DYNAMIC VOLTAGE RESTORER AGAINST BALANCED AND UNBALANCED VOLTAGE SAG/SWELLS: MODELLING AND SIMULATION

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ABSTRACT

This paper describes the problem of voltage sags and swells and its severe impact on non linear loads or sensitive loads. Severe impacts on Sensitive load itself due to voltage sags and swell. The Dynamic Voltage Restorer (DVR) is fast, flexible and efficient solution to mitigate voltage sag/swell by injecting Voltage as well as power into the system. Dynamic Voltage Restorer (DVR) is a power costumed device used in power distribution network using for voltage enhancement after occurring disturbance in the power system. The DVR can restore the load voltage within few milliseconds. The control of the compensation voltages in DVR based on dqo algorithm is discussed. Dynamic Voltage Restorer (DVR) with sinusoidal pulse width (SPWM) based controller by using the Mat lab /Simulink verify the performance of the proposed method.

Keywords: DVR, Power Quality, Park's transformation, Voltage Sags/Swells, VSI, DC Energy Storage, harmonic distortion.

I INTRODUCTION

One of the major concerns in electricity industry today is power quality problems to sensitive loads. This is due to the advent of a large numbers of sophisticated electrical and electronic equipment, such as computers, programmable logic controllers, variable speed drives, and so forth. The use of these equipments very often requires power supplies with very high quality. Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, voltage interruption, flicker, harmonics distortion, impulse transient, and interruptions [1]. Power distribution systems, should ideally provide their customers with an uninterrupted flow of energy with a smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially distribution systems, have numerous nonlinear loads, which significantly affect the quality of the power supply. As a result of these nonlinear loads, the purity of the supply waveform is lost in many places. This ends up producing many power quality problems [7], [8].
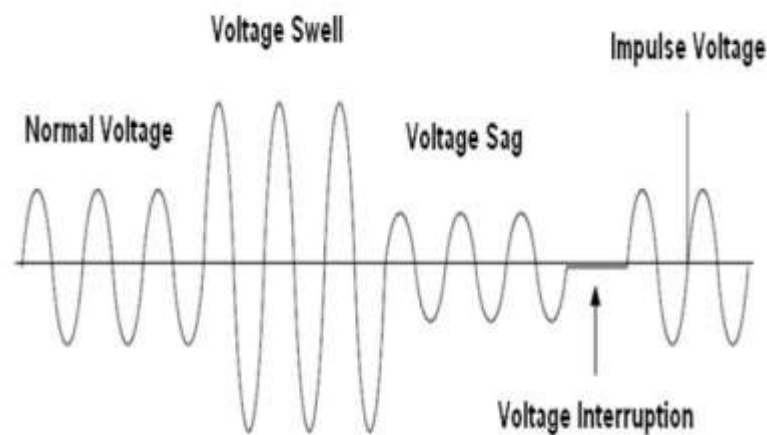
Fig. 1. Regular Power- Quality Problems in Power System

Power Quality Problems

An important percentage of all power quality problems are of the voltage-quality type where what matters is the deviation of the voltage waveform from its ideal form. The typical power quality disturbances are voltage sags voltage swells, interruptions, phase shifts, harmonics and transients. [6],[7],[9]

Voltage Sag

Voltage sag is considered the most severe since the sensitive loads are very susceptible to temporary changes in the voltage. A voltage Sag is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage Sag magnitude is ranged from 10% to 90% of nominal voltage (which corresponds to 90% to 10% remaining voltage) and with a duration from half a cycle to 1 min. It is considered as the most serious problem of power quality. It is caused by faults in the power system or by the starting of large induction motor [7,8,11].

Voltage Swell

Voltage swell is defined as an increase in the root mean square (RMS) voltage from 1.1 to 1.8 per unit for duration from 0.5 cycles to 1 min. Voltage swells are not as important as voltage sags because they are less common in distribution systems. The main causes for voltage swell are switching of large capacitors or start/stop of heavy loads [12,13].

Harmonics

The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency. The main causes for harmonic distortion are rectifiers and all non-linear loads, such as power electronics equipment including VSDs [7, 13].

Voltage Transients

They are temporary and undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20kV) that last for a very short time. Flicker: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz. The main causes are frequent start/stop of electric motors (for instance elevators), oscillating loads [14]. Figure -1 shows the sketch of a voltage waveform with physical power- quality problems.

II. OPERATION OF DVR

Dynamic Voltage Restorer is a series connected device designed to maintain a constant RMS voltage value across a sensitive load. DVR is a Custom Power Device used to eliminate supply side voltage disturbances. The term custom power refers to the use of power electronics controllers in a distribution system, especially, to deal with various power-quality problems. From Figure-2. DVR also known as the Series Voltage Booster (SVB) or the Static Series Compensator (SSC), is a device that utilizes solid state (or static) power electronic components, and is connected in series to the utility primary distribution circuit [5]. The DVR maintains the load voltage at a desired magnitude and phase by compensating the voltage sags/swells and voltage unbalances presented at the point of common coupling.
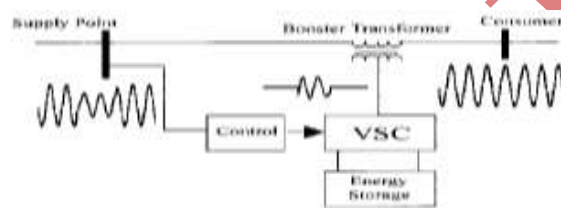

Figure-2 Simplified Circuit for Role and Location of DVR in the Distribution System

III DVR BASIC CONFIGURATION AND COMPONENTS
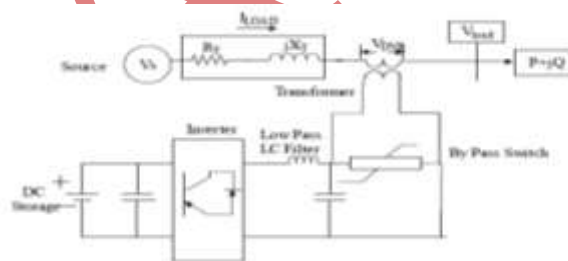
The DVR consists of 6 major parts:

Figure. 3. Basic Component of a DVR

3.1. Voltage Source Inverter (VSI)

Voltage source inverter (VSI) is low voltage and high current with step up injection transformer is used to boost up the injected voltage. The Voltage Source Inverter (VSI) or simply the inverter, converts the dc voltage from the energy storage unit (or the dc link) to a controllable three phase ac voltage. The inverter switches are normally fired using a sinusoidal Pulse Width Modulation (PWM) scheme. Since the vast majority of voltage sags seen on utility systems are unbalanced, the VSI will often operate with unbalanced switching functions for the three phases, and must therefore treat each phase independently. Moreover, Sag on one phase may result in a swell on another phase, so the VSI must be capable of handling both sags and swells simultaneously. Another

topology of the DVR is the use of multi-inverter system in cascade. This topology will add the voltage of the single cascaded inverters in series in order to obtain the desired inverter voltage. This method gets rid of the injection transformer used in the basic configuration of the DVR. This arrangement is often called a transformer-less or multilevel or a cascade inverter DVR [6-7].

3.2 Injection Transformers

The three single-phase injection transformers are used to inject missing voltage

to the system. The electrical parameters of series injection transformer should be selected correctly to ensure the maximum reliability and effectiveness [4]. To integrate the injection transformer correctly into the DVR, the MVA rating, the primary winding voltage and current ratings, the turn-ratio and the short-circuit impedance values of transformers are required [5].

3.3 Passive Filters

The nonlinear characteristics of semiconductor devices cause distorted waveforms associated with high frequency harmonics at the inverter output.
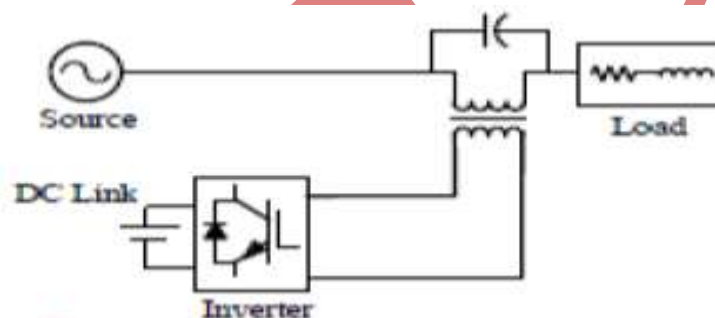

Figure. 4. DVR with load side filter

Passive filters are placed at the high voltage side of the DVR to filter the harmonics. These filters are placed at the high voltage side as placing the filters at the inverter side introduces phase angle shift which can disrupt the control algorithm [5,9]
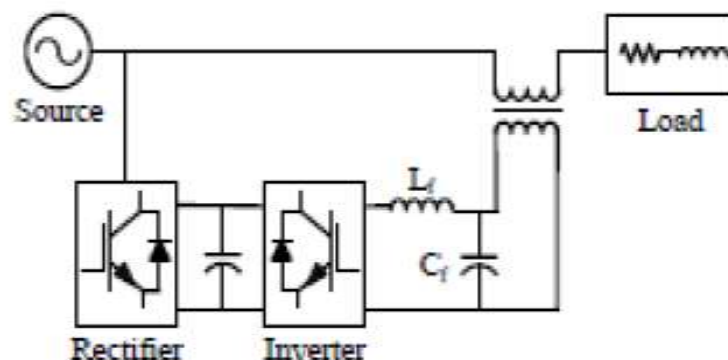
3.4 Energy storage

Figure. 5. DVR with Supply Rectified Energy

It is responsible for energy storage in DC form. Flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors can be used as energy storage devices. It is supplies the real power requirements of the system when DVR is used for compensation.

3.5 Capacitor
DVR has a large DC capacitor to ensure stiff DC voltage input to inverter

3.6 By-Pass Switch
It is used to protect the inverter from high currents in the presence of faulty conditions. In the event of a fault or a short circuit on downstream, the DVR changes into the bypass condition where the VSI inverter is protected against over current flowing through the power semiconductor switches. The rating of the DVR inverters becomes a limiting factor for normal load current seen in the primary winding and reflected to the secondary winding of the series insertion transformer. For line currents exceeding the rating, a bypass scheme is incorporated to protect the power electronics devices [13].

IV CONTROL OF DVR

The basic functions of a DVR controller 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 abc reference frame to dqo reference. For simplicity zero phase sequence components is ignored. The detection is carried out in each of the three phases. The control scheme for the system 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 used as a modulation signal allows to generate 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 PLL circuit is used to generate a unit sinusoidal Wave in phase with mains voltage.

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$
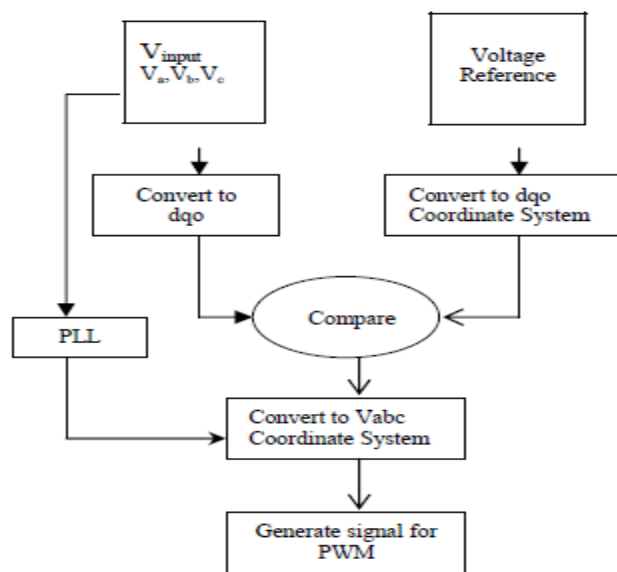
(1st)

Figure 6: Flow chart of feed forward control technique for DVR based on dqo transformation.

Equation (1st) defines the transformation from three phase system a,b,c to dqo stationary frame. In this transformation, phase A is aligned to the direct axis(d-axis) that is in quadrature with the q-axis. The theta (θ) is defined by the angle between phase A to the d-axis [12,13].
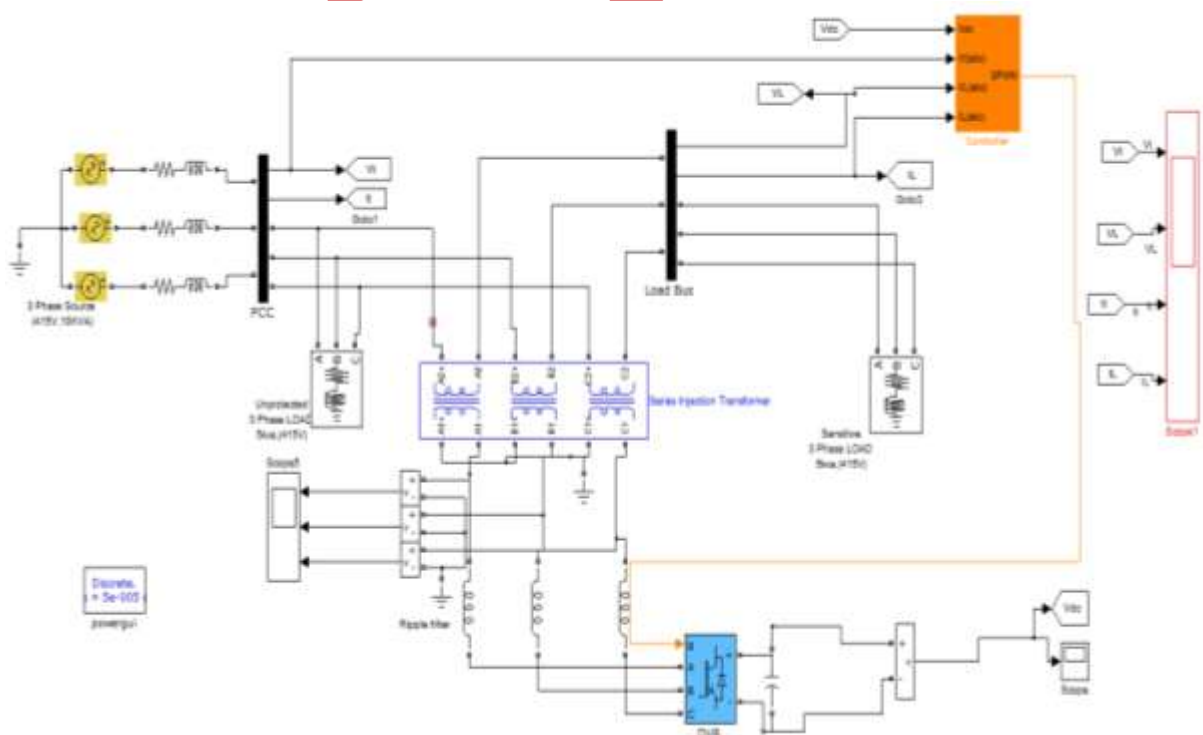
V. MATLAB MODELLING AND SIMULATION

Figure 7: DVR system configuration.

By using the MAT LAB and its Simulink and Sim Power System toolboxes the DVR is modelled and simulated. The MAT LAB model of the DVR is shown in figure. The three-phase programmable source is connected to the three-phase load through the DVR. The load is a lagging power factor load. The VSI of the DVR is connected to the system using an injection transformer. Also, a ripple filter for filtering the switching ripple in the terminal voltage is connected across the terminals of the secondary of the transformer. The dc bus capacitor of DVR is selected based on the transient energy requirement and the dc bus voltage is selected based on the injection voltage level. The dc capacitor decides the ripple content in the dc voltage.The control algorithm for the DVR is simulated in MATLAB. The control algorithm shown in Fig.-6 is modelled for DVR control. The reference load voltages are derived from the sensed terminal voltages, load supply voltages and the dc bus voltage of the DVR. A pulse width modulation (PWM) controller is used over the reference and sensed load voltages to generate gate signals for the IGBT's of the VSI.

VI SIMULATION RESULTS AND DISCUSSION

A detailed simulation of the DVR control system was performing using MATLAB/SIMULINK program in order to verify the operation. The performance of the DVR is demonstrated for different supply voltage disturbances such as sag and swells in supply voltage.

Voltage Sags

The first simulation shows of three phase voltage sag are simulated. The simulation started with the supply voltage 50% sagging as shown in Figure 8(a).In Figure 8 (a) also shows a 50% voltage sag initiated at 0.15s and it is kept until 0.35s, with total voltage sag duration of 0.2s. Figures 8 (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 p.u. The effectiveness of the DVR under unbalanced conditions is shown in figure 9, in figure 9 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 9 (a).
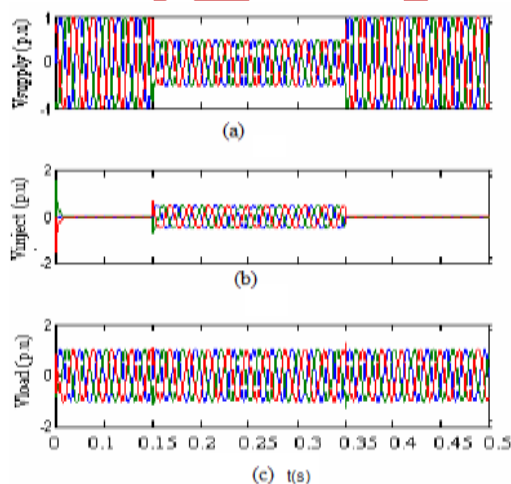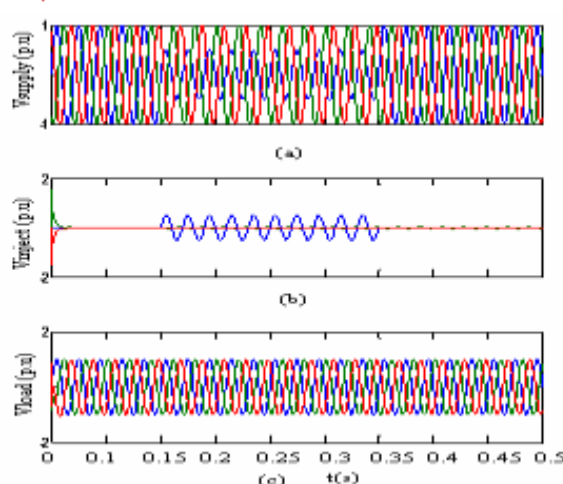

Figure 8

Figure. 9

Figure 8 Three-phase voltages sag: (a)-Source voltage, (b)-Injected voltage, (c)-Load

Figure. 9 Single-phase voltage sag: (a)-Sourcevoltage, (b)-Injected voltage, (c)-Load voltage

The DVR injected voltage and the load voltage are shown in Figures 9(b) and (c) respectively. Its corresponding load voltages are shown in Figure 9(c) where it is possible to see that the compensation method is keeping the load voltages constant at 1 p.u.
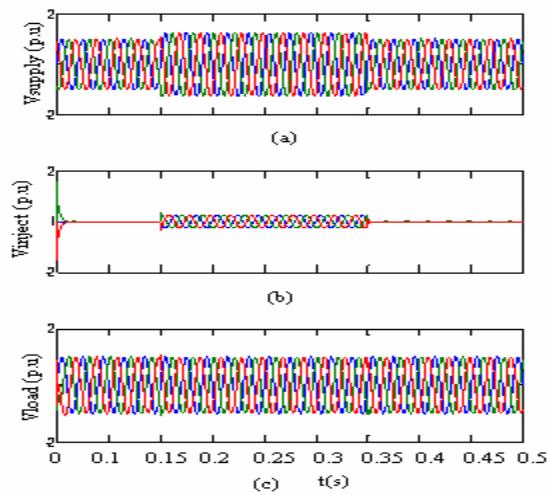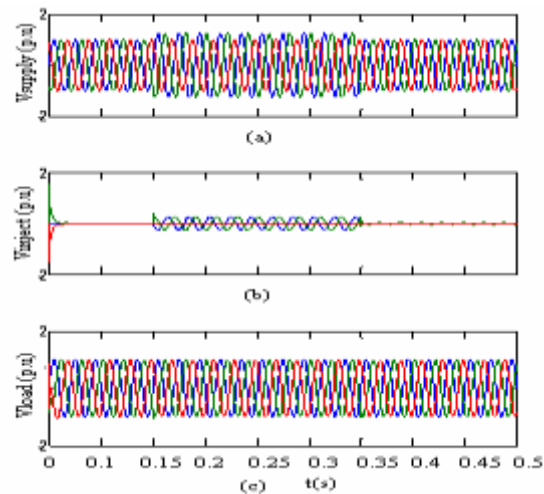

Figure-10   **Figure-11**

Figure-10: Three-phase voltages swell: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage

Figure-11: Two-phase voltages swell: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage

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 10 (a). As observed from this figure the amplitude of supply voltage is increased about 25% from its nominal voltage. Figures 10(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. Figure-11 shows that the performance of the DVR with an unbalanced voltage swells. In this case, two of the three phases are higher by 25% than the third phase as shown in Figure 11(a). The injected voltage that is produced by DVR in order to correct the load voltages and the load voltages maintain at the constant are shown in Figures 11 (b) and (c), respectively.

VII CONCLUSION

The modelling 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. From simulation results also show that the DVR compensates the sags/swells quickly and provides excellent voltage regulation. The DVR handles both balanced and unbalanced situations without any difficulties and injects 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.

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