



## MITIGATION OF VOLTAGE SAGS/SWELLS USING DYNAMIC VOLTAGE RESTORER (DVR)

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### ABSTRACT

This paper describes the effectiveness of using dynamic voltage restorer (DVR) in order to mitigate voltage sags and swells in low voltage distribution systems. A dynamic voltage restorer based on the dq0 algorithm is discussed. The proposed control scheme is very effective to detect any disturbance in low voltage distribution systems. Simulation results using Matlab/Simulink are presented to verify the effectiveness of the proposed scheme.

**Keywords:** low voltage, dynamic voltage restorer, voltage sags, voltage swells.

### 1. INTRODUCTION

Power quality phenomena or power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform voltage and the current its ideal waveform. [1].

Voltage sags last until network faults are cleared and typically range from a few milliseconds to several seconds [3]. 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. [2].

Voltage swells are not as important as voltage sags because they are less common in distribution systems. Voltage sag and swell can cause sensitive equipment (such as found in semiconductor or chemical plants) to fail, or shutdown, as well as create a large current unbalance that could blow fuses or trip breakers. These effects can be very expensive for the customer, ranging from minor quality variations to production downtime and equipment damage [5].

This paper Introduces Dynamic Voltage Restorer (DVR) and its operating principle. Then, analyses of the voltage compensation methods are presented. At the end, simulation results using MATLAB/SIMULINK are illustrated and discussed.

### 2. POWER CIRCUIT OF DYNAMIC VOLTAGE RESTORER

The DVR is a custom power device that is connected in series with the distribution system as shown in figure 1. The main components of the DVR consists of an injection transformer, harmonic filter, series VSI (VSC), an energy storage and control system (as shown in Figure-1).

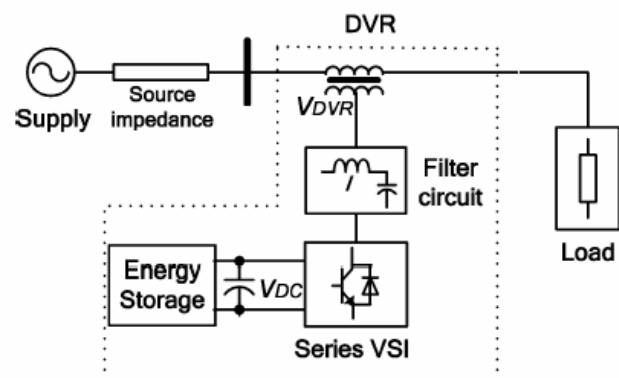


Figure-1. DVR operation.

The basic function of the DVR is to inject a dynamically controlled voltage  $V_{DVR}$  generated by a forced commutated converter in series to the bus voltage by means of a booster 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  $V_L$ . 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.

The DVR works independently of the type of fault or any event that happens in the system, provided that the whole system remains connected to the supply grid, i.e. the line breaker does not trip. For most practical cases, a more economical design can be achieved by only compensating the positive and negative sequence components of the voltage disturbance seen at the input of the DVR. This option is Reasonable because for a typical distribution bus configuration, the zero sequence part of a disturbance will not pass through the step down transformer because of infinite impedance for this component.

The DVR has two modes of operation which are: standby mode and boost mode. In standby mode ( $V_{DVR}=0$ ), 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 ( $V_{DVR} > 0$ ), the DVR is injecting a compensation voltage through the booster transformer due to a detection of a supply voltage disturbance [4].

can be maintained. The series injected voltage of the DVR can be written as

$$V_{inj} = V_L + V_s \tag{1}$$

Where

$V_L$  is the desired load voltage magnitude  
 $V_s$  is the source voltage during sags/swells condition  
 The load current  $I_L$  is given by,

$$I_L = \left( \frac{(P_L \pm J * Q_L)}{V_L} \right) \tag{2}$$

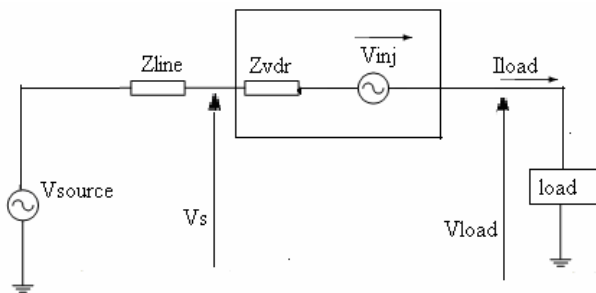


Figure-2. Equivalent circuit of DVR.

Figure-2 shows the equivalent circuit of the DVR, when the source voltage is drop or increase, the DVR injects a series voltage  $V_{inj}$  through the injection transformer so that the desired load voltage magnitude  $V_L$

3. PROPOSED METHOD

A. Main circuit

Figure-3 shows the configuration of the proposed DVR design using MATLAB/SIMULINK, where the outputs of a three-phase half-bridge inverter are connected to the utility supply via wye-open connected series transformer.

Once a voltage disturbance occurs, with the aid of dqo transformation based control scheme, the inverter output can be steered in phase with the incoming ac source while the load is maintained constant. As for the filtering scheme of the proposed method, output of inverter is installed with capacitors and inductors.

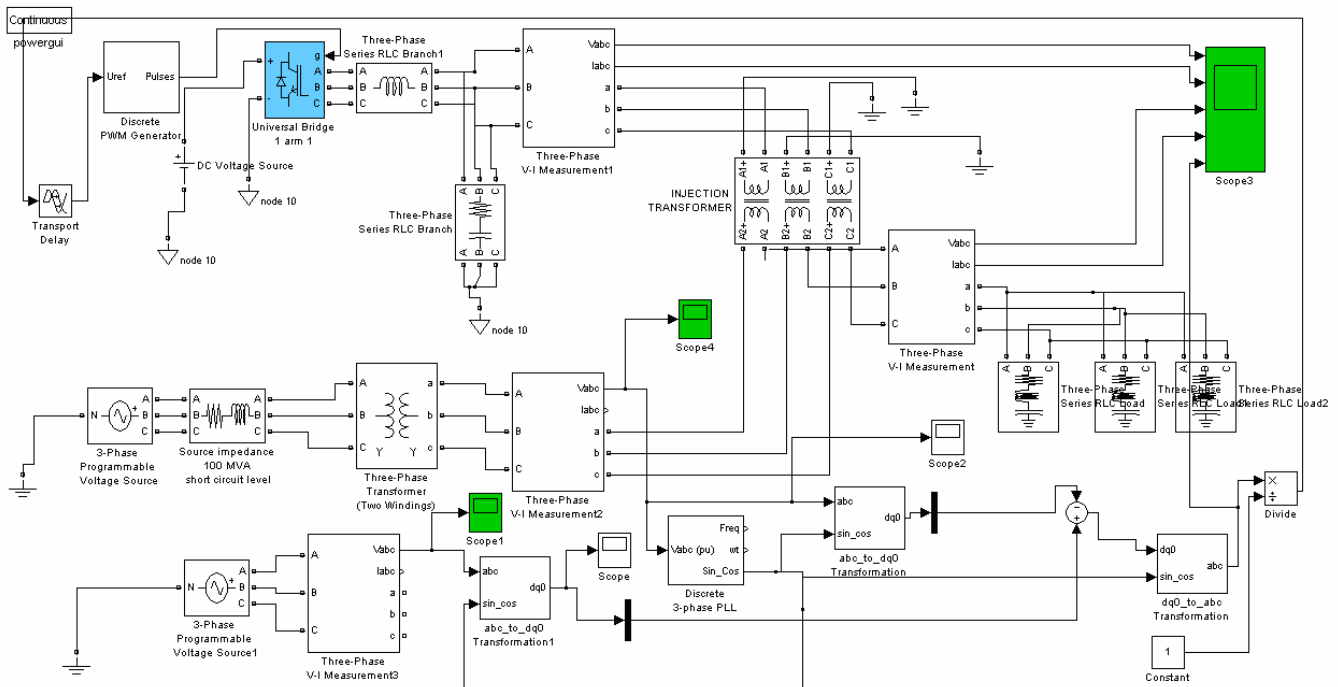


Figure-3. Proposed system configuration.

B. Control methods

The basic functions of a controller in a DVR are the detection of voltage sag/swell events in the system; computation of the correcting voltage, generation of

trigger pulses to the sinusoidal PWM based DC-AC inverter, correction of any anomalies in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift



the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags/swells.

The dqo transformation or Park's transformation [6-7] is used to control of DVR.

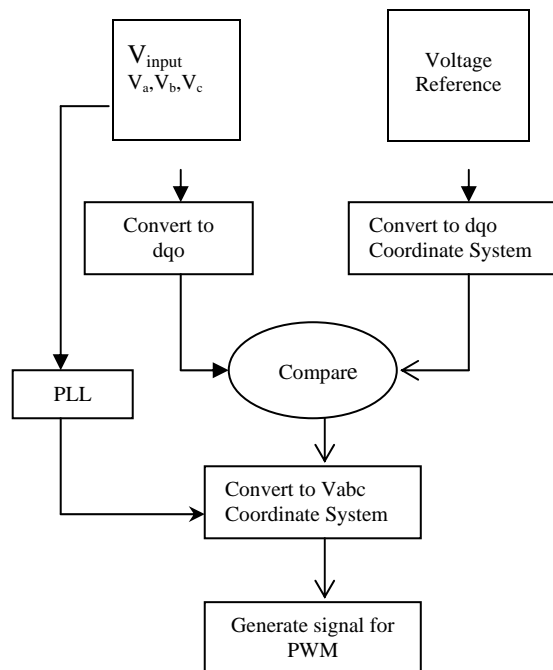
The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from a-b-c reference frame to d-q-o reference. For simplicity zero phase sequence components is ignored.

Figure-4 illustrates a flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases.

The control is based on the comparison of a voltage reference and the measured terminal voltage ( $V_a, V_b, V_c$ ). The voltage sags is detected when the supply

drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value.

The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches (IGBT's) constituting the voltage source converter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation. The block diagram of the phase locked loop (PLL) is illustrated in Figure-4. The PLL circuit is used to generate a unit sinusoidal wave in phase with mains voltage.



**Figure-4.** Flow chart of feed forward control technique for DVR based on dqo transformation.

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (3)$$

Equation (3) defines the transformation from three phase system a, b, c to dqo stationary frame. In this transformation, phase A is aligned to the d-axis that is in

quadrature with the q-axis. The theta ( $\theta$ ) is defined by the angle between phase A to the d-axis.

#### 4. SIMULATION RESULTS AND DISCUSSIONS

A detailed simulation of the DVR control system was performing using MATLAB/SIMULINK program in order to verify the operation. The parameters of the DVR system are as follows (Table-1):

**Table-1.** System data.

Supply Voltage	240V
Series transformer turns ratio	1:2
DC link Voltage	120V
Filter Inductance	0.5mH
Filter capacitance	1uF
Load resistance	200Ω
Load inductance	200mH

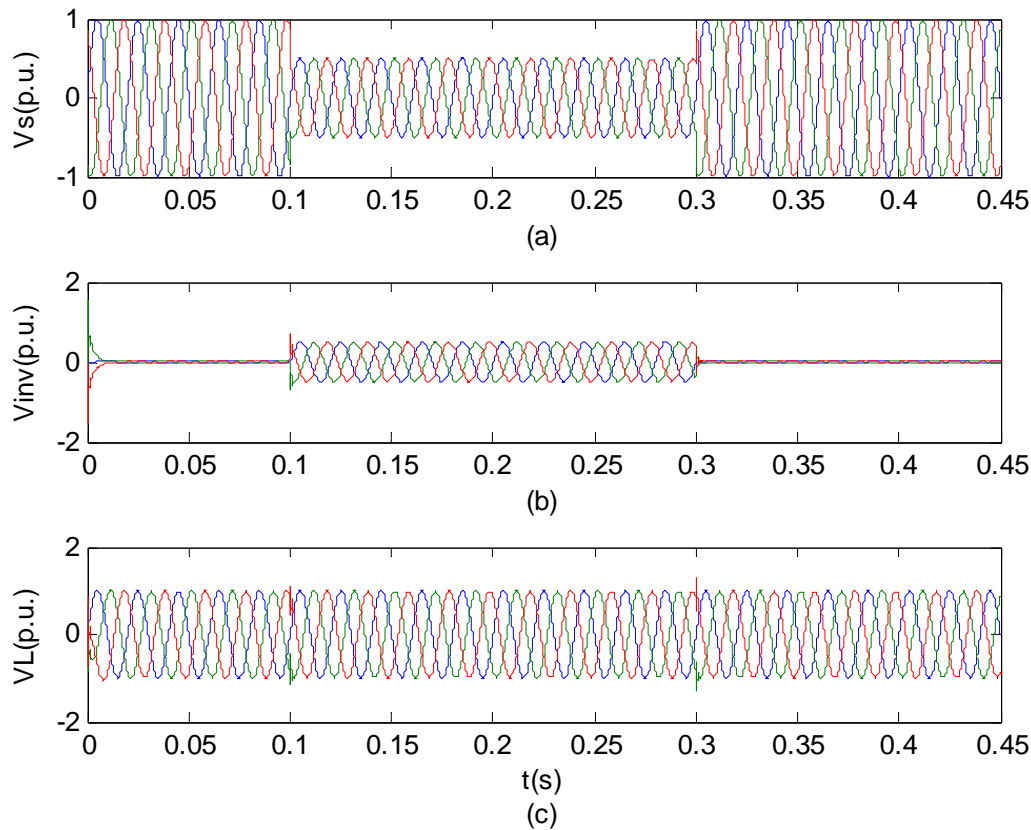
In order to understand the performance of the DVR along with control, in voltage sags and swells mitigation, a simple distribution network is simulated using MATLAB (Figure-3). Voltage sags and swells are simulated by temporary connection of different impedances at the supply side bus. A DVR is connected to the system through a series transformer with a capability

to insert a maximum voltage of 50% of the phase to ground system voltage. Apart from this, a series filter is also used to remove any high frequency components of power. The load considered in the study is a 5 KVA capacity with lagging power factor.

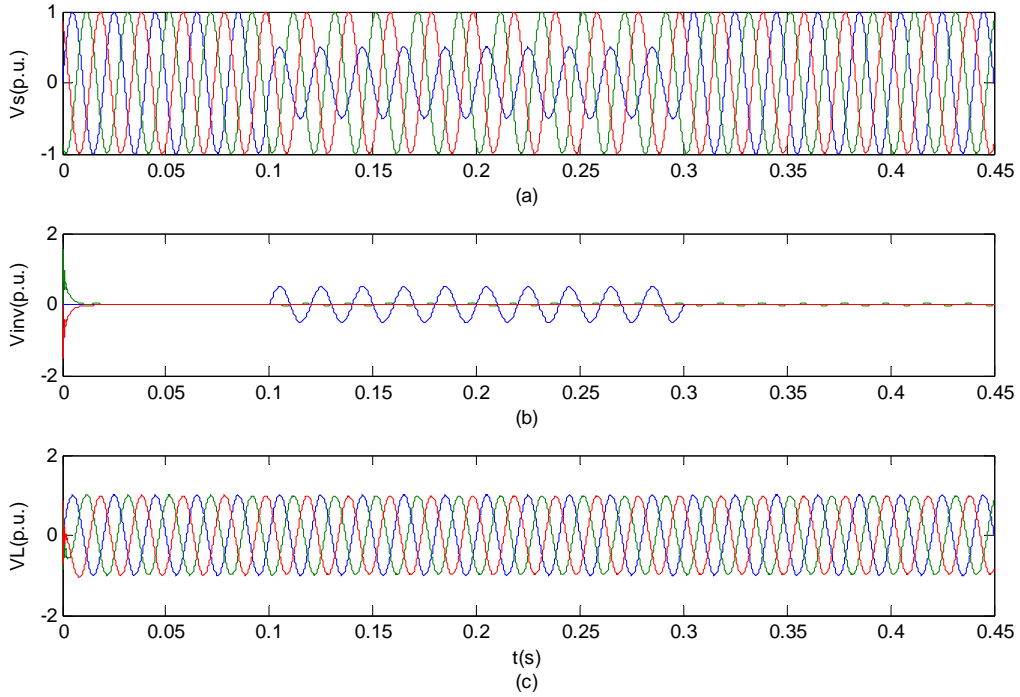
#### 4.1 Voltage sags

The first simulation of three phase voltage sag is simulated and a 50% three-phase voltage sag occurring at the utility grid is shown in Figure-5 (a).

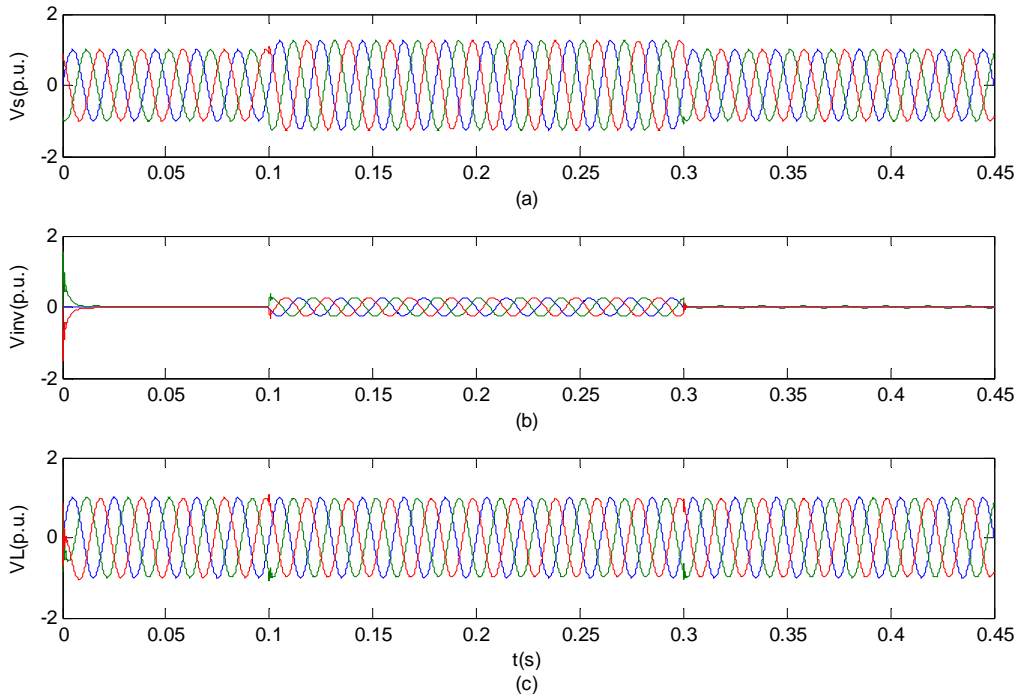
In Figure-5 (a) also shows a 50% voltage sag initiated at 0.1s and it is kept until 0.3s, with total voltage sag duration of 0.2s. Figures-5 (b) and (c) show the voltage injected by the DVR and the corresponding load voltage with compensation. As a result of DVR, the load voltage is kept at 1 pu.



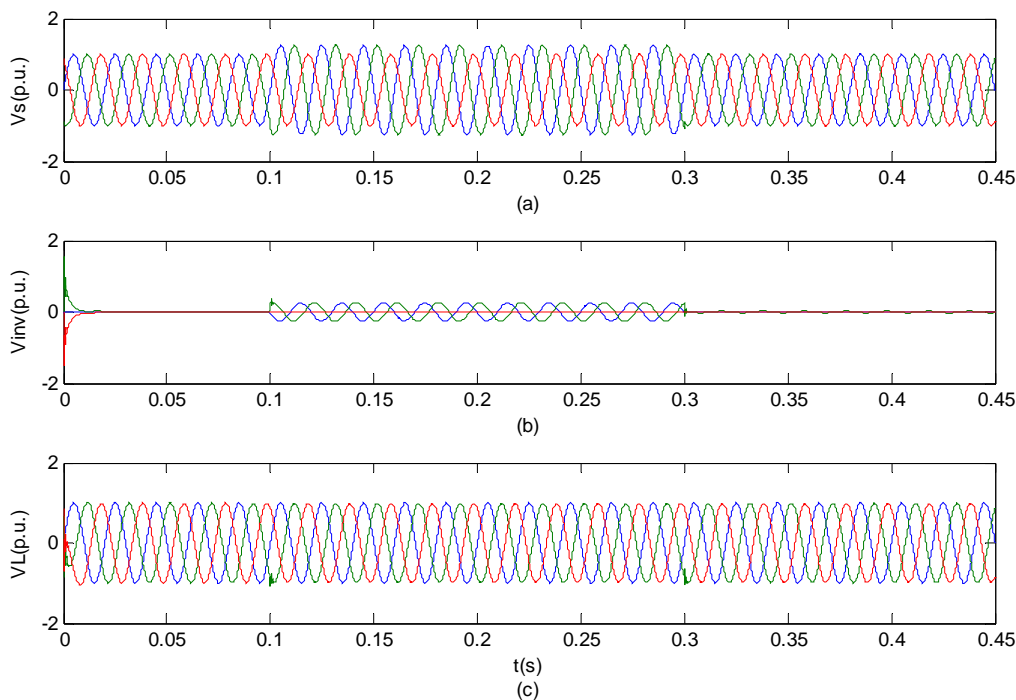
**Figure-5.** Three-phase voltages sag: (a)-Supply voltage, (b)-voltages injected by the DVR, (c)- voltage at load.



**Figure-6.** Single-phase voltage sag: (a)-supply voltage, (b)-voltage injected by the DVR, (c)- voltage at load.



**Figure-7.** Three-phase voltages swell: (a)supply voltage, (b)voltage injected by the DVR, (c)- voltage at load.



**Figure-8.** Two-phase voltages swell: (a) supply voltage, (b) voltage injected by the DVR, (c)-voltage at load.

The effectiveness of the DVR under unbalanced conditions is shown in Figure-6, in Figure-6 also shows the occurrence of 50% single phase voltage sag on a utility grid. Through simulation the supply voltage with one phase voltage dropped down to 50% as shown in Figure-6 (a). The DVR injected voltage and the load voltage are shown in Figures-6 (b) and (c) respectively. Its corresponding load voltages are shown in Figure-6(c) where it is possible to see that the compensation method is keeping the load voltages constant at 1 p.u

#### 4.2 Voltage Swells

The second simulation shows the DVR performance during a voltage swell condition. The simulation started with the supply voltage swell is generated as shown in Figure-7 (a). The amplitude of supply voltage is increased about 25% from its nominal voltage. Figures-7(b) and (c) show the injected and the load voltage respectively. As can be seen from the results, the load voltage is kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR reacts quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the supply voltage. The performance of the DVR with an unbalanced voltage swell is shown in Figure 8. In this case, two of the three phases are higher by 25% than the third phase as shown in Figure-8(a). The injected voltage that is produced by DVR in order to correct the load voltage and the load voltage are shown in Figures-8(b) and (c), respectively.

#### 5. CONCLUSIONS

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. A control system based on dqo technique which is a scaled error of the between source side of the DVR and its reference for sags/swell correction has been presented. The simulation shows that the DVR performance is satisfactory in mitigating voltage sags/swells.

The main advantage of this DVR is low cost and its control is simple. It can mitigate long duration voltage sags/swells efficiently. Future work will include a comparison with a laboratory experiments in order to compare simulation and experimental results.

#### ACKNOWLEDGEMENT

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