Dynamic Voltage Restorer incorporating dq0 Transformation Enhancing Power Quality

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ABSTRACT
A fast and efficient solution to voltage sag/swell problem is Dynamic voltage restorer (DVR). DVR is a power electronic based device that provides three phase controllable voltage source whose voltage vector i.e. magnitude and angle is added to the source voltage during sag event, to restore the load voltage to pre-sag condition. The DVR is designed for protecting the whole plant with loads in the range of some MVA. The load voltage can be restored within few milliseconds using DVR.

Several configurations and control methods are suggested for the DVR. In this paper, an overview of the DVR, its function, configuration, components, compensating strategies and control methods are viewed along with the device capabilities and limitations.

General Terms
Series Voltage Booster, Static Series Compensator, Compensation strategy, Phase locked loop.

Keywords
Dynamic Voltage Restorer (DVR), Voltage Sag, Power Quality, Custom Power

1. INTRODUCTION
The dynamic voltage restorer (DVR) is also referred as the Series Voltage Booster (SVB) or the Static Series Compensator (SSC), is a device that utilizes solid state (or static) power electronic components, which are series connected to the utility primary distribution circuit. The three phase controllable voltage provided by the DVR, whose vector (magnitude and angle) adds to the source voltage to restore the load voltage to pre sag condition [1].
Modern power systems are complex networks, in which hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks [1]. The main concern of consumers is the quality and reliability of power supplies at various load centers where they are located at. Even though the power generation in most well developed countries is fairly reliable but the supply quality is not so reliable. Power distribution systems, ideally, should provide their consumers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [2]. However, in practice the Power systems especially the distribution systems, have number of nonlinear loads, which affect the quality of power supplies significantly. As a result of these nonlinear loads, the original pattern of the waveform of supplies is lost. This ends up in producing many power quality issues. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality problems [3]. The consequence of power quality problems could range from a simple nuisance flicker in the electrical lamps to loss of thousands of dollars due to production shutdown.
A power quality problem is defined as any manifested problem in voltage/ current or leading to frequency deviations that result in failure or disoperation of customer equipment [3-4]. Power quality problems are associated with an extensive number of electromagnetic phenomena in power systems with broad ranges of time frames such as short duration variations, long duration variations and other disturbances. Short duration variations are mostly caused due to either fault conditions or energization of large loads that require high starting current. Depending on the relation between electrical distance and impedance, grounding types and transformers connections between the node and faulted load location, there can be a temporary loss of voltage or temporary voltage reduction (sag) or voltage rise (swell) at different nodes of the system [5].

Voltage sag is defined as a sudden reduction of supply voltage down 90% to 10% of nominal, followed by a short recovery period. According to the standards a typical duration of sag is 10 ms to 1 minute. Voltage sag can cause loss of production in automated processes since voltage sag can trip a motor or cause its controller or malfunction. Voltage swell is defined as a sudden increase of supply voltage up 110% to 180% in rms voltage at the network fundamental frequency with duration from 10 ms to 1 minute. Switching off a large inductive load or energizing a large capacitor bank is a typical system event that causes swells [1]. To compensate the voltage sag/swell in a power distribution system, appropriate devices are needed to be installed at suitable locations. These devices are typically placed at the point of common coupling (PCC) which is defined as the point where the ownership of the network changes. The DVR is one of the custom power devices [6-8] which can improve power quality, especially, voltage sags and voltage swells. As the root/basic concerns is for the quality of supply as a result of more sensitive loads in the system conditions, an appropriate understanding of the devices for eliminating power quality problems is important. This would allow us to make use of the functions of such devices in a better way with efficient control techniques. Hence, in this paper an attempt is made to understand the functions of DVR incorporating dq0 transformation implemented using MATLAB.

2. DYNAMIC VOLTAGE RESTORERS
A DVR is a device that injects dynamically controlled voltage Vinj(t) in series to the bus voltage by means of a booster transformer as depicted in Figure 1. There are three single phase booster transformers connected to a three phase converter with energy storage system and control circuit [9].

The amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage$v_L(t)$. Thus, any differential voltage caused by transient disturbance in the ac feeder will be compensated by an equivalent voltage that is generated by the converter and injected on the medium voltage level through the booster transformer.

The DVR works independently of the type of fault occurring in the system, provided that the whole system is connected to the supply grid, i.e. the line breaker is in operation. A more economical design can be achieved by only compensating the positive and negative sequence components [10, 11] of the voltage disturbance observed at the input of the DVR, because the zero sequence component of a disturbance will not pass through the step down transformers due to infinite impedance to this component [12, 13]. An equivalent circuit diagram [13] and the principle of series injection [6, 7] for sag as well as swell compensation are depicted in Figure 2.

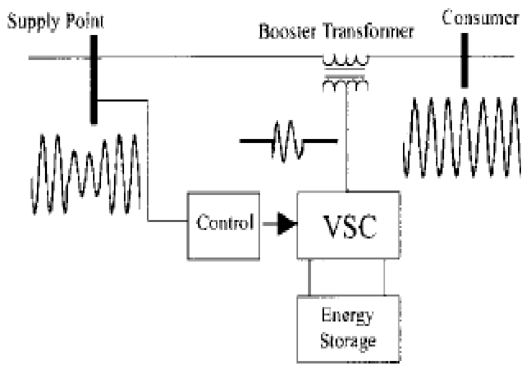

Fig 1: Schematic diagram of DVR System

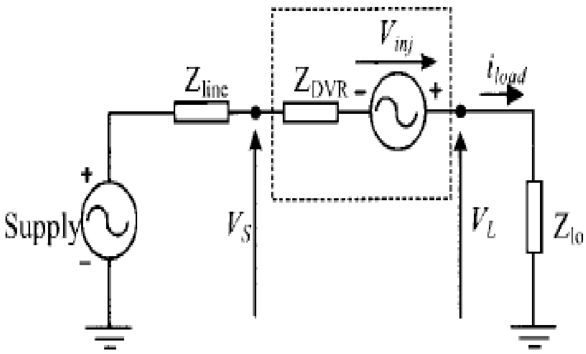

Fig 2: Equivalent circuit of DVR

Mathematically expressed, the injection satisfies:

$$v_L(t) = v_s(t) + v_{nj}(t) \quad (1)$$

where the load voltage is vL(t) , the swelled supply voltage is vs(t) and the voltage injected by the mitigation device is vnj(t) as shown in figure 2.

During normal voltage conditions, each phase load power is given by (2):

$$S_L - V_L I_L^* = P_L - jQ_L \quad (2)$$

where IL is the load current, and PL and QL are the active and reactive load power components, respectively, during a sag/swell. When the mitigation device is active and restores normal voltage, the following equation is applicable to each phase:

$$S_L = P_L - jQ_L = (P_s - jQ_s) + (P_{inj} - jQ_{inj}) \quad (3)$$

where the sag subscript refers to the sagged supply quantities. Te inject subscript refers to quantities injected by the mitigation device.

3. CONTROL STRATEGY OF DVR

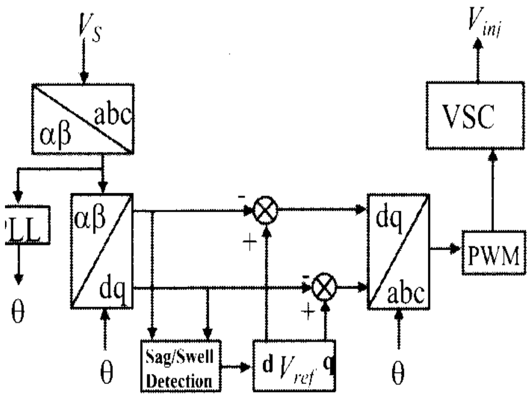

Fig 3: Control strategy of DVR

Figure 3 shows the basic control scheme of DVR [14]. In this figure supply voltage is connected to a transformation block that converts stationary frame to αβ frame. Output of this block is connected to phase locked loop (PLL) and another transformation block converts αβ frame to rotating frame dq [14], which detects the phase and changes the axis of supply voltage. This detection block detects the voltage sag or swell. If the voltage sag or swell occurs this block generates a reference load voltage and injection voltage is generated by difference in between the two voltages, which is applied to the voltage source converter to produce the preferred voltage through PWM [14].

4. SIMULATION RESULT

The simulation shows the DVR performance during the voltage swell condition. The simulation started with the supply voltage swell is generated in figure 4. The amplitude of the supply voltage is increased about 25% from its nominal value. Figure 5 and 6 show the injected voltage by the DVR and load voltage respectively. The load voltage is kept higher the nominal value with the help of DVR and DVR injects the negative voltage magnitude to correct the supply voltage. Figure 8 shows the corrected load voltage with reduced swell after dq0 transformation.

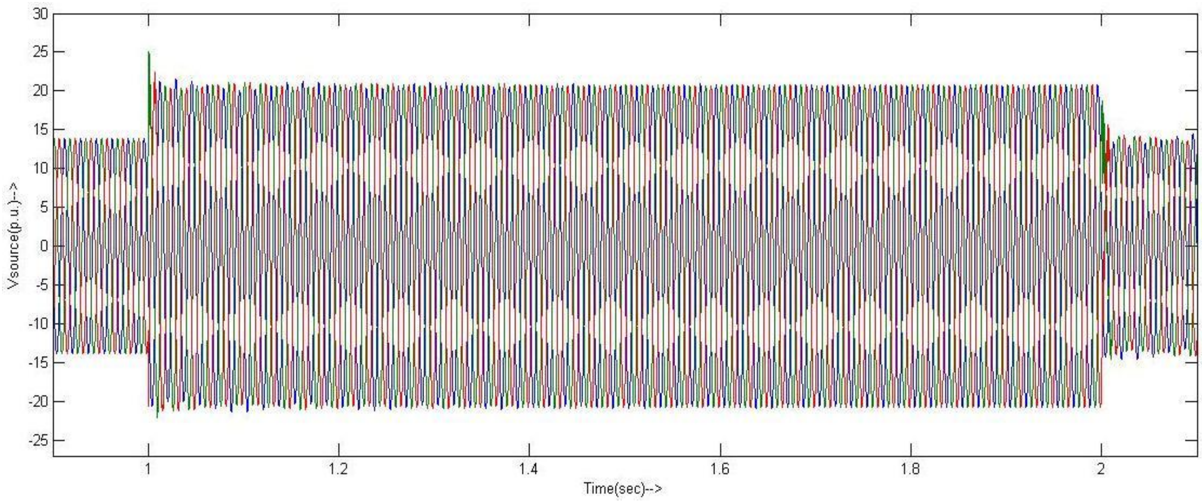

Fig 4: Three phase voltage source

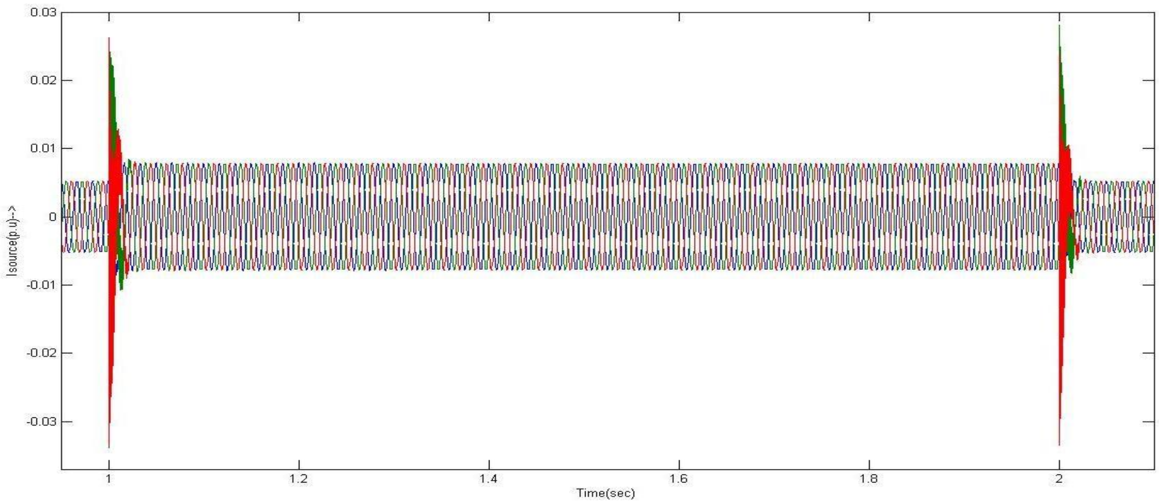

Fig 5: Three phase current source

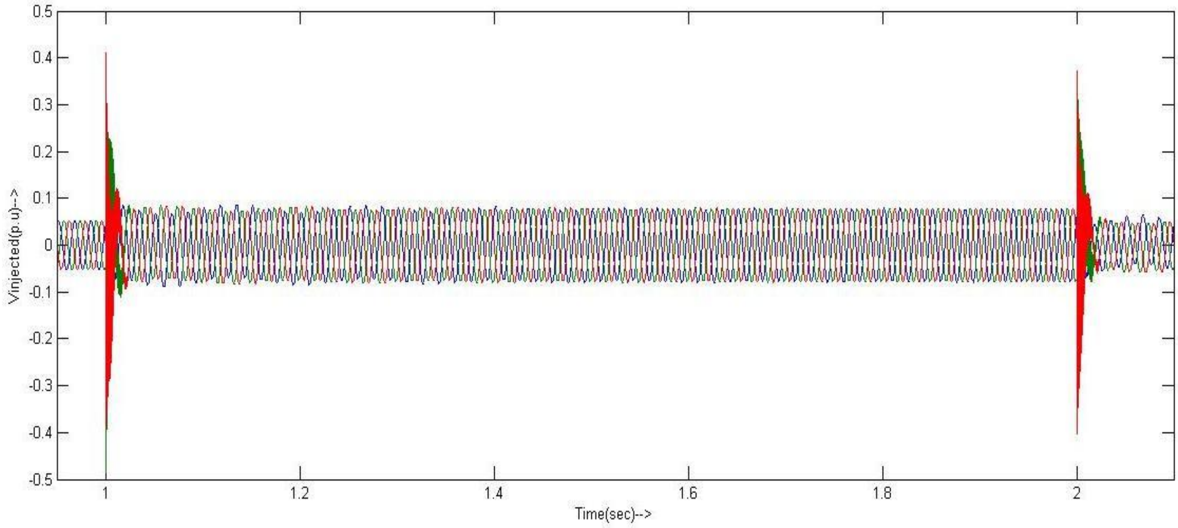

Fig 6: Three phase injected voltage

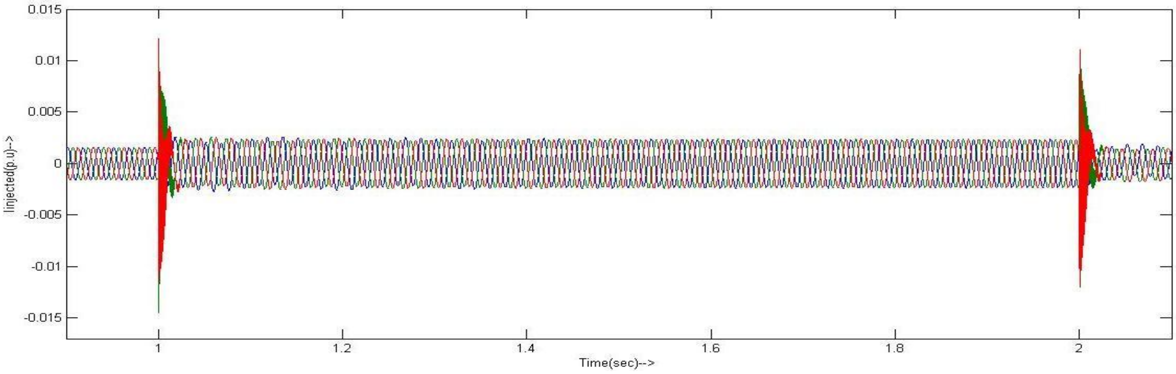

Fig 7: Three phase injected current

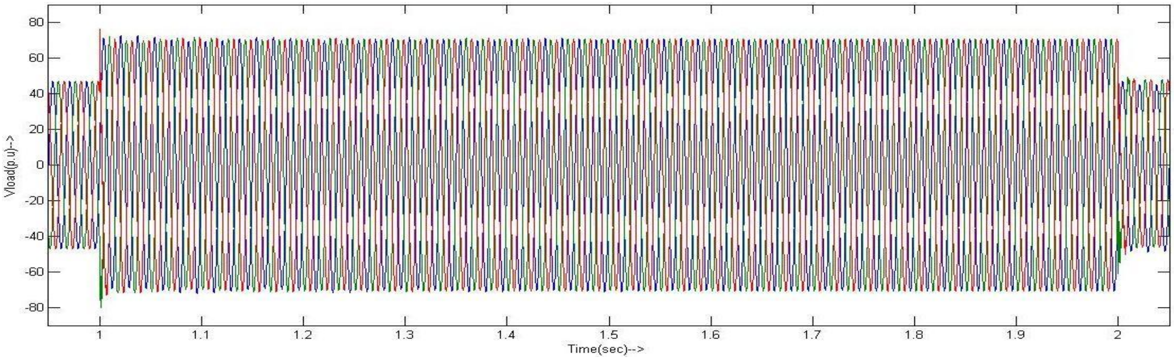

Fig 8: Three phase load voltage swell after dq0 transformation

5. CONCLUSION

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. A control system based on dq0 technique which is a scaled error of the between source of the DVR and its reference for sag/swell correction has been presented. Performance of DVR in mitigating voltage sags/swells.

The main advantage of this DVR is low cost and its control is simple. It can mitigate long duration voltage sag/swells efficiently. Future work will include a comparison with a laboratory experiments in order to compare simulation and experimental results.

6. REFERENCES

[1] Ghosh, A., and Ledwich, G., 2002. Power Quality Enhancement Using Custom Power Devices, Kluwer Academic Publishers.

[2] Hingorani, N. G. 1995. Introducing Custom Power, in IEEE Spectrum, 32, 41-48,.

[3] Sankaran, C. 2001. Power Quality, CRC Press.

[4] Santoso, S. 2002. Electrical Power System Quality, Mcgraw –Hill.

[5] Chung Y. H., Kwon, G. H., Park, T. B. and Lim, K. Y. 2003. Voltage Sag and Swell Generator for Evaluation of Custom Power Devices, in IEEE. Power Eng. Society, 4, 2507.

[6] Ghosh, A., Jindal, A. K., Joshi, A. 2003. Inverter Control Using Output Feedback for Power Compensating Devices, in TENCON-2003, 1, 15-17

[7] Sybille G. and Giroux P. 2002. Simulation of FACTS Controllers Using the MATLAB power System Boackset and Hypersim Real-Time Simulator in IEEE Power Eng. Society, 1, 00.488-491.

[8] Sannino A. and Svensson J. 2002. Static Series Compensator for Voltage Sag Mitigation Supplying Nonlinear Loads, in IEEE Power Eng. Society, 2.

[9] Ming Hu and Heng Chen 2000. Modelling and Controlling of Unified Power Quality Component, in APSCOM-00, 2, 431-435.

[10] Nilsson, S. 1999. Special Application Considerations for Custom Power Systems, in IEEE Power Eng. Society, 2, 1127-1131.

[11] Buxton, R. 1998. Protection from Voltage Dips with Dynamic Voltage Restorer, in IEE Half day colloquium.

[12] Osborne, M. M., Kitchin, R. H. and Ryan, H. M. 1995. Custom Power Technology in Distribution Systems: an Overview, in IEE North Eastern Center Power Section Symposium, 10/1-10/11.

[13] Liu, J. W., Choi S. S. and Chen S. 2003. Design of Step Dynamic Voltage Regulator for Power Quality Enhancement, in IEEE Transactions on Power Delivery, 18, 1403-1409.

[14] Boonchiam, P. and Mithulananthan, N. 2006. Understanding of Dynamic Voltage Restorers Through MATLAB Simulation Thammasat Int. J. Sc. Tech., Vol. 11, No. 3, (July-September 2006).