Control Scheme for DVR with Battery Energy Storage System based on SRF theory

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***Abstract*—Voltage sag is the most common power quality (PQ) problem and it causes more economic losses. The dynamic voltage restorer (DVR) is a solution to address the voltage-related PQ problems. An algorithm based on synchronous reference- frame theory is developed for generating reference compensating voltages for the DVR control. The control technique used here is able to reduce the rating of VSC by using a battery energy storage system (BESS). The simulation of the algorithm has been carried out in MATLAB/SIMULINK and the results are presented.**

***Index Terms*— dynamic voltage restorer, power quality, synchronous reference frame theory, unit vector, voltage sag**

I. INTRODUCTION

Voltage sags can be defined as the rms voltage decrease between 10 and 90% of the nominal voltage for more than one half cycles to one minute [1]. Voltage sags are a common reason for the failures in most of production plants and for end user equipment malfunctions. Particularly, the tripping of an equipment in a production industry can cause production interruption and thereby significant loss in production and profit. One of the solution for this problem is to make the equipment more tolerant to sags. It can be done either by intelligent control or by storing enough "ride-through" energy in equipment. In recent years, due to increased use of sensitive devices in modern industries, different methods have been used for compensating voltage sags. An alternative method, instead of modifying each of the components in a plant to be tolerant against the voltage sags, is to install a plant-wide uninterruptible power supply (UPS) system or a dynamic voltage restorer (DVR) on the incoming supply for mitigating voltage sags for shorter periods. DVR is now widely used to improve the PQ and compensate the load voltage. DVRs can eliminate most sags, and minimize the risk of load tripping for very deep sags.

A dynamic voltage restorer (DVR) is a series custom power device for the mitigation of voltage sags. The injected voltage can be generated either by a voltage-source inverter with an energy storage or conventionally by an ac–dc–ac converter or by a direct converter without the dc link. Control unit is the heart of the DVR where its main function is to detect the presence of voltage sags in the system, to calculate the required compensating voltage for the DVR and to generate the reference voltage for PWM generator to trigger on the PWM inverter. An algorithm based on synchronous reference- frame theory is developed here for generating reference compensating voltages for the DVR control. The SRFT (Synchronous Reference Frame Theory) based algorithm has advantage of calculation of voltages or currents in simple conversion[5]. The computation involves the conversion of voltages and currents from stationary frame to rotating frame and then the reference signals from rotating frame to the stationary frame. The reference load voltage is obtained using unit vector estimation.

In this paper, the control based on SRFT for a DVR is demonstrated with a reduced-rating of voltage source converter (VSC). The PWM switching method is used. The proposed algorithm is validated through simulation carried out in MATLAB/SIMULINK.

II. DVR COMPONENTS AND OPERATIONAL PRINCIPLE

A. DVR Components

A typical DVR-connected system is shown in Fig. 1, where the DVR consists of a series-connected injection transformer, a voltage-source inverter, a filter circuit, and an energy storage unit which is connected to the dc link. Before injecting the inverter output to the system, it should be filtered to eliminate the harmonics due to switching in the inverter.

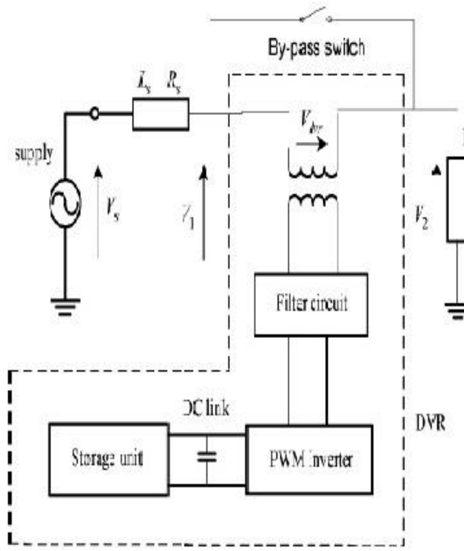

Fig 1. Basic Circuit of DVR

In practical situations, the injection transformer of DVR is connected in parallel with a bypass switch (Fig. 1). When there is no voltage disturbance, the injection transformer and hence, the DVR will be short circuited by switch in order to minimize losses and so maximize the cost effectiveness. The voltage V_{dvr} is inserted such a way that the load voltage V_{load} has constant magnitude and is undistorted, even when the supply voltage V_s is not constant or is distorted. The PWM generates sinusoidal signals comparing a sinusoidal wave with sawtooth wave and sending appropriate gate pulse to the switches of inverter.

B. Operational Principle

The phasor diagram in fig. 2 shows the various voltage injection schemes of the DVR. $V_{L(pre-sag)}$ is a voltage across the load before the voltage sag. During the voltage sag, the voltage is reduced to V_s with a phase lag angle. Now, the DVR injects a voltage in a way so as to maintain the load voltage at a magnitude before sag.

Based on the phase angle of the load voltage, the injection of voltages can be realized in four methods. V_{inj1} represents the voltage- injected in-phase with the supply voltage. With the injection of V_{inj2}, the load voltage magnitude remains same but it leads Vs by a small angle. In V_{inj3}, the load voltage retains the same phase as that of the pre-sag condition, which may be an optimum angle considering the energy source. In $V_{inj4,}$ the injected voltage is in quadrature with the current, and this method is suitable for a capacitor-supported DVR as this method involves no active power. However, a minimum possible rating of the converter can be achieved by V_{inj1}. The DVR is operated in this scheme with a battery energy storage system (BESS). In this paper, the in phase compensation technique is used.

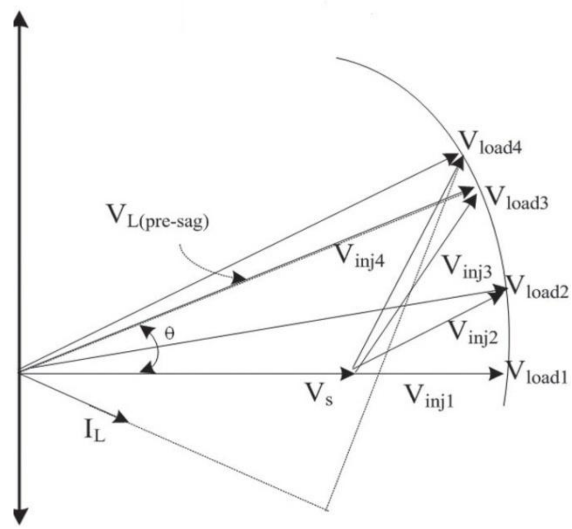

Fig 2. Phasor diagram of voltage injection schemes

Fig. 3 shows a schematic diagram of a three-phase DVR connected to restore the voltage of a three-phase critical load. A three-phase supply is connected to a critical load through a three-phase series injection transformer. The equivalent voltage of the supply of phase A v_{Ma} is connected to the point of common coupling (PCC) v_{Sa} through the short-circuit impedance Z_{sa}. The voltage injected by the DVR in phase A v_{Ca} is in such a way that the load voltage v_{La} is of rated magnitude and is undistorted. A three-phase DVR is connected to the line in order to inject a voltage in series with line using three single-phase transformers T_r. L_r and C_r represents the filter components used to filter out the ripples of the injected voltage. A three-leg VSC with the insulated-gate bipolar transistors (IGBTs) is used as a DVR, and at its dc bus, a BESS is connected.

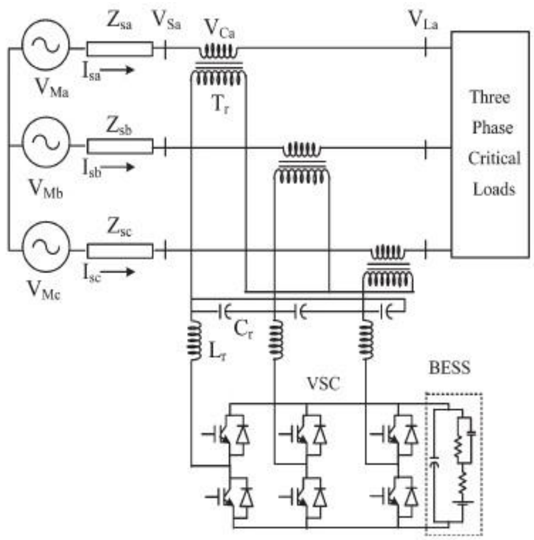

Fig 3. DVR connected system with BESS

III. CONTROL OF DVR

The sag compensation using DVR can be performed by either injecting or absorbing the reactive or real power. When in phase compensation technique is used, the voltage injected is in phase with current. The DVR hence injects real power. So a battery is required at the dc bus of VSC. Fig. 4 shows the DVR control block based on SRF theory. The SRF theory is used for the estimation of reference signal. The voltages at the PCC v_S and at the load terminal v_L are sensed for obtaining the IGBTs' gate signals. The reference load voltage V_L* is extracted using the derived unit vector [4]. The conversion of load voltages (V_{La},V_{Lb},V_{Lc}) to the rotating reference frame is done using abc-dqo conversion using Park's transformation with the unit vectors estimated using a phase-locked loop and is given by

$$\begin{bmatrix} v_{Lq} \\ v_{Ld} \\ v_{L0} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} v_{Laref} \\ v_{Lbref} \\ v_{Lcref} \end{bmatrix} \quad (1)$$

Similarly, reference load voltages (V_{La}*, V_{Lb}*, V_{Lc}*) and voltages at the PCC v_S are also converted to the rotating reference frame. Then, the DVR voltages are obtained in the rotating reference frame as follows

$$v_{Dd} = v_{Sd} - v_{Ld} \quad (2)$$

$$v_{Dq} = v_{Sq} - v_{Lq} \quad (3)$$

The reference DVR voltages are obtained in the rotating reference frame by

$$v_{Dd}^{*} = v_{Sd}^{*} - v_{Ld}^{*} \quad (4)$$

$$v_{Dq}^{*} = v_{Sq}^{*} - v_{Lq}^{*} \quad (5)$$

The error between the reference and actual DVR voltages in the rotating reference frame is controlled using two proportional–integral (PI) controllers.

The reference DVR voltages are obtained from a reverse Park's transformation taking V_{Dd}* from eqn.4, V_{Dq}* from eqn.5, V_{D0}* as zero and is given by

$$\begin{bmatrix} v_{dvra}^{*} \\ v_{dvrb}^{*} \\ v_{dvrc}^{*} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & 1 \end{bmatrix}\begin{bmatrix} v_{Dq}^{*} \\ v_{Dd}^{*} \\ v_{D0}^{*} \end{bmatrix} \quad (6)$$

Reference voltages of DVR (v_{dvra}*, v_{dvrb}*, v_{dvrc}*) and actual voltages of DVR (v_{dvra}, v_{dvrb}, v_{dvrc}) are used in a pulsewidth modulated (PWM) controller to generate gating pulses for a VSC of the DVR. The PWM controller has a switching frequency of 10 kHz.

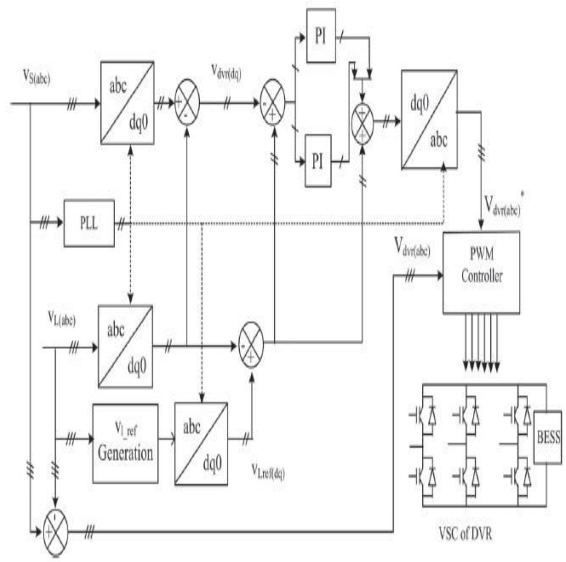

Fig 4. Control block of DVR using SRF method

IV. SIMULATION AND RESULTS

The DVR-connected system consisting of a three-phase supply, critical loads, and the series injection transformer is shown in Fig. 3. It is modeled in MATLAB/Simulink along with a sim power system toolbox and is shown in Fig. 5.

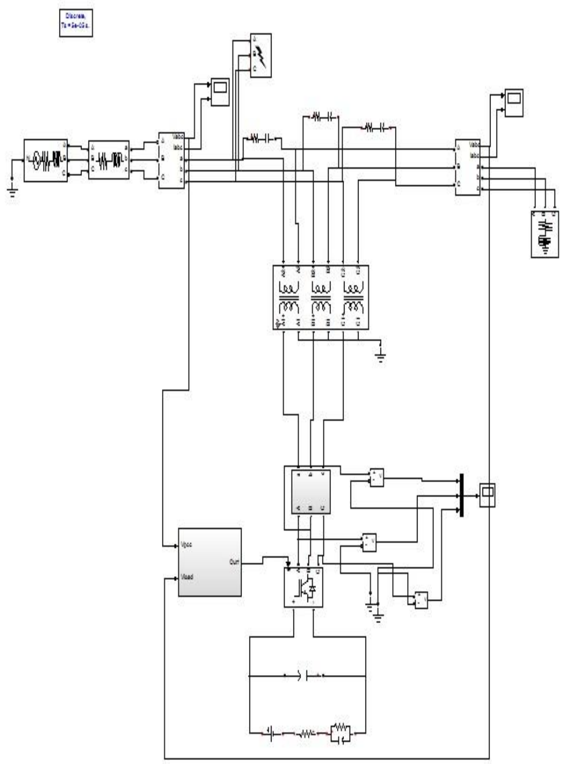

Fig 5. MATLAB model of DVR with BESS

The load considered is a 10-kVA 0.8-pf lag linear load. The control algorithm for the DVR shown in Fig. 4 is also modeled in MATLAB. The reference DVR voltages are derived from PCC voltages (v_{sa},v_{sb},v_{sc}) and load voltages (v_{La},v_{Lb},v_{Lc}). A PWM controller is used over the reference and sensed DVR voltages to generate the gating pulse for the IGBTs of the VSC of the DVR.

Fig. 6 shows the transient performance of the system under voltage sag. At 0.2 s, a sag in supply voltage is created. It is observed that the load voltage is regulated to constant amplitude.

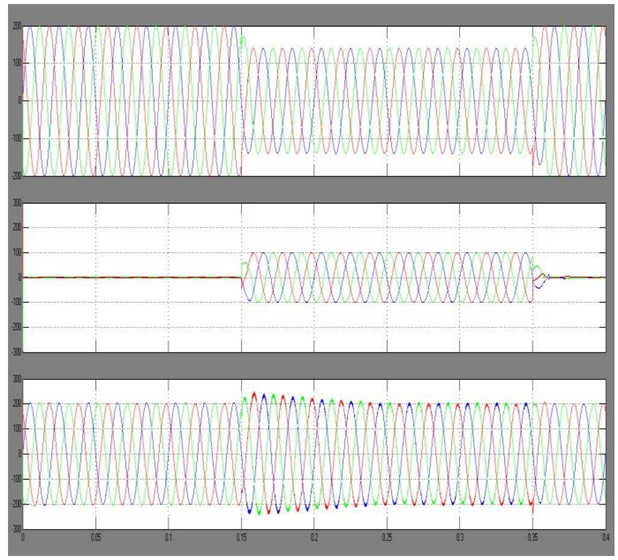

Fig 6. (a) Source voltage (b) Injected DVR voltage (c) Load voltage

The voltages at load and PCC of phase A are shown in Fig. 7, which shows the in-phase injection of voltage by the DVR. The load voltage has been maintained sinusoidal by the injection of proper compensation voltage by the DVR.

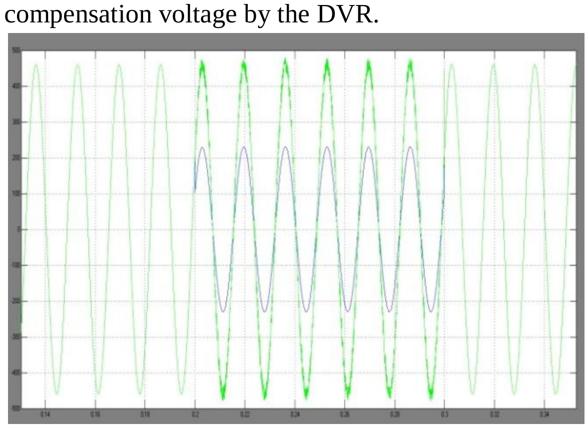

Fig 7. Voltage at PCC and load terminal

V. CONCLUSION

The operation of DVR using control technique utilizing SRF Theory is explained. For different types of power quality issues control schemes varies. A new control technique is adopted to reduce the rating of Voltage Source Converter. During in-phase voltage injection scheme the rating of VSC is minimized. Simulation results show that with this control, the DVR can protect sensitive loads successfully from voltage sag.

REFERENCES

[1] M. H. J. Bollen, *Understanding power quality problems*, IEEE press New York, 2000.

[2] R. C. Dugan, M. F. McGranaghan, S. Santoso, and H.W. Beaty, *Electrical Power Systems Quality*. New York, USA:McGraw-Hill, 2004

[3] J. G. Nielsen and F. Blaabjerg, - A detailed comparison of system topologies for dynamic voltage restorers, ‖ *IEEE Trans. Ind. Appl.*, vol. 41, no. 5, pp. 1272–1280, Sep./Oct. 2005.

[4] A. Chandra, B. Singh, B. N. Singh, and K. Al-Haddad, - An improved control algorithm of shunt active filter for voltage regulation, harmonic elimination, power-factor correction, and balancing of nonlinear loads, ‖ *IEEE Trans. Power Electron.*, vol. 15, no. 3, pp. 495–507, May 2000.

[5] A. Ghosh and A. Joshi, - A new algorithm for the generation of reference voltages of a DVR using the method of instantaneous symmetrical components, ‖ *IEEE Power Eng. Rev.*, vol. 22, no. 1, pp. 63–65, Jan. 2002.

[6] A. Ghosh and G. Ledwich, - Compensation of distribution system voltage using DVR, ‖ *IEEE Trans. Power Del.*, vol. 17, no. 4, pp.1030–1036, Oct. 2002M.

[7] A. Y. Goharrizi, S. H. Hosseini, M. Sabahi, and G. B. Gharehpetian, - Three-phase HFL-DVR with independently controlled phases, ‖ *IEEE Trans. Power Electron.*, vol. 27, no. 4, pp. 1706–1718, Apr. 2012.