with reference to voltage level at fault point, area/zone of fault, or the fault type can be developed to help utilities focus on their system improvements to examining the existing system, system modifications aimed at mitigating or reducing voltage sags can also be identified, thus enabling cost benefits analysis. Possible such system structural changes that can be identified include. Reconnection of a customer from one voltage level to another, Installation of Ferro-resonant transformers or time delayed under voltage, drop out relay to facilitate easy ride - through the sag. Application of static transfer switch and energy storage system., Application of fast acting synchronous condensers, Neighborhood generation capacity addition , Increase service voltage addition through transformer tap changing, By enhancement of system reliability

III. DYNAMIC VOLTAGE RESTORER

3.1 Basic configuration of DVR

Among the several type of power quality problems (sags, swells, harmonics) voltage sags are the most severe type of disturbances. In order to overcome problems associated with power quality, the concept of custom power devices is introduced in recent times. One of those devices most recognizable and good in performance is the Dynamic Voltage Restorer, which is the most efficient and effective modern custom power device used in power distribution networks. The general arrangement of the DVR is composition of Injection/ Booster transformer, Harmonic filter, Storage Devices, Voltage Source Converter (VSC), and DC charging circuit, Control and Protection system.

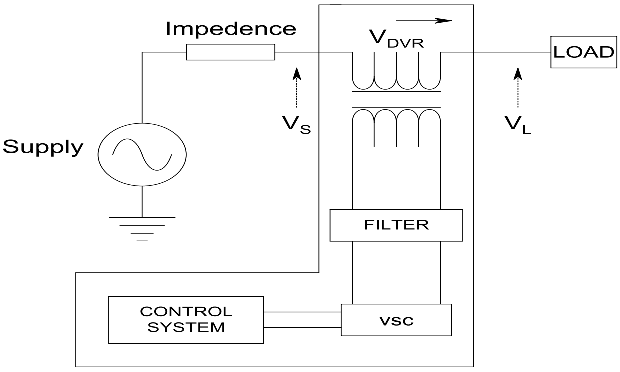

Fig. 3.1 Schematic diagram of DVR

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 3.1, the DVR is located on approach of sensitive loads. If a fault occurs on other lines, DVR inserts series voltage VDVR and compensate 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 VL. 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.

3.2 Construction of DVR

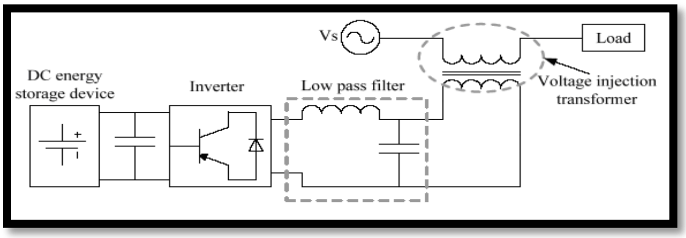

Fig. 3.2 Working Construction of DVR

A DVR is a solid state power electronics switching device consisting of whichever GTO or IGBT, a capacitor depository as a power storage device and inoculation transformer. It is linked in series between a distribution and a load

The DVR is capable to generate or absorb reactive power but the active power injection of the device must be provided by an external energy source or energy storage system. The response time of DVR is very short and is limited by the power electronics devices and the voltage sag detection time.

3.2.1 Energy Storage Unit

Various devices such as Flywheels, Lead acid batteries, Superconducting Magnetic energy storage (SMES) and Super-Capacitors can be used as energy storage devices. The main function of these energy storage units is to provide the desired real power during voltage sag. The amount of active power generated by the energy storage device is a key factor, as it decides the compensation ability of DVR. Among all others, lead batteries are popular because of their high response during charging and discharging But the discharge rate is dependent on the chemical reaction rate of the battery so that the available energy inside the battery is determined by its discharge rate.

3.2.2 Voltage Source 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. In order to boost the magnitude of voltage during sag, in DVR power circuit a step up voltage injection transformer is used. Thus a VSI with a low voltage rating is sufficient.

3.2.3 Passive Filters

To convert the PWM inverted pulse waveform into a sinusoidal waveform, low pass passive filters are used. In order to achieve this it is necessary to eliminate the higher order harmonic components during DC to AC conversion in Voltage Source Inverter which will also distort the compensated output voltage. These filters which play a vital role can be placed either on high voltage side i.e. load side or on low voltage side i.e. inverter side of the injection transformers. We can avoid higher order harmonics from passing through the voltage transformer by placing the filters in the inverter side. Thus it also reduces the stress on the injection transformer. One of the problems which arise when placing the filter in the inverter side is that there might be a phase shift and voltage drop in the inverted output. So this could be resolved by placing the filter in the load side. But this would allow higher order harmonic currents to penetrate to the secondary side of the transformer, so transformer with higher rating is essential.

3.2.4 Voltage Injection Transformers

The primary side of the injection transformer is connected in series to the distribution line, while the secondary side is connected to the DVR power circuit. Now 3 single phase transformers or 1 three phase transformer can be used for 3 phase DVR whereas 1 single phase transformer can be used for 1 phase DVR. The type of connection used for 3 phase DVR if 3 single phase transformers are used is called “Delta-Delta” type connection. If a winding is missing on primary and secondary side then such a connection is called “Open-Delta” connection which is as widely used in DVR systems Basically the injection transformer is a step up transformer which increases the voltage supplied by filtered VSI output to a desired level and it also isolates the DVR circuit from the distribution network. Winding ratios are very important and it is predetermined according to the required voltage at the secondary side. High winding ratios would mean high magnitude currents on the primary side which may affect the components of inverter circuit. When deciding the performance of DVR, the rating of the transformer is an important factor. The winding configuration of the injection transformer is very important and it mainly depends on the upstream distribution transformer. In case of a Δ-Y connection with the grounded neutral there will not be any zero sequence current flowing into the secondary during an unbalance fault or an earth fault in the high voltage side. Thus only the positive and negative sequence components are compensated by the DVR.

3.3 DVR Operating Modes

The DVR has two modes of operation which are: standby mode and boost mode. In standby mode (VDVR=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 (VDVR>0), the DVR is injecting a compensation voltage through the booster transformer due to a detection of a supply voltage disturbance.

3.4 Compensation Techniques

3.4.1 Pre-sag Compensation

Pre-sag compensation is a method which is generally used for non linear loads such as thyristor controlled drives. In non linear loads the voltage magnitude as well as he phase angle needs to be compensated. Figure 4.3 below describes the pre-sag compensation technique. A higher rated energy storage device and voltage injection transformers are needed for this technique. The magnitude of the required voltage by the DVR can be calculated as follows:

$$V_{dvr} = \sqrt{V_L^2 + V_s^2 - 2\,V_L V_s \cos\delta}$$

Whereas the required phase angle θ to be compensated can be calculated as follows:

$$\theta_{dvr} = \tan^{-1} \frac{V_s \sin\delta}{V_s \cos\delta - V_L}$$

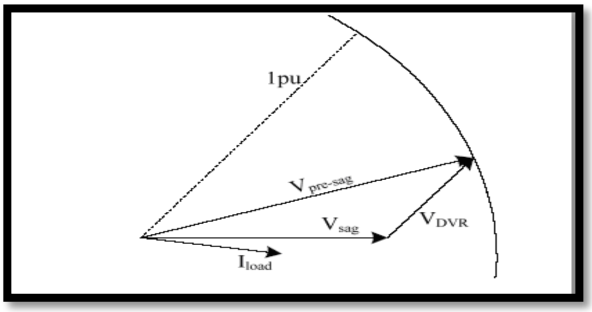

Fig. 3.3 Pre-Sag Compensation Techniques

3.4.2 in-Phase Compensation

This technique of compensation is generally used for active loads. Only compensation for voltage magnitude is required whereas no phase compensation is required. In this particular method the compensated voltage is in phase with the sagged voltage. It is clear from the Figure 4.4, that there is a phase shift between the voltages before the sag and after the sag. Figure 4.4 In-Phase Compensation Techniques

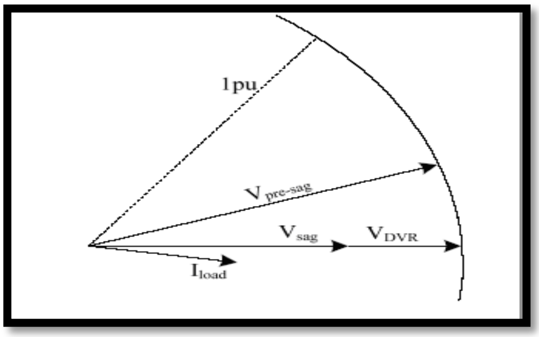

Fig. 3.4 In-Phase Compensation Techniques

It should be noted that the techniques mentioned in 3.4.1 and 3.4.2 need both the real and reactive power1 for the compensation and the DVR is supported by an Energy storage device.

IV. MODELING AND SIMULATION

4.1 MATLAB model for SAG condition

The Matlab model of system during sag condition is shown in fig below:-

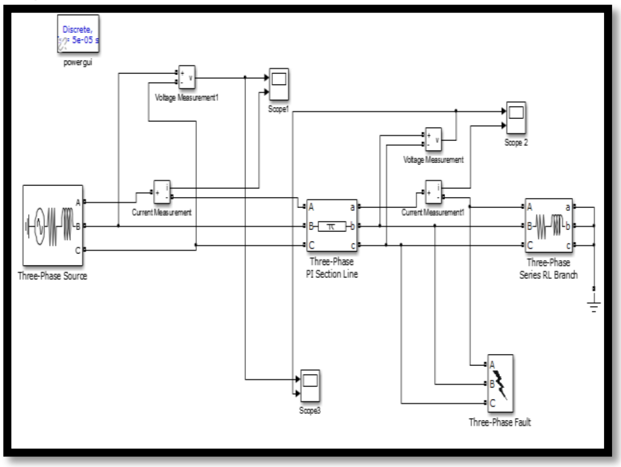

Fig 4.1- MATLAB model of system without DVR during SAG condition

The simulation results during SAG condition of the system is shown in fig below:-

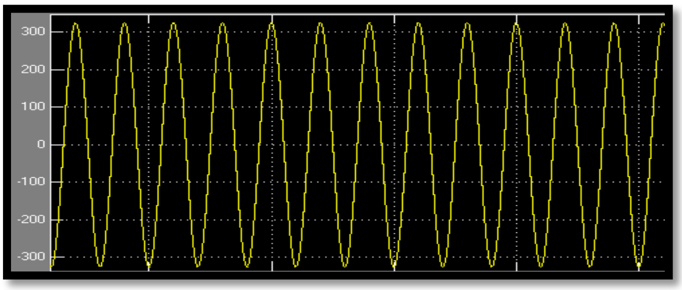

Fig 4.2- Normal voltage waveform

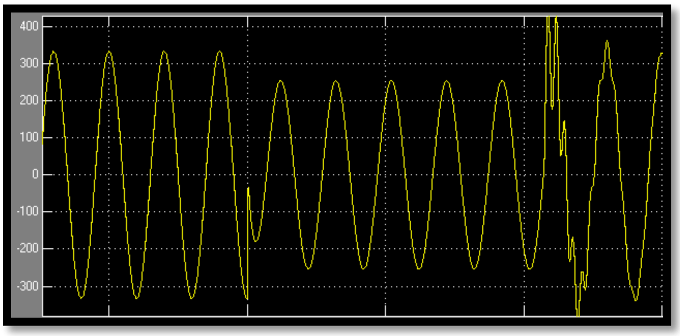

Fig 4.3- Voltage SAG in output voltage waveform

SAG for different value for fault Resistance:

If fault Resistance = 75 ohms

So voltage sag is about 23 %

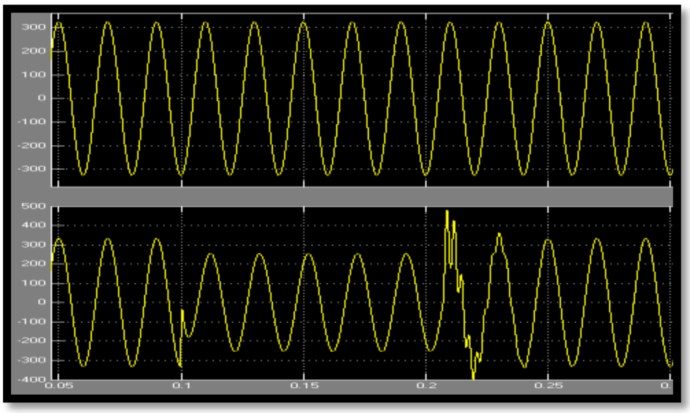

Fig 4.4- Comparison of Normal condition and SAG condition waveform

If fault Resistance = 100 ohms

So voltage sag is about 16 %

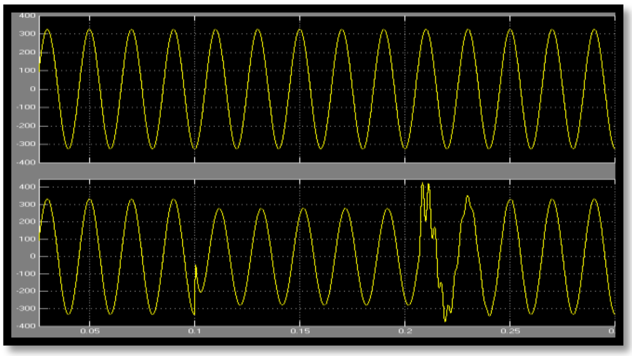

Fig 4.5- SAG condition waveform for different Fault Resistance

Now, If fault Resistance = 50 ohms
So voltage sag is about 36 %

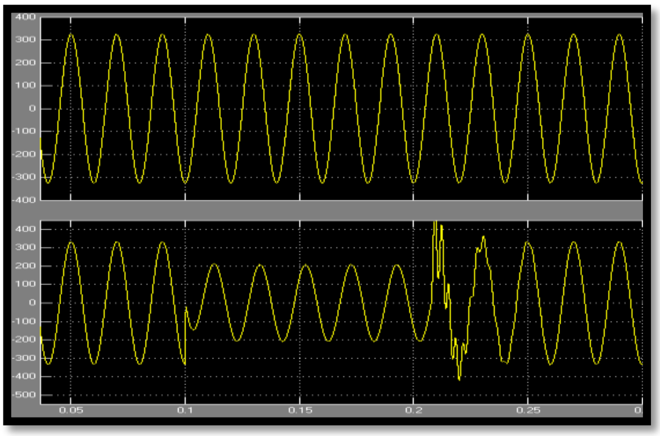

Fig 4.5 - SAG condition waveform for different Fault Resistance

4.2 Voltage Sag Mitigation Using PI Controller

The voltage sag mitigation using PI controller is easily done. The MATLAB- SIMULINK model of voltage sag mitigation using PI Control Strategy is shown in fig below:-

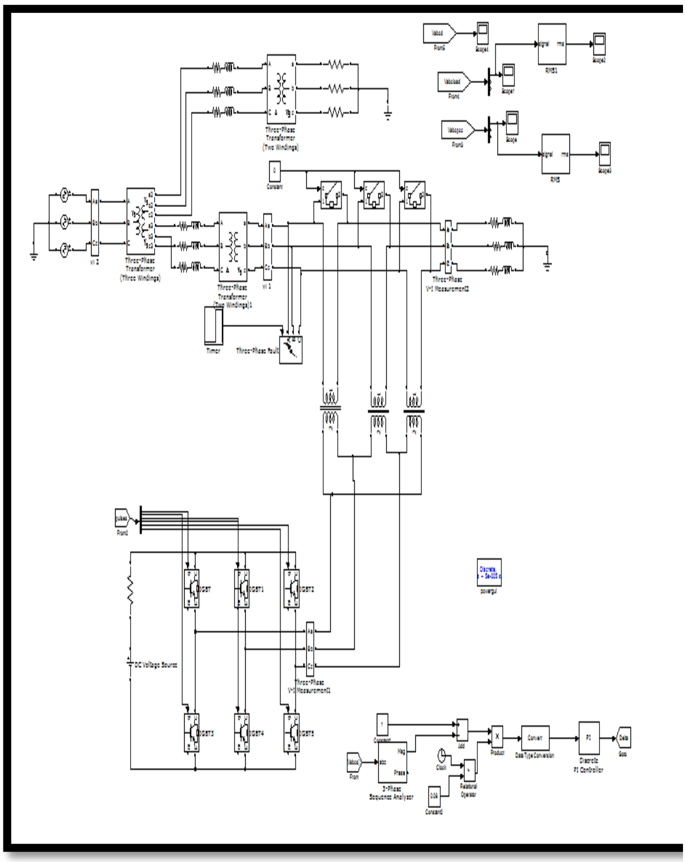

Fig 4.6- Voltage Sag mitigation Using PI Controller

The PI controller is provided for comparison and relation development between the reference value and running condition value. The PI Controller calculates the value of power angle which is given to trigonometric function calculation of sine and cosine angle value after that it is given for dqo-transformation which compare with the reference value or carrier signal for generating the pulses for IGBT Devices for mitigation of voltage sag condition. The injecting transformers are provided for the distribution line control for compensation using DVR.

The Subsystems for voltage sag condition in the system without DVR Control Strategy is shown in the fig below with their simulation results:-

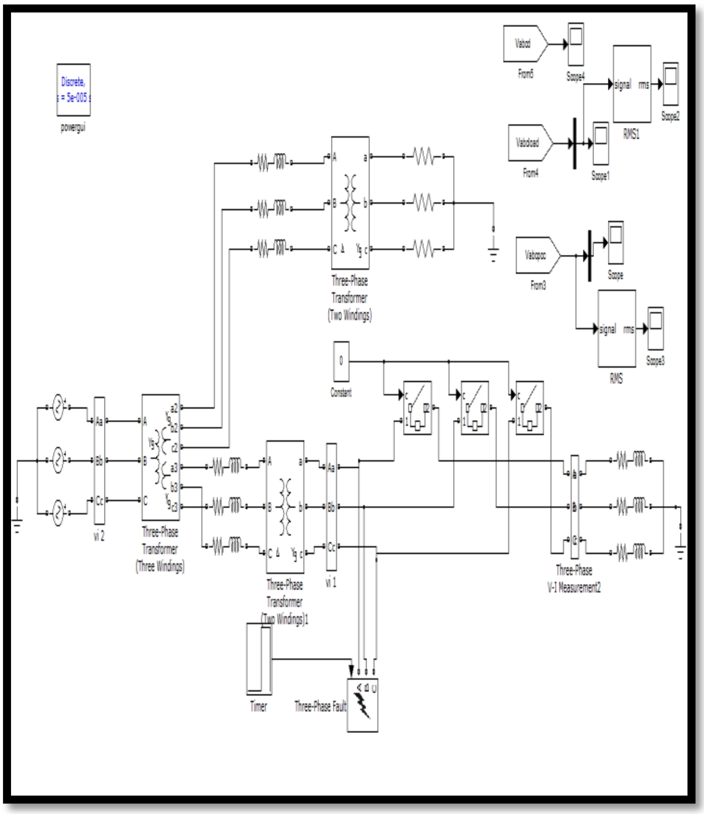

Fig. 4.7- Voltage Sag condition without DVR Control Strategy

The Simulation of this model shows that voltage Sag condition occurs at input side and the point of common coupling. The simulation results of these conditions are shown in the fig below:-

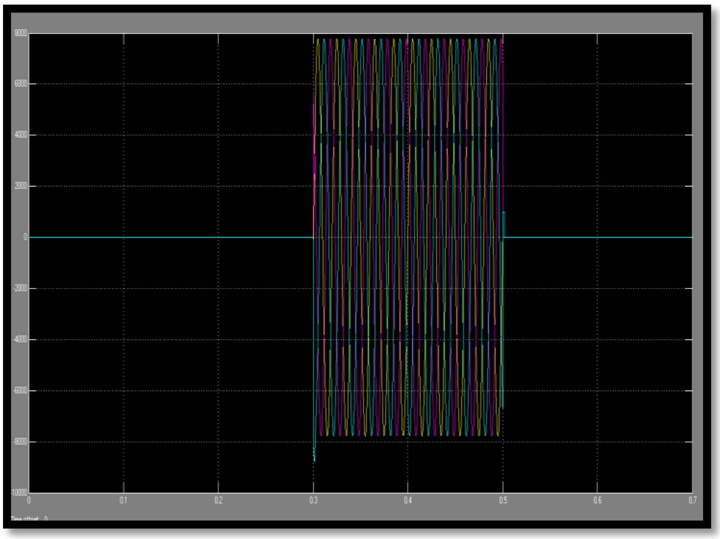

Fig.4.8- Voltage SAG Condition at input Side

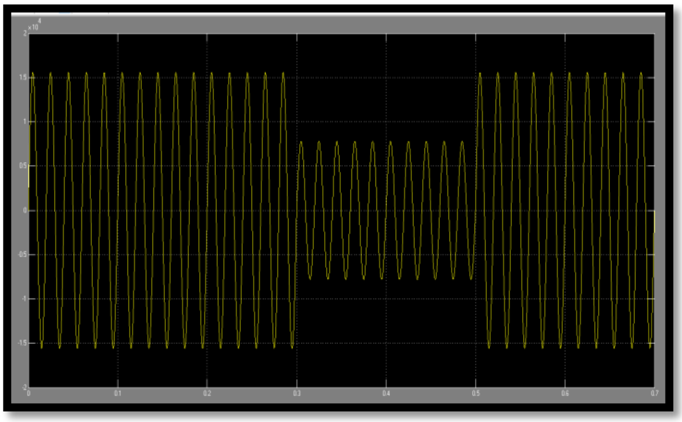

Fig.4.9- Voltage Sag condition at PCC (Point of Common Coupling) point

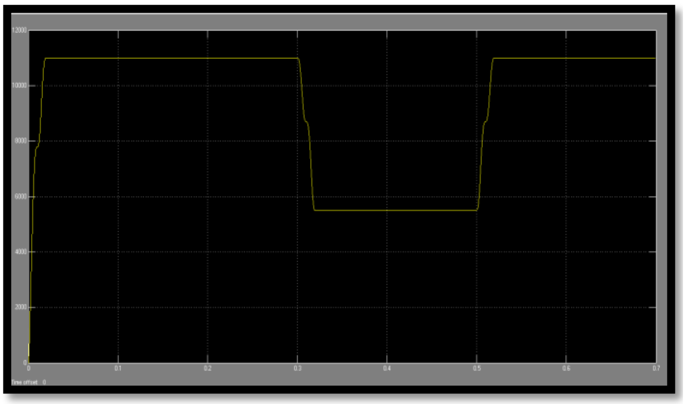

Fig 4.10-R.M.S value of Voltage Sag condition at point of common coupling

Now the PI control Strategy is apply in this system for voltage sag mitigation as discussed above. The Model of this system is shown in the fig below:-

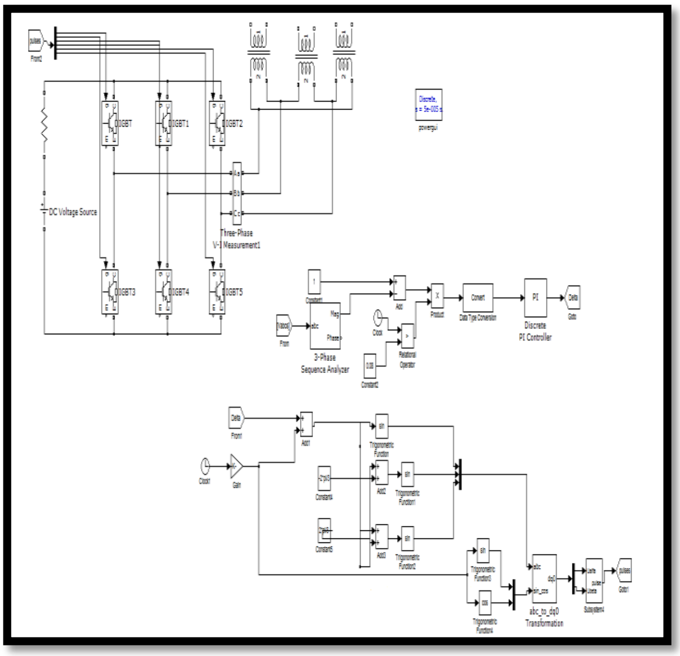

Fig 4.11- DVR Control strategy for Voltage Sag mitigation

After applying the PI control Strategy the voltage sag condition is mitigated as shown in fig below:-

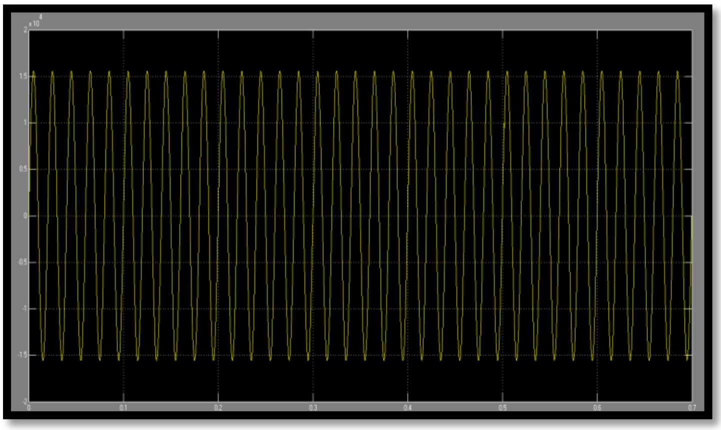

Fig 4.12- Voltage sag mitigated and pure sinusoidal output waveform

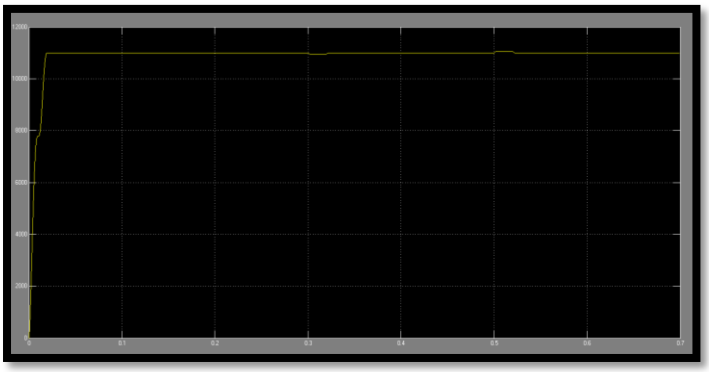

Fig 4.13- R.M.S value of Load side mitigated voltage sag condition waveform

V. CONCLUSION

This paper has proposed and modeled a Dynamic Voltage Restorer (DVR) Based on PI control strategy for voltage sag mitigation. The steps of developing the model of the DVR have been explained in details. The ability of the DVR to maintain the load voltage under different voltage sags and swells has been verified using time domain simulations. The model of the DVR with the PI control can be further enhanced by having fixed frequency hysteresis voltage controller. In addition, a faster sag/swell detection technique can be also developed and modeled to improve the response of the DVR.

REFERENCES

[1] Raunak Jangid, Kapil Parkh, Pradeep Anjana, “Reducing the Voltage Sag and Swell Problem in Distribution System Using Dynamic Voltage Restorer with PI Controller”, International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-3, Issue-6, January 2014.

[2] Fawzi AL Jowder, Member, IEEE, “Modelling and Simulation of Dynamic Voltage Restorer (DVR) Based on Hysteresis Voltage Control”, The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON) Nov. 5-8, 2007, Taipei, Taiwan.

[3] M.kanakaraj, Mrs.S.Thirukkovai, “Voltage

Sag/Swell Compensation using Fuel cell fed Inverter Based Dynamic Voltage Restorer", IEEE-international Conference On Advances In Engineering, Science And Management (ICAESM - 2012) March 30, 31, 2012

[4] U. T. Patil, A. R. Thorat, "Hysteresis Voltage Control Technique in Dynamic Voltage Restorer for Power Quality Improvement", IEEE-international Conference On Advances In Engineering, ISBN:978-1-4673-6150-7/13

[5] Rosli omar, Nasrudin abd rahim, Marizan sulaiman, "Modelling and simulation for voltage sags/swells mitigation using dynamic voltage restorer (DVR)" , Journal of Theoretical and Applied Information Technology, University Of Malaya, Kuala Lumpur, Malaysia.

[6] Chen Songsong, Wang Jianwei, Gao Wei,Hu Xiaoguang, "Research and Design of Dynamic Voltage Restorer" IEEE-international Conference On Advances In Engineering, ISBN:978-1-4673-0311-8/12

[7] Rosli Omar, N.A Rahim, "Implementation and Control of a Dynamic Voltage Restorer Using Space Vector Pulse Width Modulation (SVPWM) for Voltage Sag Mitigation", Faculty of Electrical Engineering, Department of Electrical Engineering, Technical University Malaysia Malacca, Faculty of Engineering, University Of Malaya, Ayer Keroh Malacca, Malaysia. Kuala Lumpur, Malaysia.

[8] Priyanka Kumari, Vijay Kumar Garg, "Simulation of Dynamic Voltage Restorer Using Matlab to Enhance Power Quality in Distribution System", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, Vol. 3, Issue 4, Jul-Aug 2013.

[9] Rosli Omar and Nasrudin Abd Rahim, "Mitigation of voltage sags/swells using Dynamic voltage restorer (dvr)", ARPN Journal of Engineering and Applied Sciences, ISSN 1819-6608, VOL. 4, NO. 4, JUNE 2009.

[10] Rasool M. Imran, Jyoti Srivastava, "Using of Dynamic Voltage Restorer (DVR) to Mitigate Sag & Swell Voltage during Single Line to Ground & Three-Phase Faults", International Journal Of Modern Engineering Research (IJMER), ISSN: 2249–6645 , Vol. 4 ,Issue- 2 ,Feb. 2014.

[11] K. Satyanarayana Raju, Avala Ramulu, "Compensation of voltage sag and swell using dynamic voltage restorer", International Research Journal of Engineering and Technology (IRJET) , ISSN: 2395-0056 ,Volume: 02 Issue: 03 ,June-2015.

[12] P.Ananthababu, B.Trinadha, K.Ram Charan, "Performance of Dynamic Voltage Restorer against Voltage sags and swells using space vector PWM Technique", International Conference on Advances in Computing, Control and Telecommunication Technologies Journal of Engineering and Technology, ISBN:978-0-7695-3915-7/09.

[13] Tripti Shahi, K.P.Singh, "Mitigation of Voltage Sags/Swells to Enhance Power Quality of Distribution System Using a Custom Power Device (DVR)", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (An ISO 3297: 2007 Certified Organization) Vol. 3, Issue 7, July 2014.

[14] "IEEE Recommended Practice for Monitoring Electric Power Quality", IEEE Std 1159-1995, ISBN 1-55937-549-3.

[15] Power Quality in Electrical System, Alexander Kusko, Marc Thompson,McGraw Hill Professional.

[16] Electrical Power Systems Quality, R.C.Dugan, S.Santoso, McGraw Hill Education.