



Mitigation of Voltage SAG Problem Using Dynamic Voltage Restorer (DVR)

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ABSTRACT: The power quality (PQ) requirement is one of the most important issues for power system. The main problems of the power quality like voltage sags/swells in low voltage distribution systems and on the transmission side due to sensitive loads. There are different methods to compensation of voltage sag and swell, one of the most popular methods of sag and swell compensation is Dynamic Voltage Restorer (DVR), The Dynamic Voltage Restorer (DVR) is series-connected power electronics based device. It provides advanced and economic solution to compensate voltage sag and swell. This device can be implemented to protect a group of medium or low voltage consumers. This study presents compensation of sags and swells voltage during single line to ground (SLG) and three-phase faults. Simulation results carried out by Matlab/Simulink verify the performance of the proposed method.

KEYWORDS: power quality, Dynamic Voltage Restorer, single line to ground, Voltage Source Converter, Windowed Fast Fourier Transform.

I.INTRODUCTION

Dynamic Voltage Restorer (DVR) can provide the most cost effective solution to mitigate voltage sags and swells by establishing the proper voltage quality level that is required by customer. When a fault happens in a distribution network, sudden voltage sag will appear on adjacent loads. DVR installed on a sensitive load, restores the line voltage to its nominal value within the response time of a few milliseconds thus avoiding any power disruption to the load. There are many different methods to mitigate voltage sags and swells, but the use of a DVR is considered to be the most cost efficient method. The most common choice for the control of the DVR is the PI Controller since it has a simple structure and It can offer relatively a satisfactory performance over a wide range of operation. The main problem of this simple controller is the correct choice of the PI gains and the fact that by using fixed gains, the controller may not provide the required control performance, when there are variations in the system parameters and operating conditions. Various control strategies have been developed to mitigate the voltage sag and swell have been proposed for three phase voltage source PWM converters. They can be divided into two main groups: linear and non-linear, linear controllers include the ramp-comparison current regulator, Synchronous PI regulator, state feedback regulator and predictive and dead-beat regulator. The hard-switched converter and the neural network and Fuzzy Logic (FL) based regulators belong to the non-linear controllers. It appears that the non-linear controller is more suitable than the linear type since the DVR is truly a non-linear system. The DVR is a non-linear device due to the presence of power semiconductor switches in the inverter bridge. This paper introduces Dynamic Voltage Restorer (DVR) and its operating principle, also presents the proposed controllers of PI and fuzzy controllers. Then, simulation results using MATLAB-SIMULINK provide a comparison between the proposed and the conventional PI controllers in terms of performance in voltage sag/swell compensation at the end, discussions of the results and conclusion are given.

Literature Review

Mr. Y. Prakash and Dr. S. Sankar[27] proposed algorithm is applied to some disturbances in load voltage caused by induction motors starting, and a three-phase short circuit fault. Also, the capability of the proposed DVR has been tested to limit the downstream fault current. The current limitation will restore the point of common coupling voltage and protect the DVR itself. The idea here is that the DVR acts as a virtual impedance with the main aim of protecting the pcc voltage during downstream fault without any problem in real power injection into the DVR.

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Haluk GOZDE and M.Cengiz[28] Proposed an artificial intelligence based optimization method is applied to optimize the gains of PID controller for Automatic Voltage Regulator (AVR) system. A dynamic performance of the controller which is optimized with Chaotic Particle Swarm Optimization (CPSO) algorithm is compared with the results which are obtained with standard Particle Swarm Optimization (PSO). The transient response analysis is used in order to determine the performances of the methods.

Ali O Al-Mathnani, Hussain Shareef and Azah Mohamed[29] proposed fast DVR with controller to compensate the short outage, reduced the harmonic distortion and transient voltage for balanced and unbalanced load. In-phase method with continuous two vector control algorithm is used to detect and compensate ΔV and ΔQ variables during voltage sag and voltage compensation. When there is any phase angle or phase jump in supply voltage the reference voltage is adjusted to track the phase angle of the supply voltage. A phase locked loop is used to keep the load voltage synchronized continuously and tracks the source voltage. It is shown that the proposed DVR controller improves the system power quality. Photovoltaic (PV) system with boost converter is designed to maintain the DC source voltage. Simulation was carried out using PSCAD/EMTDC.

II. REAL MODAL OF DYNAMIC VOLTAGE RESTORER

Among the power quality problems voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also add other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations [7,9].

A. DVR Basic Configuration and Components

Fig 1 shows the schematic diagram of DVR. It consists of an Injection transformer, Harmonic filter, Storage Devices, a Voltage Source Converter (VSC), and DC charging circuit and Control and Protection system

Fig 1 Schematic diagram of DVR

1. Energy Storage Unit

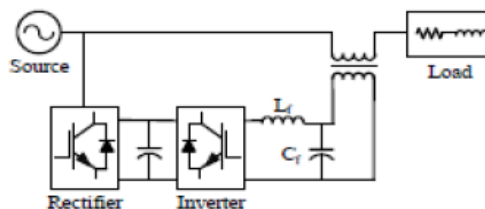


Figure 2. DVR with supply rectified energy

During voltage sag, the DVR injects a voltage to restore the load supply voltages. The DVR needs a source for this energy. Two types of system are considered; one using stored energy to supply the delivered power as shown in Figure 2, and the other having no internal energy storage, where energy is taken from the incoming supply through a shunt converter as shown in Figure 2.

2. Inverter Circuit

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The Voltage Source Inverter (VSI) or simply the inverter converts the dc voltage from the energy storage unit (or the dc link) to a controllable three phase ac voltage. The inverter switches are normally fired using a sinusoidal Pulse Width Modulation (PWM) scheme. Since the vast majority of voltage sags seen on utility systems are unbalanced, the VSI will often operate with unbalanced switching functions for the three phases, and must therefore treat each phase independently. Moreover, sag on one phase may result in a swell on another phase, so the VSI must be capable of handling both sags and swells simultaneously. Another topology of the DVR is the use of multi-inverter system in cascade. This topology will add the voltage of the single cascaded inverters in series in order to obtain the desired inverter voltage. This method gets rid of the injection transformer used in the basic configuration of the DVR. This arrangement is often called a transformer-less or multilevel or a cascade inverter DVR [6-7].

3. Filter Unit

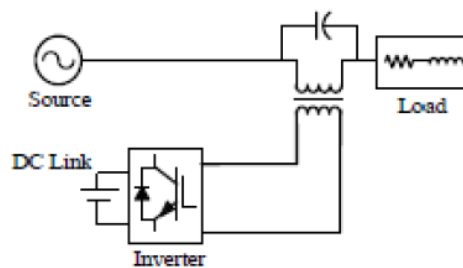


Figure 3. DVR with load side filter

The nonlinear characteristics of semiconductor devices cause distorted waveforms associated with high frequency harmonics at the inverter output. To overcome this problem and provide high quality energy supply, a harmonic filtering unit is used. These filters can be placed either in the inverter side as shown in Figure 2 or in the line side as shown in Figure 3.

4. Series Injection Transformer

Three single-phase injection transformers are used to inject the missing voltage to the system at the load bus. To integrate the injection transformer correctly 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. The existence of the transformers allow for the design of the DVR in a lower voltage level, depending upon the stepping up ratio.

III. COMPENSATION METHODS IN DVR

The type of the compensation strategy mainly depends upon the limiting factors such as DVR power ratings, various conditions of load, voltage sag type. Some loads are sensitive towards phase angle jump and some are sensitive towards change in magnitude and others are tolerant to these [16]. Therefore, the control strategies depend upon the type of load characteristics; there are three different methods of DVR voltage injection which are:

- (a) Pre-sag compensation method
- (b) In-phase compensation method
- (c) Voltage tolerance method with minimum energy injection

(a) Pre-Sag/Dip Compensation Method

The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition, so that the load voltage can be restored back to the pre-fault condition. Compensation of voltage sags in the both phase angle

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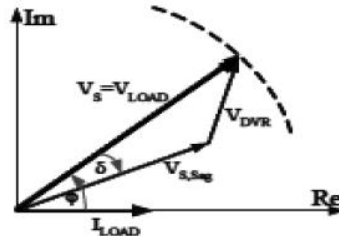


Figure 4. Pre-Sag compensation

and amplitude. Sensitive loads would be achieved by pre-sag compensation method as shown in Figure 3. In this method the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions. The voltage of DVR is given below:

$$VDVR = V_{pre\ fault} - V_{sag}$$

(b) In-Phase Compensation Method

In this method the injected voltage is in phase with the supply side voltage irrespective of the load current and pre-fault voltage as shown in Figure 5. The phase angles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage are satisfied. The load voltage is given below: $|VL| = |V_{pre-fault}|$ One of the advantages of this method is that the amplitude of DVR injection voltage is minimum for certain voltage sag in comparison with other strategies. Practical application of this method is in non-sensitive loads to phase angle jump.

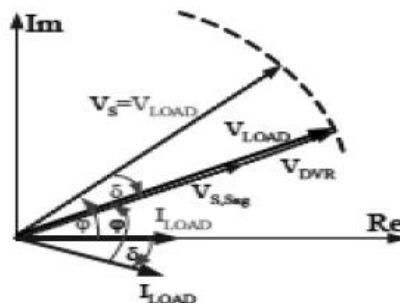


Figure 5. In-phase Compensation
 (Magnitude compensation only)

(c) Voltage Tolerance Method with Minimum Energy Injection

A small drop in voltage and small jump in phase angle can be tolerated by the load itself. If the voltage magnitude lies between 90%-110% of nominal voltage and phase angle variations between 5% -10% of nominal state that will not disturb the operation characteristics of loads. Both magnitude and phase are the control parameter for this method which can be achieved by small energy injection. In this method, the phase angle and magnitude of corrected load voltage within the area of load voltage tolerance are changed.

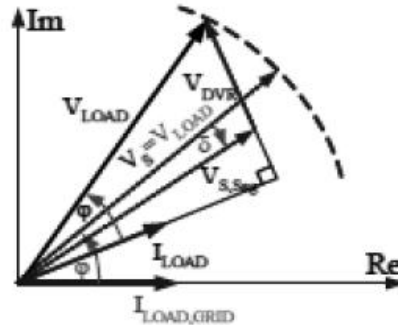


Figure 6. Voltage Tolerance Method

The small voltage drop and phase angle jump on load can be tolerated by load itself. The sensitivity of loads to phase angle jump and voltage magnitude is different.

IV. SAG DETECTION TECHNIQUES

A voltage sag detection technique detects the occurrence of the sag, the start point, the end point, sag depth (magnitude to be restored) and phase shift. Common voltage sag detection techniques are summarized as follows [11-12]:

A. Peak value method

The simplest method of monitoring the supply is to monitor the peak, or amplitude, of the supply voltage, then comparing it with a reference. A controller could be set to recognize if there is a difference greater than a specified value (10%) and switch in the inverter.

B. Root Mean Square (rms) method

The start time of the sag can be defined as the first point of V_{rms} when drops below 0.9pu. To find the end time of the sag, search for an interval where V_{rms} drops below 0.9pu for at least half a cycle. The recovery time is then chosen as the first point in this interval.

C. Fourier Transform (FT)

The FT is achieved through orthogonal decomposition of power system signal. In general, a trigonometrically orthogonal function set or exponential orthogonal function set is utilized. By applying FT to each supply phase, it is possible to obtain the magnitude and phase of each of the frequency components of the supply waveform. For practical digital implementation Windowed Fast Fourier Transform (WFFT) is used, which can easily be implemented in real time control system. The only drawback of this method is that it takes one cycle to return the accurate information about the sag depth and its phase, since FT uses an averaging technique.

D. Space Vector method

The three phase voltages V_{abc} are transformed into a two dimension voltage V_{dq} , which in turn can be transferred into magnitude and angle. Any deviation in any quantity reveals the occurrence of an event. Comparing these quantities with reference ones will quantify the disturbance in the dq-frame, which had to be transformed back to the abc frame. This method has no time delay, yet requires complex controller.

It appears that the nonlinear controller is more suitable than the linear type since the DVR is truly a non-linear system due to the presence of power semiconductor switches in the inverter bridge. The most non-linear controllers are the Artificial Neural Networks (ANN), Fuzzy Logic (FL) and Space Vector Pulse Width Modulation (SVPWM) [19-24].

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ANN control method has adaptive and self-organization capacity. The ANN has inherent learning capability that can give improved precision by interpolation. FL controllers are an attractive choice when precise mathematical formulations are not possible. When a FL controller is used, the tracking error and transient overshoots of PWM can be considerably reduced. SVPWM control strategy is to adopt a space vector of the inverter voltage to get better performance of the exchange is gained in low switching frequency conditions.

V. CONTROL TECHNIQUES

A. Linear Controllers

The three main voltage controllers, which have been proposed in literature, are feed forward (open loop), Feedback (closed loop) and Multi-loop controller [13-18]. The feed-forward voltage controller is the primary choice for the DVR, because of its simplicity and fastness. The supply voltage is continuously monitored and compared with a reference voltage; if the difference exceeds a certain tolerance, the DVR injects the required voltage. The drawback of the open loop controller is the high steady state error. In the feedback control, the load voltage is measured and compared with the reference voltage; the missing voltage is supplied by the DVR at the supply bus in a feedback loop. This controller has the advantage of accurate response, but it is complex and time-delayed. Multi-loop control is used with an outer voltage loop to Control the DVR voltage and an inner loop to control the load current. This method has the strengths of feed-forward and feedback control strategies, on the expense of complexity and time delay.

B. Non-linear Controllers

It appears that the nonlinear controller is more suitable than the linear type since the DVR is truly a non-linear system due to the presence of power semiconductor switches in the inverter bridge. The most non-linear controllers are the Artificial Neural Networks (ANN), Fuzzy Logic (FL) and Space Vector Pulse Width Modulation (SVPWM) [19-24]. ANN control method has adaptive and self-organization capacity. The ANN has inherent learning capability that can give improved precision by interpolation. FL controllers are an attractive choice when precise mathematical formulations are not possible. When a FL controller is used, the tracking error and transient overshoots of PWM can be considerably reduced. SVPWM control strategy is to adopt a space vector of the inverter voltage to get better performance of the exchange is gained in low switching frequency conditions.

VI. RESULT AND DISCUSSION

In order to show the performance of the DVR in voltage sags mitigation, a simple radial distribution network is simulated using MATLAB/SIMULINK. and shown in fig 7. The parameters of the main components are listed in the Table

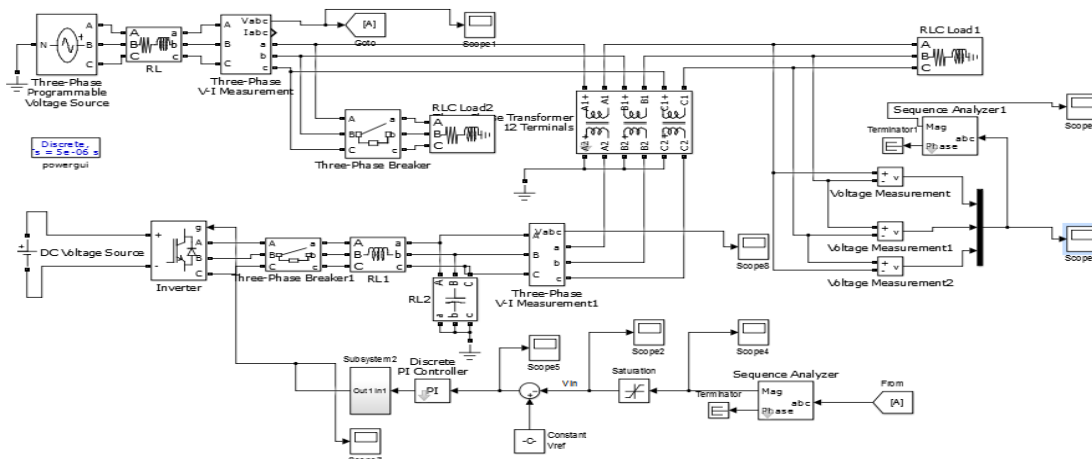


Figure 7 Model Figure



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A Three-phase 15 kV, 50Hz programmable voltage source is connected to a feeder and it is step down to 415V, 50 Hz through 15kV/415V transformer at Point of Common Coupling (PCC).

The DVR is connected in series between PCC and the nonlinear load with the help of an injection transformer .The primary side of injection transformer is connected in series with the load and secondary side is connected in delta to the DVR.A three phase fault is applied to the system in order to see the voltage sag. The DVR uses self-commutating IGBTsolid-state power electronic switches to mitigate voltage sags in the system. The voltage controlled three single-phase full bridges PWM inverters are used to produce compensating voltage. These inverters are connected to the common DC voltage source. The DC voltage source is an external source of supplying DC voltage to the inverter for AC voltage generation.

Table-I
TEST SYSTEM PARAMETERS

Sr. No	Parameter	Rating
1	Supply Voltage	15kV
2	Load transformer rating	6.6KVA
3	DC Bus battery Amplitude	2600V
4	Filter inductance	0.0225H
5	Filter capacitance	0.02F
6	Load resistance	0.001Ohms
7	Load inductance	0.002H

The basic function of the DVR is to inject a dynamically controlled voltage into the bus voltage by means of an voltage injection transformer. 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 disturbances in the ac feeder will be compensated by an equivalent voltage. The DVR works independently to any of the type of fault or any event that happens in the system

Highly inductive load are applied to the test system to analyse the performance of DVR. Such faults are applied to the system during 50-150ms. Due to this voltage sag will occur.

Fig 5.1(a) shows the load voltage without DVR when a highly inductive load is applied and it is observed that 85% Voltage sag is initiated at 0.05s and it is kept until 0.15s, with total voltage sag duration of 0.1s. Fig 5.1(b) shows the RMS Voltage without DVR. Due to the condition.

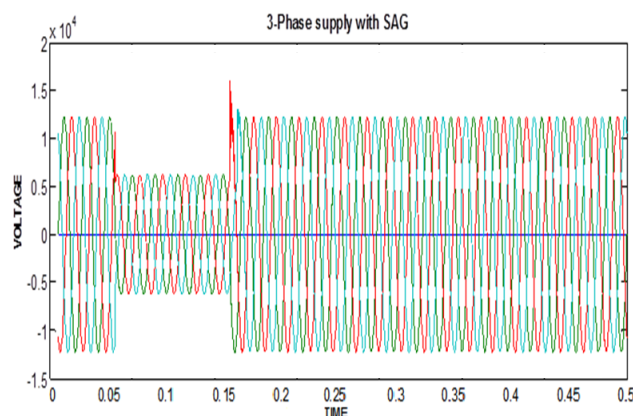


Fig5.1 (a) Load voltage without DVR

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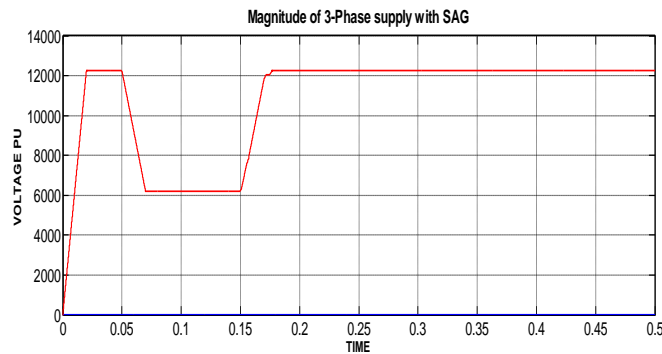


Fig 5.1(b) RMS Voltage without DVR.

Now DVR with the proposed controls scheme is connected to the system. Fig 5.2 (a) shows the injected voltage by the DVR with PI controller during 0.2ms to 0.25ms to the system with the help of injection transformer in order to maintain the load voltage constant.

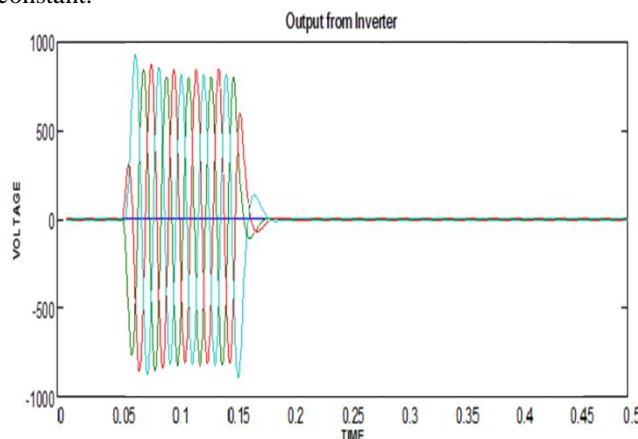


Fig 5.2 (a) Injected voltage by the DVR

The amplitude index is kept fixed at 1pu, in order to obtain the highest fundamental voltage component at the controller output.

$$k = \frac{V_{\text{Control}}}{V_{\text{Trin}}} = 1 \text{ pu}$$

V_{Control} is the peak amplitude of the control signal

V_{Trin} is the peak amplitude of the triangular signal

The switching frequency is set at 1035Hz. The frequency modulation index is given by,

$$m_f = \frac{f_s}{f_1} = \frac{1035}{50} = 20.7$$

Where f_1 is the fundamental frequency?

The modulating angle is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 120° and 240°, respectively [10-11]. It can be seen that the control implementation is kept very simple by using only voltage measurements as the feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the simulation results. Fig 5.3 Pulses generated by Discrete PWM Generator. Fig 5.4 shows that the input of PI controller.

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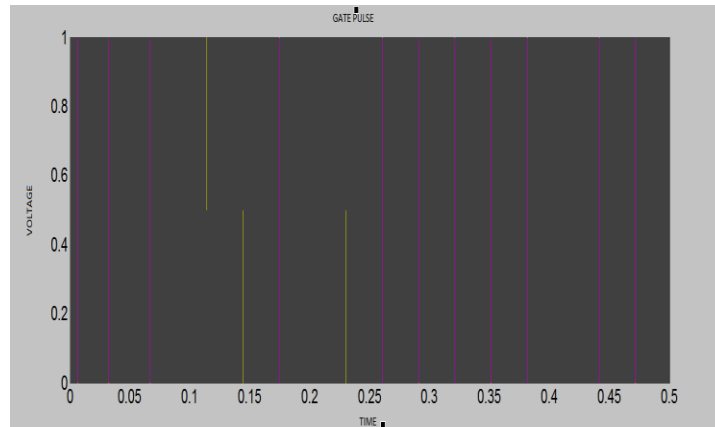


Fig 5.3 Pulses generated by Discrete PWM Generator..

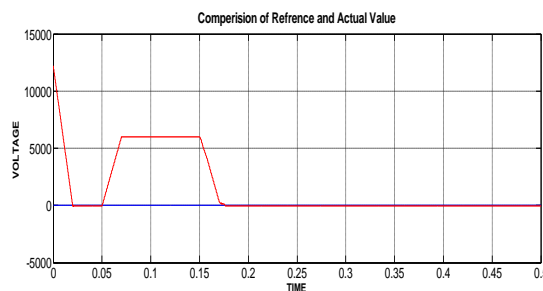


Fig 5.4 Input of PI controller

Fig 5.4(a) shows the load Voltage after compensation with PI controller... Here the load voltage is 98% of the supply voltage. Fig 5.4(b) shows the load RMS Voltage after compensation using PI controller. Here RMS voltage is maintained to 98% at the sensitive load point. From the below figures it is concluded that using PI controller performance of DVR is more satisfactory then the conventional method

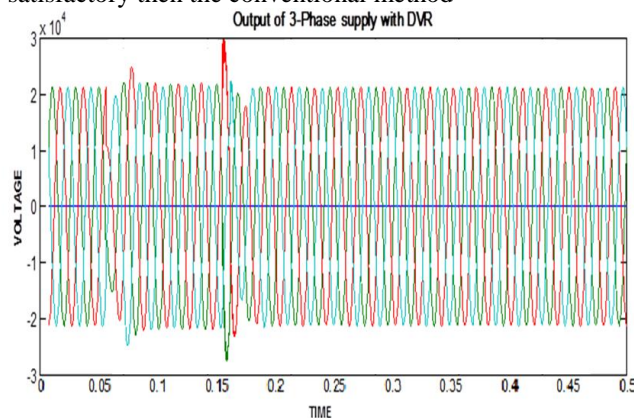


Fig 5.4(a) Load Voltage after compensation with DVR.



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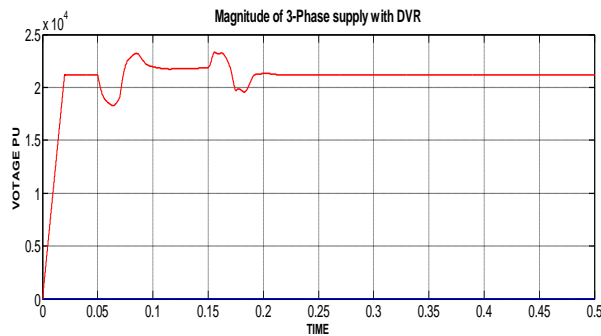


Fig 5.4(a) RMS Voltage after compensation with DVR.

VII.CONCLUSION

In this paper the main objectives for the utilization of the studied equipment to mitigate the voltage sag. In order to protect critical loads from more severe fault in distribution network. The facility available in MATLAB/SIMULINK is used to carry out extensive simulation study. Supply voltage is compared with reference voltage to get error signal which is given to the gate pulse generation circuit as a reference sine wave which is compared with carrier signal to get pulses for inverter. Voltage sag values are major factors in estimating the DC storage value. The effectiveness of a DVR system mainly depends upon the rating of DC storage rating and the percentage voltage sag. In the test system it is observed that after a particular amount of voltage sag, the voltage level at the load terminal decreases.

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