Using of Dynamic Voltage Restorer (DVR) to Mitigate Sag & Swell Voltage during Single Line to Ground & Three-Phase Faults

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ABSTRACT: *The power quality (PQ) requirement is one of the most important issues for power system. The main problems of the power quality like voltage sags/swells in low voltage distribution systems and on the transmission side due to sensitive loads. There are different methods to compensation of voltage sag and swell, one of the most popular methods of sag and swell compensation is Dynamic Voltage Restorer (DVR), The Dynamic Voltage Restorer (DVR) is series-connected power electronics based device. It provides advanced and economic solution to compensate voltage sag and swell. This device can be implemented to protect a group of medium or low voltage consumers. The new configuration of DVR has been proposed using improved d-q-0 controller. This study presents compensation of sags and swells voltage during single line to ground (SLG) and three-phase faults. 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 & three phase faults.*

I.   Introduction

As well known, quality of the power is facing a various problems such as voltage sags/swells, surge, flicker, voltage imbalance, interruptions and harmonic distortion, Voltage sags/swells can occur more frequently than other Power quality problems, also these sags/swells are the most severe power quality disturbances in the power distribution system. One of the most important custom power devices that have 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 and voltage unbalance at the point of common coupling (PCC). 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 [5].

Voltage sags/swells caused by unsymmetrical line-to-line, single line-to-ground (SLG), double line-to-ground and symmetrical three phase faults. 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 [10].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. Voltage swell, on the other hand, is defined as an increase in rms voltage for durations from 0.5 cycles to 1 minute. Typical magnitudes are between 1.1 and 1.8 up. IEEE 519 1992 and IEEE 1159-1995 describe the voltage sags/swells as shown in Figure 1.
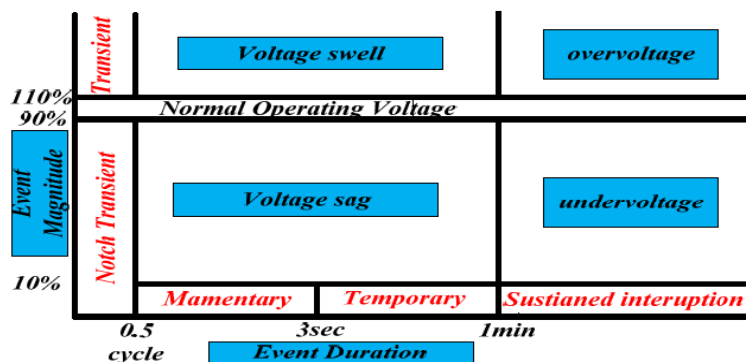

Figure (1) Voltage reduction standard of IEEE 1159-1995

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].

II.   Dynamic Voltage Restorer

In 1994, L. Gyugyi proposed a device 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 [15]. In this paper, a DVR design essentially contains a voltage source inverter (VSI), an injection transformer connected between the AC voltage supply and the sensitive load, a DC energy storage device, and a control system as shown in Figure 2.
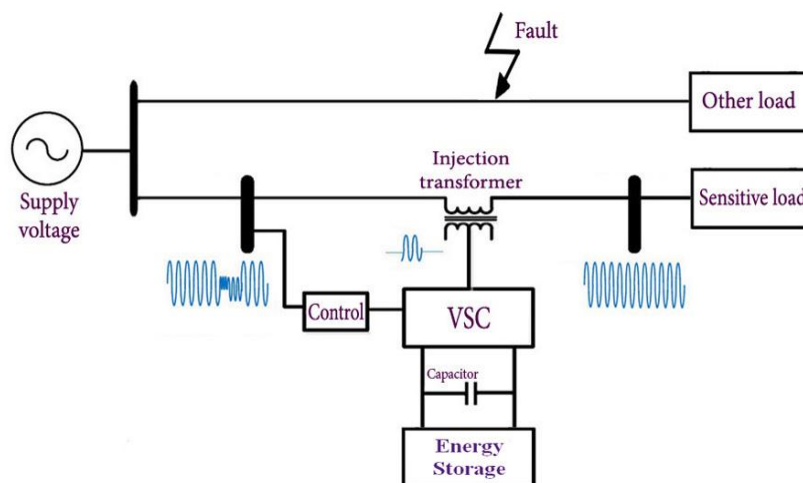

Figure (2) Basic DVR topology

The main function of the DVR is the protection of sensitive loads from voltage sags/swells coming from the network.

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, capacitance and superconducting coil. 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 and to make sure that's only the swell or sag voltage is injected to the injection transformer.

The three-phase transformers connection used in the three-phase DVR can be configured either in delta/open or star/open connection. In case of asymmetrical fault in the high voltage side, the zero sequence current flowing almost zero, if the distribution transformer connection in Ä-Y with the grounded neutral. As such connection, the DVR only mitigates the positive and negative sequence components [15].

III.   Compensation Methods in DVR

The type of the compensation strategy mainly depends upon the limiting factors such as DVR power ratings, various conditions of load, voltage sag type. Some loads are sensitive towards phase angel jump and some are sensitive towards change in magnitude and others are tolerant to these [16]. Therefore, the control strategies depend upon the type of load characteristics; there are three different methods of DVR voltage injection which are:
(a) Pre-sag compensation method
(b) In-phase compensation method
(c) Voltage tolerance method with minimum energy injection

(a) Pre-Sag/Dip Compensation Method
The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition, so that the load voltage can be restored back to the pre-fault condition. Compensation of voltage sags in the both phase angle

and amplitude. Sensitive loads would be achieved by pre-sag compensation method as shown in Figure 3. In this method the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions. The voltage of DVR is given below:
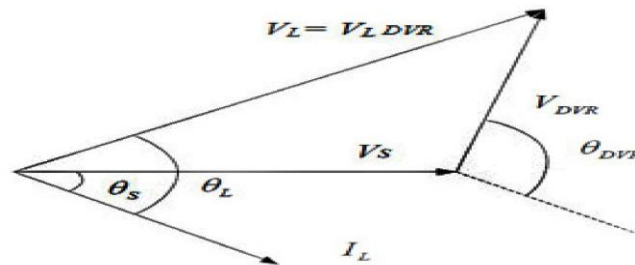
$V_{DVR} = V_{pre\ fault} - V_{sag}$

Figure (3) phasor diagram of pre-sag/dip method

(b) In-Phase Compensation Method
In this method the injected voltage is in phase with the supply side voltage irrespective of the load current and pre-fault voltage as shown in Figure 4. The phase angles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage are satisfied. The load voltage is given below:

$|VL| = |V_{pre-fault}|$

One of the advantages of this method is that the amplitude of DVR injection voltage is minimum for certain voltage sag in comparison with other strategies. Practical application of this method is in non-sensitive loads to phase angle jump.
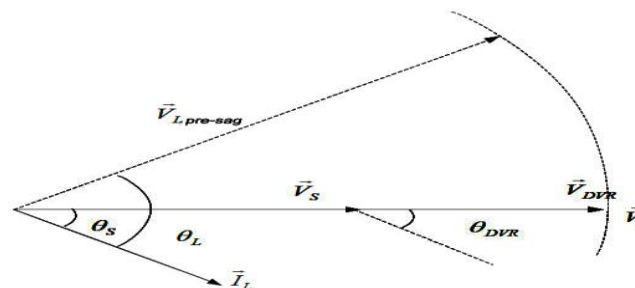

Figure (4) phasor diagram of in phase method

(c) Voltage Tolerance Method with Minimum Energy Injection
A small drop in voltage and small jump in phase angle can be tolerated by the load itself. If the voltage magnitude lies between 90%-110% of nominal voltage and phase angle variations between 5% -10% of nominal state that will not disturb the operation characteristics of loads. Both magnitude and phase are the control parameter for this method which can be achieved by small energy injection. In this method, the phase angle and magnitude of corrected load voltage within the area of load voltage tolerance are changed. The small voltage drop and phase angle jump on load can be tolerated by load itself. The sensitivity of loads to phase angle jump and voltage magnitude is different.
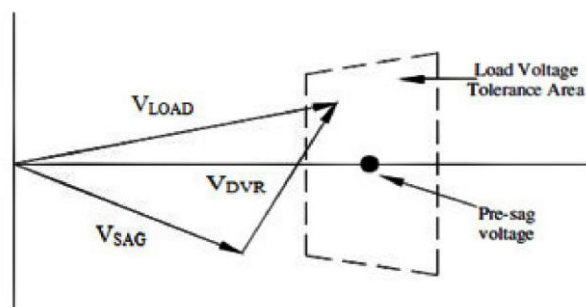

Figure (5) voltage tolerance method with minimum energy injection

IV.   Propose Control Technique

The control system of a DVR plays an important role, with the requirements of fast response when voltage sag/swells are occur. When voltage sag/swells are detected, the DVR should react as fast as possible and injects AC voltage to the grid. It can be implemented using a Space Vector PWM control technique based on the voltage reference and instantaneous values of supply and load voltage. There are various basic rules 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. The 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).

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

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

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

Phase locked loop (PLL) is used to generate unit sinusoidal wave in phase with main voltage. The abc components are given to generate three phase pulses using PWM technique. Proposed control technique block is shown in Figure 6. The flow chart of the DVR operation is shown in Figure 7.
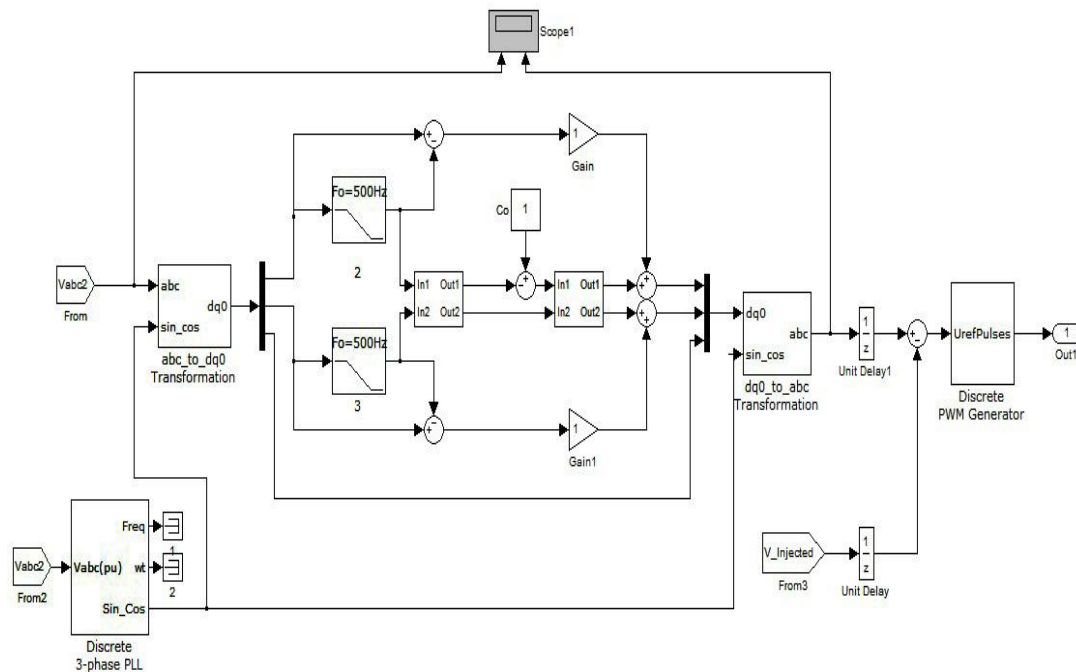

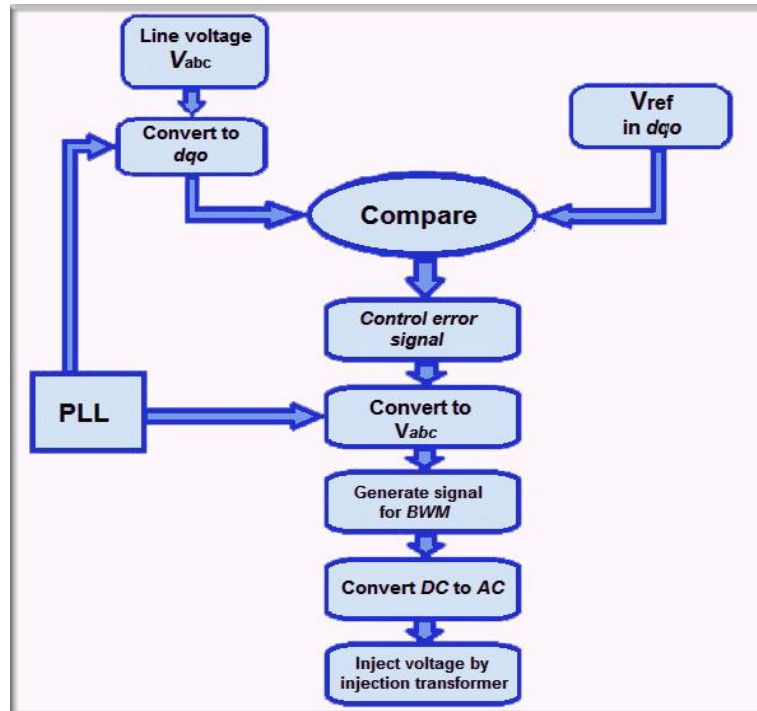Figure (6) Block diagram control scheme of DVR

Figure (7) Flow chart of DVR operation

V. Simulations and Results

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 shows the single phase voltage sag. The simulation started with the supply voltage 50% sagging as shown in Figure 9 (a). The Figure 9 (a) also shows a 50% voltage sag initiated at 0.1 sec and it is kept until 0.2 sec, with total voltage sag duration of 0.1 sec. Figure 9 (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, and the Figure 10 shows the occurrence of 50% three phase voltage sag on utility grid, also the injected voltage and load voltage are shown.

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 three phase voltage swell as shown in Figure 12(a). Figures 12(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. Figures 11 (a), (b), and (c) show the single phase voltage swell, injected voltage by the DVR and the load voltage respectively.

In addition, as a result of SLG fault. An unbalanced voltage sag is created immediately after the fault as shown in Figure 13(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 13(b) and (c) respectively.

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 14(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 14(b) and (c), respectively.

The Figure 8 shows the Matlab/Simulink of power system grid under the fault condition connected to the Dynamic Voltage Restorer. The table 1 summarizes the specification of the simulation of the DVR.

Supply voltage per phase	400V
Source voltage	22KV
Series transformer turn ratio	1:1

DC bus voltage	150
Source resistance	0.8Ω
Line frequency	50
Line impedance	L = 1mH, R = 0.01Ω
Filter inductance	7mH
Filter capacitance	$10\mu F$

Table (1) System parameters and constant values

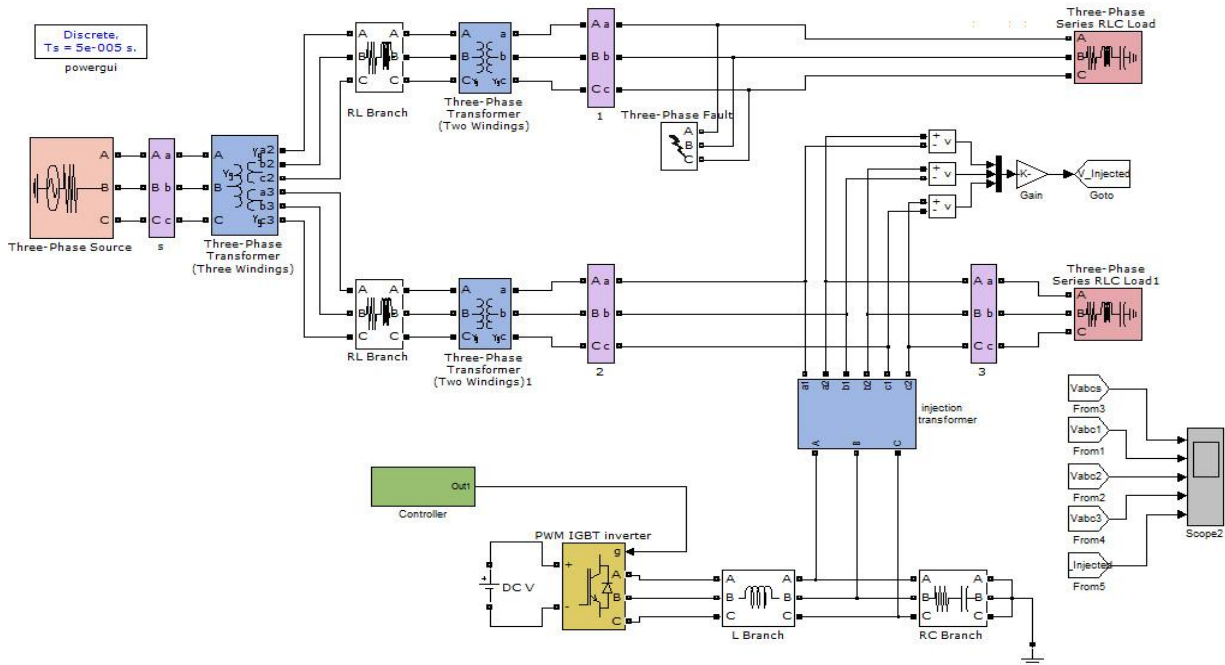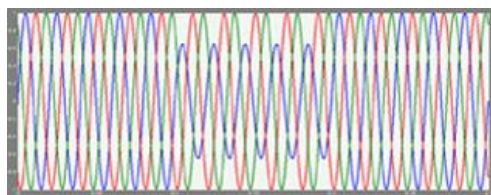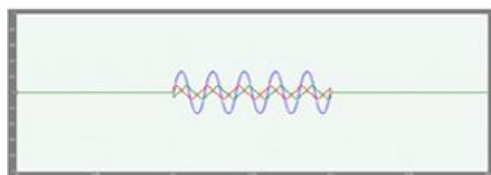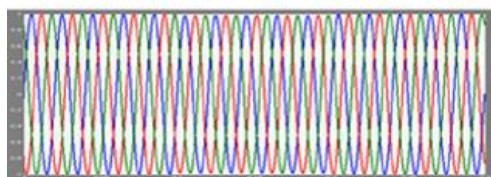Figure (8) Matlab model of the DVR connected system
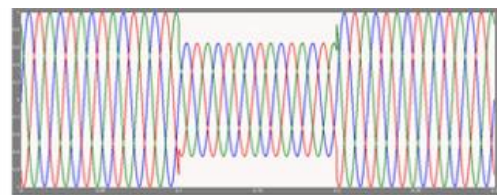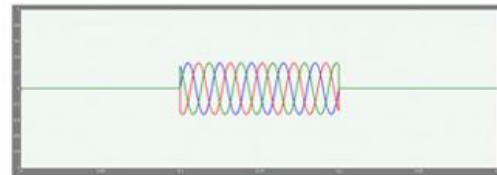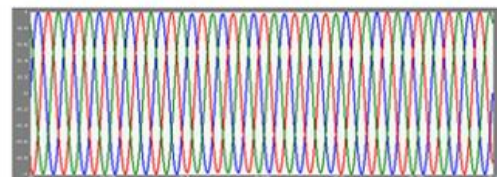

Figure (9) Single phase voltage sag
a) Source voltage b) Injected voltage c) Load voltage

Figure (10) Three phase voltage sag
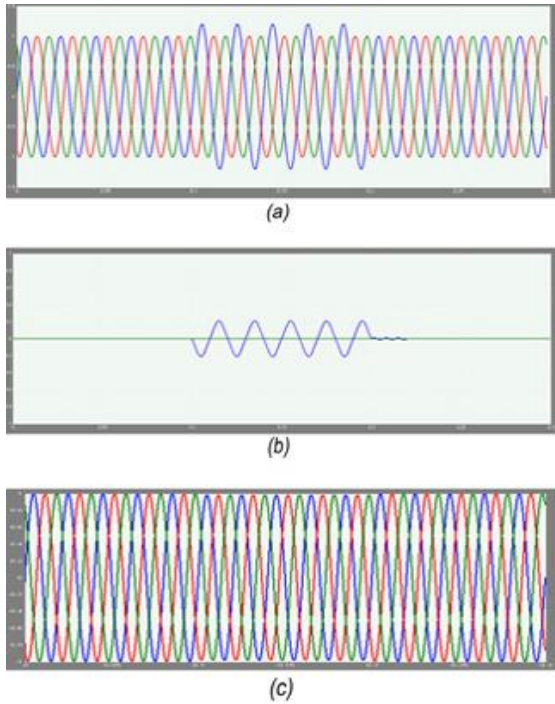a) Source voltage b) Injected voltage c) Load voltage

Figure (11) Single phase voltage swell
a) Source voltage b) Injected voltage c) Load voltage
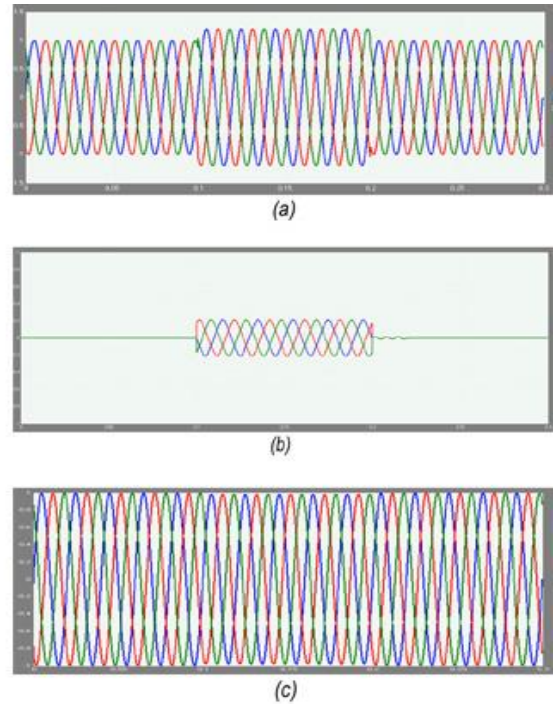

Figure (12) Three phase voltage swell
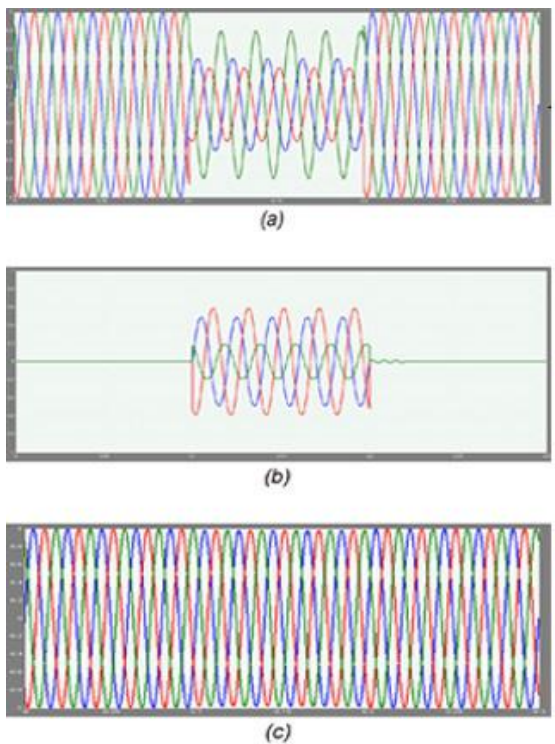a) Source voltage b) Injected voltage c) Load voltage

Figure (13) Unbalanced voltage sag
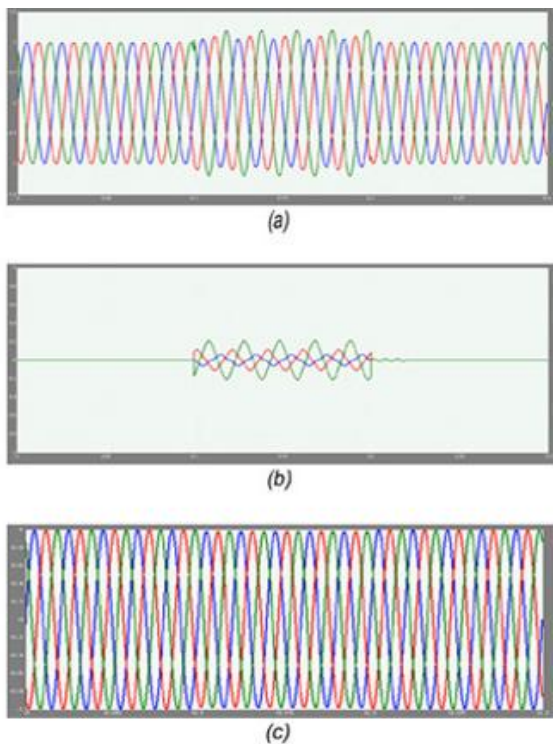a) Source voltage b) Injected voltage c) Load voltage

Figure (14) Unbalanced voltage swell
a) Source voltage b) Injected voltage c) Load voltage

V. Conclusions

A comprehensive study of a DVR as a powerful custom power device has been shown with aid of matlab/Simulink. The main advantages of DVR are low cost, simpler implementation, require less computational efforts and its control is simple as compared to other methods. 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. 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.

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