Compensation of Harmonics by Reduced-Rating Dynamic Voltage Restorer with a Battery Energy Storage System

S.Ravikanth[1], A.Niharika [2]
[1]Assistant Professor, DVR&Dr.HS MIC College of Technology, Kanchikacherla, A.P, India
[2]PG Scholar, DVR&Dr.HS MIC College of Technology, Kanchikacherla, A.P, India

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Abstract- There are different types of voltage injection methods which are considered in new control technic to reduce the rating of the Voltage Source Converter used in DVR setup. A new control technique is suggested to control the capacitor-supported DVR. The control of a DVR is showed with a reduced-rating VSC. Unit vectors will be used for estimating the reference load voltages. Here The synchronous reference frame theory is used for the conversion of voltages from rotating vectors to the stationary frame. The compensation of the voltage sag, swell, and harmonics is demonstrated using a reduced-rating DVR.. Technologies such as custom power devices are emerged to provide protection against power quality problems. The DVR can regulate the load voltage from the problems such as sag, swell, and harmonics in the supply voltages. Hence, it can protect the critical consumer loads from tripping and consequent losses. Here we used PI and PID control technique is used to get the performance of the entire system.

Key Words: **Dynamic voltage restorer (DVR), power quality, unit vector, voltage harmonics, voltage sag, voltage swell.**

I. INTRODUCTION

Power Quality problems in the present-day distribution systems are addressed in the literature due to the increased use of sensitive and critical equipment pieces such as communication network, process industries, and precise manufacturing processes. Power quality problems such as transients, sags, swells, and other distortions to the sinusoidal waveform of the supply voltage affect the performance of these Equipment pieces. Technologies such as custom power devices are came out to provide protection against power quality problems. Custom power devices are mainly of three categories such as series-connected compensators known as dynamic voltage restorers (DVRs), shunt-connected compensators such as distribution static compensators, and a combination of both series and shunt-connected compensators known as unified power quality conditioner. The DVR can regulate the load voltage from the problems such as sag, swell, and harmonics in the supply voltages. Hence, it can safeguard the critical consumer loads from tripping and sequential losses. The custom power devices are originated and installed at consumer point to meet the power quality standards such as IEEE-519. Voltage sags in an electrical grid are not always possible to clear because of the finite clearing time of the faults that cause the voltage sags and the propagation of sags from the transmission and distribution systems to the low-voltage loads. Voltage sags are the common reasons for a disturbance 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. A solution to this problem is to make the equipment to efficient to tolerate sags, either by intelligent control or by storing "ride-through" energy in the equipment. An alternative solution, instead of modifying each component in a plant to be tolerant against voltage sags, is to install a plant wide uninterruptible power supply system for longer power interruptions or a DVR on the incoming supply to reduce voltage sags for shorter periods. DVRs can eliminate most of the sags and minimize the risk of load tripping for very deep sags, but their main drawbacks are their standby losses, the equipment cost, and also the protection scheme required for downstream short circuits.

II.POWER QUALITY

The contemporary container crane industry, like many other industry segments, is often enamoured by the bells and whistles, colour full diagnostic displays, high-speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer based improvements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the mortar which bonds the Foundation blocks. Power quality also affects terminal operating economics, our environment, and initial investment in power distribution systems to support new crane installations. To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: ‘Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.' As we are all aware, container crane performance requirements continue to increase at an astounding rate. Next generation container cranes, already in the bidding process, will require average power demands of 1500 to 2000 kW – almost double the total average demand three years ago. The rapid growth in power demand levels, an increase in container crane population, SCR converter crane drive retrofits and the large AC and DC drives needed to power and control these cranes will increase awareness of the power quality issue in the very near future.

For the purpose of this article, we shall define power quality problems as:
‘Any power problem that results in failure of customer equipment, clears itself as an economic burden to the user, or produces negative impacts on the environment.’
When applied to the container crane industry, the power issues which degrade power quality include:

- Power Factor
- Harmonic Distortion
- Voltage Transients
- Voltage Sags or Dips
- Voltage Swells

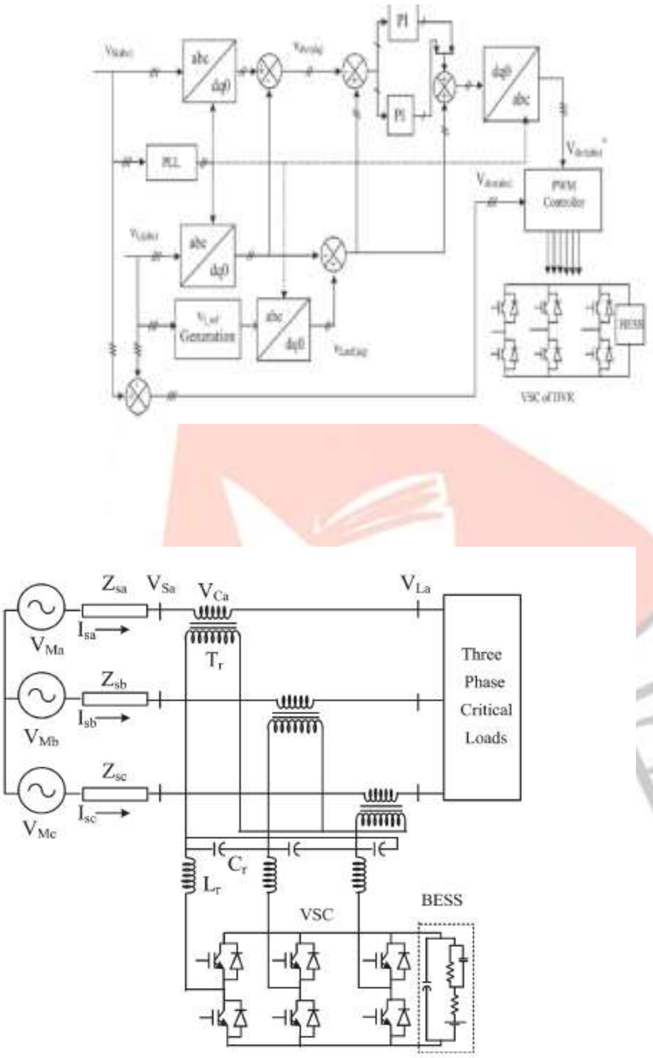

Fig.2 Internal SRF control scheme

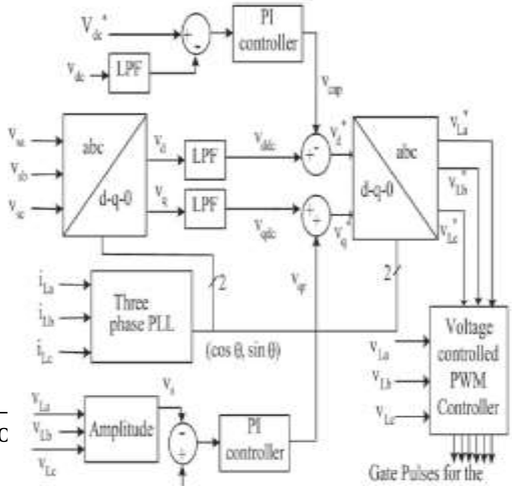

Fig.3 control scheme of DVR

III.DVR Operation and Control

The major purpose is to increase the capacity utilization of distribution feeders (by reducing the RMS values of the line currents for a defined power demand), reduce the losses and improve power quality at the load bus. The major assumption was to neglect the variations. In the source voltages, this essentially implies that the dynamics of the source voltage is much slower than the load dynamics. The fast changes in the source voltage cannot be ignored; these can affect the performance of critical loads such as (a) semiconductor fabrication plants (b) paper mills (c) food processing plants and (d) automotive assembly plants. The major common disturbances in the source voltages are the voltage sags or swells that can be due to (i) disturbances arising in the transmission system, (ii) adjacent feeder faults and (iii) fuse or breaker operation. Voltage sags of even 10% lasting for 5-10 cycles can result in huge damage in critical loads. The voltage sags can arise due to symmetrical or unsymmetrical faults. In the latter case, negative and zero sequence components are also present. Uncompensated nonlinear loads in the distribution system can cause harmonic components in the supply voltages. To reduce the problems caused by poor power quality of power supply, series connected compensators are used. These are called as Dynamic Voltage Restorer (DVR) in the literature as their primary application is to compensate for voltage sags and swells. However, the control methods are different Also, a DVR is expected to respond fast (less than 1/4 cycle) and thus employs PWM converters using IGBT or IGCT devices. The first DVR entered commercial service on the Duke Power System in U.S.A. in August 1996. It has a rating of 2 MVA with 660 kJ of energy storage and is capable of compensating 50% voltage sag for a period of 0.5 seconds (30 cycles). It was installed to protect a highly automated yarn manufacturing and rug weaving facility.

Since then, several DVRs have been installed to protect microprocessor fabrication plants, paper mills etc. Typically, DVRs are made of modular design with a module rating of 2 MVA or 5 MVA. They have been installed in substations of voltage rating from 11 kV to 69 kV. A DVR has to supply energy to the load during the voltage sags. If a DVR has to supply active power over longer periods, it is convenient to provide a shunt converter that is connected to the DVR on the DC side. As a matter of fact, one could envisage a combination of DSTATCOM and DVR connected on the DC side to compensate for both load and supply voltage variations. In this section, we discuss the application of DVR for fundamental frequency voltage. Fig. 3 shows a control block of the DVR in which the SRF theory is used for reference signal estimation. The voltages at the PCC *vS* and at the load terminal *vL* are sensed for driving the IGBTs' gate signals. The reference load voltage $V * L$ is extracted using the derived unit vector. Load voltages (*VLa*, *VLb*, *VLc*) are converted to the rotating reference frame using *abc−dqo* conversion using Park’s transformation with unit vectors (sin*,* θ*,* cos*,* θ) derived using a phase-locked loop as

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

$$v_{Dd} = v_{Sd} - v_{Ld}$$

$$v_{Dq} = v_{Sq} - v_{Lq}.$$

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

Control of Self-Supported DVR for Voltage Sag, Swell, and Harmonics Compensation

Fig. 4 shows a schematic of a capacitor-supported DVR connected to three-phase critical loads, and Fig. 6 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 *vS* 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 components of voltages in the *d*- and *q*-axes are,

$$v_d = v_{\mathrm{ddc}} + v_{\mathrm{dac}}$$

$$v_q = v_{\mathrm{qdc}} + v_{\mathrm{qac}}.$$

IV. MATLAB /SIMULINK RESULTS

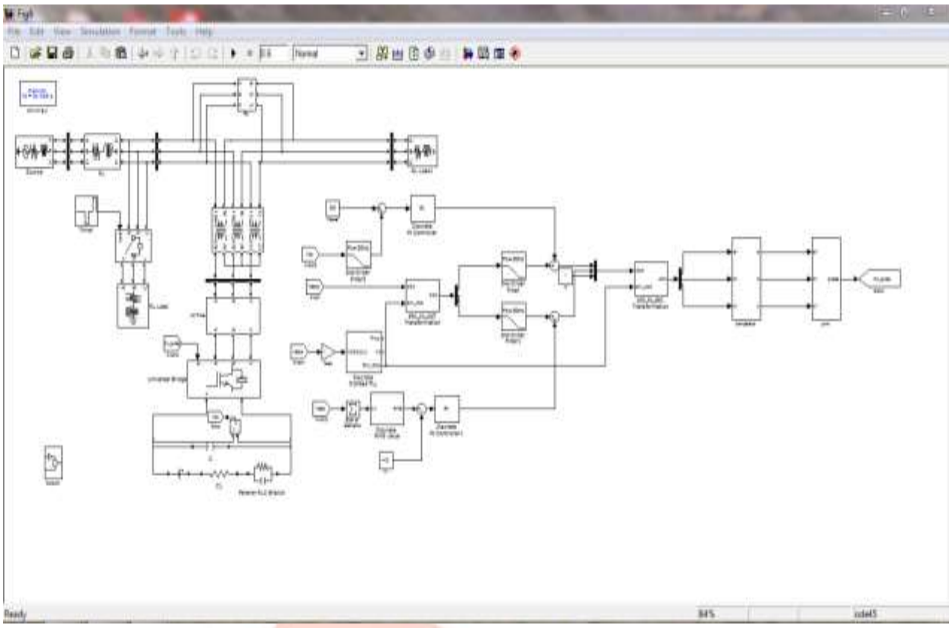

Fig.4 Matlab circuit for BESS supported DVR with PI controller

Fig.5 Dynamic performance of DVR with in-phase injection during voltage sag and swell applied to critical load with PI

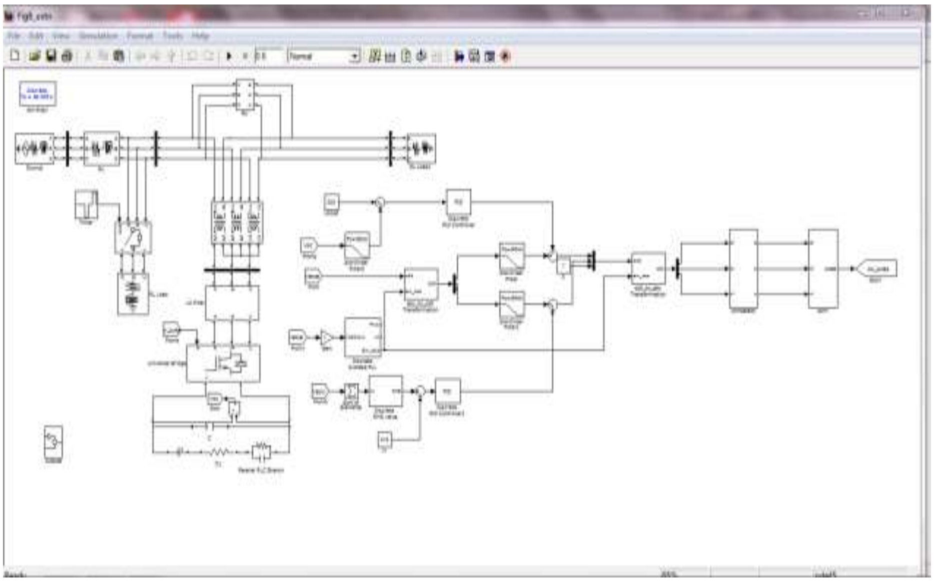

Fig.6 Matlab circuit for BESS supported DVR with PID controller.

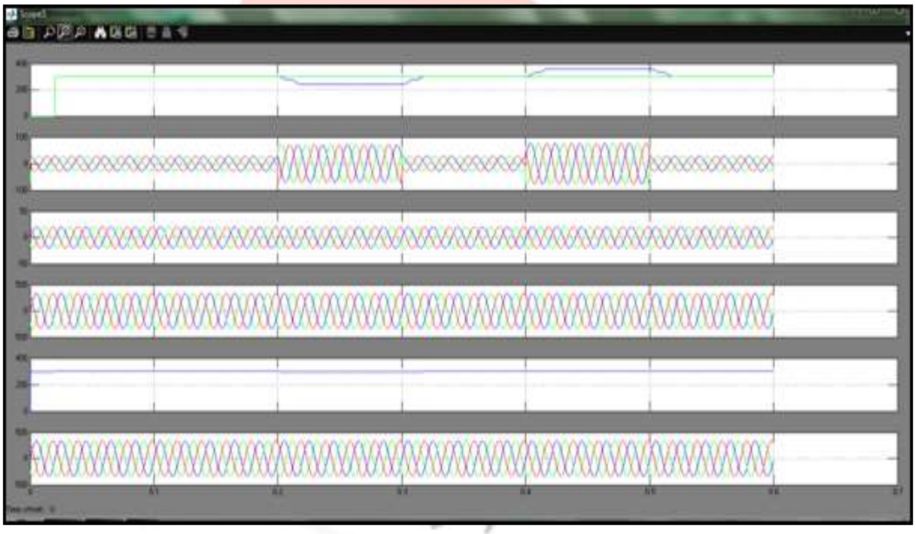

Fig.7 Dynamic performance of DVR with in-phase injection during voltage sag and swell applied to critical load with PID

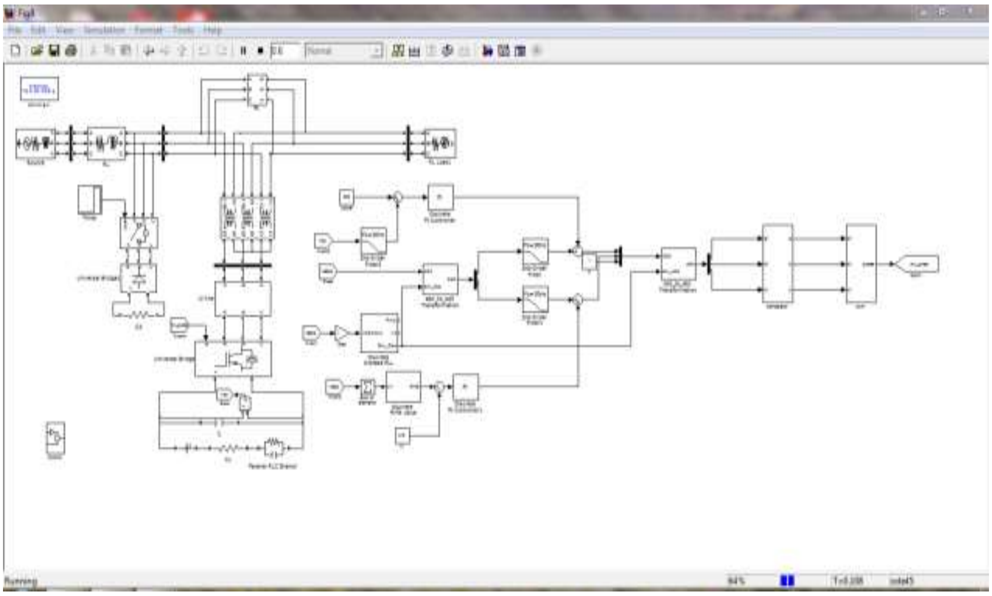

Fig.8 Dynamic performance of DVR during harmonics in supply voltage applied to critical load with PI

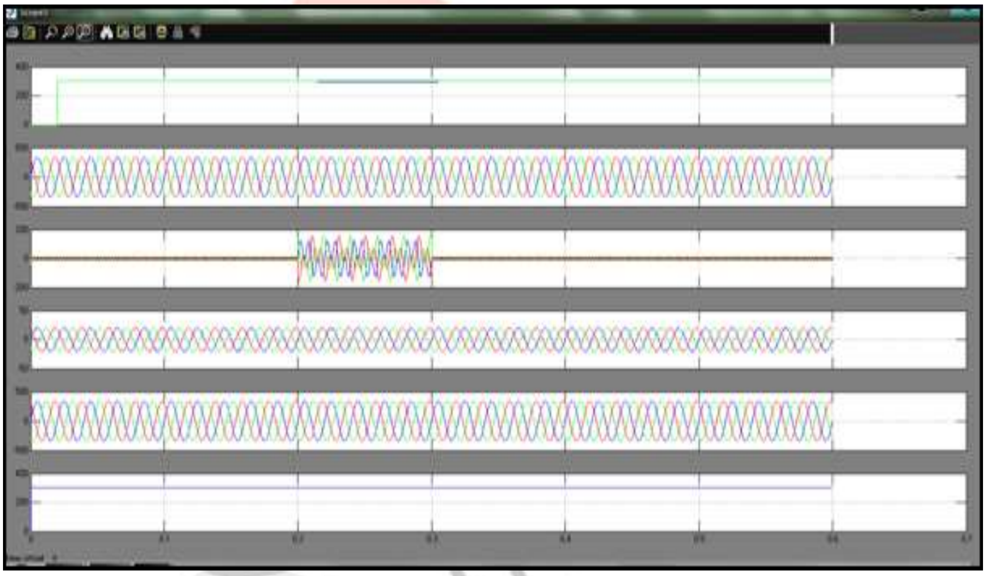

Fig.9 Dynamic performance of DVR during harmonics in supply voltage applied to critical load with PI

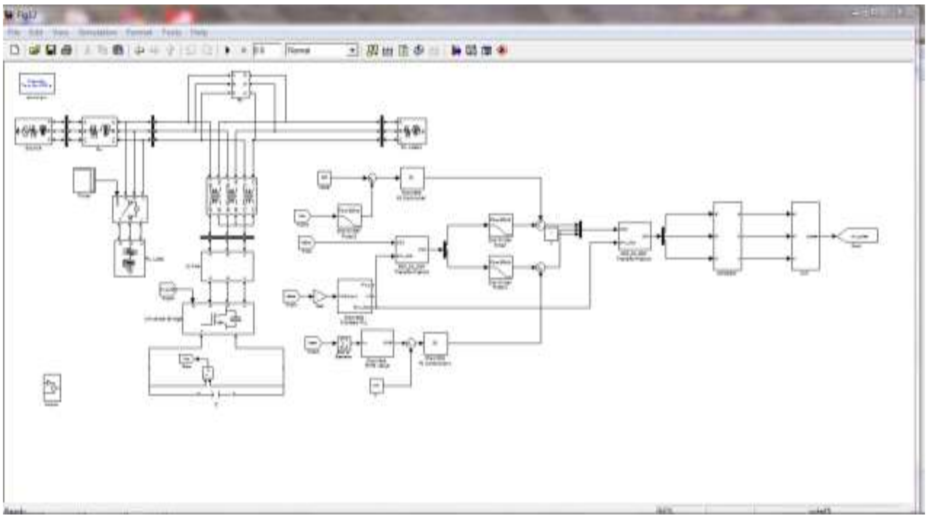

Fig.10 Dynamic performance of the capacitor-supported DVR during voltage sag and voltage swell applied to critical load

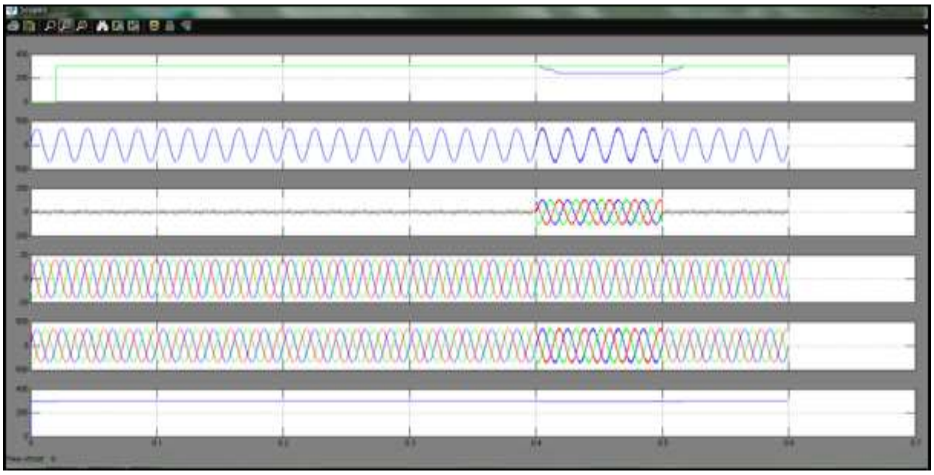

Fig.11 Dynamic performance of the capacitor-supported DVR

V. 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 a minimum rating of DVR but at the cost of an energy source at its dc bus. The entire system performance is observed by using PI and PID controllers.

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