Investigation on D-STATCOM Operation for Power Quality Improvement in a Three Phase Three Wire Distribution System with a New Control Strategy

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Abstract

This paper deals with the issue of modeling and analysis of power controllers, power electronic-based equipment aimed at improving the reliability, stability and quality of power flows in low voltage distribution networks. A new control scheme is proposed to generate the PWM signal based on the measurements of voltage, and no reactive power measurements are required. The operation of the proposed control method is presented for D-STATCOM. Simulations and analysis are carried out in MATLAB/PLECS with this control method for the proposed systems. The reliability of the control scheme in the system response to the voltage instabilities due to system faults or load variations is proved obviously in the simulation results.

Keywords: D-STATCOM, PWM, VSC, MATLAB/PLECS.

1. INTRODUCTION

The advancement in the technology, in the last decade has seen drastically increase in the electrical loads and multiplying in numbers of complexity of the equipment that is highly sensitive to poor quality of distribution. Several large industrial users are reported to have experienced huge financial losses as a result of even minor lapses in the quality of electricity supply. Mineski et al. (2004) reported that many efforts have been made to remedy the situation with solutions based on the use of the latest power electronic technology. The system developed by Reed & Giroux (1999) is implemented a number of flexible control strategies are developed to improve the efficiency and control of the emerging power system applications. Among this, the algorithm taken from Iravani & Crow (1994 & 2000) distribution Static Compensator (D-STATCOM) based on the VSC principle has been used in this paper to perform the modeling and analysis of such controllers for a wide range of operating conditions. MATLAB/PLECS' highly-developed simulation software with the graphical interface has been used for implementation of the PWM controller reported in this paper for the D-STATCOM. It relies only on voltage measurements for its operation. Effects of load variation, voltage sags and system faults on the linear and non-linear loads are investigated, and the control of voltage disturbances and harmonic distortions are analyzed and simulated.

2. VSC-BASED CONTROLLERS

This section presents an overview of the VSC-based power controller is discussed in the paper.

2.1 D-STATCOM

Figure1a and Figure1b show the basic diagrams of DSTATCOM system connected as a shunt compensator. DSTATCOM system consists of a standard three-phase Insulated Gate Bipolar Transistor (IGBT) based three legs VSC bridge with the input ac inductors and a dc energy storage device to obtain a self-supporting dc bus. A three-phase ac source with line impedance feeds power to balanced/unbalanced linear and non-linear load. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. The VSC connected in shunt with the ac system provides a multi-functional topology which can be used for up to three quite distinct purposes:

- Voltage sag mitigation, voltage regulation and compensation of reactive power
- Correction of the power factor
- Elimination of harmonics.

A dynamic model of DSTATCOM is developed in MATLAB environment to simulate its behavior. The design approach of the control system determines the priorities and functions developed. In this paper, the D-STATCOM is used to regulate voltage at the point of common coupling. The control is based on sinusoidal PWM and only requires the measurement of the rms voltage at the load point as explained in Section III.

3. Sinusoidal PWM-based control

This section describes the PWM-based control scheme with reference to the D-STATCOM. The aim of the control scheme is to maintain constant voltage magnitude at the point where the 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. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response.

4. D-STATCOM Simulations and Results

Figure 2a and figure 2b shows the test system implemented in MATLAB/PLECS to carry out simulations for the D-STATCOM. The test system comprises a 11kV transmission system with linear and non-linear loads. A coupling transformer is connected to a point of common coupling and to the VSC bridge. A D-STATCOM is connected to the transformer to provide instantaneous voltage support at the load point. The capacitor on the dc side provides the D-STATCOM energy storage capabilities. To show the effectiveness of this controller in providing continuous voltage regulation, simulations were carried out with and without D-STATCOM connected to the system. A set of simulations was carried out for the test system shown in figure 3. The simulations are carried out in two different operating conditions.

- The non-linear load is tested without STATCOM which introduces high level of harmonics in the load current and intern disturb the source. The THD was measured at this condition without STATCOM which is about 11.07%.
- Now the proposed system is connected to the same setup of non-linear load through the switch and system was simulated for a period of 10s. Appropriate waveforms are studied and presented as shown in the Figure3 & Figure 4. It is observed that the proposed system is compensating disturbances in the load current by reducing the harmonics to THD level of about 4.00% as per IEEE standards IEEE 519. As shown in the Figure5.

The MATLAB/PLECS is used to verify the effectiveness of D-STATCOM with the circuit parameters for 11kv, 50Hz, system. The switching frequency is set at 10 kHz, the DC link voltage is 8000V in the simulation. Here two system setups is made as with D-STATCOM and With-out D-STATCOM.

In the simulation study the D-STATCOM is connected in shunt with the 11kV system and the simulation is set to run for 3sec. The figure 4b shows the compensation effect response of DSTATCOM under un-balanced condition. It's obvious that change in load current due to un-balanced load is compensated by the contribution of proposed DSTATCOM control scheme. For simplicity, reliability and to speed up the simulation PLECS is used. Simulation results shows that reactive power is flowing from the DC capacitor link for active compensation and hence the power factor is always corrected near to unity in a very short period. Figure 6 shows the raising characteristics of capacitor voltage. This maintains the system properly with balanced condition by supplying required reactive power whenever the system gets disturbed.

In spite of sudden load variations, the regulated rms voltage shows a reasonably smooth profile, where the transient overshoots are almost nonexistent. The magnitude of these transients is kept very small with respect to the reference voltage. In fact, they do not last for more than one cycle.

5. Conclusion

This paper discusses a new concept of voltage regulation, sag mitigation, harmonics reduction and power factor correction in power distribution system for both balanced and unbalanced load using D-STATCOM. This scheme is versatile and can be applied to various kinds of distribution networks. One of the major advantages of the scheme is opposed to fundamental frequency switching schemes already available in the MATLAB/PLECS, this PWM control scheme only requires voltage measurements. Furthermore it is easy to implement in real time as the desired compensated parameters are directly computed. This scheme also is computationally simple, as it does not require complicated transformations.

A closed loop control scheme, consisting of an outer DC capacitor voltage loop and an inner I_c current control loop, is proposed for D-STATCOM. The control scheme maintains the balanced voltage level at the D-STATCOM terminal to regulate the DC capacitor voltage. It has been shown that the D-STATCOM is able to regulate voltage in the distribution network against disturbances raised in the network. In addition to power distribution applications and the benefits offered by D-STATCOM for improved system operations, this technology will also be extremely beneficial when implemented for the interconnection of certain renewable energy sources to the power system network, and also this will be tremendous worth for industrial and small consumer's application.

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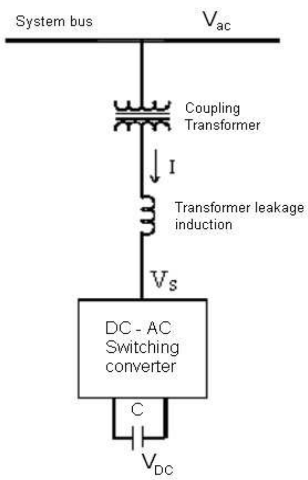

Figure 1a.Basic configuration of D-STATCOM

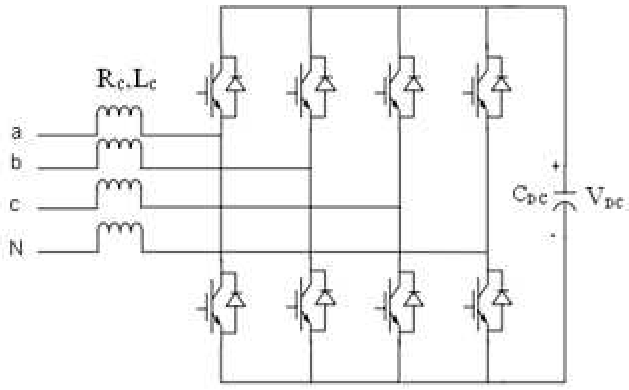

Figure 1b. Schematic diagram of D-STATCOM

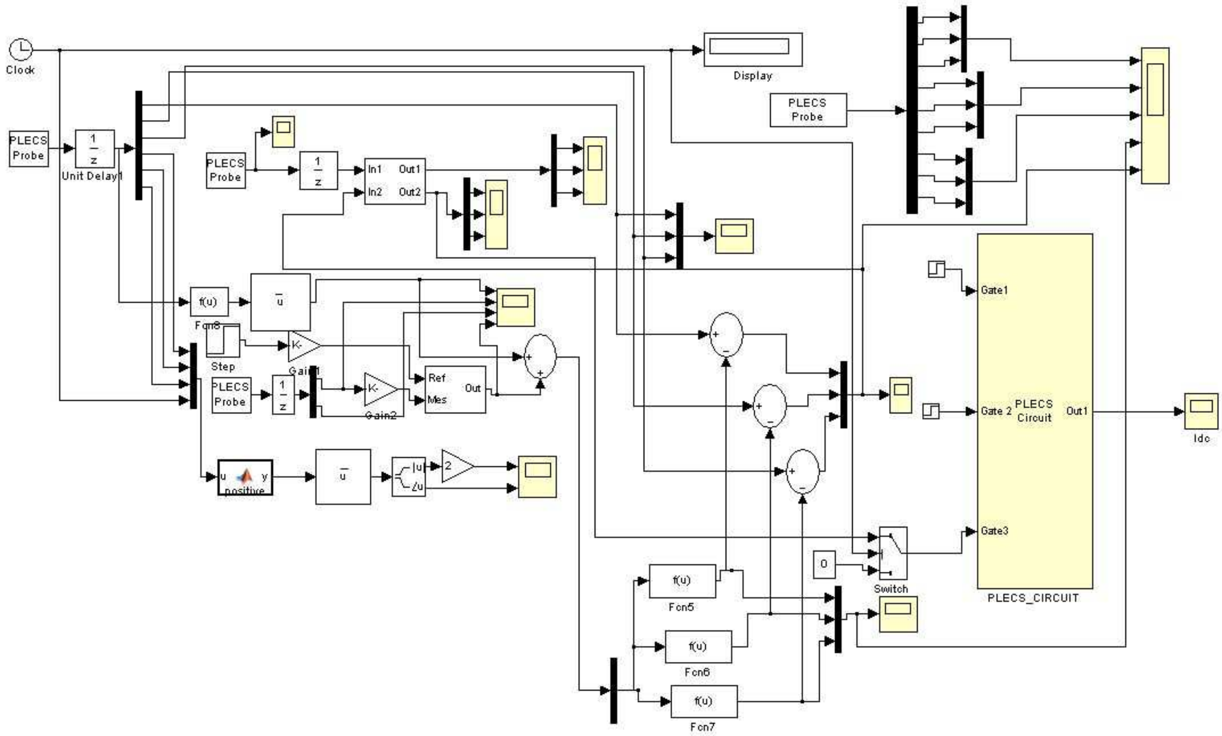

Figure 2a. Simulation of DSTATCOM control system using MATLAB/PLECS

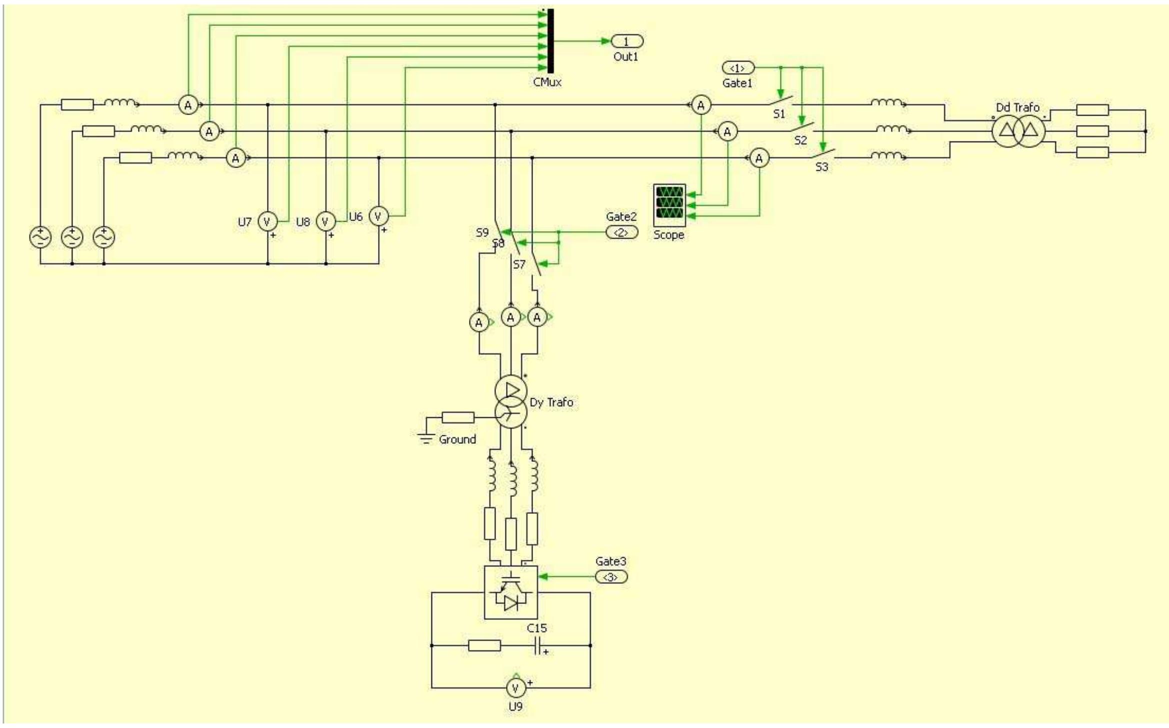

Fig 2b. Simulation of D-STATCOM using MATLAB/PLECS

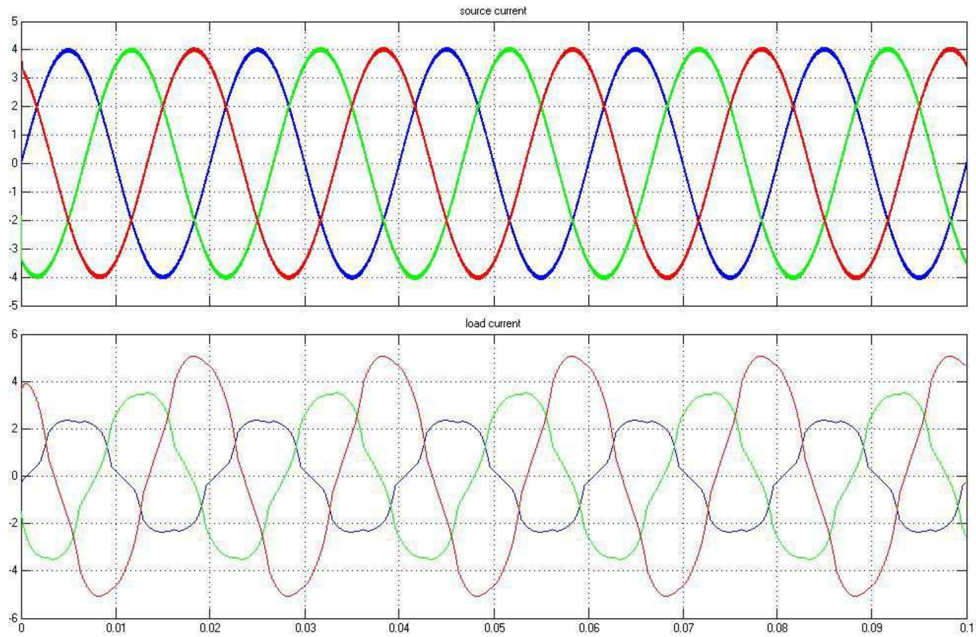

Figure 3. Performance of DSTATCOM with Non-Linear Loads for Voltage Regulation and Load Balancing

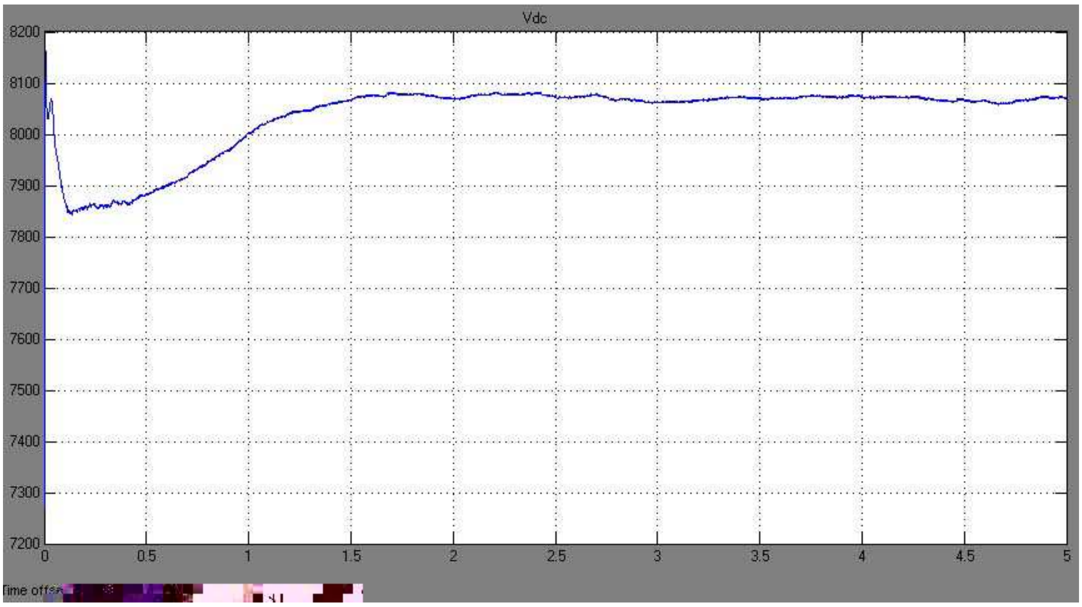

Figure 4. Load current waveforms (i) without STATCOM is connected (top)
(ii) with STATCOM connected (bottom)

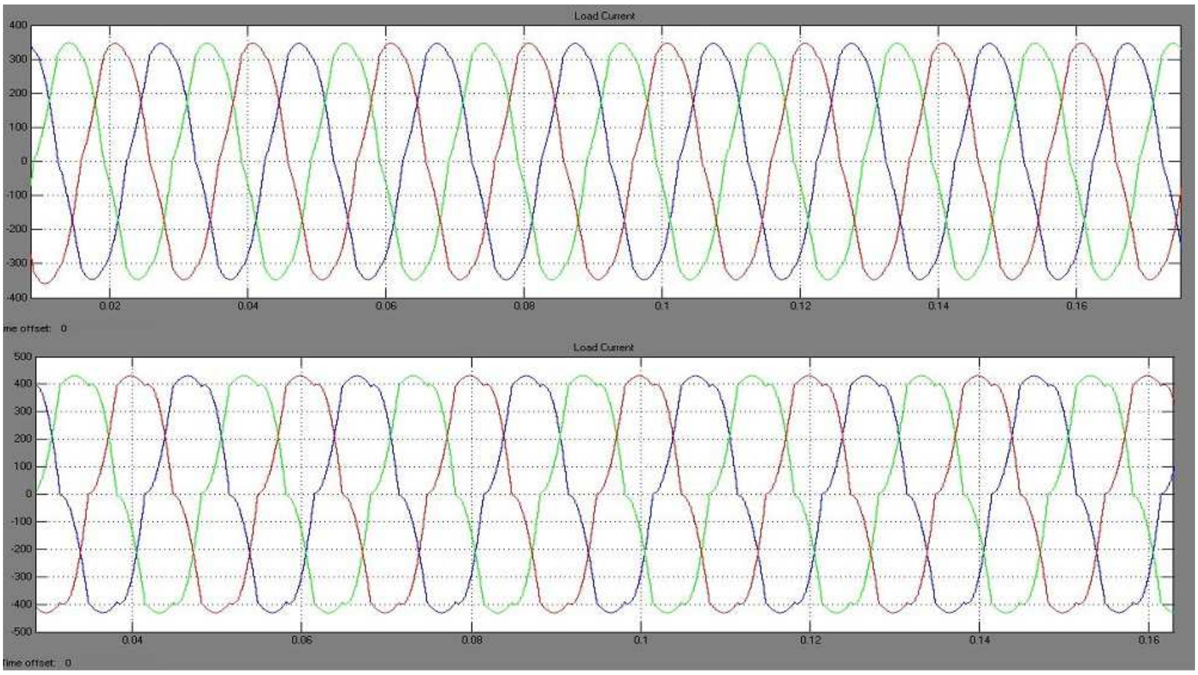

Figure 5 Harmonics in the load current (i) without STATCOM and (top) (ii) with STATCOM (bottom)

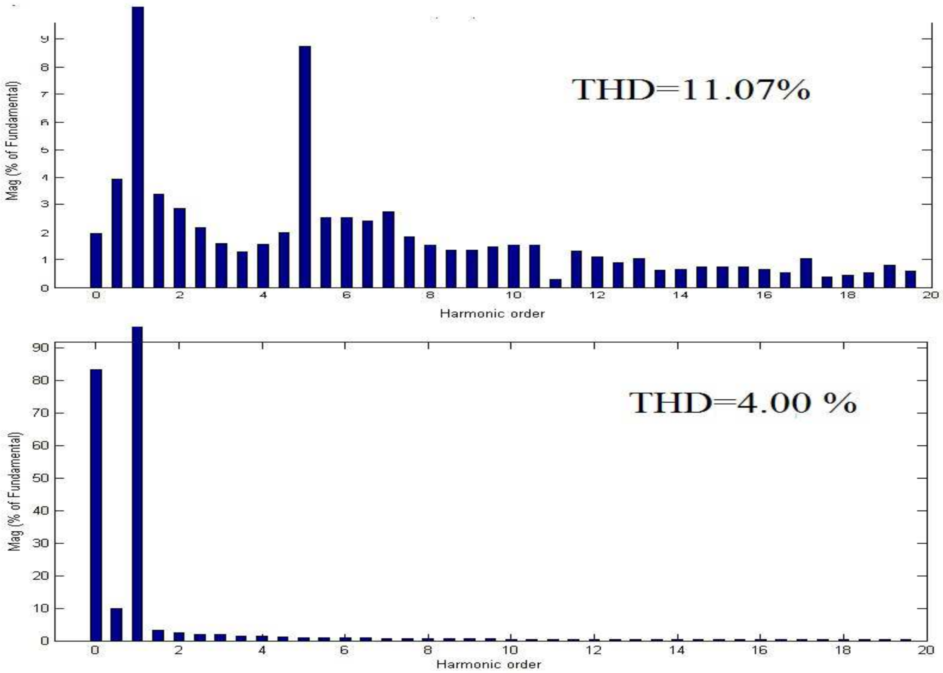

Figure 6 DC link capacitor voltage level