

CONTROL OF REDUCED-RATING DYNAMIC VOLTAGE RESTORER

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Abstract—In this white paper, different voltage injection schemes for dynamic voltage restorers (DVRs) are analyzed with particular focus on a new method used to minimize the rating of the voltage source converter (VSC) used in DVR. A new control technique is proposed to control the capacitor-supported DVR. The control of a DVR is demonstrated with a reduced-rating VSC. The synchronous reference frame theory is used. The compensation of the voltage sag, swell is showed using a reduced-rating DVR.

Keywords—Dynamic voltage restorer (DVR), power quality, voltage harmonics, voltage sag, voltage swell.

I. Introduction

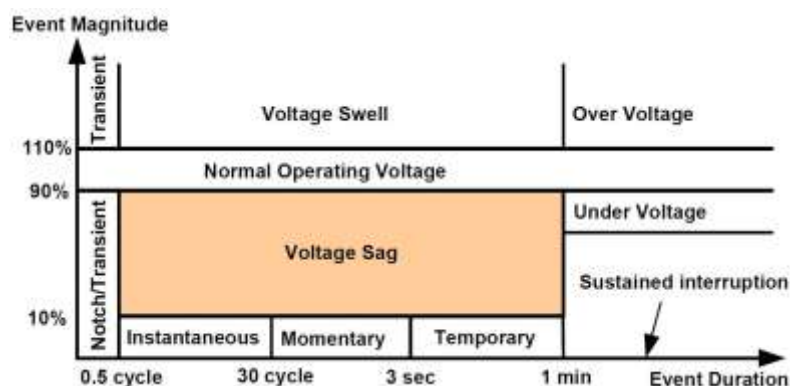
Power Quality is surely an important concern in most industries today, because of the increase in the number of load sensitive to power disturbances. The power quality is an index to quality of current and voltage available to industrial, commercial and household consumers of electricity. The problem regards both the utilities and customers. For the utilities, to provide adequate power quality is a moving objective because of changes in user equipment and requirements.

Power quality is a topic embracing a large field. On one side, several different events are involved in power quality: spikes or surges, sags, swells, outages, under and over voltages, harmonics, flicker, frequency deviations, and electrical noise. Voltage sags in electrical grid are not always possible to avoid because of finite clearing time of faults that cause the voltage sag. Voltage sag are the common reason for interruption in production plants and for end user equipment malfunctions in general. In particular, tripping of equipment in a production line can cause production interruption and significant costs due to loss of production. This project uses the DVR Custom power devices for power quality improvement in the distribution system. DVRs can eliminate most of the sags and minimize the risk of load tripping for very deep sag. The synchronous reference frame (SRF) theory is used for the control of DVR.

Sources of Power Quality Problems

Power Electronic Devices
IT and Office Equipment
Arcing Device
Large Motor Starting
Load Switching

Power Quality Problems

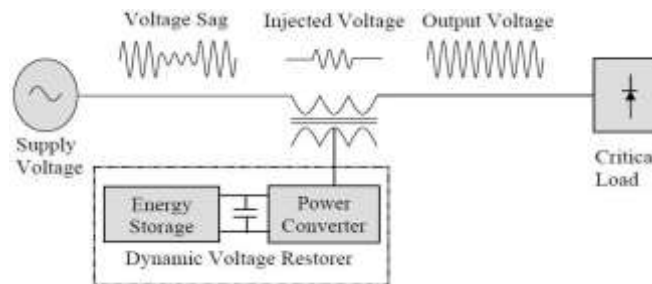
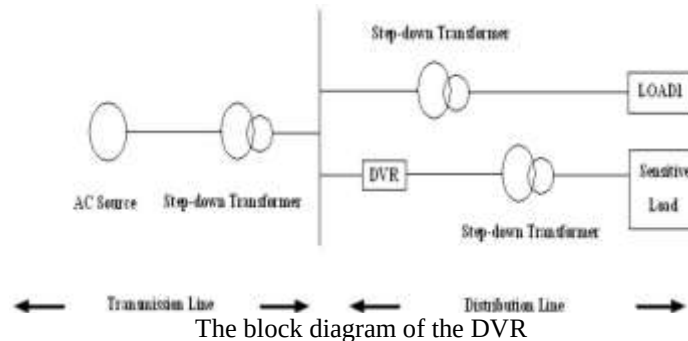


II. Dynamic Voltage Restorer

A power electronic converter based series compensator that can protect critical loads from all supply side disturbances other than outages is called a dynamic voltage restorer. The restorer is capable of generating or absorbing independently controllable real and reactive power at its AC output terminal. This device employs solid-state power electronic switches in a pulse-width modulated (PWM) inverter structure. It injects a set of three-phase AC output voltages in series and synchronism with the distribution feeder voltages. The amplitude and phase angle of the injected voltages are variable thereby allowing control of the real and reactive power exchange between the device and the distribution system. The DC input terminal of the restorer is connected to an energy source or an energy storage device of appropriate capacity.

Location of DVR

DVR is a series connected solid state device that injects voltage in to the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC).



The Synchronous Reference Frame (SRF) Theory (dq0 Transformation or PARK's Transformation). The park's transformation is used to control of a DVR. The dq0 method gives the sag depth and phase shift information with start and end times. The compensation for voltage sags using a DVR can be performed by injecting or absorbing the reactive power or the real power. When the injected voltage is in quadrature with the current at the fundamental frequency, the compensation is made by injecting reactive power and the DVR is with a self-supported dc bus. However, if the injected voltage is in phase with the current, DVR injects real power, and hence, a battery is required at the dc bus of the VSC.

A. Control of DVR With BESS for Voltage Sag & Swell

Fig.5.2 shows a control block of the DVR in which the SRF theory is used for reference signal estimation. The voltage at the PCC vs and at the load terminal VL are sensed for deriving the IGBTs' gate signals. Load voltages (VL_a, VL_b, VL_c) are converted to the rotating reference frame using abc-dq0 conversion using Park's transformation with unit vectors (sinθ, cosθ) derived using a phase-locked loop as

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

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.

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

Reference DVR voltages (v^*_{dvra} , v^*_{dvrb} , v^*_{dvrc}) and actual DVR voltages (v_{dvra} , v_{dvrb} , v_{dvrc}) are used in a pulse width modulated (PWM) controller to generate gating pulses to a VSC of the DVR. The PWM controller is operated with a switching frequency of 10 kHz.

System parameters :

AC line voltage: 415 V, 50 Hz

Line impedance: $L_s = 3.0$ mH, $R_s = 0.01 \Omega$

Linear loads: 10-kVA 0.80-pf lag

DC voltage of DVR: 300 V

AC inductor: 2.0 mH

Gains of the d-axis PI controller: $K_{p1} = 0.5$, $K_{i1} = 0.35$

Gains of the q-axis PI controller: $K_{p2} = 0.5$, $K_{i2} = 0.35$

PWM switching frequency: 10 kHz

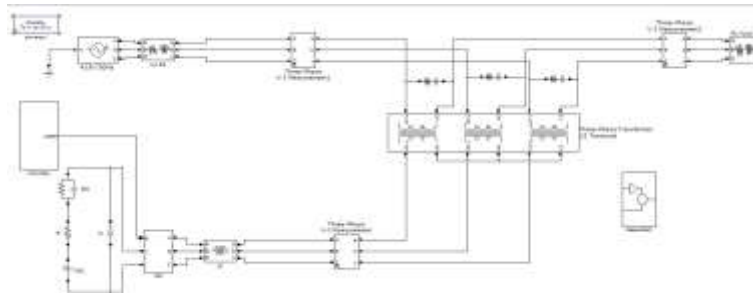


Fig : Simulink model of DVR with BESS

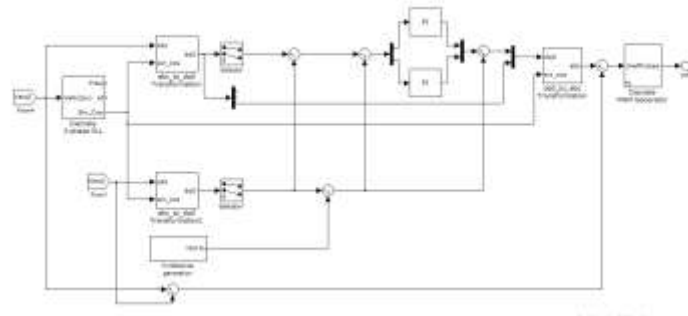


Fig : Control block of DVR with BESS.

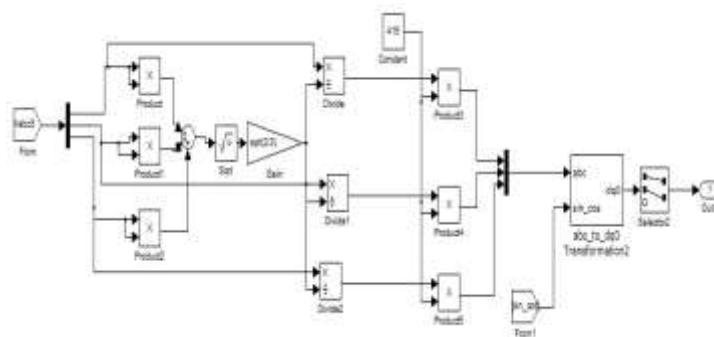


Fig : Reference voltage generation

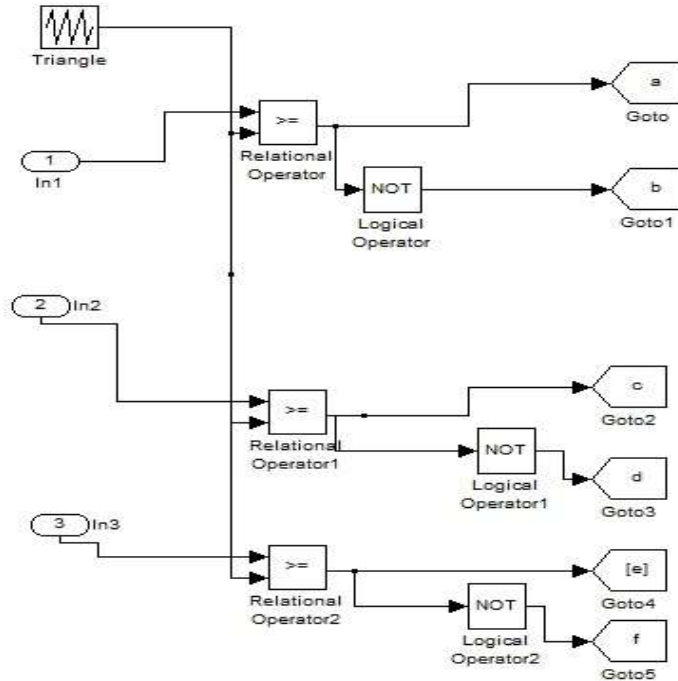


Fig : Pulse generation

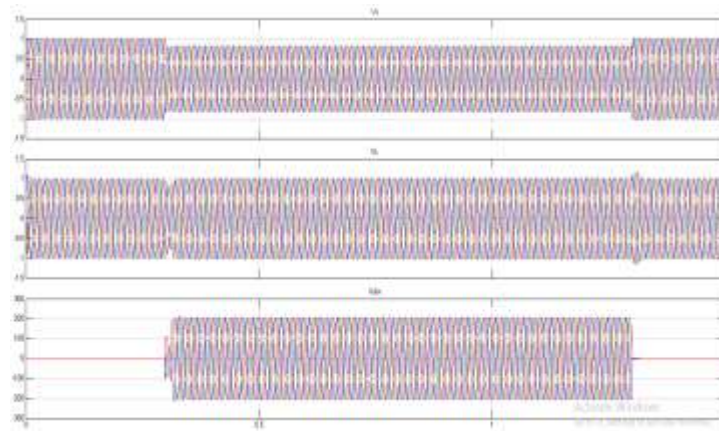


Fig : Sag mitigation by DVR with BESS

B. Control of Self-Supported DVR for Voltage Sag & Swell Fig. 5.3 shows a capacitor-supported DVR connected to three-phase critical loads, and Fig. 5.4 shows a control block of the DVR in which the SRF theory is used for the control of self-supported DVR. Voltages at the PCC v_s are converted to the rotating reference frame using abc-dqo conversion using Park's transformation. The harmonics and the oscillatory components of the voltage are eliminated using low pass filters (LPFs). The compensating strategy for compensation of voltage quality problems considers that the load terminal voltage should be of rated magnitude and undistorted. In order to maintain the dc bus voltage of the supported capacitor, a PI controller is used at the dc bus voltage of the DVR. K_p and K_i are the proportional and the integral gains of the dc bus voltage PI controller. The amplitude of load voltage V_L at the PCC is calculated from the ac voltages (v_{La} , v_{Lb} , v_{Lc}) as

$$V_L = (2/3)^{1/2} (v_{La}^2 + v_{Lb}^2 + v_{Lc}^2)^{1/2}$$

Reference load voltages (v^*_{La} , v^*_{Lb} , v^*_{Lc}) in the abc frame are obtained from a reverse Park's transformation. The error between sensed load voltages (v_{La} , v_{Lb} , v_{Lc}) and reference load voltages is used over a controller to generate gating pulses to the VSC of the DVR.

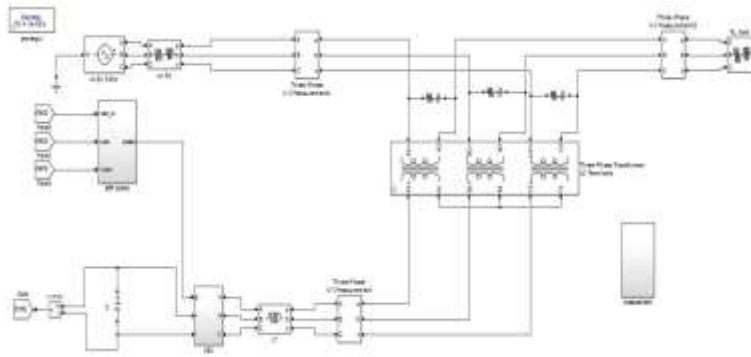


Fig : Self supported DVR

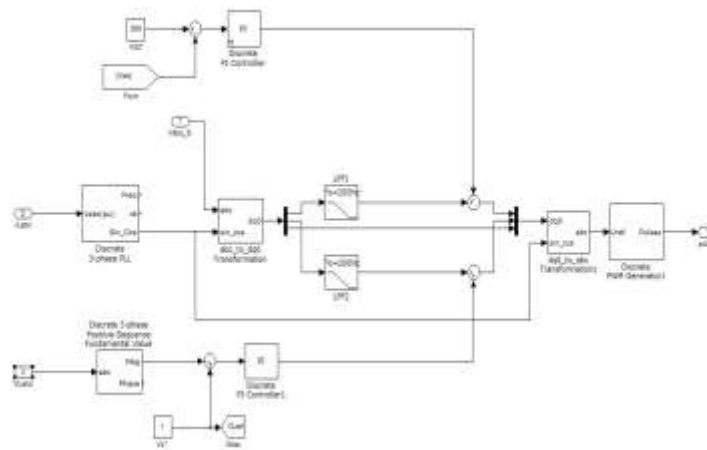


Fig : Control of a self supported DVR

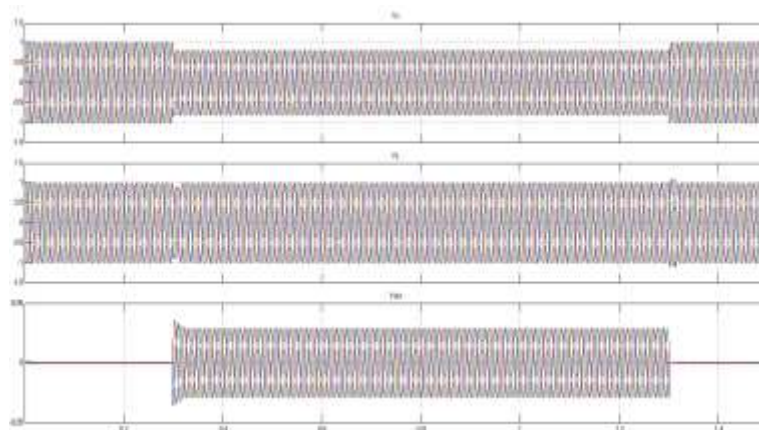


Fig : Sag mitigation by self supported DVR

III. Comparison

DVR with BESS

- It works efficiently when its inject voltage at any angle with the current and inject both active as well as reactive power.
- Minimum possible rating when voltage injection is in-phase.
- As per the calculations the rating of the DVR is 10.392 KVA for the same system parameters
- It can affect on rating of energy storage.

Capacitor Supported DVR

- It works efficiently when inject voltage only at the quadrature with the current and inject only reactive power to the system.
- No active power injection accept small losses.
- As per the calculations the rating of the DVR is 6.8 KVA for the same system parameters
- It can affects the rating of the voltage source converter.

IV. Conclusion

The operation of a DVR has been demonstrated with a new control technique using various voltage injection schemes. A comparison of the performance of the DVR with different schemes has been performed with a reduced-rating VSC, including a capacitor-supported DVR. The reference load voltage has been estimated using the method of unit vectors, and the control of DVR has been achieved, which minimizes the error of voltage injection. The SRF theory has been used for estimating the reference DVR voltages. It is concluded that the voltage injection in-phase with the PCC voltage results in minimum rating of DVR but at the cost of an energy source at its dc bus.

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