

# **Protection from Voltage Sags and Swells by Using FACTS Controller**

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**ABSTRACT:** Voltage sags and swells in the medium and low voltage distribution grid are considered to be the most frequent type of power quality problems based on recent power quality studies. 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 dynamic response to the disturbance. 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 dqo 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.

**KEY WORDS:** Dynamic Voltage Restorer (DVR), voltage sags, voltage swells, low voltage.

## **I. 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].

There are many different methods to mitigate voltage sags and swells, but the use of a custom Power device is considered to be the most efficient method. The concept of custom Power was introduced by N.G. Hingorani in 1995. Like Flexible AC Transmission Systems (FACTS) for transmission systems, the term custom power pertains to the use of power electronics controllers in a distribution system, especially, to deal with various power quality problems. Just as FACTS improves the power transfer capabilities and stability margins, custom power makes sure customers get pre-specified quality and reliability of supply.

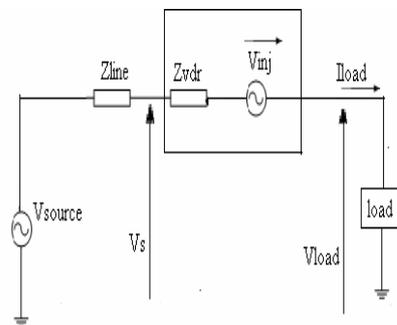
This pre-specified quality may contain a combination of specifications of the following [6]: low phase unbalance, no power interruptions, low flicker at the load voltage, low harmonic distortion in load voltage, magnitude and duration of overvoltages and undervoltages within specified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage.

There are many types of Custom Power devices. Some of these devices include: Active Power Filters (APF), Battery Energy Storage Systems (BESS), Distribution STATIC synchronous compensators (DSTATCOM),

Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Surge Arresters (SA), Super conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid-State Transfer Switches (SSTS), Solid State Fault Current Limiter (SSFCL), Static Var Compensator (SVC), Thyristor Switched Capacitors (TSC), and Uninterruptible Power Supplies (UPS) [7, 8].

Each of Custom Power devices has its own benefits and limitations. The most effective type of these devices is considered to be the Dynamic Voltage Restorer (DVR). There are numerous reasons why the DVR is preferred over the others. A few of these reasons are presented as follows. The SVC pre-dates the DVR, but the DVR is still preferred because the SVC has no ability to control active power flow [9]. Another reason is that the DVR costs less compared to the UPS [10, 11]. Not only the UPS is costly, it also requires a high level of maintenance because batteries leak and have to be replaced as often as every five years [11]. Other reasons include that the DVR has a higher energy capacity and lower costs compared to the SMES device [9]. Furthermore, the DVR is smaller in size and costs less compared to the DSTATCOM [9]. Based on these reasons, it is no surprise that the DVR is widely considered as an effective custom power device in mitigating voltage sags [12]. In addition to voltage sags and swells compensation, DVR can also added other features such as harmonics and Power Factor correction. Compared to the other devices, the DVR clearly provides the best economic solution for its size and capabilities.

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 are illustrated and discussed.



**Figure-1.** DVR operation.

## II. 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).

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.

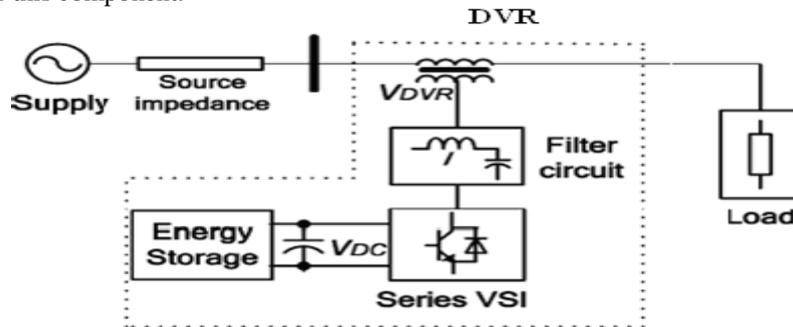


Figure-2. Equivalent circuit of DVR.

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].

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  $V_L$  can be maintained.

The series injected voltage of the DVR can be written as

$$V_{inj} = V_L + V_s$$

Where

$V_L$  is the desired load voltage magnitude

$V_s$  is the source voltage during sags/swells condition

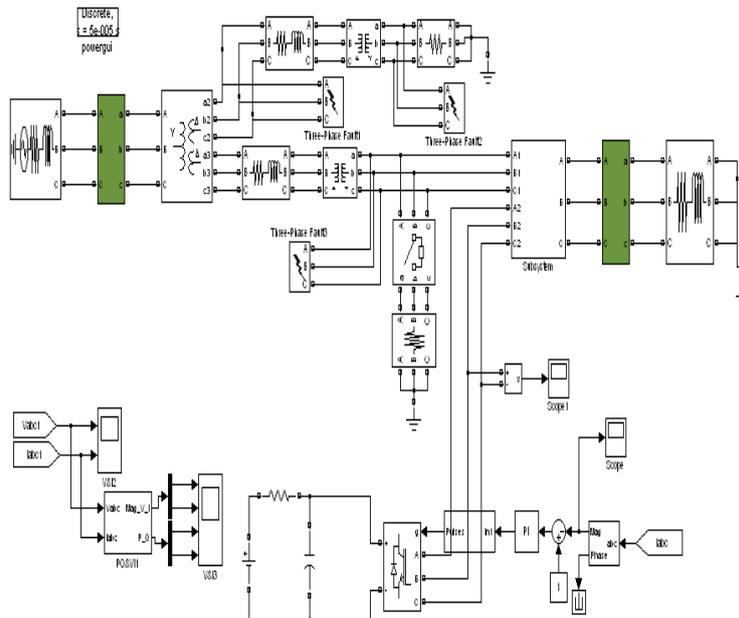
### III. PROPOSED METHOD

#### 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.

**B. Control methods**



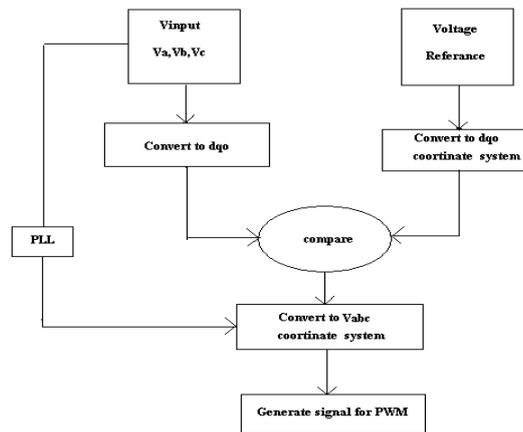
**Figure-3.** Proposed system configuration.

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 (Va, Vb, Vc). 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.

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.

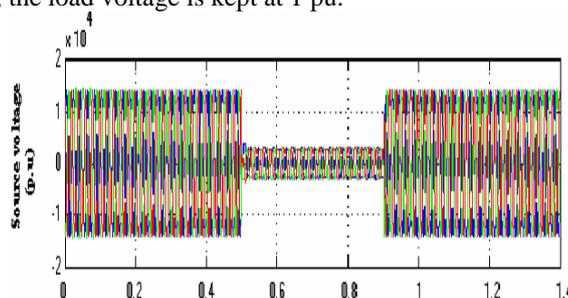
#### IV. SIMULATION RESULTS AND DISCUSSIONS

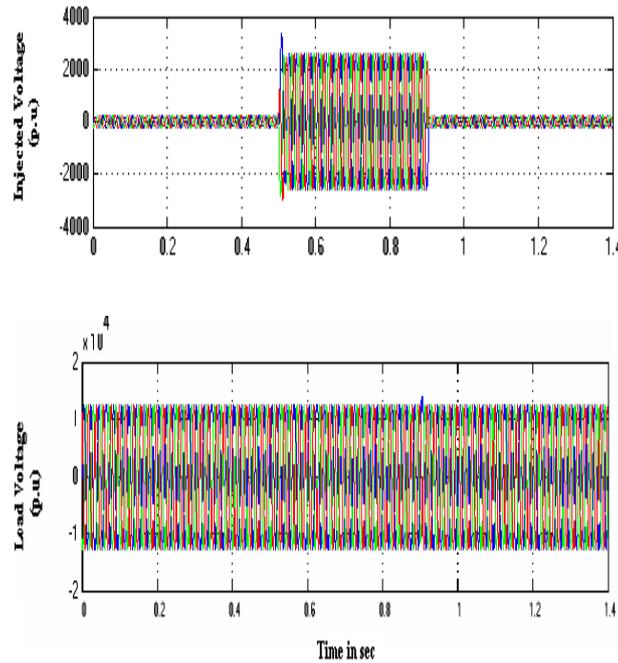
A detailed simulation of the DVR control system was performing using MATLAB/SIMULINK program in order to verify the operation. The parameters of the DVR system are as follows: In order to understand the performance of the DVR along with control, in voltage sags and swells mitigation, a simple distribution 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.

##### 4.1 Voltage sags

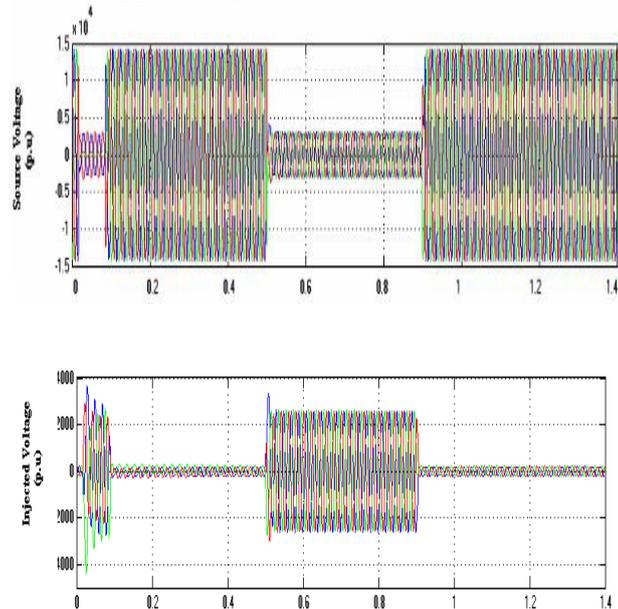
The first simulation of three phase voltage sag is simulated and a 50% three-phase voltage sag occurring at the utility grid is shown in Figure-5 (a).

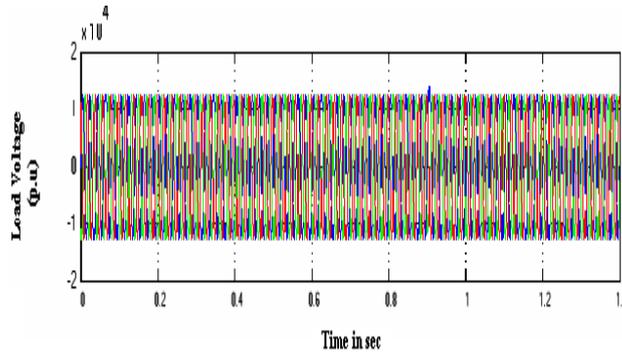
In Figure-5 (a) also shows a 50% voltage sag initiated at 0.5s and it is kept until 0.9s, with total voltage sag duration of 0.4s. Figures-5 (b) and (c) show the voltage injected by the DVR and the corresponding load voltage with compensation. As a result of DVR, the load voltage is kept at 1 pu.



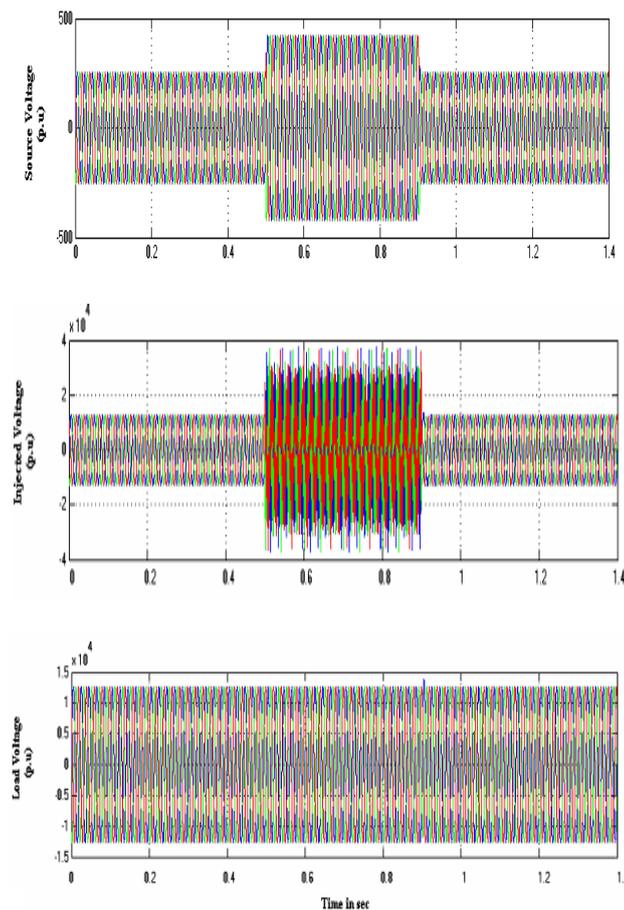


**Figure-5.** Three-phase voltages sag: (a)-Supply voltage, (b)-voltages injected by the DVR, (c)- voltage at load.

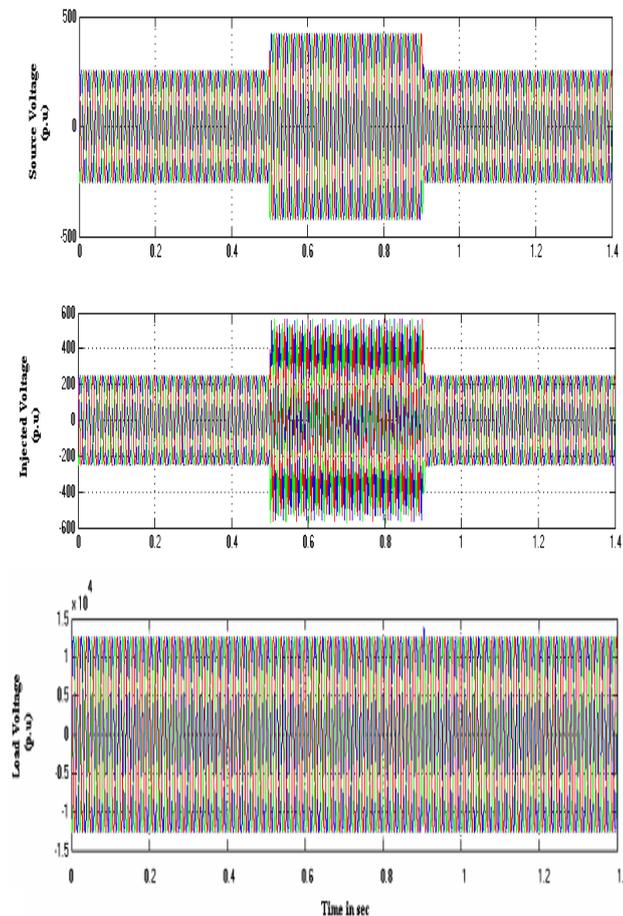




**Figure-6.** Single-phase voltages sag: (a)-Supply voltage, (b)-voltages injected by the DVR, (c)- voltage at load.



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



**Figure-8.** Two-phase voltages swell: (a)-Supply voltage, (b)-voltages 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.

## V. 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.

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