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COMPENSATION OF SAGS AND SWELLS VOLTAGE USING DYNAMIC VOLTAGE RESTORER (DVR) DURING SINGLE LINE TO GROUND AND THREE-PHASE FAULTS

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Abstract- This paper deals with modeling and simulation technique of a Dynamic Voltage Restore (DVR). The DVR is a dynamic solution to protect sensitive loads against voltage sags and swells. The DVR can be implemented to protect a group of medium voltage or low voltage consumers. The new configuration of DVR has been proposed using improved d-q-0 controller technique. This study presents compensation of sags and swells voltage during single line to ground (SLG) fault and three-phase fault. Simulation results carried out by Matlab/Simulink verify the performance of the proposed method.

Keywords: Dynamic Voltage Restorer, Voltage Sags, Voltage Swells, Single Line to Ground (SLG) Fault, Three-Phase Fault.

I. INTRODUCTION

Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions [1]. Voltage sags/swells can occurs more frequently than other Power quality phenomenon. These sags/swells are the most important power quality problems in the power distribution system [18].

One of the most important custom power devices that has been created to improve the performance of power quality is Dynamic Voltage Restorer (DVR). The DVR maintains the load voltage at a nominal magnitude and phase by compensating the voltage sag/swell, voltage unbalance and voltage harmonics presented at the point of common coupling [10, 11, 12]. These systems are able to compensate voltage sags by increasing the appropriate voltages in series with the supply voltage, and therefore prevent loss of power.

In 1994, L.Gyugyi proposed an apparatus and a method for dynamic voltage restoration of utility distribution network. This method uses real power in order to inject the faulted supply voltages and is commonly known as the Dynamic Voltage Restorer [13]. In this paper, a conventional DVR design essentially contains a voltage source inverter (VSI), an injection transformer connected between the AC voltage supply and the sensitive load, and a DC energy storage device, as shown in Figure 1.

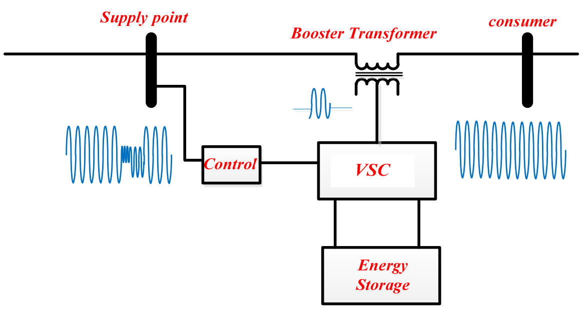


Figure 1. Basic DVR topology

Control unit is the heart of the DVR where its main function is to detect the presence of voltage sags in the system, calculating the required compensating voltage for the DVR and generate the reference voltage for PWM generator to trigger on the PWM inverter. This paper tries to compensate three phase voltage sag and swell, single voltage sag (SLG) and unbalance voltage sag and swell by the aid of the DVR, moreover, their Total Harmonic Distortion (*THD*) are presented. Simulation results carried out by Matlab/Simulink verify the performance of the proposed method.

II. VOLTAGE SAGS/SWELLS

Voltage sags/swells caused by unsymmetrical line-to-line, single line to ground (SLG), double-line-to-ground and symmetrical three phase faults effects on sensitive loads, the DVR injects the independent voltages to restore and maintained sensitive to its nominal value The injection power of the DVR with zero or minimum power for compensation purposes can be achieved by choosing an appropriate amplitude and phase angle [9].Voltage sags can occur at any instant of time, with amplitudes ranging from 10-90% and a duration lasting for half a cycle to one minute [2]. Voltage swell, on the other hand, is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 minute. Typical magnitudes are between 1.1 and 1.8 up. Swell magnitude is also described by its remaining voltage, in this case, always greater than 1.0. [3]. IEEE 519-1992 and IEEE 1159-1995 describe the voltage sags/swells as shown in Figure 2.

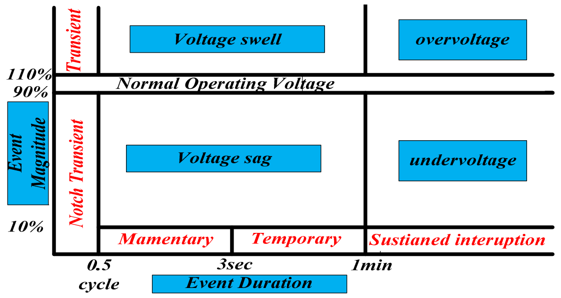


Figure 2. Voltage reduction standard of IEEE 1159-1995

Due to the fact that voltage swells are less common in distribution systems, they are not as important as voltage sags. 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 customers, ranging from minor quality variations to produce downtime and equipment damage [4].

III. DVR MODELING

The main function of the DVR is the protection of sensitive loads from voltage sags/swells coming from the network. The DVR is shown in Figure 3 which consists of the injection transformer, filter unit, PWM inverter, and energy storage and control system that is used to mitigate voltage sag in power distribution system [17].

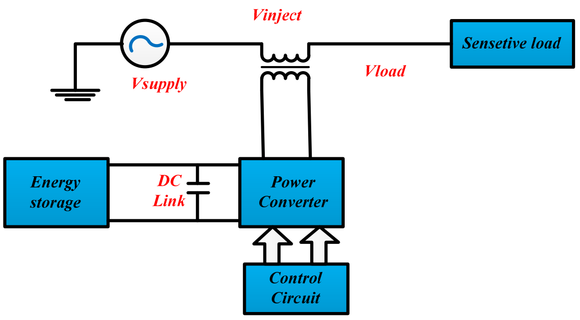


Figure 3. Schematic diagram of congenital DVR

The DVR is connected in series between the source voltage or grid and sensitive loads through injection transformer. There are several types of energy storage that has been used in the DVR such as battery, superconducting coil and flywheels. These types of energy storages are very important in order to supply active and reactive power to the DVR. The controller is an important part of the DVR for switching purposes. The switching converter is responsible to do conversion process from DC to AC. The inverter ensures that only the swells or sags voltage is injected to the injection transformer [5, 8].

The three-phase transformers connection used in the three-phase DVR can be configured either in delta/open or star/open connection as shown in Figure 3. In case of asymmetrical fault in the high voltage side, the zero sequence current flowing almost zero, if the distribution transformer connection in Δ-Y with the grounded neutral. As such connection, the DVR only mitigates the positive and negative sequence components [14].

One of the efficient methods to inject the DVR compensating voltage is pre-sag compensation method. The Pre-sag compensation method is to track supply voltage continuously and compensates load voltage during fault to pre-fault condition. Figure 4 shows the single-phase vector diagram of the pre-sag compensation. In this method, the load voltage can be restored ideally, but injected active power cannot be controlled and is determined by external conditions such as the type of faults and load condition. Figure 5 shows the flow chart of basic concept of the DVR operation.

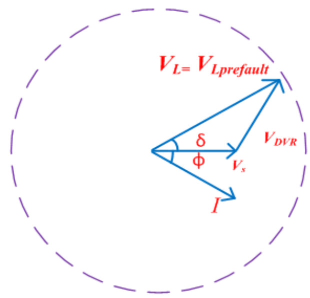


Figure 4. Vector diagram of pre-sag compensation

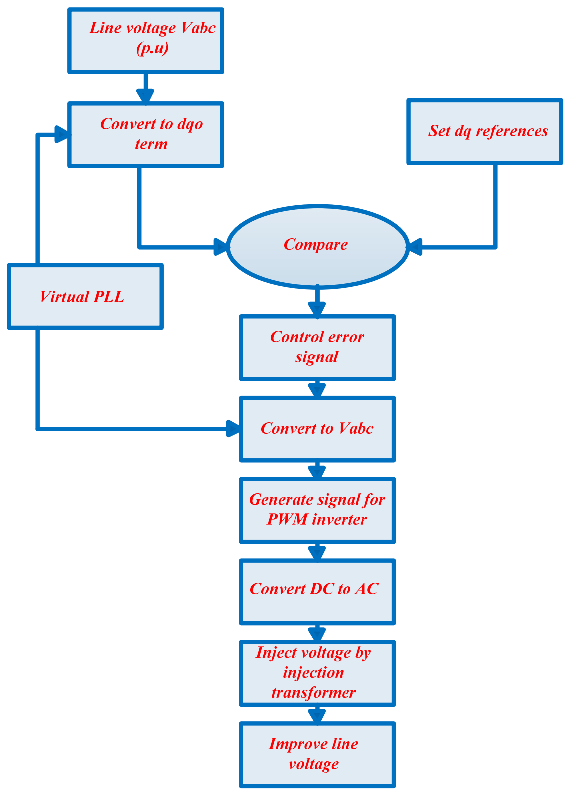


Figure 5. Flow chart of DVR operation

If a fault occurs on other lines, the DVR inserts series voltage V_{DVR} and compensates load voltage to pre fault value. 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. The line breaker does not trip. For most practical cases, an economical design can be achieved by only compensating that it is reasonable because for a typical distribution bus, the zero sequence part of a disturbance will not pass through the step down transformer because of infinite impedance for this component. The positive and negative sequence components of the voltage disturbance are at input of the DVR.

IV. DVR CONTROL TECHNIQUE

When voltage sags/swells are detected, the DVR should react as fast as possible and injects ac voltage to the grid. It can be implemented using a feedback control technique based on the voltage reference and instantaneous values of supply and load voltage. There are various basic roles of a controller in a DVR: detection of the voltage sag/swell occurrences in the system; calculation of the compensating voltage, generation of the trigger pulses of PWM inverter and stop triggering pulses when the occurrence has passed [6, 7].

The control system employs abc to dqo transformation to dq0 voltages. During normal condition and symmetrical condition, the voltage will be constant and d-voltage is unity in pu and q-voltage is zero in pu, but during the abnormal conditions it varies. After comparison d-voltage and q-voltage with the desired voltage, error d and error q are generated. These error components are converted into abc component using dq0 to abc transformation [15, 16].

This dq0 method gives the information of the depth (d) and phase shift (q) of voltage sag with start and end time. The load voltage is transformed to V_d, V_q and V_0 based on park transformation according Equations (1), (2), (3) and Equation (4) defines the transformation from three phase system a, b, c to dq0 stationary frame.

$$\vec{V}_d = \frac{2}{3}[V_a \cos \omega t + V_b \cos(\omega t - \frac{2\pi}{3}) + V_c \cos(\omega t - \frac{2\pi}{3})] \quad (1)$$

$$\vec{V}_q = \frac{2}{3}[V_a \sin \omega t + V_b \sin(\omega t - \frac{2\pi}{3}) + V_c \sin(\omega t - \frac{2\pi}{3})] \quad (2)$$

$$\vec{V}_0 = [V_a + V_b + V_c]/3 \quad (3)$$

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos(\theta - 2\pi/3) & 1 \\ -\sin(\theta) & -\cos(\theta - 2\pi/3) & 1 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (4)$$

Phase Locked Loop (PLL) is used to generate unit sinusoidal wave in phase with main voltage. This abc components are given to generate three phase Pulses using Pulse Width Modulation (PWM) technique. Proposed control technique block is shown in Figure 6.

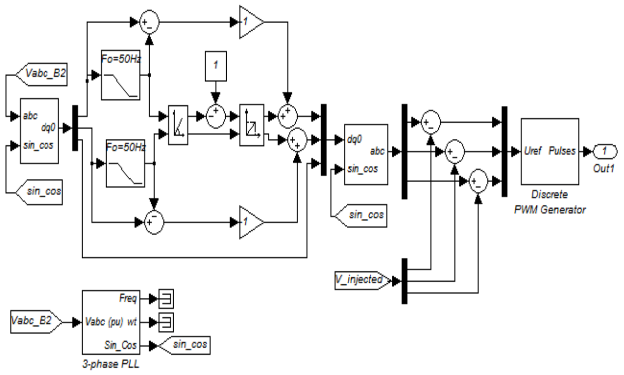


Figure 6. Block diagram control scheme of DVR

V. POWER SYSTEM STUDY MODEL

The performance of the designed DVR, as shown in Figure 7, is evaluated using Matlab/Simulink. Table 1 provides the specification of the simulation and experimental results of the DVR.

Table 1. System parameters and constant values

Main supply voltage per phase	400 V
Series transformer turn ratio	1:1
DC BUS Voltage	150 V
Source voltage	22 KV
Source resistance	0.8 Ω
Line frequency	50 Hz
Line impedance	L_S=1mH, R_s=0.01 Ω
Filter inductance	7 mH
Filter capacitance	10 μF

Investigation on the DVR performance can be observed through testing under various disturbances condition on the source voltage. The proposed control algorithm was tested for balanced and unbalanced voltages sags/swells in low voltage distribution system.

The first simulation show of three phase voltage sag is simulated. The simulation started with the supply voltage 50% sagging as shown in Figure 8(a). The Figure 8(a) also shows a 50% voltage sag initiated at 0.1sec and it is kept until 0.2sec, with total voltage sag duration of 0.1sec. Figures 8(b) illustrates the voltage injected by the aid of DVR and (c) shows the corresponding load voltage with compensation. As a result of the DVR, the load voltage is kept at 1 pu.

Single Voltage Sag is created by fault of single line to ground (SLG) is shown in Figure (9), moreover, the Figure shows the occurrence of 50% single phase voltage sag on utility grid. Through simulation the supply voltage with one phase voltage dropped down to 50% as shown in Figure 9(a).The DVR injected voltage and the load voltage are shown in Figures 9(b) and (c), respectively.

In addition, As a result of SLG fault. An unbalanced voltage sag is created immediately after the fault as shown in Figure 10(a), the supply voltage with two of the phase voltages dropped down to 60-80%. The DVR injected voltage and the load voltage are shown in Figure 10(b) and (c), respectively.

The second simulation shows the DVR performance during a voltage swell condition. In case of balance voltage swell, the source voltage has increased about 20-25% of its nominal value. The simulation results of the balance voltage swells as shown in Figure 11(a).

Figures 11(b) and (c) show the injected and the load voltage respectively. The swells voltages occur at the time duration of 0.1 sec and after 0.2 sec the voltage will restore back to its normal value. As can be seen from the results, the load voltage is kept at the nominal value with help of the DVR.

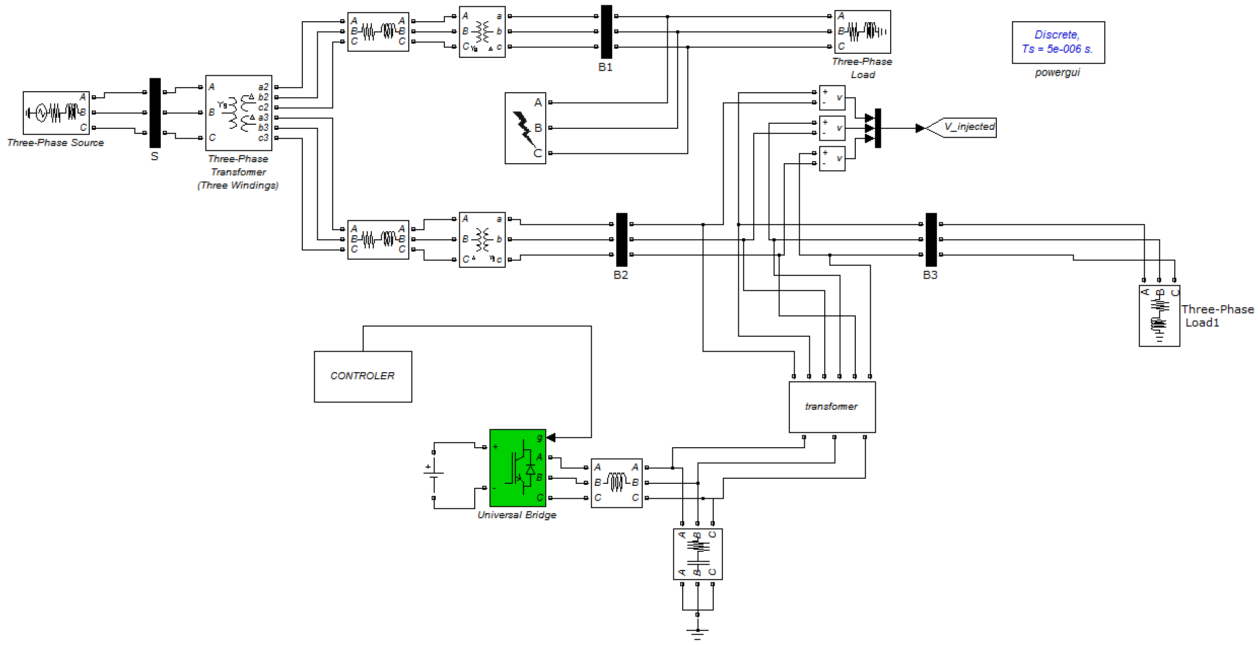


Figure 7. Matlab model of the DVR connected system

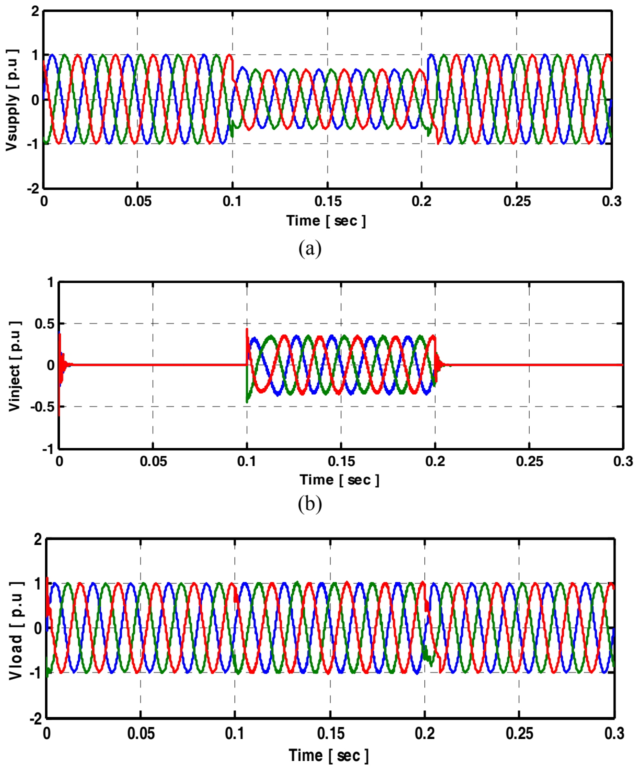


Figure 8. Three-phase voltage sag
(a) Source voltage (b) Injected voltage (c) Load voltage

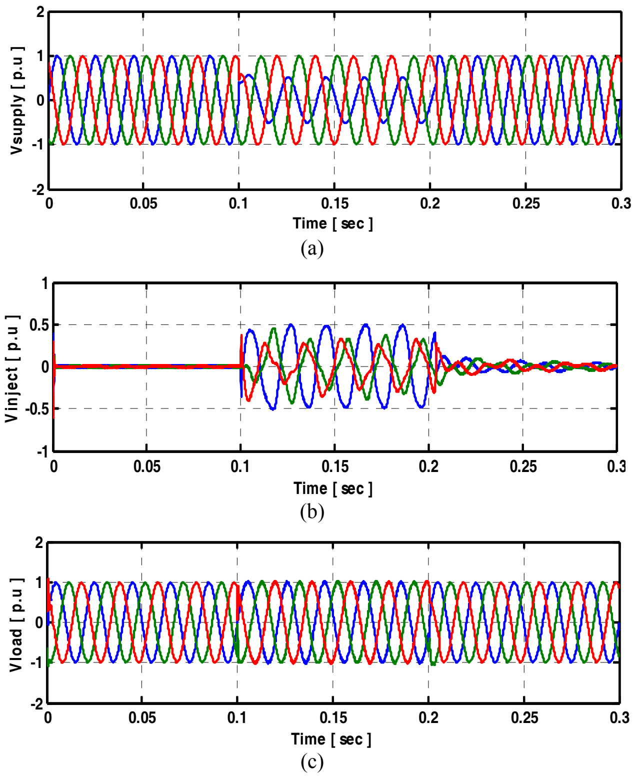


Figure 9. Single-phase voltage sag
(a) Source voltage (b) Injected voltage (c) Load voltage

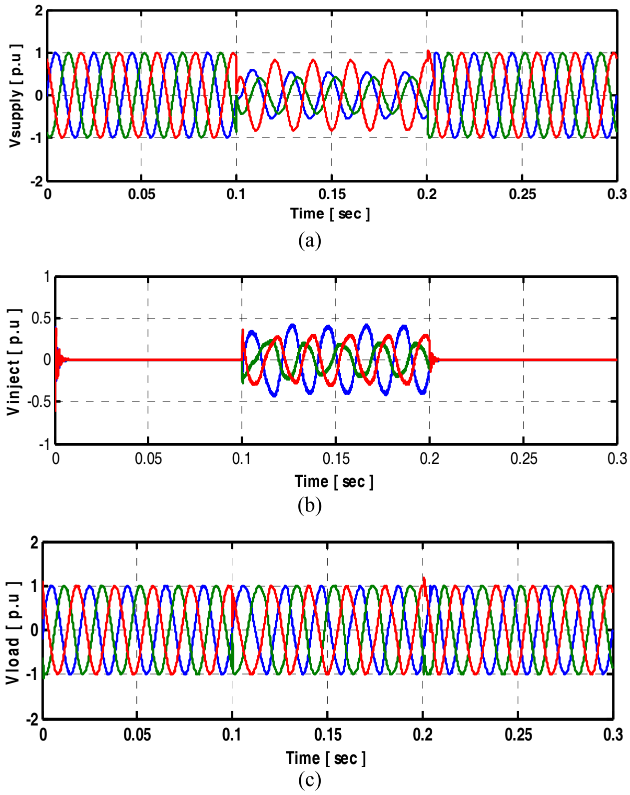


Figure 10. Unbalanced voltage sag
(a) Source voltage (b) Injected voltage (c) Load voltage

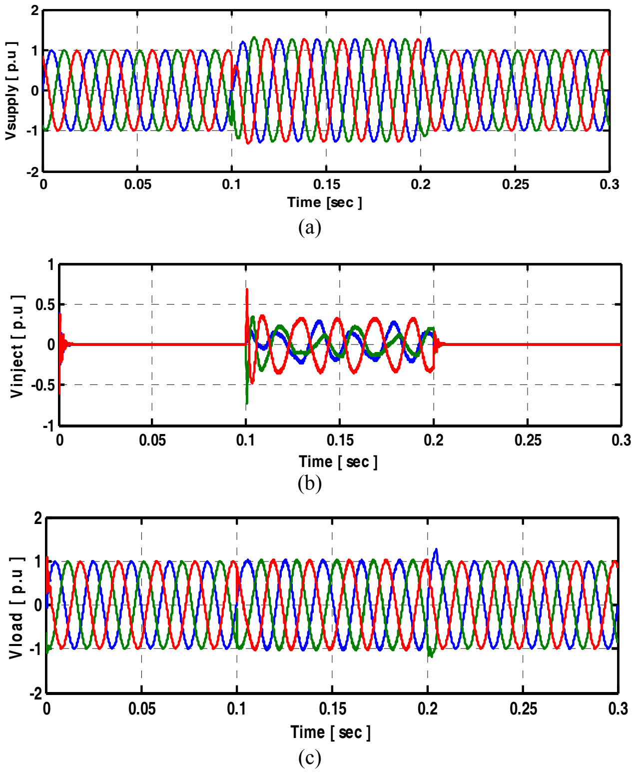


Figure 11. Three-phase voltages swell
(a) Source voltage (b) Injected voltage (c) Load voltage

In case of unbalance voltage swells, this phenomenon caused due to single phase to ground fault. One of the phase of voltage swells has increased around 20-25% with duration time of swells is 0.1 sec .The swells voltage will stop after 0.2 sec as shown in Figure 12(a). At this stage the DVR will injects the missing voltage in order to compensate it and the voltage at the load will be protected from voltage swells problem.

The injected voltage that is produced by the DVR in order to correct the load voltages and the load voltages maintain at the constant level are shown in Figures 12(b) and (c), respectively. Figure (13) illustrates total harmonic distortion (*THD*) for the compensated load voltage by the DVR for sags and swells.

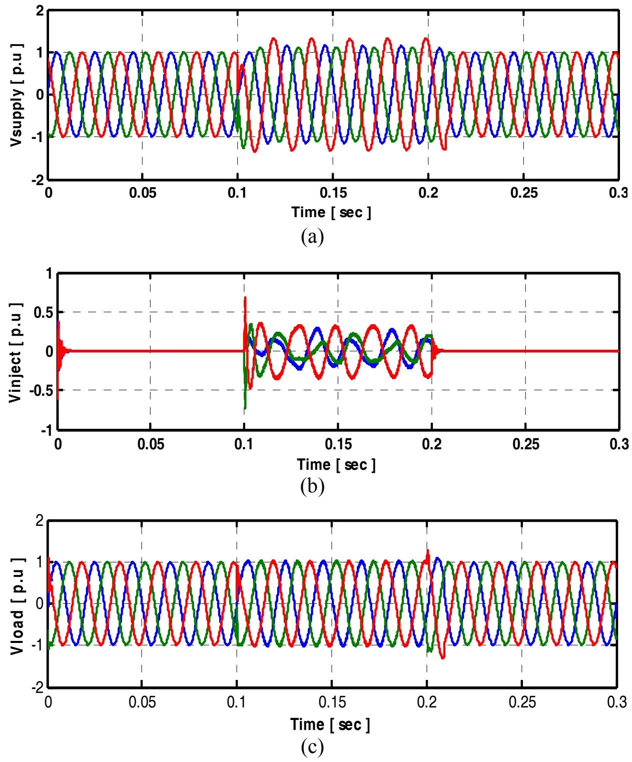
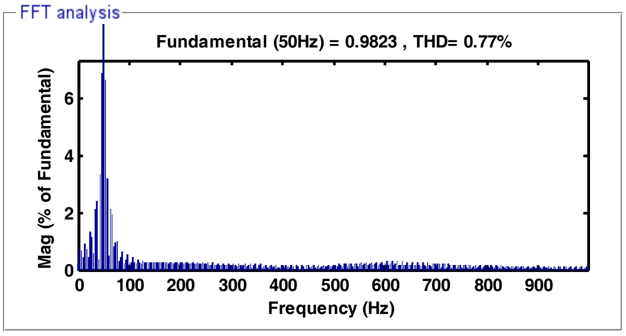


Figure 12. Unbalanced voltage swell
(a) Source voltage (b) Injected voltage (c) Load voltage

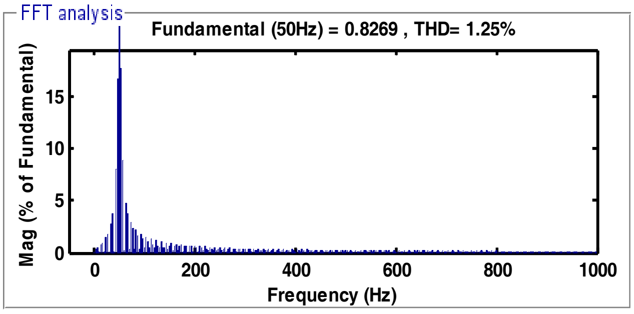
VI. CONCLUSIONS

The DVR modeling and simulation has been shown by the aid of Matlab/Simulink. The control system is based on dq0 technique which is a scaled error, between source side of the DVR and its reference for compensating sags and swells. The simulation shows that the DVR performance is efficient in mitigation of voltage sags and swells.

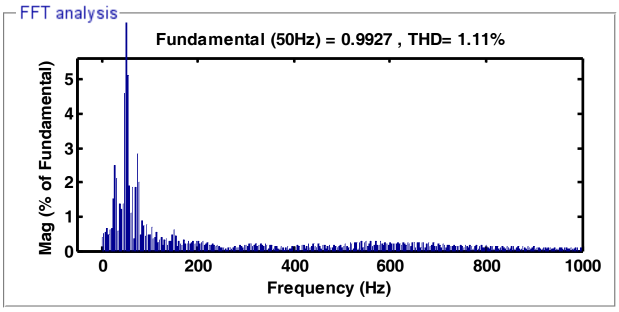
According to the simulation results, the DVR is able to compensate the sags and swells during single line to ground (SLG) fault and three-phase fault. As result of the FFT analysis, the compensated load voltage by the DVR has appropriate *THD*. The DVR handles both balanced and unbalanced situations without any difficulties. It injects an appropriate voltage component to correct any anomaly rapidly in the supply voltage; in addition, it keeps the load voltage balanced and constant at the nominal value.



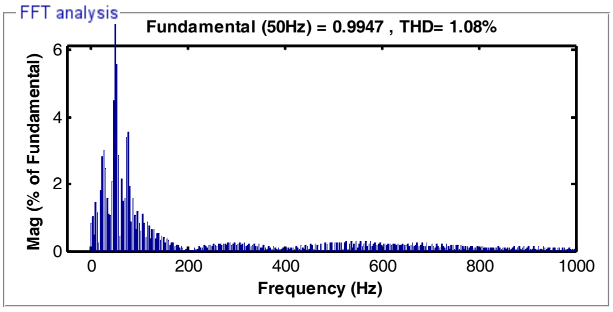
(a)



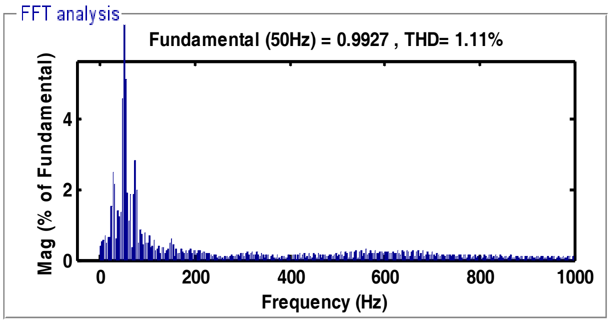
(b)



(c)



(d)



(e)

Figure 13. *THD* of compensated load voltage (a), three-voltage sag (b), single-phase voltage sag (c), unbalanced voltage sag (d), three-phase voltage swell (e) unbalanced voltage swell

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