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PERFORMANCE OF DVR UNDER VOLTAGE SAG AND SWELLS CONDITIONS FOR POWER QUALITY IMPROVEMENTS

S. Punnepalli [1]   I. Prabhakar Reddy [2]

1. Electrical Engineering Department, PBR VITS, JNTU A, Nellore, India, sriharipe@gmail.com
2. Electrical Engineering Department, NEC, JNTU A, Nellore, India, isanaka2008@gmail.com

Abstract- Power quality is one of the major concerns in the present era. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipment. One of the major problems dealt here is the power sag. Their impact on sensitive loads is severe. Different solutions have been developed to protect sensitive loads against such disturbances but the DVR is considered to be the most efficient and effective solution. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. This research described DVR principles and voltage restoration methods for balanced and/or unbalanced voltage sags and swells in a distribution system. Simulation results are presented to illustrate and understand the performances of DVR under voltage sags/swells conditions.

Keywords: Dynamic Voltage Restorer (DVR), Voltage Sags, Voltage Swells, Custom Power, Power Quality, In-Phase Compensation (IPC), In-Phase Advance Compensation (IPAC).

I. INTRODUCTION

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells, and harmonics. Voltage dips are considered one of the most severe disturbances to the industrial equipment. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling.

The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high-speed transients cannot be compensated. Some sags are not corrected within the limited period of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly.

Another power electronic solution to the voltage regulation is the use of a Dynamic Voltage Restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid-state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage.

II. DYNAMIC VOLTAGE RESTORER

Figure 1 shows a typical DVR series connected topology [4]. A Dynamic Voltage Restorer (DVR) is a recently proposed series connected solid-state device that injects voltage into the system in order to regulate the load side voltage. The DVR was first installed in 1996. The DVR essentially consists of a Voltage Source Inverter (VSI), inverter output filter and an energy storage device connected to the DC link. The basic operation principle of the DVR is to inject an appropriate voltage in series with the supply through injection transformer whenever voltage sag or voltage swell is detected.

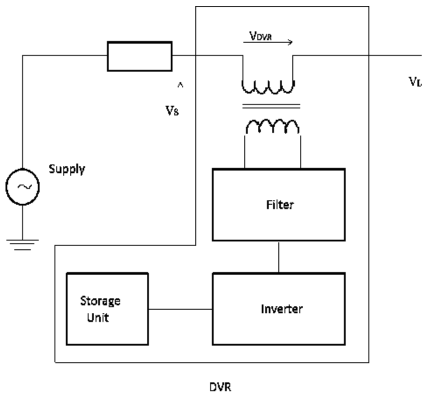


Figure 1. DVR series connected topology

In addition to voltage sags and swells compensation, DVR can perform other tasks such as harmonic compensation and power factor correction. Compared to other custom power devices, the DVR clearly provides the best economic solution for its size and capabilities. This research introduced Dynamic Voltage Restorer (DVR) and its voltage compensation methods [5]. At end, simulation results using MATLAB were illustrated and discussed.

The general configuration of the DVR consists of an Injection/Booster transformer, a harmonic filter, a Voltage Source Converter (VSC), DC charging circuit and a control and protection system.

A. Conventional DVR Voltage Injection Method

A number of factors including finite DVR power rating, different load conditions, and different types of voltage sag can limit the possibility of compensating voltage sag. Some loads are very sensitive to phase angle jump and others are tolerant to it. Therefore, the control strategy depends on the type of load characteristics. There are three distinguishing methods to inject DVR compensating voltage.

B. Pre-Dip Compensation (PDC)

The PDC method tracks supply voltage continuously and compensates load voltage during fault to pre-fault condition. In this method, the load voltage can be restored ideally, but the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions. The lack of the negative sequence detection in this method leads to the phase oscillation in the case of single-line faults. Figure 2 shows the single-phase vector diagram of this method. According to Figure 2, the apparent power and the active power of DVR are as follows:

$$\begin{cases} S_{1DVR} = I_L V_{1DVR} \\ S_{1DVR} = I_L \sqrt{V_L^2 + V_S^2 - 2V_L V_S \cos(\theta_L - \theta_S)} \end{cases} \quad (1)$$

$$P_{1DVR} = I_L \left(V_L \cos(\theta_L) - V_S \cos(\theta_S) \right) \quad (2)$$

where, the magnitude and angle of the DVR voltage are:

$$V_{1DVR} = \sqrt{V_L^2 + V_S^2 - 2V_S V_L \cos(\theta_L - \theta_S)} \quad (3)$$

$$\theta_{1DVR} = \tan^{-1}\left(\frac{V_L \sin\theta_L - V_S \sin\theta_S}{V_L \cos\theta_L - V_S \cos\theta_S} \right) \quad (4)$$

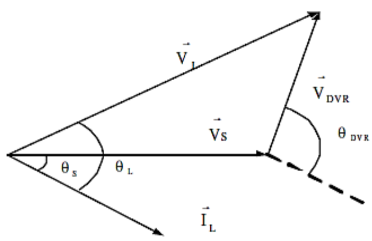


Figure 2. Single-phase vector diagram of the PDC method

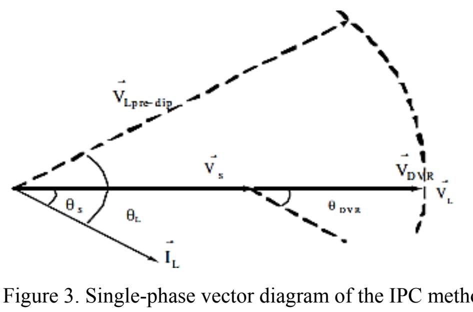


Figure 3. Single-phase vector diagram of the IPC method

C. In-Phase Compensation (IPC)

This is the most used method in which the injected DVR voltage is in phase with the supply side voltage regardless of the load current and pre-fault voltage as shown in Figure 3. The IPC method is suitable for minimum voltage or minimum energy operation strategies. In other word, this approach requires large amounts of real power to mitigate the voltage sag, which means a large energy storage device. The apparent and active powers, the magnitude, and angle of the DVR voltage are as follows:

$$S_{2DVR} = I_L V_{DVR} = I_L \left(V_L - V_S \right) \quad (5)$$

$$P_{2DVR} = I_L V_{DVR} \cos\theta_S \quad (6)$$

$$V_{2DVR} = V_L - V_S \quad (7)$$

$$\theta_{2DVR} = \theta_S \quad (8)$$

D. In-Phase Advance Compensation (IPAC)

Pre-Dip and in-phase compensation method must inject active power to loads to correct voltage disturbance. However, the amount of possible injection active power is confined to the stored energy in DC-link, which is one of the most expensive components in DVR. Due to the limit of energy storage capacity of DC-link, the DVR restoration time and performance are confined in these methods. For the sake of controlling injection energy, in phase advance compensation method was proposed. The injection active power is made zero by means of having the injection voltage phasor perpendicular to the load current phasor.

This method can reduce the consumption of energy stored in DC-link by injecting reactive power instead of active power. Reducing energy consumption means that ride-through ability is increased when the energy storage capacity is fixed. On the other hand, the injection voltage magnitude of in phase advance compensation method is larger than those of pre-dip or in-phase compensation methods and the voltage phase shift can cause voltage waveform discontinuity, inaccurate zero crossing and load power swing.

Therefore, in phase advance compensation method should be adjusted to the load that is tolerant to phase angle jump, or transition period should be taken while phase angle is moved from pre-fault angle to advance angle. In short, IPAC method uses only reactive power and unfortunately, not al1 the sags can be mitigated without real power, consequently, this method is only suitable for a limited range of sags.

III. SIMULATION

In order to show the performance of the DVR in voltage sags and swells mitigation, a simple distribution network was simulated using MATLAB (Figure 4). A DVR was connected to the system through a series transformer with a capability to insert a maximum voltage of 50% of the phase to ground system nominal voltage. In this simulation, the In-Phase Compensation (IPC) method was used. The load considered in the study is a 5.5 MVA capacity with 0.92 PF, lagging.

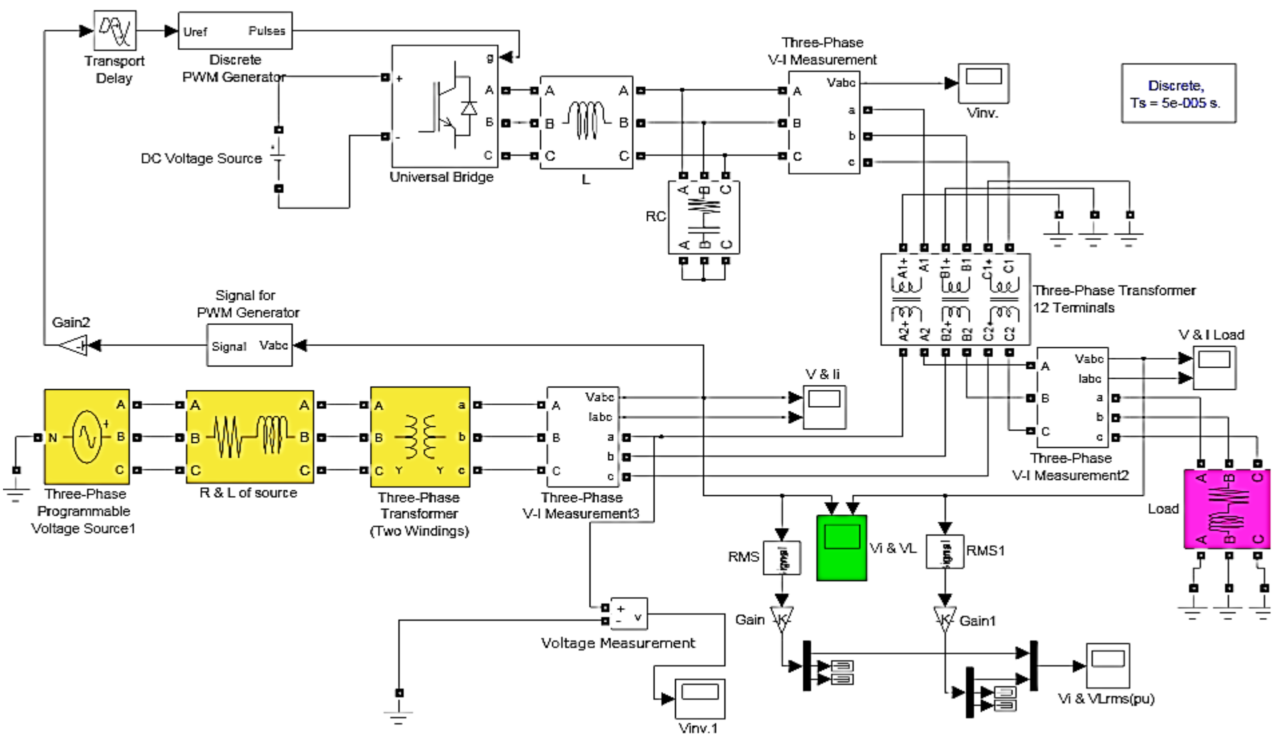
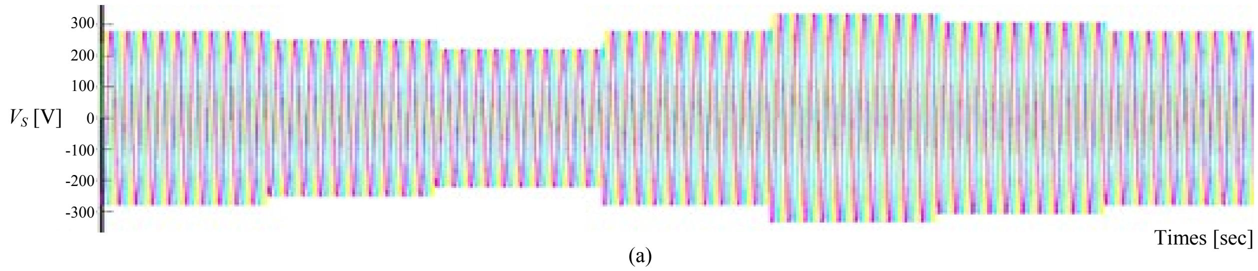
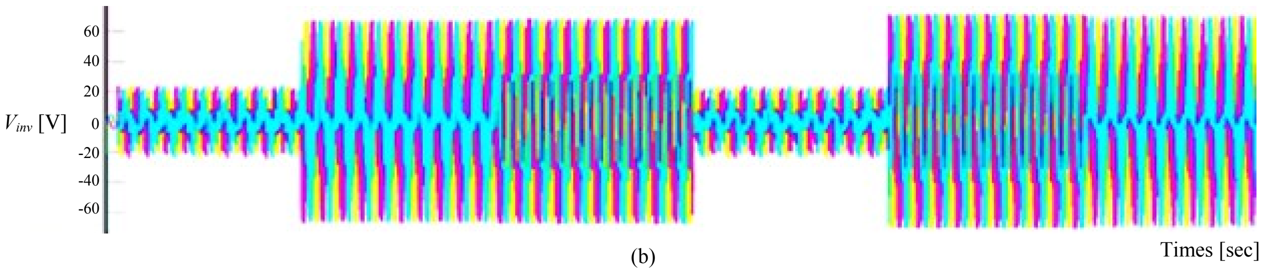


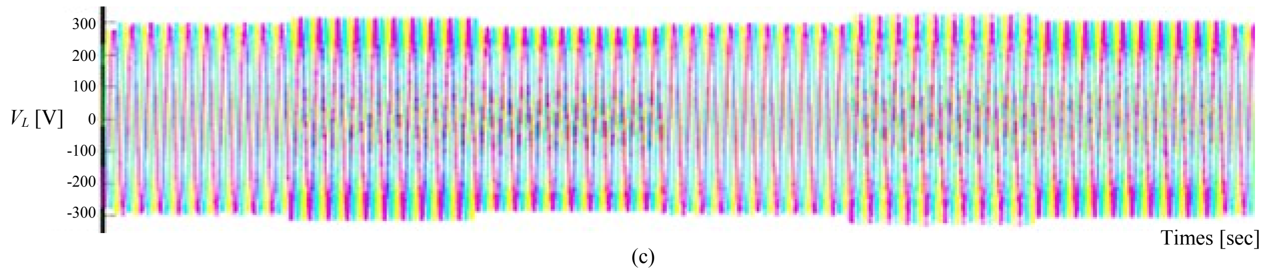
Figure 4. Simulink diagram of three-phase distribution network with DVR



(a)



(b)



(c)

Figure 5. Three-phase voltage sag, (a) Source voltages, (b) Injected voltages, (c) Load voltages

A. Voltage Sags

A case of three-phase voltage sag was simulated and the results are shown in Figure 5. The Figure 5(a) shows a 50% voltage sag initiated at 200 ms and it is kept until 400 ms, with total voltage sag duration of 200 ms. Figures 5(b) and 5(c) show voltage injected by the DVR and the compensated load voltage, respectively. As a result of DVR, load voltage is kept constant throughout the simulation, including voltage sag period. Observe that during normal operation, the DVR is doing nothing. It quickly injects necessary voltage components to smooth the load voltage upon detecting voltage sag.

In order to understand the performance of the DVR under unbalanced conditions, single-phase voltage sag was simulated and the results are shown in Figure 7. The supply voltage with one phase voltage dropped down to 50% is shown in Figure 7(a). The DVR injected voltage and the load voltage are shown in Figures 7(b) and 7(c), respectively. As can be seen from the results, the DVR was able to produce the required voltage component rapidly and helped to maintain a balanced and constant load voltage.

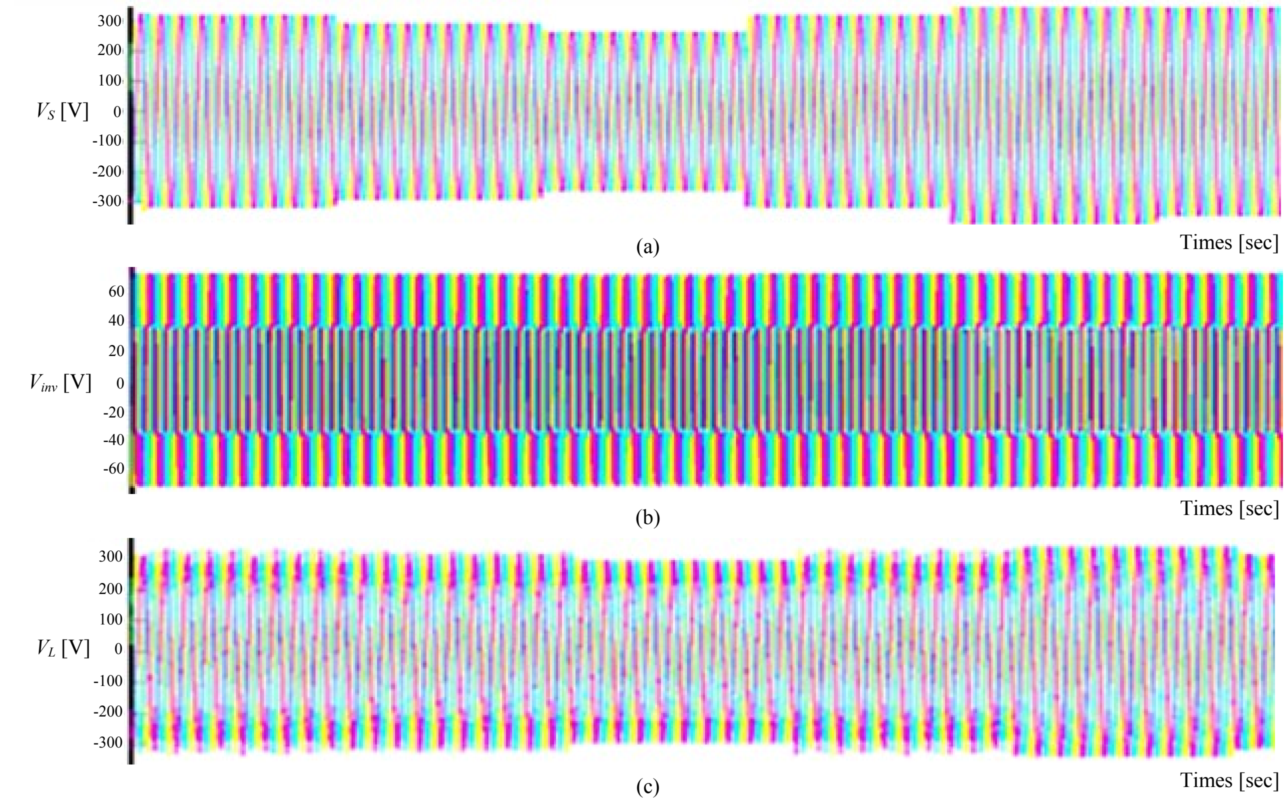


Figure 6. Three-phase voltage swell, (a) Source voltages, (b) Injected voltages, (c) Load voltages

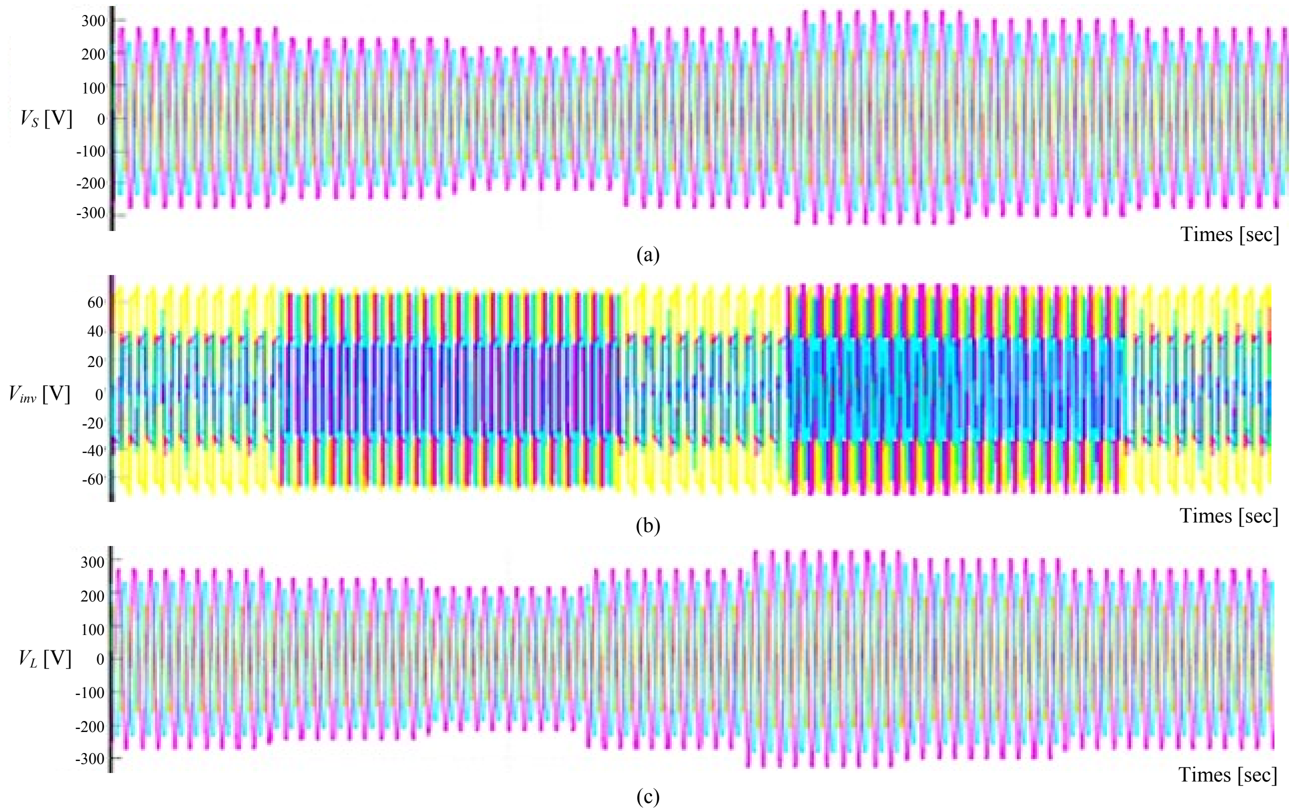


Figure 7. Single-phase voltage sag, (a) Source voltages, (b) Injected voltages, (c) Load voltages

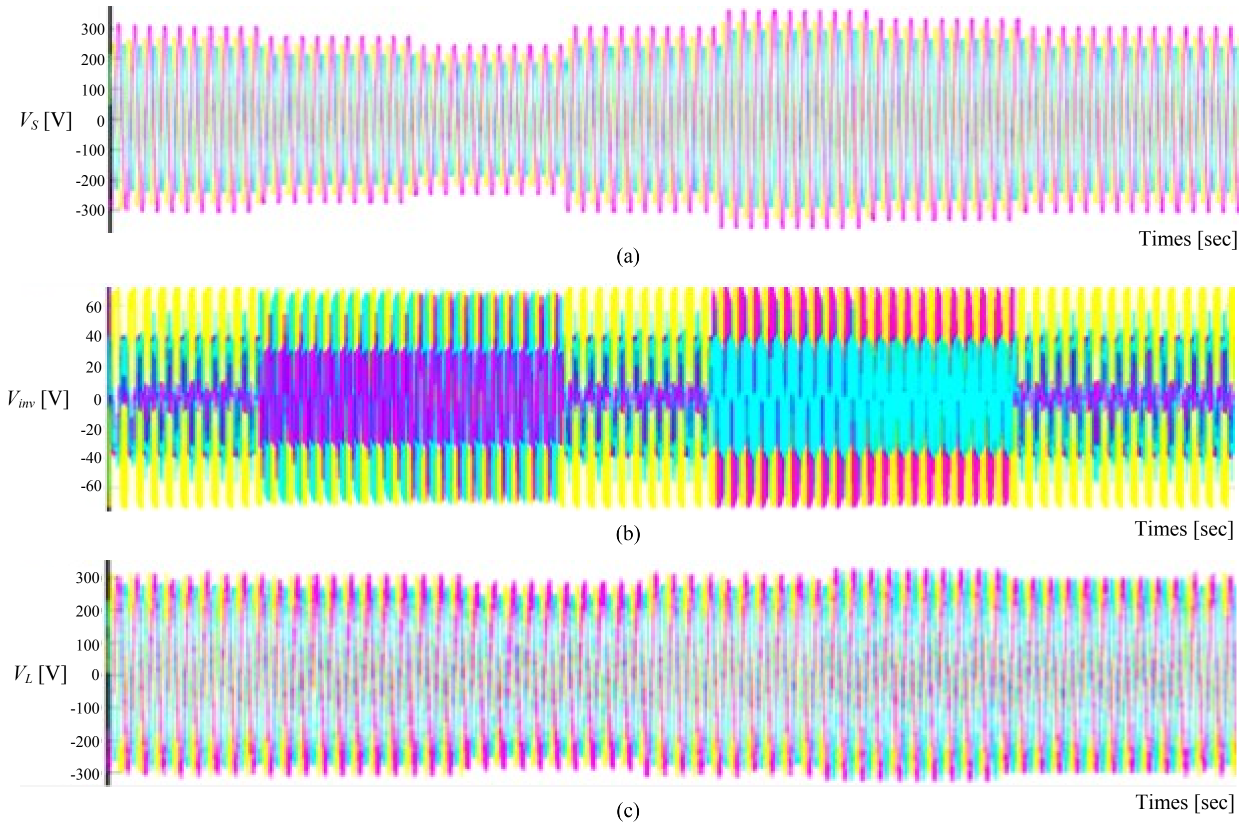


Figure 8. Single-phase voltages swell, (a) Source voltages, (b) Injected voltages, (c) Load voltages

B. Voltage Swells

The performance of DVR for a voltage swell condition was investigated. Here, supply voltage swell was generated as shown in Figure 6(a). The supply three-phase voltage amplitudes were increased about 125% of nominal voltage. The injected three-phase voltage that was produced by DVR in order to correct the load voltage and the load voltage are shown in Figure 6(b) and 6(c), respectively.

As can be seen from the results, the load voltage was kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR reacted quickly to inject the appropriate voltage component (negative voltage magnitude) to correct supply voltage. Simulation results show that the output voltage of controller can track the reference signal quickly and accurately and therefore compensate disturbances.

In order to understand the performance of the DVR under unbalanced conditions, single-phase voltage swell was simulated and the results are shown in Figure 8. The supply voltage with one phase voltage dropped down to 50% is shown in Figure 8(a). The DVR injected voltage and the load voltage are shown in Figures 8(b) and 8(c), respectively.

C. Advantages

DVR is one of the most common series device connected to the AC network via transformer, which was originally conceived to protect against voltage sag and swells during abnormal conditions in distribution systems [1].

Its range of applicability can be extended with a suitable control scheme. The basic operating principle of DVR is voltage stabilization by connecting a series voltage source between sensitive load and power supply source. The control scheme must be sufficient to restore the sensitive load voltage to its ideal state [10].

IV. CONCLUSIONS

In this paper, an overview of DVR is presented. DVR is an effective custom power device for voltage sags and swells mitigation. The impact of voltage sags on sensitive equipment is severe. Therefore, DVR is considered an efficient solution due to its relatively low cost and small size, also it has a fast dynamic response. The simulation results showed clearly the performance of the DVR in mitigating voltage sags and swells.

The DVR handled both balanced and unbalanced situations without any difficulties and injected the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value. The efficiency and the effectiveness in voltage sags/swells compensation showed by the DVR makes him an interesting power quality device compared to other custom power devices.

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BIOGRAPHIES

Srihari Punnepalli was born in Nellore, Andhra Pradesh, India, 1985. He received the B.Sc. degree in Electrical and Electronic Engineering and the M.Sc. degree in Electrical Power Engineering from University of JNTU, India in 2007 and 2012, respectively. Currently, he is an Assistant Professor in Electrical and Electronics Department, PBR VITS, Kavali, SPSR Nellore, A.P, India. His research interests are in the area of power quality and FACTS.

Isanaka Prabakar Reddy received his Ph.D. degree from JNT University, Anantapur, India. His research interests are in the areas of power electronics and drives and FACTS.