Research Paper Engineering

Mitigation of Voltage Sags / Swells using Dynamic Voltage Restorer (DVR)

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ABSTRACT

The power quality is simply the interaction of electrical power with electrical equipment. The power quality problems include voltage sags, swells, impulses/transients, high frequency noise, voltage flicker etc. These disturbances are unacceptable at utility sector. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipments. Dynamic Voltage Restorer (DVR) is one of the custom power device solve the voltage related problems, which is efficient, effective in power distribution networks and a fast dynamic response to the disturbances. This paper presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) test systems using MATLAB/ SIMULINK Software. The results show that DVR operates as expected during balanced voltage sag and voltage swell.

Keywords: Voltage Sags/Swells, DVR, Custom Power.

I. INTRODUCTION

A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end use equipments. Power quality problems are associated with an extensive number of electromagnetic phenomena in power systems with broad ranges of time frames such as long duration variations, short duration variations and other disturbances. Short duration variations are mainly caused by either fault conditions or energization of large loads that require high starting currents [2][3].

The most common form of power quality disruption is the voltage sag (balanced and unbalanced), which accounts for about 70% of all power disturbances.

To overcome this voltage sag problem, the DVR is used to protect sensitive loads from all kinds of supply side disturbances[1].

II. DVR System Configuration

The Dynamic Voltage Restorer (DVR) essentially consists of a series inverter Voltage Source Inverter (VSI) and an energy storage device connected to the DC link shown in Figure 1.

Usually the connection is made via a transformer, but configurations with direct connection via power electronics also exist. The resulting voltage at the load bus bar equals the sum of the grid voltage and the injected voltage from the DVR. The converter generates the reactive power needed while the active power is taken from the energy storage. The energy storage can be different depending on the needs of compensating.

The basic operation principle of the DVR is to inject an appropriate voltage in series with the supply through injection transformer whenever voltage sag or voltage swell is detected [4]. DVR can also perform other tasks such as harmonic compensation and improve Power Factor.

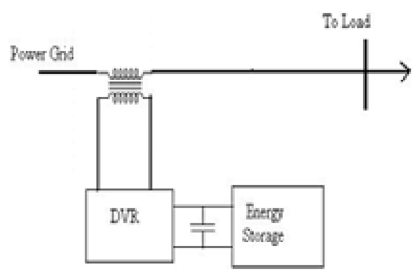


Figure 1. Standard Configuration of DVR

III. Series Voltage Injection

Voltage source inverter (VSI) can be used to generate the ac voltage at desired frequency with controllable amplitude and phase angle. This generated voltage can't be directly fed into the line as inverter output voltage has switching harmonics[10]. DVR is the combination of VSI and filter. DVR is primarily used to mitigate the sag swell problems in receiving end voltage [7]. In a transmission system, it can be used to improve the voltage stability, transient stability and to damp the power oscillations. Basic Series Voltage Compensated Line is shown in Figure 3.

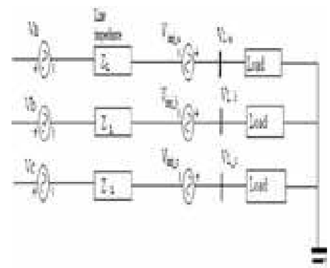


Figure 2. Basic Series Voltage Compensated Line

A typical DVR connection is shown in Figure 2. It is connected in series with the distribution feeder-2 that supplies a sensitive load. For a fault clearing or switching at point A of the incoming feeder or fault in the distribution feeder-1, the voltage at feeder-2 will sag. Without the presence of the DVR, this will trip the sensitive load causing a loss of production. The DVR can protect the sensitive load by inserting voltages of controllable amplitude, phase angle and frequency (fundamental and harmonic) into the distribution feeder via a series insertion transformer shown in Figure 3. It is however to be mentioned that the rating of a DVR is not unlimited.

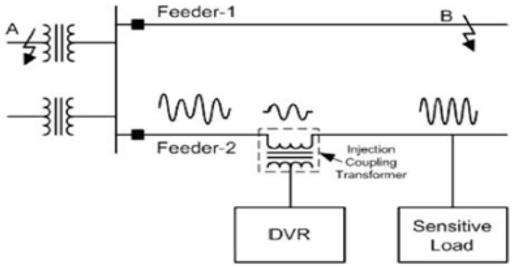


Figure 3. DVR in Line to Protect Sensitive Load

IV. Minimal Energy Injection Technique

This is basically reactive power compensation technique. In this, the injected voltage is in phase quadrature with the load current. Therefore no active power is injected by the DVR. Phasor diagram for quadrature injection is shown in Figure 4. In the phasor diagram radius of arc AB is Vnom. IL denotes the load current. From the phasor diagram, the general equation relating the electrical quantities is

$$|V_S| = \left(|V_{nom}|^2 - 2|V_{nom}||V_{inj}|\sin\phi + |V_{inj}|^2\right)$$

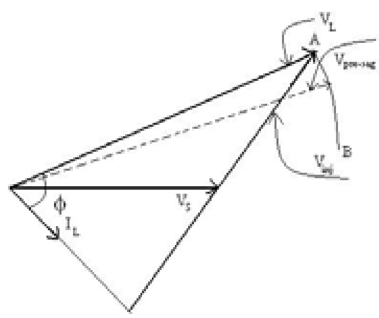


Figure 4. Phasor Diagram of Minimum Energy Injection Technique

Where,
Φ is the power factor angle of the load

By this technique any arbitrary level of sag cannot be compensated. There is a minimum value of source voltage ($V_{S\text{-}min}$) beyond which the load voltage cannot be restored to the nominal value.

From the phasor diagram and this minimum voltage V_S^{min} is given by

$$|V_s^{min}| = |V_{nom}|\cos\phi$$

And in this case, injected voltage by the DVR is given by

$$|V_{inj}| = |V_{nom}|\sin\phi$$

Also, the reactive power demanded from the DVR is calculated as follows

$$Q_{DVR} = |I_L||V_{nom}|.\sin\phi - \left(|V_S|^2 - |V_{nom}|^2.\cos\phi\right); V_S \geq V_S^{min}$$

V. MODELING OF DVR

The compensation of voltage sag/swell can be limited by a number of factors, including finite DVR power rating, loading conditions, power quality problems and types of sag/swell. If a DVR is a successful device, the control is able to handle most sags/swells and the performance must be maximized according to the equipment inserted[6]. Otherwise, the DVR may not be able to avoid tripping and even cause additional disturbances to the loads.

1. Mathematical Modeling for Voltage Injection by DVR System

Consider the schematic diagram shown in Figure 5

$$Zth = Rth + Xth$$
$$VDVR + Vth = VL + ZthIL$$

When dropped voltage happened at VL, DVR will inject a series voltage VDVR through the injection transformer so that the desired load voltage magnitude VL can be maintained [8]. Hence

$$V_{DVR} = VL + Z_{th}I_L - V_{th}$$

$$I_L = \left(\frac{P_L + jQ_L}{V_L}\right)^*$$

When VL is considered as a reference, therefore;

$$V_{DVR}\angle\alpha = V_L\angle 0^0 + Z_{th}I_L\angle(\beta-\theta) - V_{th}\angle\delta$$

Here , and δ are the angle of VDVR, Zth and Vth, respectively and θ is the load power factor angle with

The power injection of the DVR can be written as $S_{DVR} = V_{DVR}I_L^*$

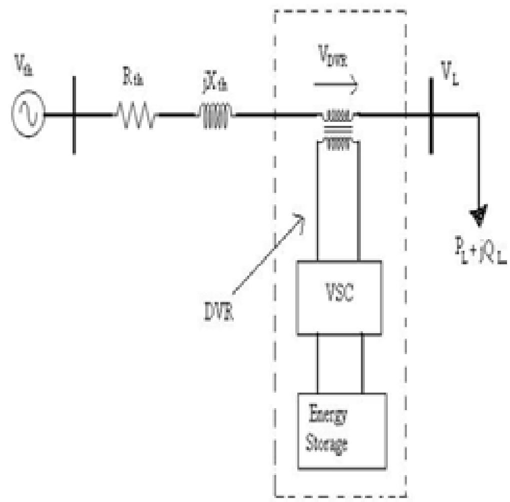


Figure 5. Calculation for DVR Voltage Injection

2. Phase Locked Loop (PLL)

A PLL is a device which causes one signal to track another one. It keeps an output signal synchronizing with a reference input signal in frequency as well as in phase. More, precisely the PLL is a servo system, which controls the phase of its output signal in such a way that the phase error between out phase and reference phase reduce to a minimum [9].

The angle information is typically extracted using some form of phase locked loop (PLL). The quality of phase lock directly affects the performance of the control loops in all the above applications. Voltage unbalance, frequency variation and phase jumps are common disturbances faced by equipment interfaced with the electric utility

To obtain a relation between the estimation error in terms measured variables, the SRF approach is adopted.

Let V_a, V_b, V_c be a set of balanced, three phase voltage signals, defined as

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \begin{bmatrix} V\cos\theta \\ V\cos(\theta - \frac{2\pi}{3}) \\ V\cos(\theta + \frac{2\pi}{3}) \end{bmatrix}$$

These are first transformed with respect to a stationary, Cartesian reference frame using the following transformation.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3/2} & \sqrt{3/2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

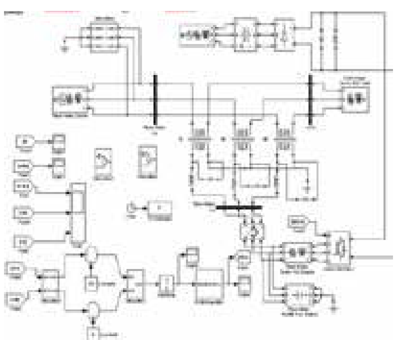
The transformed voltages are then referred to a rotating reference frame, which has same angular phase as the estimator output, θ^* . This transformation is defined as

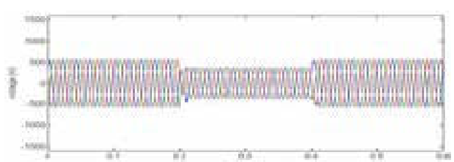
$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta^* & -\sin\theta^* \\ \sin\theta^* & \cos\theta^* \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix}$$

VI. SIMULATION RESULTS

Simulation of the DVR is performed in MATLAB SIMULINK using the above control technique. The parameters of the test system for simulation are given below.

Controllable Power rating (P) =10 KW Utility line to line Voltage=200V
Line inductance (L)=1.0 mH
Line resistance (R)=0.04
ohm Frequency =60 Hz
Rms voltage of Vc=12V





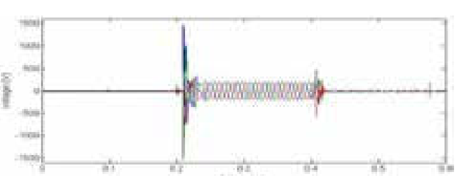


Figure 6. Simulink Model of DVR
Figure 6.1 (a) 3-Phase voltage at PCC
Figure 6.1 (b) 3-Phase injected voltage

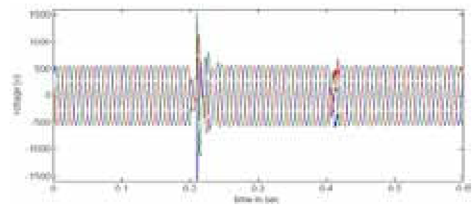


Figure 6.1(c) 3-Phase V at load point

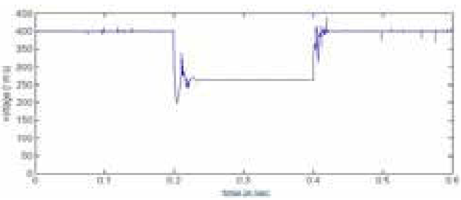


Figure 6.1 (d) RMS load voltage with sag

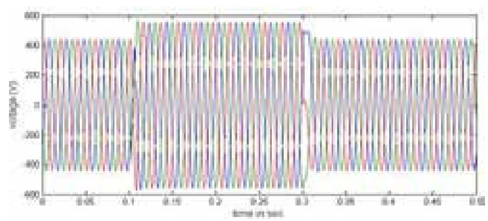


Fig 6.1(e) Three phase voltage at PCC

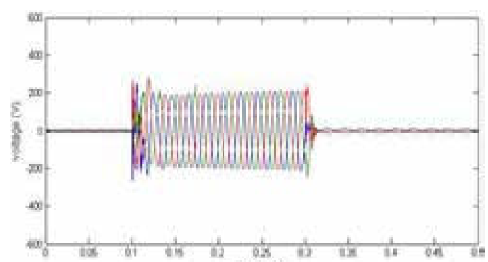


Figure 6.1 (f) Three phase injected voltage

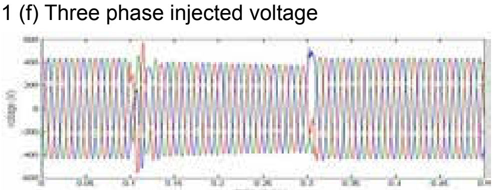


Figure 6.1 (g) Three phase voltage at load point

VII. CONCLUSION

This paper deals with the dynamic model of DVR and is one of the effective custom power device for voltage sags and swells mitigation. The impact of voltage sags on sensitive equipment is severe. Therefore, DVR is considered to be an efficient solution due to its relatively low cost and small size, also it has a fast dynamic response. The simulation results show clearly the performance of a DVR in mitigating voltage sags and swells. 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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