Simulation of FACTS and Custom Power Devices in Distribution Network to improve Power Quality

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***Abstract*— While early FACTS devices consisted mainly of Thyristor-controlled/switched RLC/transformer components, the newer generation is based on the self-commutated voltage-source power converters. Different shunt FACTS devices, namely Static VAR compensator (SVC) and Static Synchronous Compensator (STATCOM), Dynamic voltage restorer (DVR) are used in transmission line using the actual line model. In this paper, we describe the power quality problem of voltage sag and swell and its severe impact on non linear loads or sensitive loads.**

This work is then extended to custom power equipment, namely Distribution Static Compensator (D-STATCOM) and Dynamic Voltage Restorer (DVR) aimed at enhancing the reliability and quality of power flows in low voltage distribution networks. Finally MATLAB/SIMULINK based model is developed and simulation results are presented.

***Keywords*— power quality, voltage swell, voltage sag, SVC, DSTATCOM, DVR.**

I. INTRODUCTION

The voltage generated by power stations has a sinusoidal waveform with a constant frequency. Any disturbances to voltage waveform can result in problems related with the operation of electrical and electronic devices. Users need constant sine wave shape, constant frequency and symmetrical voltage with a constant rms value to continue the production. This increasing interest to improve overall efficiency and eliminate variations in the industry have resulted more complex instruments that are sensitive to voltage disturbances. The typical power quality disturbances are voltage sags, voltage swells, interruptions, phase shifts, harmonics and transients. Among the disturbances, voltage sag is considered the most severe since the sensitive loads are very susceptible to temporary changes in the voltage. This paper addresses the transient studies of electrical networks with embedded, power electronics-based, FACTS and Custom Power (CP) controllers. The FACTS controller considered here is the basic Static Var Compensator (SVC) with FC-TCR arrangement. The CP controllers include Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR).

The paper is organized as follows: in Section II, the FC-TCR arrangement of SVC is discussed. Section III presents the theory behind Voltage Source Converter (VSC) – Based Controllers namely, D-STATCOM and DVR. In Section IV, the PWM schemes for devices are described. Then in Section V, the test cases are presented and the simulation results are discussed and, finally, in Section VI, some conclusive remarks are drawn.

II. STATIC VAR COMPENSATOR

By providing dynamic reactive power, svc can be used for the purpose of regulating the system voltage, compensating the voltage at reasonable level, improving the capacity of the transmission line. From the operational point of view, the SVC adjusts its value automatically in response to changes in the operating conditions of the network. By suitable control of its equivalent reactance, it is possible to regulate the voltage magnitude at the SVC point of connection, thus enhancing significantly the performance of the power system [6],[7],[8]. In its simplest form, SVC consists of a TCR in parallel with a bank of capacitors. Fig. 1(a) shows the schematic diagram of the most basic FC/TCR arrangement of the SVC. Its equivalent variable susceptance representation is shown in Fig. 1(b). An ideal variable shunt compensator is assumed to contain no resistive components, i.e. $G_{SVC}=0$..

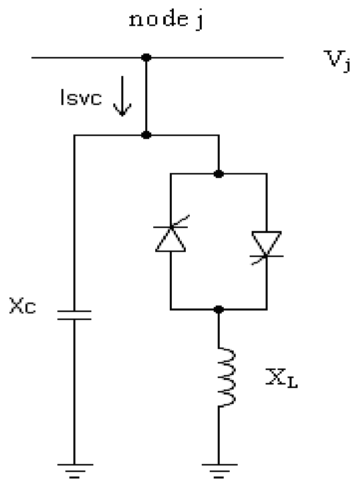

Fig.1 (a) Schematic representation of an FC-TCR arrangement of SVC

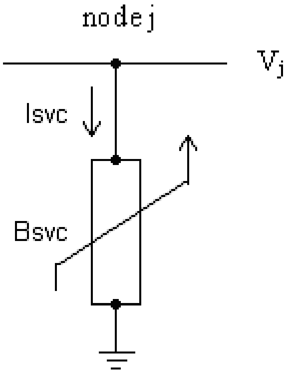

Fig.1 (b) Variable Susceptance representation

Accordingly, it draws no active power from the network. On the other hand, its reactive power is a function of nodal voltage magnitude at the connection point, say node j , and the SVC equivalent susceptance, B_{SVC} .

$$P_j = 0$$

$$Q_j = -\left|V_j\right|^2 B_{SVC}$$

The graphical modeling and implementation of FC-TCR arrangement is explained in Section V of this paper.

III. VSC-BASED CONTROLLERS

In this section, an overview of the VSC-based Custom- Power controllers are presented.

A. D-STATCOM

The STATCOM, when used in low-voltage distribution systems is normally identified as Distribution STATCOM (DSTATCOM). In its simplest form, it consists of a two-level VSC, a dc energy storage device; a coupling transformer connected in shunt with the ac system, and associated control circuits. Fig. 2 shows the schematic representation of the DSTATCOM. The active power flow is controlled by the angle between the ac system and VSC voltages and the reactive power flow is controlled by the difference between the magnitudes of these voltages [4]. The D-STATCOM controller continuously monitors the load voltages and currents and determines the amount of compensation required by the ac system for a variety of disturbances.

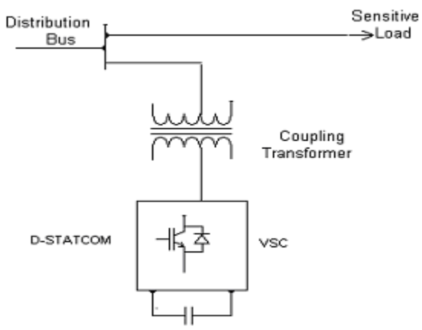

Fig. 2. Basic Configuration of D-STATCOM

The VSC connected in shunt with the ac system serves three distinct purposes:

1) Voltage regulation and compensation of reactive power;

2) Correction of power factor;

3) Elimination of current harmonics.

The control scheme is explained in Section IV of this paper.

B. DVR

The DVR consists of a VSC, a switching control scheme, a DC energy storage device and a coupling transformer similar to D-STATCOM, but here the coupling transformer is connected in series with the ac system. It is commonly used for voltage sag mitigation at the point of connection. Fig. 3 shows the schematic representation of DVR. The VSC generates a three-phase ac output voltage which is controllable in phase and magnitude. These voltages are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference. The control scheme implemented for DVR is explained in Section IV of this paper.

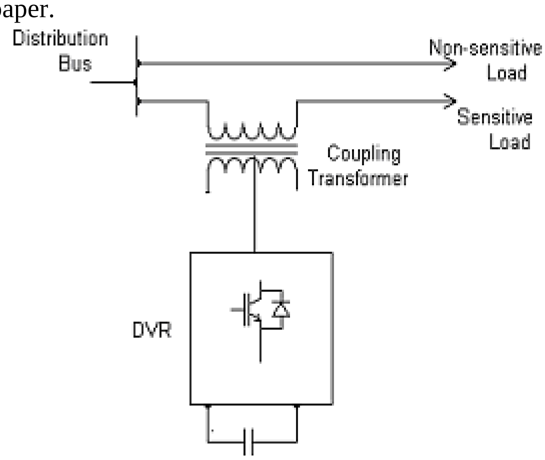

Fig 3. Basic Configuration of DVR

IV. PWM CONTROL SCHEME

This section describes the PWM-based control scheme with reference to the D-STATCOM and DVR. The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the rms voltage at the load point i.e., no reactive power measurements are required [1]. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Because distribution network is a relatively low power application, PWM methods offer a more flexible option than the fundamental frequency switching methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses. The D-STATCOM control system exerts voltage angle control as follows: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal and generates the required delay angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage. In the PWM generators, the sinusoidal *Vcontrol* signal is phase modulated by means of the delay angle. The modulated signal *Vcontrol* is compared against a triangular signal (carrier) in order to generate the switching signals for the VSC valves.

V. TEST CASES AND SIMULATION RESULTS

This section is divided into three parts. Simulations relating to FC-TCR are presented first followed by the simulations carried out for D-STATCOM and DVR. Fig.4 shows the test system implemented in MATLAB/SIMULINK to carry out simulations for the FC-TCR topology. The aim of the SVC in this application is to provide voltage regulation following load variations.

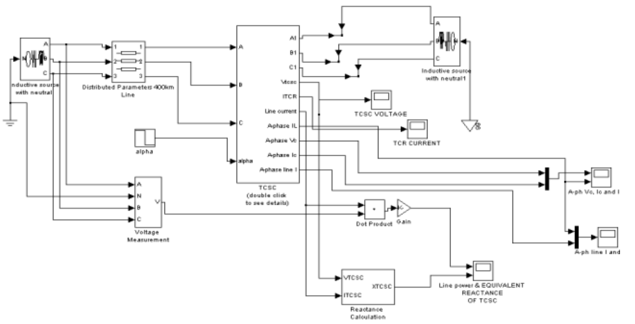

Fig. 4. Matlab/Simulink Model of SVC

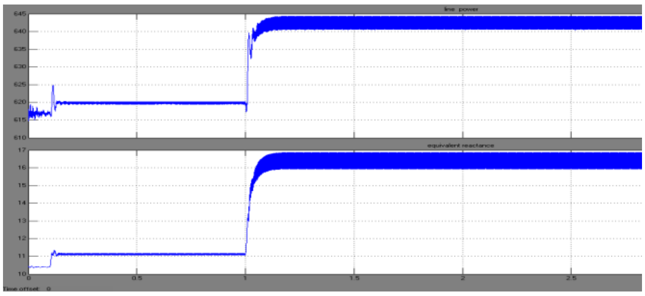

Fig.5 Line power and equivalent reactance of SVC

It is clear from these results that the SVC is an effective system controller which may be used to provide voltage regulation at the point of connection and to improve substantially the voltage quality in power systems.

B. D-STATCOM Simulations and Results

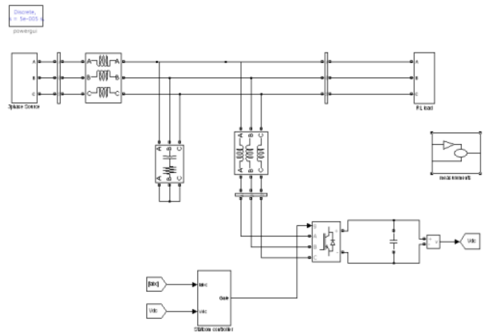

Fig.6. Complete MATLAB model of STATCOM

Fig.6 shows the complete MATLAB model of DSTATCOM along with control circuit. The power circuit as well as control system are modelled using Power System Block set and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. DSTATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection.

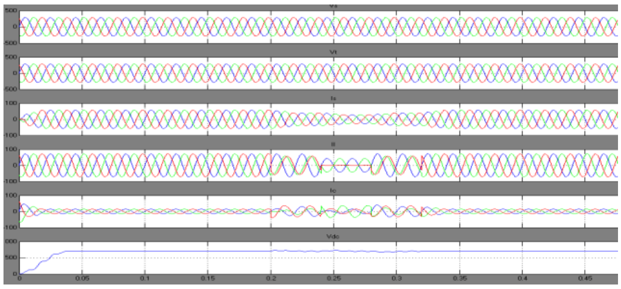

Fig.7 Simulation results for linear RL load

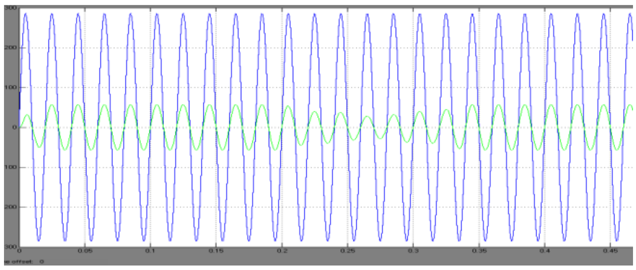

Fig.8 Simulation results power factor for linear RL load

C. DVR Simulations and Results

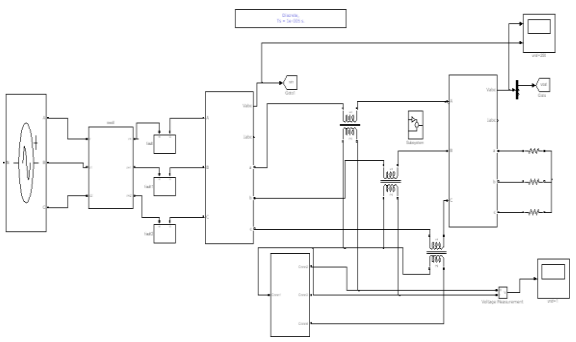

Fig.9. Matlab/Simulink model of the dynamic voltage restorer

Fig.9 shows the Matlab/Simulink model of the dynamic voltage restore. It mains consists of four bock source block, sag/swell creation block, DVR block and load block. Here DVR injecting the voltage into the line by use of coupling transformer.

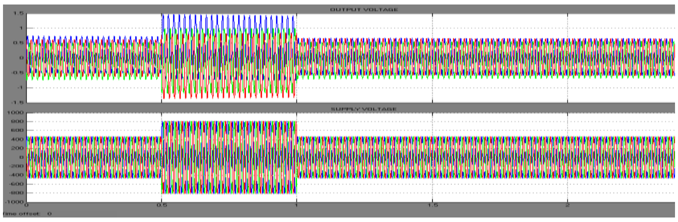

Fig.10 Output and supply voltage without DVR

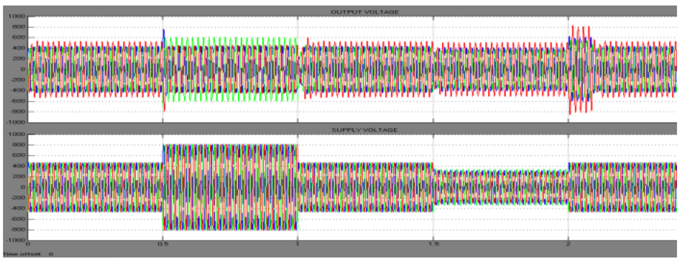

Fig.11 Simulation results of output ,supply voltage with DVR

Using the facilities available in MATLAB/SIMULINK, the DVR is simulated to be in operation only for the duration of the fault, as it is expected to be the case in a practical situation. When the DVR is in operation the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained close to the original value, as shown in Fig.11. The PWM control scheme controls the magnitude and the phase of the injected voltages, restoring the rms voltage very effectively. The sag mitigation is performed with a smooth, stable, and rapid DVR response; no transient overshoots are observed when the DVR comes in and out of operation .It should be noted that in the DVR, the dc voltage is supplied by a dc source as opposed to the dc capacitor used in the DSTATCOM. Several simulations were carried out to assess the performance of the DVR. As expected, the DVR required a higher rating of dc storage device to provide appropriate levels of sag mitigation when the fault was applied near the source point. This is due to the short electrical distance between the point in fault and the DVR coupling transformer. Clearly, the Controller must be designed to satisfy the most sever case, where the voltage sag is due to a fault quite close to the sensitive load.

VI. CONCLUSION

This paper has presented the power quality problems such as voltage dips, swells, distortions and harmonics. Compensation techniques of custom power electronic devices DVR, DSTATCOM and Facts device SVC was presented. This paper has discussed the electromagnetic transient models of FC-TCR arrangement of Static Var Compensator (SVC), Distribution STATCOM (D-STATCOM) and Dynamic Voltage restorer (DVR). These models were then applied to the study of power quality and their voltage regulation capabilities were studied. The simulations carried out showed that the FC-TCR arrangement of SVC, the DVR and the D-STATCOM provide excellent voltage regulation capabilities.

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