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Study of Dynamic Voltage Restorer (DVR) for Mitigation of Voltage Sags

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Abstract: The Dynamic Voltage Restorer (DVR) has become popular as a cost effective solution for the protection of sensitive loads from voltage sags. This study deals with modeling and simulation of a DVR for mitigation of voltage sags. The DVR restores constant load voltage and voltage wave form by injecting an appropriate voltage. The MATLAB/Simulink Simpower System toolbox has been used to validate the proposed mathematical model for balanced and unbalanced load in the utility voltage. This paper presents a model for DVR to mitigate sags, thereby achieving the improvement of utility power factor as well as power sharing between the DVR and the utility. The power sharing will be as per requirement to compensate the sags considering the available distributed generation (DG). The simulation results have shown validation through computer simulation by using Matlab-SimPowerSystems toolbox.

Keywords: Balanced load, dynamic Voltage Restorer, distributed generation, unbalanced load, voltage sags

1.0 INTRODUCTION

The ever growing complexity of the power system and the faults associated make it impossible to always maintain the desired specifications with regards to voltage magnitude, frequency, and harmonic distortion at the point of common coupling [1]. Voltage sag is broadly considered as a short duration voltage variation and method of characterization involves both magnitude and duration. The duration of voltage sag varies between five cycles to a minute.

The Dynamic Voltage Restorer (DVR) supplies the active power with help of DC energy storage and required reactive power is generated internally without any means dc storage. Its can compensate voltage at both transmission and distribution sides. Usually a DVR is installed on a critical load feeder. During the normal operating condition DVR operates in a low loss standby mode [2]. During this condition the DVR is said to be in steady state. When a disturbance occurs and supply voltage deviates from nominal value, DVR supplies voltage for compensation of sag and is said to be in transient state. The DVR is connected in series between the load and the supply voltage [3]. It basically supplies the voltage difference to transmission line and maintains the pre sag values condition in the load sides [4]. Use of DVR is proposed in low and medium voltage distribution network to protect sensitive load from sudden voltage dips/sag [5]. Pulse width modulated inverter is used to vary the amplitude and the phase angle of the injected voltages, thus allowing the control of both real and reactive power exchange between the distribution system and the load [6]. For proper voltage sag compensation, it is necessary to derive suitable and fast control scheme for inverter switching.

Small voltage sags can usually be restored through reactive power only, but for larger voltage sags, it is necessary to inject active power into the system by the DVR to mitigate the voltage sags [7]. Voltage sag is defined as a sudden reduction of supply voltage down by 90% to 10% of nominal, followed by a recovery after a short period of time [8]. The DVR is one of the custom power device, which can improve power quality, especially; voltage sags and swells [9]. In this paper, a modeling of the DVR for mitigation of voltage sag is done using the Matlab-SimPowerSystems toolbox. Simulation results are presented to show a DVR for mitigation of voltage sags. The DVR restores constant load voltage and voltage wave form by injecting an appropriate voltage.

2.0 DYNAMIC VOLTAGE RESTORER

The DVR provides three phase controllable voltage, whose vector (magnitude and angle) adds to the source voltage to restore the load voltage to pre-sag conditions. Fig. 1 is a simplified circuit for the role and location of the DVR in the distribution system. When a fault occurs on the line feeding Load 1, its voltage collapses to zero. Load 2 voltage experiences a sag which magnitude is equal to the voltage at the PCC, and the voltage of the sensitive load protected by the DVR is restored to its pre-fault value.

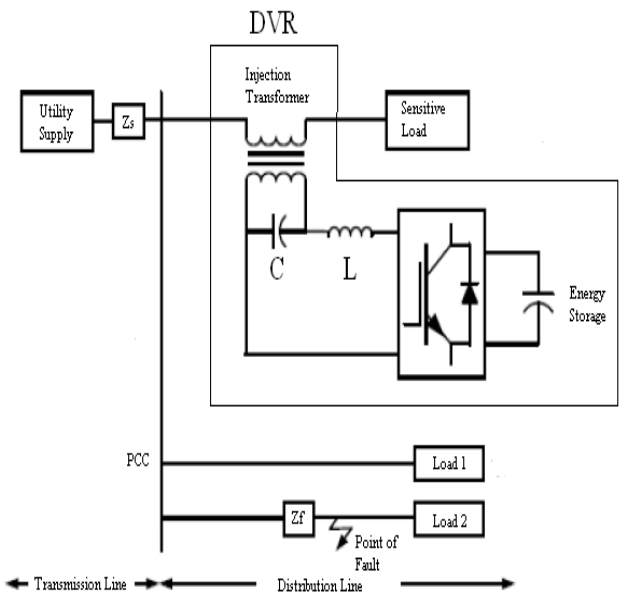

Fig. 1 Location of the Dynamic Voltage Restorer

A dynamic voltage restorer is one of the custom power devices which are used to protect sensitive loads from sag, swell and harmonics or disturbances in the supply voltage. The DVR consists of a voltage source inverter, a switching control scheme, a DC energy storage device, output filter and an injection transformer is connected in series with the ac system as shown in Fig. 2. DVR uses semi-conductor device to maintain voltage of sensitive load by injecting voltage whose magnitude, phase and frequency can be controlled.

A DVR is a device that injects a dynamically controlled voltage Vinj in series to the bus voltage by means of a injection transformer as depicted in Fig. 1. When supply voltage Utility supply (Vs) changes, the DVR injects a voltage Vinj in such a way that the desired voltage magnitude can be maintained. The DVR is simply a VSI that produces an ac output voltage and injects in series with supply voltage through a transformer. Fig. 3 shows the overall modeling of the DVR for mitigation of voltage sag is done using the Matlab-Simpowersystems.

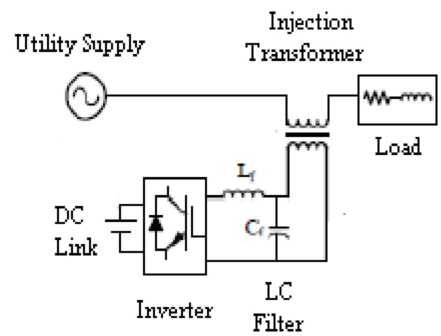

Fig. 2 Basic Components of a Dynamic Voltage Restorer

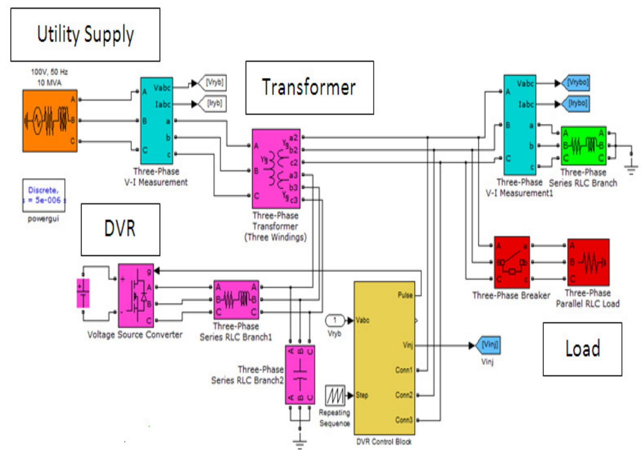

Fig. 3 Configuration of the overall of DVR in Matlab-Simpowersystem

3.0 DVR CONTROL STRATEGY

The aim of the control scheme is to maintain constant voltage magnitude at the sensitive load under voltage disturbance condition. The basic functions of a controller in a DVR are the detection of voltage sag events in the system by computation of the correcting voltage; generation of trigger pulses to the sinusoidal PWM based Voltage Source Inverter. The proposed control scheme based on comparison of actual supply voltage and desired load voltage. The error is determined based on difference between desired and measured value. In the control scheme, the actual voltage and desired voltage are measured. These voltages are converted in dq0 with the parks transformation.

$$f_{dq0} = K_s f_{abc} \quad (1)$$

Where

$$(f_{dq0})^T = (f_d f_q f_0) \quad (2)$$

$$(f_{abc})^T = (f_a f_b f_c) \quad (3)$$

Parks transformation is

$$K_s = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (4)$$

It can be shown that for the inverse transformation is

$$(K_s)^{-1} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \quad (5)$$

The control system employs abc to dq0 transformation to dq0 voltages. During normal condition and symmetrical condition, the voltage will be constant and d-voltage is unity in p.u. and q-voltage is zero in p.u. but during the abnormal conditions, it varies. After comparison d and q voltage with the desired voltage error d and q is generated. This error component is converted into abc component using dq0 to abc transformation. The detection is carried out in each of the three phases. The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va, Vb, Vc). The voltage sag is detected when the supply drops below 90% of the reference value. The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches constituting the voltage source inverter.

4.0 SIMULATION RESULTS

To verify the dynamic performance of mitigation balanced and unbalanced voltage sags, a simulation model were simulated in a Matlab SimPowerSystems toolbox.

4.1 Balanced voltage sags

Fig. 3 shows about 50% sag on 3-phase utility voltage started at 0.04 sec continued till 0.1 sec. A three-phase balanced sag may result from a three-phase balanced fault. The injected voltage that was generated after comparing utility voltage with reference is shown in Fig. 4, which is shows the corresponding sag magnitude in p.u. Now, the DVR quickly injected the desired 3-phase voltage (Green, Red and Blue) components in the utility voltage by following the amount of the sag and restored load voltage is shown in Fig. 5.

Unidirectional load voltage overshoots are visible in Fig. 5 during the transient period. These overshoots occur when the DVR is suddenly brought in for sag mitigation, as well as brought out when sag disappears. These transient disturbances are caused by sudden injection and removal of energy by switching.

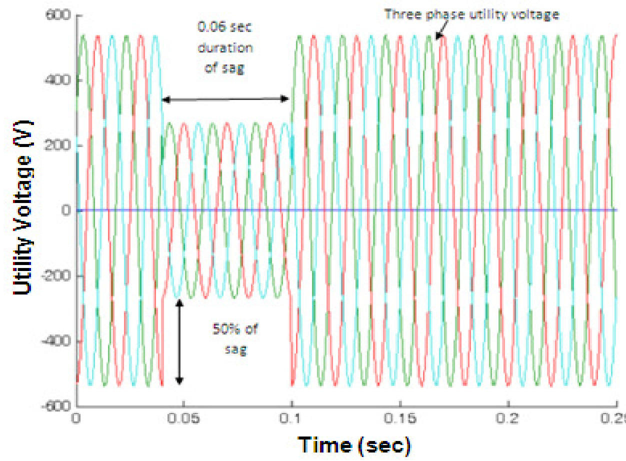

Fig. 3 Utility voltage

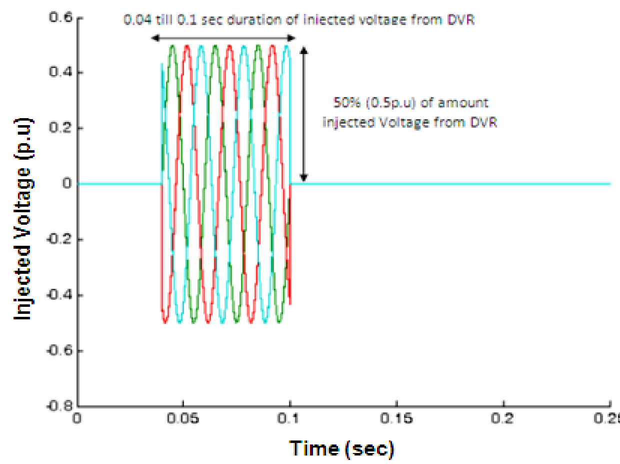

Fig. 4 Injected voltage

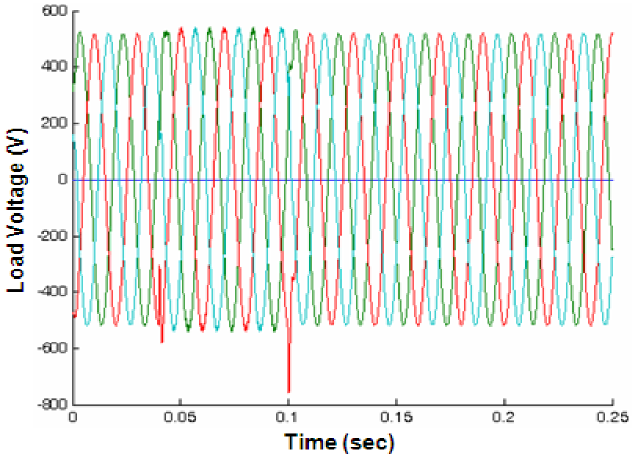

Fig. 5 Load voltage

4.2 Unbalanced Voltage sags

In order to understand the performance of the DVR under unbalanced conditions with a case of three-phase unbalanced voltage sag in utility voltage was simulated. A three-phase unbalanced sag in utility voltage is shown in Fig. 6. This Fig. shows the utility voltage with 15 %, 35%, and 25% sag in phase A, B, and C, respectively. All the three phase sags are initiated at 0.04 sec and kept until 0.1 sec.

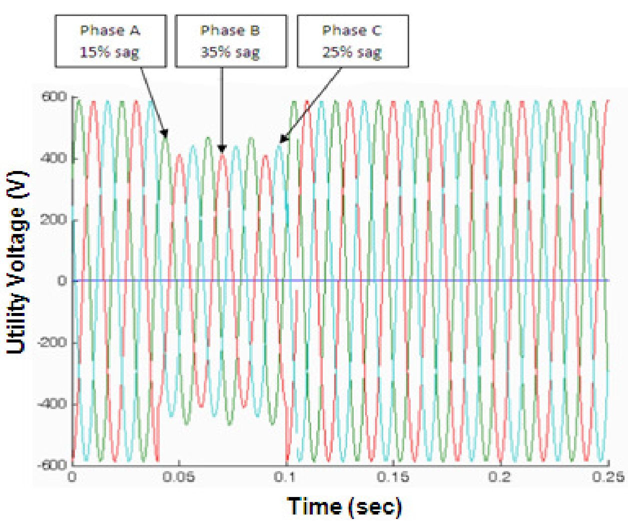

Fig. 6 Utility voltage

Fig. 7 shows the generated injected voltage after comparing 3-phase utility voltage with the reference signal, whereas the compensated load voltage is shown in Fig. 8. As seen from Fig. 7, the DVR responds quickly by injecting each required phase compensating voltage according to the error signal to mitigate the sag in each phase of utility supply voltage. In this way, load voltage is kept unchanged and balanced throughout the simulation.

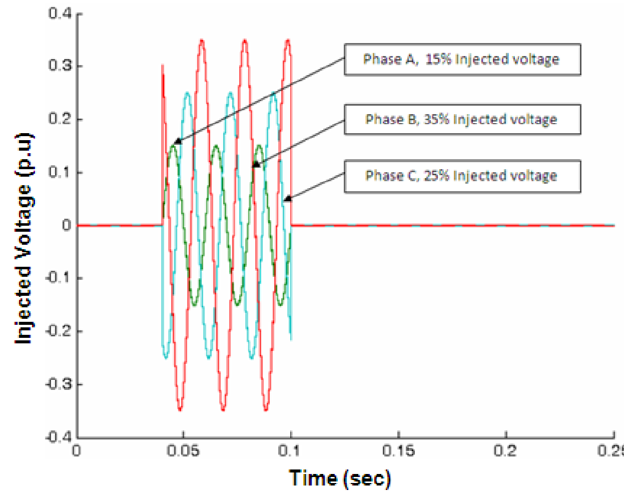

Fig. 7 Injected Voltage

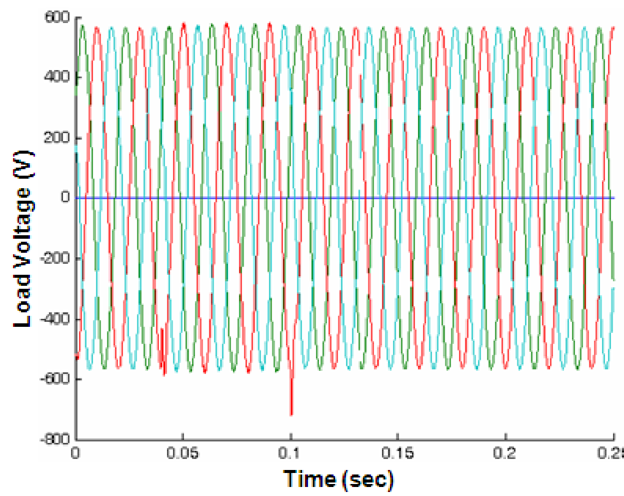

Fig. 8 Load voltage

This shows that an unbalanced voltage disturbance can be treated in a similar manner as for a balanced voltage disturbance. However, in case of unbalanced sags, the unbalanced source voltage is decomposed into their positive, negative, and zero phase sequence components. Negative and zero phase sequence components are eliminated by the negative and zero phase sequence injection voltages, so the magnitudes of the negative and zero phase sequence injection voltages are the same as their source side counterparts but with a phase displacement of 180^0. Voltage restoration is implemented with the positive phase sequence component of injected voltage.

4.0 CONCLUSION

The Dynamic Voltage Restorer (DVR) is a promising and effective device for power quality enhancement due to its quick response and high reliability. The role of a DVR in mitigating the power quality problems in terms of voltage sag is explained. The simulation results show that the DVR can contribute towards the mitigation of sags as well as share power in a manner which suits a specific customer. This study has proposed the modeling and simulation of DVR using Matlab-SimPowerSystems toolbox. Simulation result show the DVR mitigates voltage sags very fast. The DVR is an effective apparatus to protect sensitive loads from short duration voltage sags.

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