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Control of Dynamic Voltage Restorer (DVR) Using Instantaneous Symmetrical Component for Voltage Sag/Swell Mitigation

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Abstract— Power quality is one of the major concerns in the era of power system. To overcome this problem, Dynamic Voltage Restorer (DVR) is used, which eliminate voltage sag and swell in the distribution line, it is efficient and effective power electronic device. The size of DVR is small, cost is low and fast dynamic response to the disturbance. By injecting an appropriate voltage, the DVR restores a voltage waveform and ensures constant load voltage. The compensating signals are determined dynamically based on the difference between desired and measured values. The proposed control strategy is simulated in MATLAB software using simulink and sim power system toolboxes.

Keywords - Power quality, Dynamic Voltage Restorer (DVR), Instantaneous symmetrical component, Unit templates, Voltage Source Converter (VSC), Voltage sag/swell.

I. INTRODUCTION

Modern power system is complex power network, where hundreds of generating loads and thousands of loads are interconnected through transmission or distribution networks. The main concern to the customer is to provide reliable and quality of power supply. But in develop country, the generation of power supply is fairly reliable, quality of power may poor. The ideal power supply system provides their customer uninterrupted flow of energy with smooth sinusoidal voltage at contracted voltage magnitude and frequency. The power quality problem occurred due to the voltage sag, surge, flicker, voltage imbalance, interruption and harmonic problem [1,2,3]. And it may cause problem to the industries from malfunctioning of equipment to the complete shutdown of the plant. Voltage sag/swell occurs as a result of load switching, motor starting, faults, non-linear loads, Lightning etc. It has major impact on microprocessor based loads as well as the sensitive loads.

IEEE 519-1992 and IEEE 1159-1995 “IEEE recommended practice for monitoring electric power quality” describe the voltage sag/swell as shown in Table 1. [1]

Table 1. Definitions for voltage sag and swell

Type of Disturban	Voltage	Duration
Voltage Sag	0.1 – 0.9 p	0.5 – 30 cycles
Voltage Swell	1.1 – 1.8 p	0.5 – 30 cycles

Several recent surveys attributes that 92% of the all disturbances in electrical power distribution system are due to voltage sags [13]. The dynamic voltage restorer (DVR) has been proposed to protect sensitive loads from such voltage sags. It is a series connected custom power device, which is considered to be cost effective compared to other alternative voltage sag compensation devices. The location of DVR is shown in fig-1.

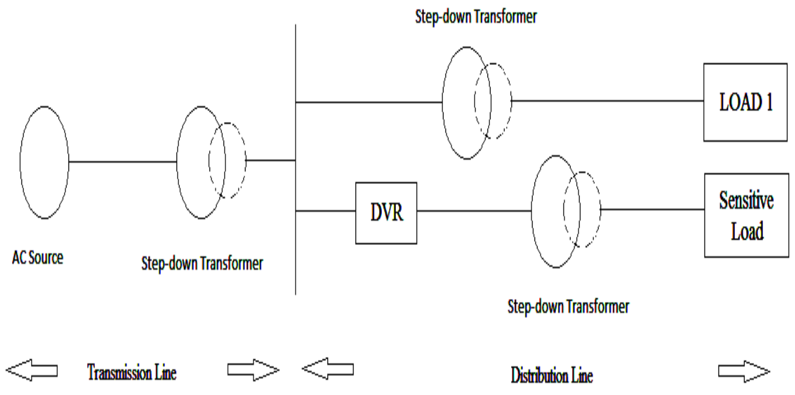

Figure 1. Location of DVR

The main function of the DVR is to maintain the supply voltage constant, if any sag or swell occurs balance voltage is injected. To achieve this functionality reference voltage waveform is generated which is similar in magnitude and phase angle to that of supply waveform. Therefore by comparing reference and actual voltage waveform any abnormality can be detected.

II. BASIC COMPONENTS OF DVR

The Dynamic Voltage Restorer (DVR), is also referred to as Series Voltage Booster (SVB) or the Static Series Compensator (SSC), is a device utilized solid state power electronic components, and it is connected in series with distribution circuit. The DVR consist of an Injection/Booster transformer, a Harmonic Filter, a Voltage Source Converter (Power converter), DC charging circuit and Control and Protection circuit as shown in the block diagram of DVR in fig. 2.

The first DVR was installed in North Carolina, for the rug manufacturing industry [11]. Another was installed to a large dairy food processing plant in Australia [13]. Its primary function is to rapidly boost up the voltage at load side in case disturbance to that load. There are various circuit topologies and control scheme are used to implement the DVR.

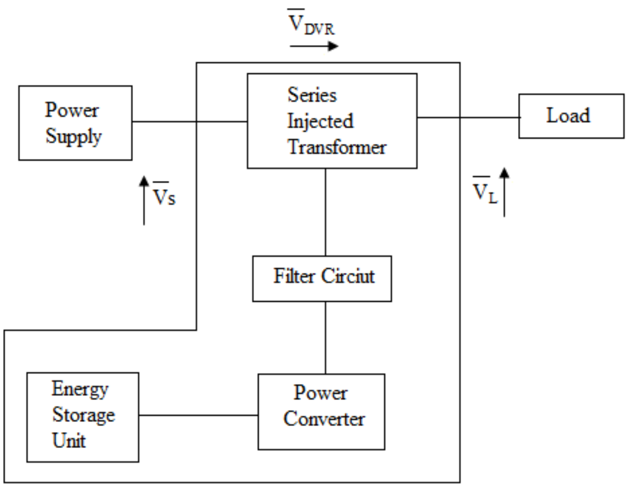

Figure 2. Block diagram of DVR circuit

The basic function of the DVR is to detect any voltage sag/swell occurred in the power line and injects the balance voltage from the DVR. This is achieved either by absorbing or injecting active or reactive power [9].

A. DC energy Storage device

It is used to supply the real power requirement for the compensation during voltage sag. Lead-acid batteries, Super Conducting Magnetic Energy Storage (SMES), Flywheels and Super capacitors can be used as the storage devices. For DC drives such as capacitors, batteries and SMES, DC to AC conversion (inverters) are needed to deliver power, whereas for flywheel, AC to AC conversion is required [4,5,8].

B. Voltage Source Inverter (VSI)

The basic function VSI is to convert DC voltage supplied by the energy storage device to an AC voltage. This is coupled to an injection transformer to the main system. Thus a VSI with low voltage rating is sufficient [4,8].

C. Passive Filter

It is used to convert PWM pulse waveform in to sinusoidal waveform. It consists of an inductor and a capacitor. It can be placed either high voltage side or low voltage side of the injection transformer. By placing it inverter side higher order harmonics are prevented from passing through the voltage transformer. And it will reduce stress on the injection transformer. When the filter is placed on the high voltage side, the higher order harmonic current do penetrate to the secondary side of the transformer, a higher rating of the transformer is required [4,8].

D. Voltage Injection Transformer

The basic function is to increase the voltage supplied by the filtered VSI output to the desired level. The high voltage side of the injection transformer is connected in series to the distribution line and low voltage side is connected to the power circuit of the DVR. In this study single phase injection transformer is used. For three has DVR, three single phase transformer can be connected either in delta/open or star/open configuration.

E. By-pass Switch

The DVR is series connected device, if fault current that occur due to fault in the downstream will flow through the inverter circuit [10]. The power electronic component are rated to the load current hence to protect the inverter from higher current, a by-pass switch is used and it is located between the inverter and the isolating transformer.

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III. DVR COMPENSATION TECHNIQUES

A compensation method by means of a DVR depends upon limiting factors such as; DVR power rating, various conditions of load, and different types of voltage sags. Compensation is achieved via real and reactive power injection. Basically three types of methods are used in the DVR which is defined and discussed below.

A. Pre-sag Compensation

This method is recommended for the non-linear loads which needs both voltage magnitude as well as phase angle to be compensated. The DVR supplies the difference between the pre-sag and the sag voltage, thus restore the voltage magnitude and phase angle to that of the pre-sag value. Figure 3 describes the pre-sag compensation. Drawback of this method is that it requires higher capacity energy storage device as well as large voltage injection transformer [5].

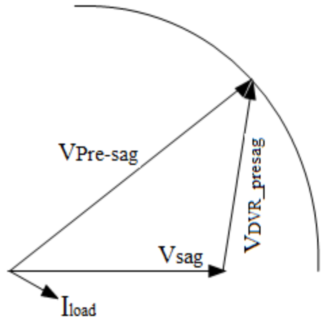

Figure 3. Pre-sag compensation technique

$$V_{DVR} = V_{Pre\text{-}sag} - V_{Sag}$$

B. In-phase compensation

Only voltage magnitude compensate in this method. The compensated voltage is in phase with the sagged voltage, therefore this technique minimize the voltage injected by the DVR. This technique is shown in figure 4, there is phase shift between the voltage before the sag and after the sag. It is recommended for the linear loads.

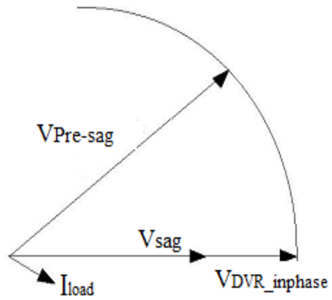

Figure 4. In-phase compensation technique

C. Energy optimization technique

In this technique the use of real power is minimized by injecting voltage by the DVR is at a 90^0 phase angle to the load current. It is shown in the figure 5, the injected voltage will be higher than that of in-phase compensation technique.

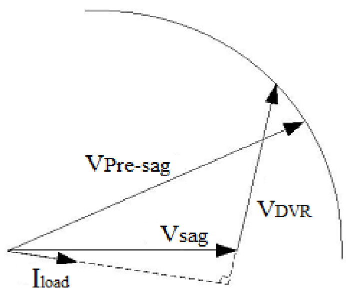

Figure 5. Energy optimized compensation technique

IV. PROPOSED CONTROL TECHNIQUE

Instantaneous symmetrical components reflect the instantaneous change in supply voltage and so it is used to detect the disturbance in power system. The proposed control technique based on unit template technique and instantaneous symmetrical component along with complex fourier transform is shown in figure 8[15].

The reference load voltage for driving the IGBT is derived as follow :

$$V_{La}^{*} = V_{ta1} - V_{ad} + V_{aq}$$
$$V_{Lb}^{*} = V_{tb1} - V_{bd} + V_{bq}$$
and,
$$V_{Lc}^{*} = V_{tc1} - V_{cd} + V_{cq}$$

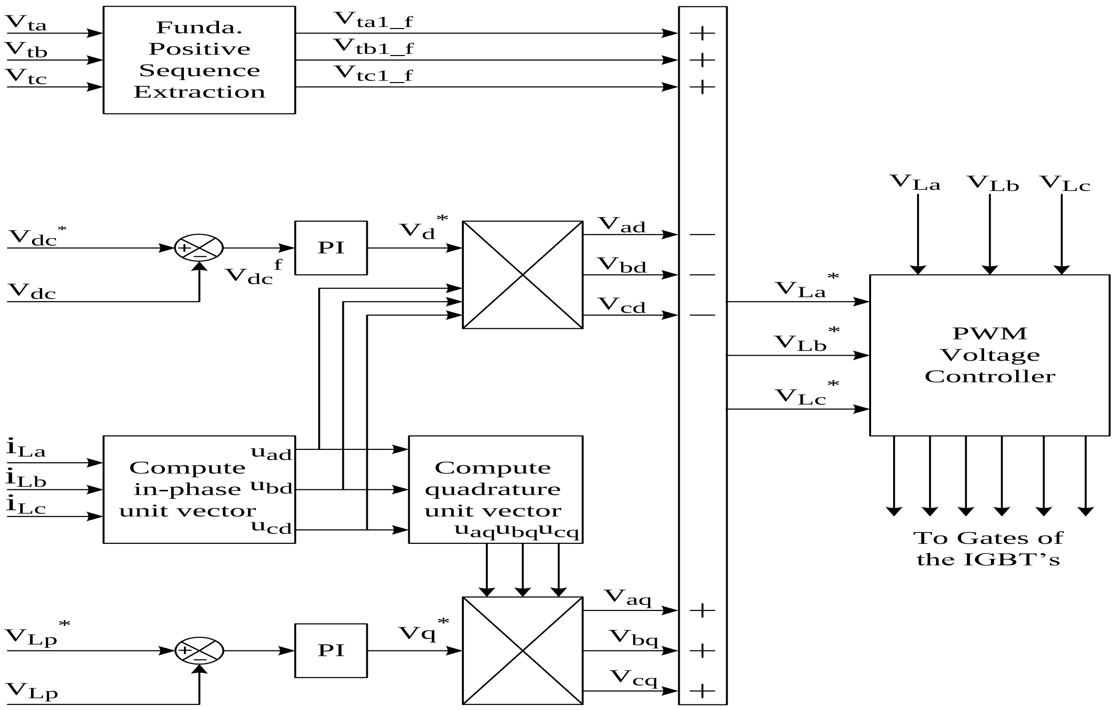

Figure 6. Block diagram of proposed control algorithm

The instantaneous symmetrical components are defined for three instantaneous voltages as follow:

$$\begin{bmatrix} Vta0 \\ Vta1 \\ Vta2 \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} Vta \\ Vtb \\ Vtc \end{bmatrix}$$

where, $a=e^{j120}$ and V_{ta0}, V_{ta1} and V_{ta2} are zero, positive and negative sequence voltage respectively.

The fundamental positive sequence source voltages denoted by V_{ta1_f}. This can be computed from the instantaneous symmetrical samples of using complex fourier transform as

$$Vta1\_f = e^{jwt} \left[\frac{1}{T} \int_{0}^{T} Vta1 e^{-jwt}\, dt \right]$$

V. MATLAB BASED SIMULATION OF DVR SYSTEM

The MATLAB model of DVR connected system is shown in the figure 7. Three phase programmable source is used to supply voltage and impedance of the system is connected in series with it. To simulate the disturbance at the PCC voltages (V_{ta}, V_{tb}, & V_{tc}) extra load is switched on in the each phase with the help of three phase breaker. The DVR is connected in series with the help injection transformer. The DC bus voltage is selected based on injection voltage level. The system data are given in the Appendix. The control algorithm for the control of DVR is simulated in the MATLAB.

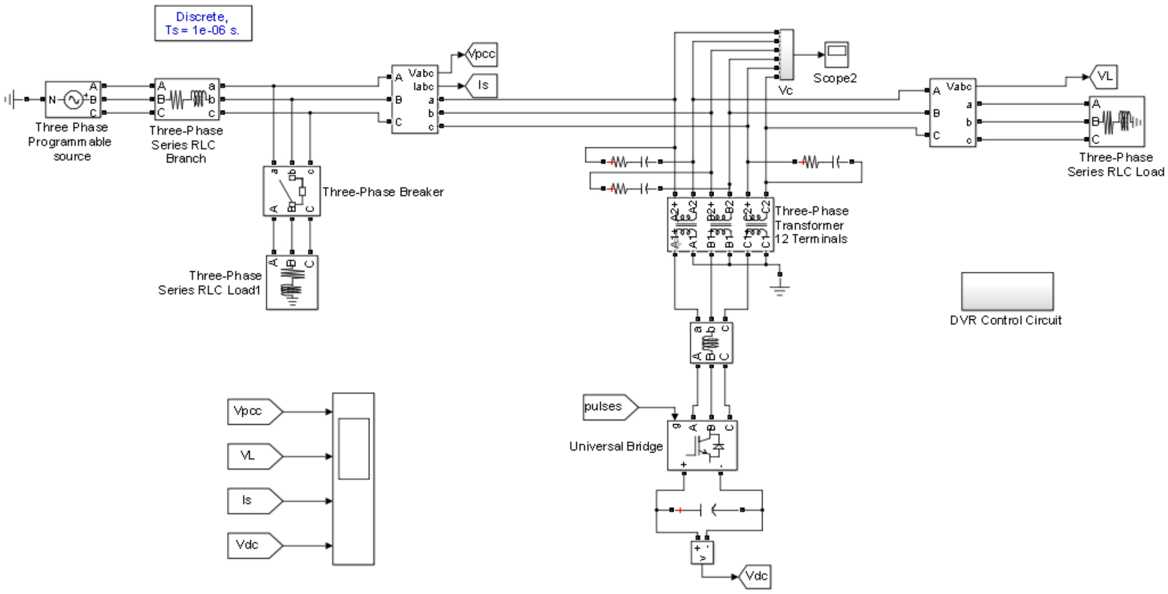

Figure 7. MATLAB model of DVR connected system

The reference voltage is generated by sensing the terminal voltage, supply current, load voltage and the dc bus voltage of the DVR. The PWM controller is used to generate gating signals for the VSC.

VI. PERFORMANCE AND RESULTS

The performance of DVR by using proposed control algorithm is tested for various power quality disturbances. A balance sag in source voltage of about 20% is introduced at 0.1 s, and it occurs for 5 cycles of ac mains. The terminal voltage (V_{pcc}), load voltage (V_L), supply current (I_s) and the dc bus voltage (V_{dc}) are shown in figure 8.

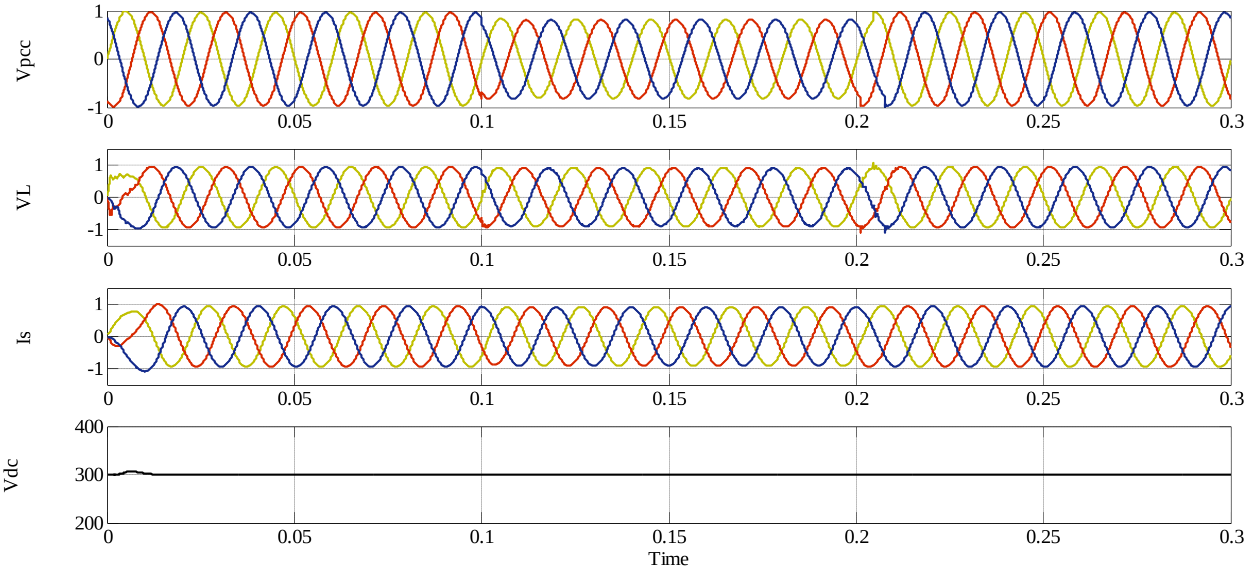

Figure 8. Compensation of balance Voltage sag using DVR

A balance swell in source voltage of about 15% is introduced at 0.1 s, and it occurs for 5 cycles of ac mains. The terminal voltage (V_{pcc}), load voltage (V_L), supply current (I_s) and the dc bus voltage (V_{dc}) are shown in figure 9.

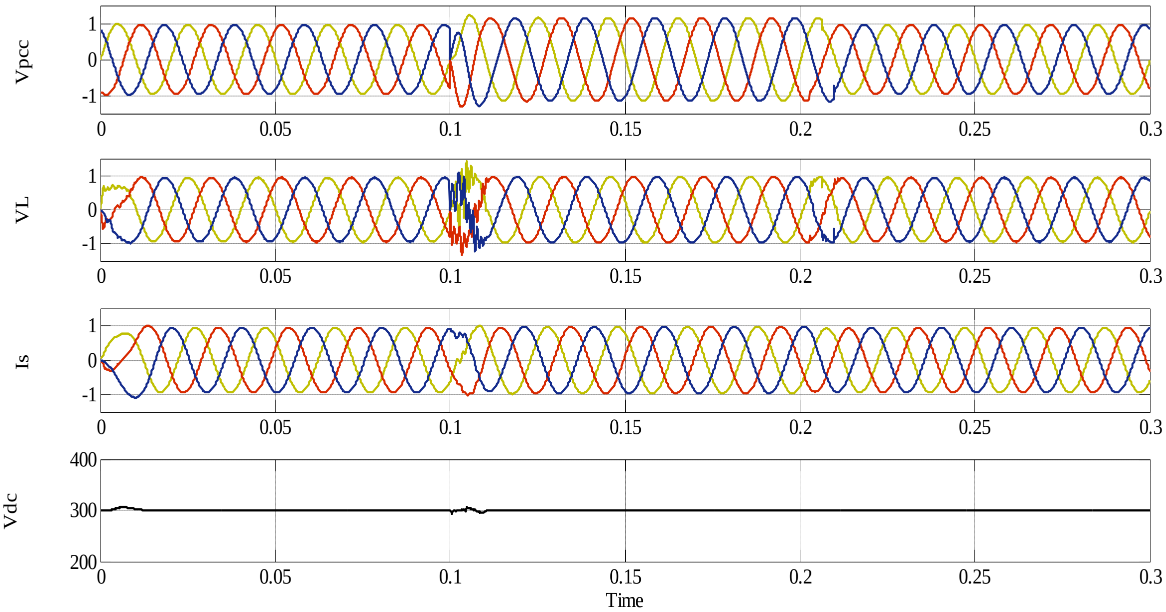

Figure 9. Compensation of balance voltage swell using DVR

An unbalance sag in source voltage of about 20% is introduced at 0.1 s, and it occurs for 5 cycles of ac mains. The terminal voltage (V_{pcc}), load voltage (V_L), supply current (I_s) and the dc bus voltage (V_{dc}) are shown in figure 10.

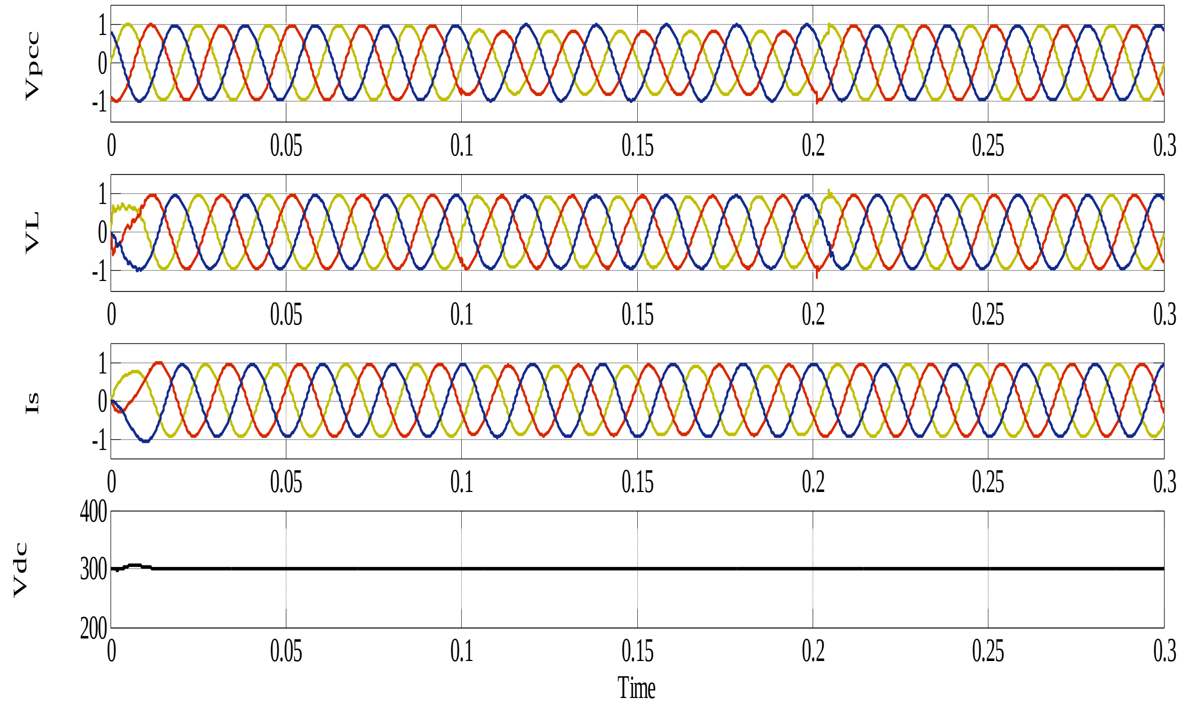

Figure 10. Compensation of unbalance voltage sag using DVR

An unbalance swell in source voltage of about 15% is introduced at 0.1 s, and it occurs for 5 cycles of ac mains. The terminal voltage (V_{pcc}), load voltage (V_L), supply current (I_s) and the dc bus voltage (V_{dc}) are shown in figure 11.

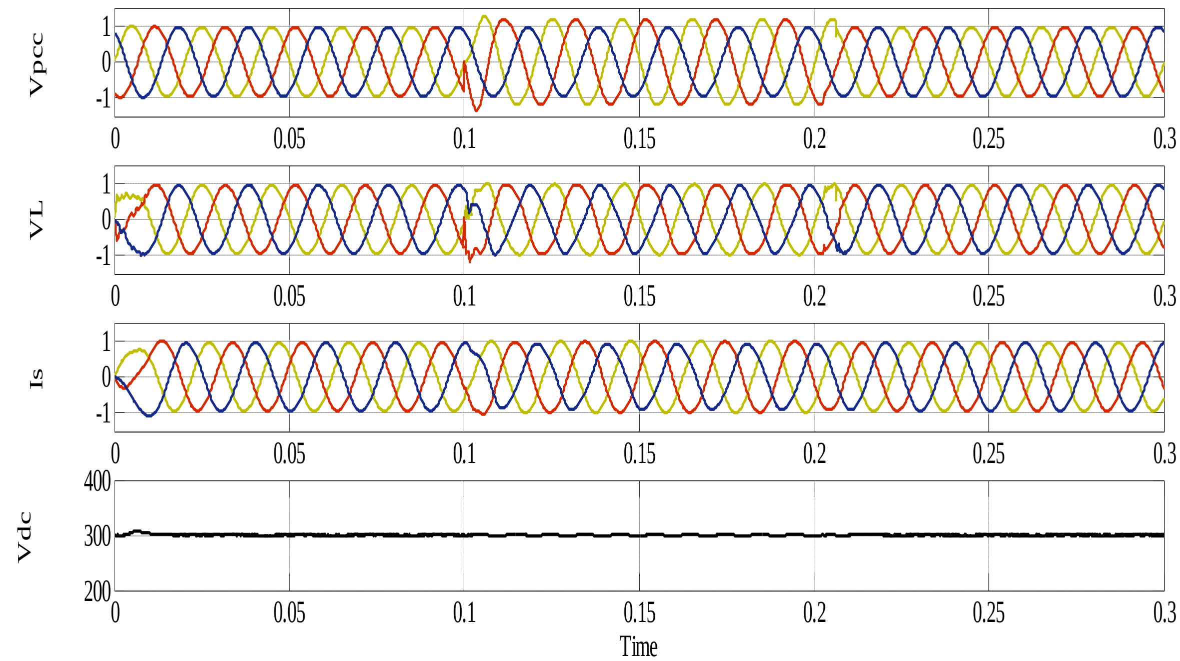

Figure 11. Compensation of unbalanced voltage swell using DVR

VII. CONCLUSION

The Dynamic Voltage Restorer (DVR) is an effective device for power quality enhancement due to its quick response and high reliability. The proposed control strategy based on instantaneous symmetrical component theory has been validated for the compensation of balance voltage sag/swell and unbalance voltage sag/swell in terminal voltage. The performance of the DVR has been observed to be satisfactory for various power quality disturbances.

VIII. APPENDIX

The parameters of the system considered are:
AC voltage source: 415 V, 50 H_z
Line impedance: Ls = 3.5mH, Rs= 0.01Ω
Load: 10 KVA, 0.8 pf lag
DC bus capacitance: 10μF
DC bus voltage: 300V

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