Compensation of Voltage Sag and Swell by Unit Vector Template Generation Technique and Synchronous Reference Frame Theory for Dynamic Voltage Restorer

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Abstract— This paper includes development of voltage control scheme that can compensate voltage sag and swell in three-phase power systems. Faults occurring in power distribution systems cause the voltage sag or swell. If a fault occurs or Heavy inductive loads are switched then the system experiences voltage sag and voltage swell problems. For sensitive loads, even voltage sags of short duration can cause serious problems in the entire system. Normally, a voltage interruption triggers a protection device, which causes shutdown of the entire system. In order to mitigate voltage sag and voltage swell, this research proposes a scheme called “DYNAMIC VOLTAGE RESTORER (DVR)”. The proposed scheme is able to quickly recognize the voltage sag and swell, and it can correct the voltage by either boosting the input voltage during voltage sag events or reducing the input voltage during voltage swell events. Among existing methods, the scheme based on the inverter system requires an inverter, a transformer, a liner control scheme. The proposed scheme can be applied at any voltage and provides cost and size advantages over existing methods. Simulations have been carried out to verify the validity of the proposed scheme.

Key words: DVR (Dynamic Voltage Restorer); SRF (Synchronous Reference Frame); UVTG (Unit Vector Template Generation); VSC (Voltage Source Converter)

I. INTRODUCTION

Due to some internal or external faults at the distribution side, the voltage level of the utility side becomes poor. The main voltage distortions are voltage sag, voltage swell, unbalanced voltage, voltage harmonics and voltage flickering. This will affect the utility side power quality. So, we can improve the power quality using DVR. DVR uses SRF theory based control and UVTG Technique based control for identification and clearance of disturbances. DVR action stable condition, whenever distort ion is not there. DVR injecting voltage through a n injection transformer at the Point of common coupling (PCC) [7]. DVR injected voltage compensates the three phase distortions in the utility.

II. DYNAMIC VOLTAGE RESTORER (DVR)

DVR is a normal three phase inverter with 120^0 or 180^0 conduction mode. It consists of six pulses, in which three pulses for positive control and the other three pulses for negative control. It comes with a DC link which stores the energy whenever it is in stable condition. Here the DVR working operation is simulated through professional SIMULINK of software called MATLAB/SIMULINK. It provides the exact operation of the device. Here the three phase distortion is created on the utility side to analyze the operation of the DVR. In this work two different control strategies are introduced for generation of gate pulses and control of DVR. The gate pulses are given by using the Hysteresis Voltage Control. The block diagram for DVR with grid connection is given in Fig.1.

III. BASIC STRUCTURE OF DVR

The general model of DVR consists of :

a) Voltage Source Converter (VSC)
b) An Injection/ Booster transformer
c) 1) Unit Vector Template Generation
   2) Synchronous Reference Frame Theory
d) Hysteresis Voltage Controller
e) DC link

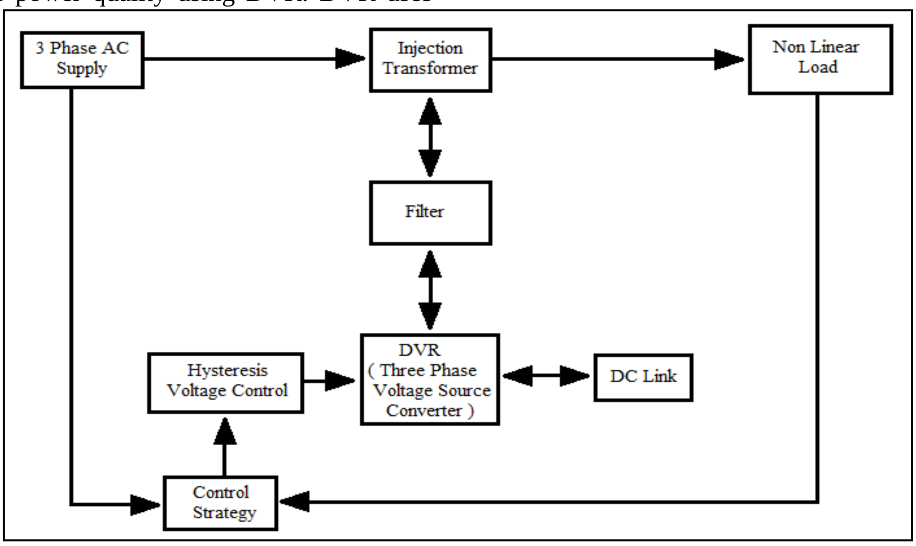

Fig. 1: Block Diagram of DVR

A. Voltage Source Converter (VSC):

A VSC is a power electronic converter consists of a dc link storage and Thyristor based switching devices, which can create a sinusoidal voltage for our need. In DVR application, VSC is used to momentarily change the utility voltage or to create the required part of the utility voltage which is missing. There are four main kinds of switching devices they are Gate Turn-Off Thyristor- GTO, Metal Oxide Semiconductor Field Effect Transistor- MOSFET, Insulated Gate Bipolar Transistor - IGBT and Integrated G ate Commutated Thyristor- IGCT. Each type has its own advantages and limitations. The IGCT is a modern compact device with superior performance and reliability that allows constructing VSC with very large power ratings. Because of the highly refined converter design with IGCTs, the DVR can compensate distortions which are beyond the capability of the earlier DVRs using conventional devices. The purpose of storage devices is to give the essential energy to the VSC through the dc link for the generation of injected voltages.

B. Injection/ Booster Transformer:

The Injection/Booster transformer is a specifically designed transformer that efforts to limit the coupling noise from the primary side to the secondary side. Its main responsibilities are:

It connects DVR to the distribution side via the High voltage windings and transformers, windings having the ratio of 1:1 and couples the injected compensating voltages created by the voltage source converters to the incoming utility voltage.

In addition to that, Injection/Booster transformer works for the purpose of isolating the load from the utility disturbances.

The necessary voltage which is generated by VSC so that the voltage at load side is perfectly balanced and regulated. The series transformer turns ratio should be suitable so that injected voltage is such that it injects a compensating voltage which will completely make the load side voltage balanced.

C. 1) Unit Vector Template Generation

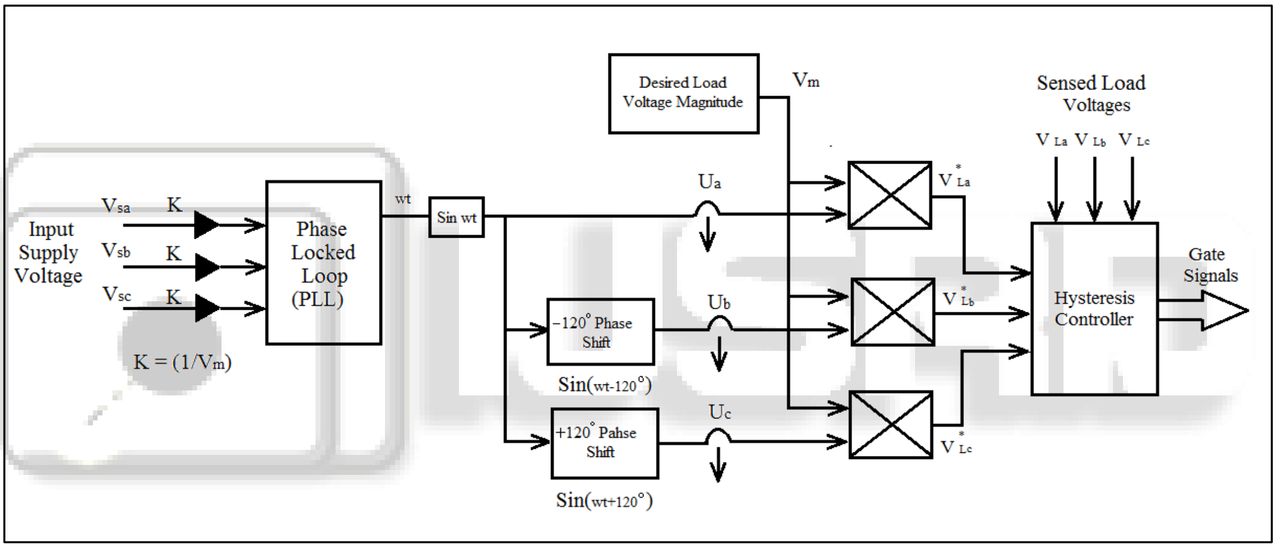

Fig. 2: Control Block Diagram of DVR Using UVTG

The control block diagram of DVR for generating reference voltage signal using UVTG is shown in Fig.2.

The component of series APF is controlled to appropriate voltage between the point of common coupling (PCC) and load so, that the load voltage becomes balanced, distortion free and maintain desired magnitude. The three phase input source voltage may be distorted or any other power quality problems are present at point of common coupling (PCC). To get unit vector template signal the input source voltage is sensed and multiplied by gain equal to $1/V_m$. (V_m is equal to peak amplitude of fundamental voltage). The phased locked loop (PLL) is used to achieve synchronization with supply voltage. The extraction of three-phase voltage reference signal for series APF is based on unit vector template generation (UVTG) is achieved by using phased locked loop (PLL) is given by equation:

$$U_a = \sin(\omega t) \quad (1)$$

$$U_b = \sin(\omega t - 120^\circ) \quad (2)$$

$$U_c = \sin(\omega t + 120^\circ) \quad (3)$$

Now multiplying the peak amplitude of fundamental input voltage with unit vector template generation (UVTG) of equation (1,2&3) gives the reference load voltage signal which is given by equation

$$V^*_{Labc} = V_m * U_{abc} \quad (4)$$

For getting distortion free load voltage (V_{Labc}), this load voltage must be equal to reference load voltage (V^*_{Labc}). The sensed load voltage (V_{Labc}) and reference load voltage (V^*_{Labc}) are compared in hysteresis controller to generate switching signals to the switches of series APF [9].

2) Synchronous Reference Frame Theory

The series active filter based on SRF method can be used to solve the voltage related power quality problems such as, voltage sag, voltage swell and voltage harmonics. The SRF method is used in series active filter for generating reference voltage signal. The supply voltages are transformed into d-q-0, which is given by equation below.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$

Where, ωt is the transformation angle and V denotes voltages. In the SRF ωt is a time varying angle. The angle ωt represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase AC voltage. Synchronous Reference Frame method (SRF) is one of the most common and probably it is the best method.

To implement the SRF method and for reference voltage calculation the phase locked loop (PLL) is used to generate the transformation angle (ωt) which presents the angular position of the reference frame. This transformation presents is known as park transformation. Figure 3 Shows the Control block diagram of SRF theory for generating voltage reference signal in Series APF. The source voltages from a-b-c coordinates are transformed to d-q-0 coordinates. Then the d axis component is passed through low pass filter to obtain the reference source voltage in d-q coordinates. [13].

The inverse park transformation is used for generating reference voltage signal which is given in equation below.

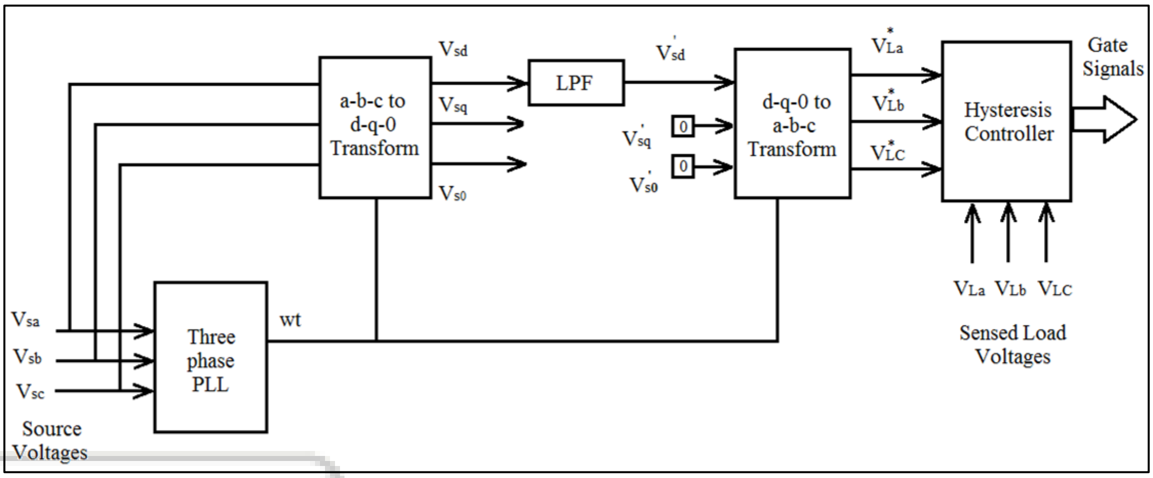

Fig. 3: Control Block Diagram of DVR Using SRF

$$\begin{bmatrix} V^*_{La} \\ V^*_{Lb} \\ V^*_{Lc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & \frac{1}{\sqrt{2}} \\ \sin\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ \sin\left(\omega t + \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix}$$

After generating reference load voltages, the reference load voltages and sensed load voltages are compared and this is given to the hysteresis controller. The pulses are generated by the Hysteresis controller are given to the VSC.

D. Hysteresis Voltage Controller

Hysteresis-band PWM is basically an instantaneous feedback voltage control technique of PWM where the actual voltage continually tracks the command voltage within a hysteresis band. Fig. 4 explains the operation principle of hysteresis band PWM. The control circuit generates the sine reference voltage wave of desired magnitude and frequency, and it is compared with actual voltage wave.

As the voltage exceeds an upper hysteresis band, the upper switch in half bridge is turned off and lower switch is turned on. As a result, the output voltage transition from +V_{dc} and-V_{dc}. In same way as voltage crosses the lower band limit, the lower switch is turned off and the upper switch is turned on.

In comparison with other control technique hysteresis voltage control has a very fast response and simple operation but the disadvantage of this method is variable switching frequency.

In Fig.5 shows the comparison between the reference load voltage (V_L^*) and sensed load voltage (V_L) and the generating error is given to hysteresis band which generates switching instants of series voltage source converter.

The control scheme decides the switching pattern of series active filter in such a way to maintain the actual load voltage of the filter to remain within a fixed hysteresis band (HB) as indicated [9].

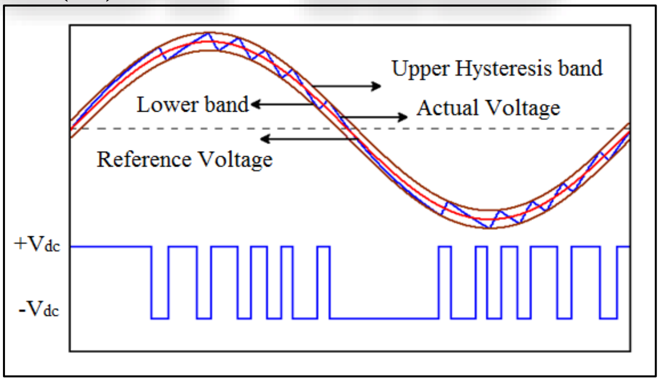

Fig. 4: Hysteresis Voltage Control Technique

The switching logic is formulated as follows

$$V_L = V_L^* - HB \quad (5)$$

$$V_L = V_L^* + HB \quad (6)$$

Where,

V_L = Actual Load Voltage

V_L^* = Reference Load Voltage

HB = Hysteresis band

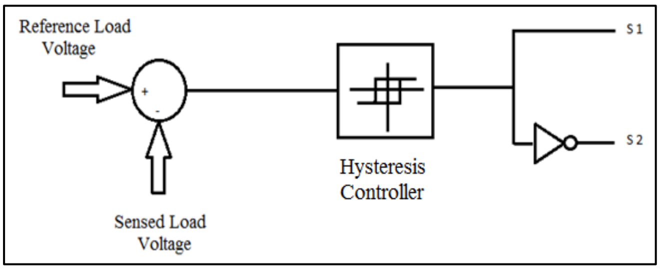

Fig. 4: Hysteresis Voltage Control

The switching frequency of the hysteresis voltage control method described above depends on how fast the voltage changes from upper limit to lower limit of the hysteresis band. Therefore, the switching frequency does not remain constant throughout the switching operation, but varies along with the voltage waveform.

E. DC Link

The dc link has two main tasks:

– The first task is to charge the dc link source during stable operation.
– The second task is to keep dc link voltage at the nominal range.

IV. PARAMETERS OF SYSTEM

Supply Voltage	415 V
Line Frequency	50 Hz
Source impedance	R = 0.01Ω & L = 0.01 mH
Load impedance	R = 50Ω & L = 1 mH
Series Transformer turns ratio	1:1
DC Voltage	415 V

Table 1: PARAMETERS OF TEST SYSTEM

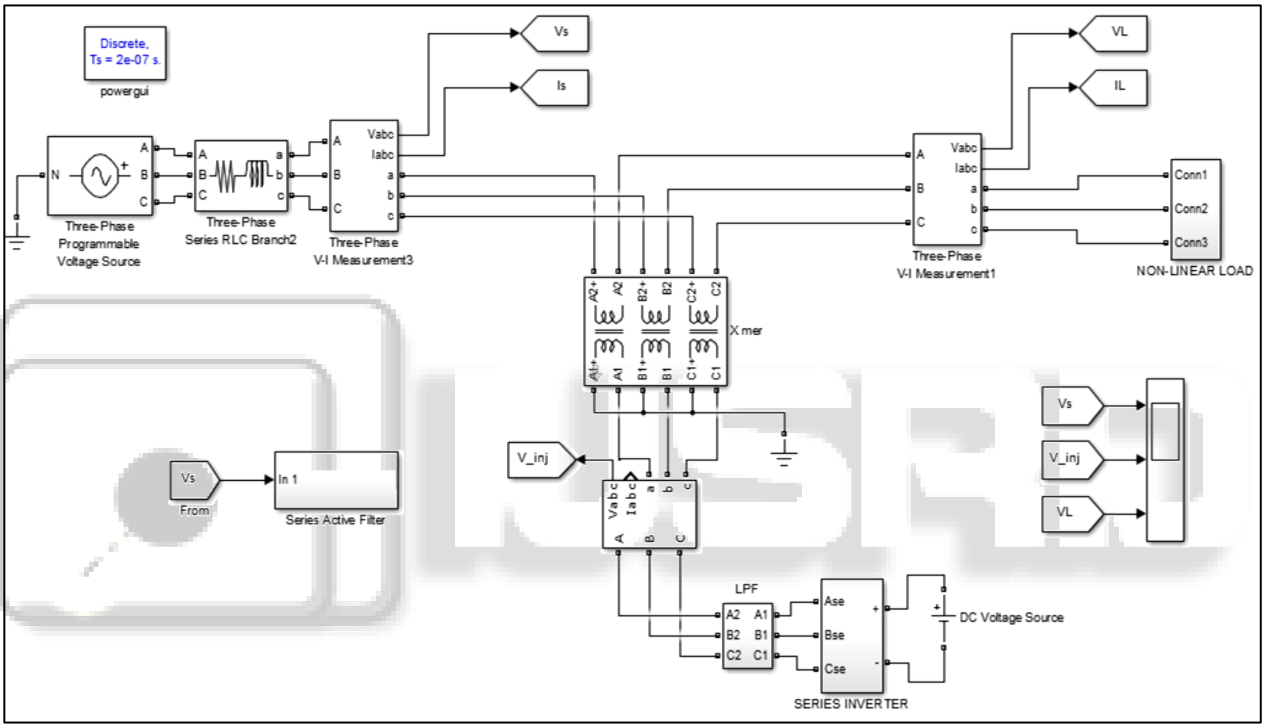

Fig.6.Simulation block diagaram

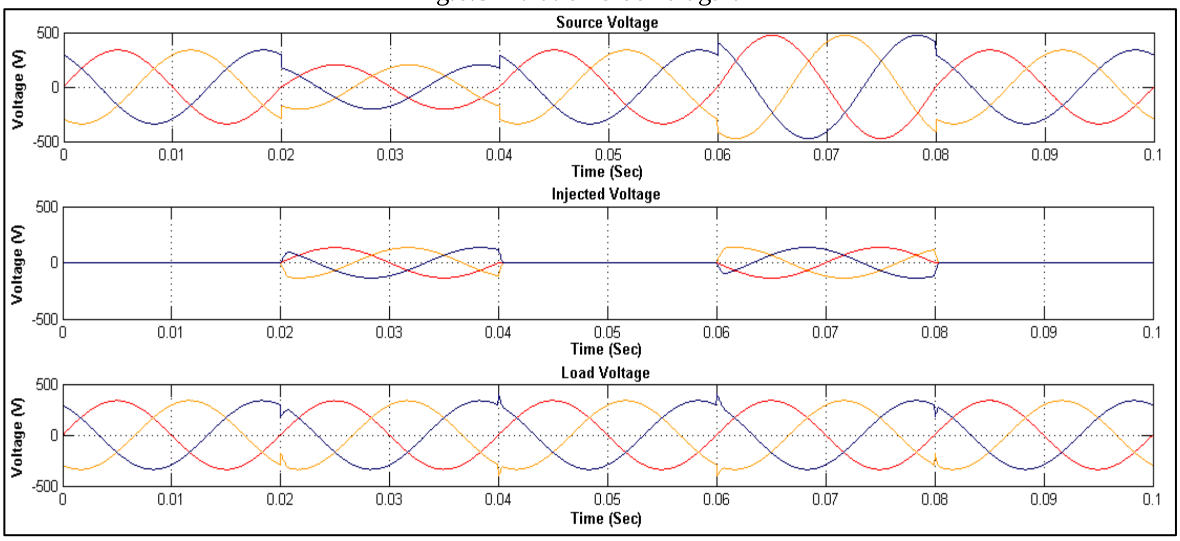

Fig. 7: Voltage waveform during Sag and Swell using UVTG

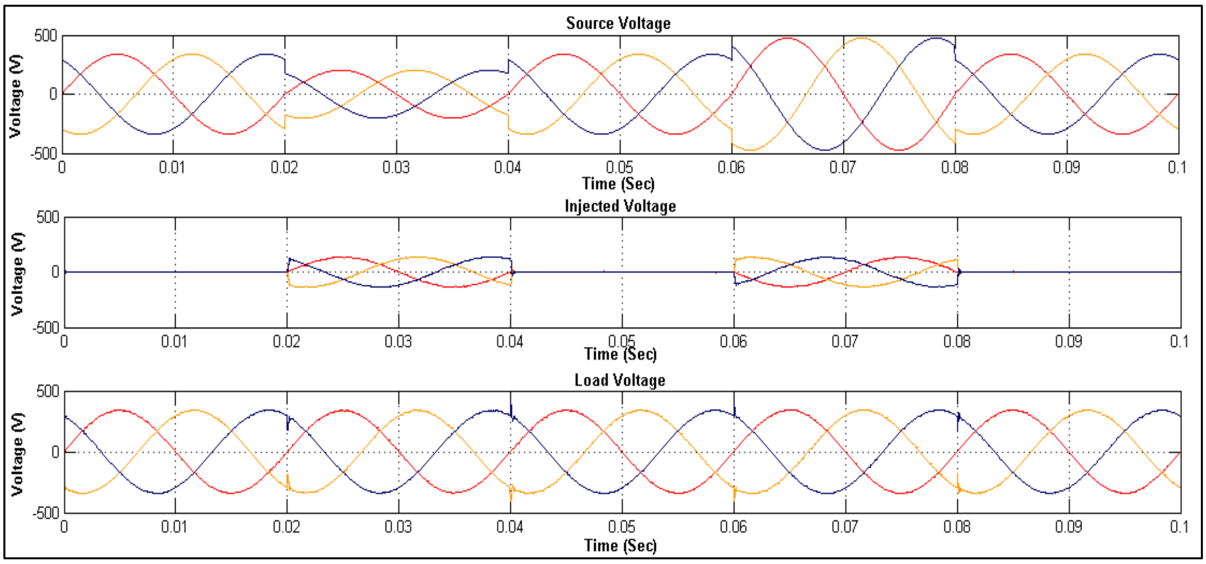

Fig. 8: Voltage waveform during Sag and Swell using SRF

DVR is used to mitigate all problems related to voltage unbalance and disturbance. It mitigate the voltage unbalance in source voltage i.e. voltage dip/rise so that the load voltage become perfectly balanced and regulated.

V. RESULTS & COMPARISON

As given in Fig.7 it is the source voltage and load voltage during sag and swell condition with UVTG technique. Sag time interval is 0.02 sec to 0.04 sec and swell time interval is 0.06 sec to 0.08 sec. The sag is due to voltage unbalance that may be caused due to faults and swell may be due to faults or capacitor switching. During the periods of voltage sag and voltage swell the voltage is injected in series with the line during 0.02 to 0.04 sec and 0.06 to 0.08 sec. In Fig.7 the load voltage of series APF during sag and swell is given. Due to operation of series APF the voltage sag from time interval 0.02 sec to 0.04 sec and voltage swell from 0.06 sec to 0.08 sec are removed and the load voltage becomes completely balanced. Now the voltage is completely balanced in whole interval of time. As given in Fig. 8 it is the source voltage and load voltage during sag and swell condition with SRF theory. Sag time interval is 0.02 sec to 0.04 sec and swell time interval is 0.06 sec to 0.08 sec.

VI. CONCLUSIONS

Power quality measures can be applied both at the user end and also at the utility level. The work identifies some important measures that can be applied at the utility level without much system upset (or design changes).This paper has presented models of custom power equipment, namely DVR and applied them to mitigate voltage dip and Voltage rise which are very prominent as per utilities are concerned. The highly developed graphic facilities available in MATLAB SIMULINK were used to conduct all aspects of model implementation and to carry out extensive simulation studies on test systems. In Simulation As compared to UVTG (Unit Vector Template Generation) the SRF (Synchronous Reference Frame) Technique is giving better voltage profile. This characteristic makes it ideally suitable for low-voltage custom power applications.

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