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Modelling and Simulation of DSTACOM for Power Quality Improvement

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Abstract - *This paper presents a distribution static compensator (DSTATCOM) for power quality improvements in terms of controlling the voltage in a three-phase distribution system. The DSTATCOM is implemented with PWM current controlled six-leg voltage source converter (VSC) and the switching patterns are generated through a PI controller. The insulated gate bipolar transistor (IGBT) based VSC is supported by a capacitor and is controlled for the required compensation of the load current. The DSTATCOM is connected to the power system feeding variable loads. Voltage dip at load end is compared in between without DSTATCOM and with DSTATCOM by considering variable loads. The PI controller based DSTATCOM system is validated through extensive simulation in MATLAB with R–L loads with a case study.*

Key Words: DSTACOM, Control techniques, topologies, VSC, power quality.

1. INTRODUCTION

Recently a lot of research is being encouraged for power quality and custom power problems in the distribution system due to non-linear loads [1–4]. In practical applications most of the loads are non-linear, such as power converters, SMPS, arc furnaces, UPS and ASDs [5,6]. These non-linear loads are introducing harmonic distortion and reactive power problems [7]. The harmonics in the system induce several undesirable issues, such as increased heating losses in transformers, low power factor, torque pulsation in motors, poor utilization of distribution plant and also affects other loads connected at the same Point of Common Coupling (PCC) [8,9]. The harmonic resonance is one of the most common problems reported in low and medium level distribution systems. It is due to capacitors which are used for power factor correction and source impedance [10]. There are mitigation techniques for power quality problems in the distribution system and the group of devices is known by the generic name of custom power devices (CPDs) [11]. Power converter based custom power devices (CPDs) are useful for reduction of power quality problems such as power factor correction, harmonics compensation, voltage sag/swell compensation, resonance due to distortion, and voltage flicker reduction within specified international standards [12,13].

The distribution static compensator (DSTATCOM) is a shunt connected CPD capable of compensating current related power quality problems. Some of the topologies of DSTATCOM for the three phase four-wire system for the mitigation of neutral current along with power quality compensation in the source current are six-leg voltage source converter (VSC), three single-phase VSCs, three-leg VSC with split capacitors [14], three-leg VSC with zig-zag transformer [15–17], and three-leg VSC with neutral terminal at the positive or negative of dc bus [18]. The voltage regulation in the distribution feeder is improved by installing a shunt compensator [19]. In this paper, PI based controller is used for the control of the DSTATCOM. A new topology of DSTATCOM is proposed for a three-phase distribution system, which is based on six-leg VSC. Six-leg VSC compensates the harmonic current and reactive power on source side. The insulated gate bipolar transistor (IGBT) based VSC is self-supported with a dc bus capacitor and is controlled for the required compensation of the load current. The DSTATCOM is designed and simulated using MATLAB software with its Simulink and power system blockset (PSB) toolboxes. Comparative assessments of the performance of DSTATCOM feeding variable loads in between without DSTATCOM and with DSTATCOM are presented. In Section 2, the description of the DSTATCOM system with operating principle is presented. Section 3 describes about the control strategy for reference current extraction. Section 4 describes a case study for the distribution system employing DSTATCOM as a power quality improvement device. In Section 5 performances have been modeled and analyzed from the obtained results under non-linear load conditions. Finally, Section 6 describes the conclusions of this work.

2. DISTRIBUTION STATIC COMPENSATOR

A DSTATCOM is a custom power device which is utilized to eliminate harmonics from the source current and also balance them in addition to providing reactive power compensation to regulate the load bus voltage. The key component of the DSTATCOM is a power Voltage Source Converter (VSC) that is based on high power electronics technologies.

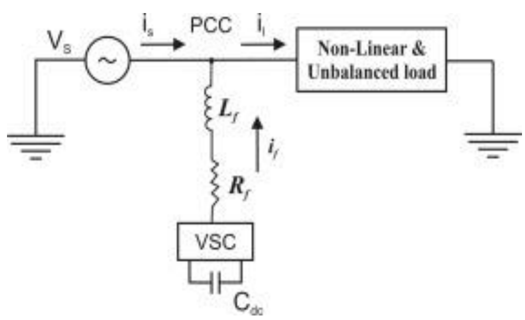

Fig. 1. Single-line diagram of the DSTATCOM.

The DSTATCOM mainly consists of DC voltage source behind self-commutated inverters using IGBT, controller and coupling transformer. The IGBT inverter with a DC voltage source can be modeled as a variable voltage source. The distribution power system can also be modeled as a voltage source. Two voltage sources are connected by a reactor representing the leakage reactance of the transformer. The principle operation modes of the DSTATCOM output current, I which varies depending upon Vo

$I=(V-V_0)/X$ (1)

where V, V_0, and X are the system voltage, output voltage of the IGBT-based inverter, and the total circuit reactance respectively. If V_0 is equal to V, then no reactive power is delivered to the system. If V_0 is greater than V, the phase angle of I is leading with respect to the phase angle of V by 90 degrees. Thus, a leading reactive power flows in the capacitive mode of the DSTATCOM.

If V_0 is lower than V, the phase angle of I is lagging with respect to the phase angle of V by 90^0. Thus, a lagging reactive power flows in the inductive mode of the DSTATCOM. The quantity of the reactive power flow is proportional to the difference between V and V_0.

Equivalent circuit of the DSTATCOM as shown in Fig. 2 is represented by a controlled voltage source (VVR) in series with transformer impedance ZVR. The voltage VVR can be regulated to control voltage of the bus k. Fig. 3 represents phasor diagram related to the DSTATCOM operation under both lagging and leading power factor modes

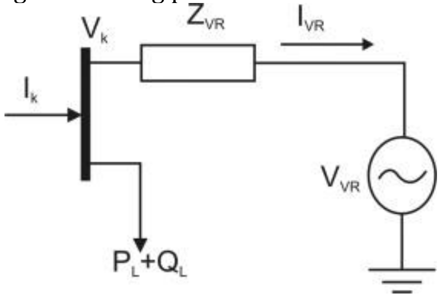

Fig. 2. Equivalent circuit of DSTATCOM

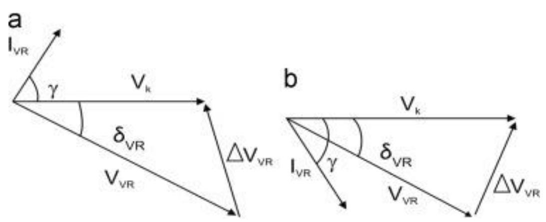

Fig.3. Phasor diagram: (a) lagging operation and (b) leading operation.

3. CONTROL STRATEGY

For the controlling of voltage source converter and DC Link voltage, different types of controllers are included to control the main module.

3.1. Harmonic Damping

There are several methods to extract the harmonic components from the detected three-phase waveforms. Among them, the so-called p-q theory based on time domain has been widely applied to the harmonic extraction circuit of active filters. The detected three-phase voltage is transformed into the d–q coordinates as shown in Fig.4. Two first order digital high pass filters (HPFs) with the same cut off frequency to extract the dc component Vhd*, Vhq* and V0 which corresponds to the fundamental frequency in the coordinates.

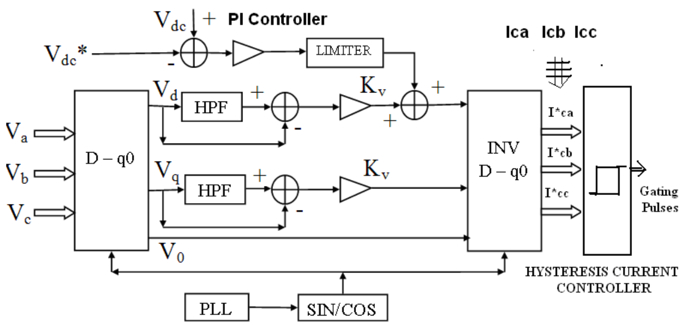

Fig.4. Block Diagram of the control circuit equipped with the function of voltage regulation and Harmonic Damping.

3.2. Voltage Regulation

In line voltage regulation part is performed by a feedback control. Two co ordinates Vd and Vq is compared with harmonic extracted voltage V_{hd}* and V_{hq}*. A gain KV amplifies and to produce current references for harmonic damping I_{hd}, I_{hq} and I_0 as given in (2), (3) and (4). The current reference for the voltage source inverter is the sum of the current references from the three parts, as follows:

$$I^*_{cd}(s) = K_V(G_h V^*_{hd} - V_d) + (V^*_{dc} - V_{dc}) \quad (2)$$

$$I^*_{cq}(s) = K_V(G_h Vq - Vq) \quad (3)$$

$$I^*_0(s) = 1/3(V_a + (V_b + V_c) \quad (4)$$

The obtained current reference is converted three phase current reference by inverse d-q transformation I^*_{ca}, I^*_{cb} and I^*_{cc}. The three phase reference compensating current is compared with the active filter compensating current extracted from ac system. Thus three phase compensating current I_{ca}, I_{cb} and I_{cc} are produced. The obtained reference current is given to a PWM scheme, which is used to generate controlled gate signal for shunt active filter.

3.4. DC LINK VOLTAGE CONTROLLER

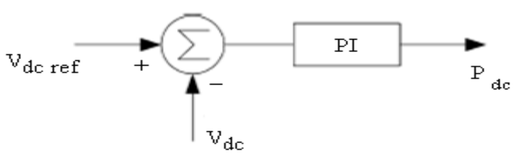

Fig.5 Conventional DC Link Voltage PI Controller.

Conventional PI Controller is used to maintain the DC Link voltage at the reference value. To maintain the dc-link voltage at the reference at the reference value, the DC Link capacitor needs a certain amount of real power which is proportional to the difference between the actual and reference voltages .The power required by the capacitor can be expressed as

$$P_{dc} = K_p(V_{dcref} - V_{dc}) + K_i \int (V_{dcref} - V_{dc})dt \quad (5)$$

4. SIMULATION OF DSTATCOM

4.1. A CASE STUDY

The six-leg voltage source converter based DSTATCOM connected to a distribution system having variable load is taken up for study. The system diagram is shown in Fig. 6 which shows the source impedance (Rs and Ls). A STATCOM of suitable rating is connected in parallel with the load. In the voltage source converter a dc capacitor is connected on the dc side to produce a smooth dc voltage. The switches in the converter represent controllable semiconductors, such as IGBT or power transistors. The IGBTs are connected anti parallel with diodes for commutation purposes and charging of the DC capacitor. For converter the most important part is the sequences of operation of the IGBTs. PWM generators are used to generate the pulses for the firing of the IGBTs. IGBTs are used in this work because it is easy to control the switch on and off of their gates and suitable for the DSTATCOM.

The overall design process can be shortened through the use of computer simulations, since it is usually easier to study the influence of a parameter on the system behavior in simulation. The dynamic and steady-state performance of DSTATCOM is observed for case study.

Table 1 shows the circuit parameters used in the DSTATCOM (shunt active filter). The simulation is carried for distribution system with and without shunt active filter. Total harmonic distortion is calculated for the system voltage and current.

The system is subjected with the load variations. The effect of variation of the load on system voltage is to be examined with and without DSTATCOM. Fig. 5.1 shows the simulink diagram of the system connected with DSTATCOM. The 400V, 50 Hz voltage source is connected with main laod and intermittent load. The DSTACOM and filter is also can bee seen in fig 6.

Table 1 Circuit parameters of DSTACOM

Source Voltage	$V_a = V_b = V_c$	400 V
Transmission Line Length	L	3.5 KM
Frequency	F	50 Hz
Line Inductance	$L_a = L_b = L_c$	6.36mH
Line Capacitor	C	40μF
DC link Capacitor	$C_{dc\ link}$	750μF

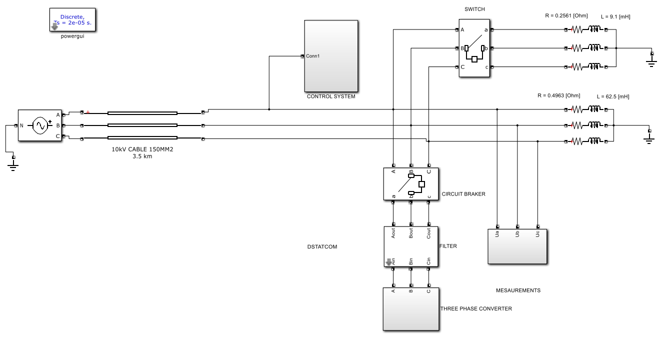

Fig. 6 Simulink diagram of DSTATCOM

5. RESULTS

The system under the study is subjected to the load perturbations. The load is varied in between time 0.1 sec to 0.3 sec. before time 0.1 sec the load resistance is 0.4963 ohm and inductance of 62.5 mH. Between time 0.1 sec to 0.3 sec. the extra star connected three phase load of series combination of 0.2561 ohm resistance and 9.1 mH is connected. The simulation is done for 0.5 second and the performance is analyzed with and without the use of DSATCOM.

5.1. Case I: Without DSTATCOM

The system is analyzed without DSTATCOM and the following results are obtained:

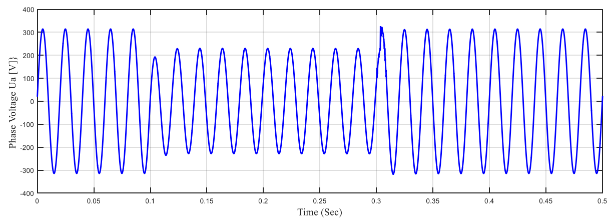

Fig. 7 Phase Voltage for phase 'A' without DSTATCOM

Fig. 7 shows the phase voltages for phase A. As the load changes at time 0.1 sec the voltage dips down from 310V to 220V for each phase. This is about 30% reduction in the voltage which is well below the recommended voltage variation standard.

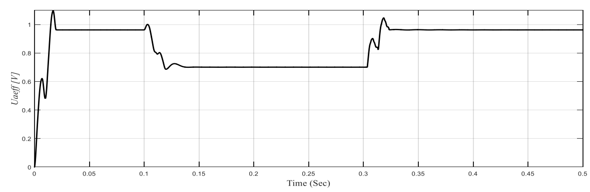

Fig. 8 Dip in voltage level (pu) without DSTATCOM

With the absence of DSTATCOM the voltage level dips down to 0.7 pu shown in fig 8. This much amount of dip in voltage cannot be tolerated as far as the sensitive load is concerned. The voltage dip can cause under performance of various equipments connected to the system.

5.2. Case II: With DSTATCOM

When DSTATCO is connected to the system the following results are obtained:

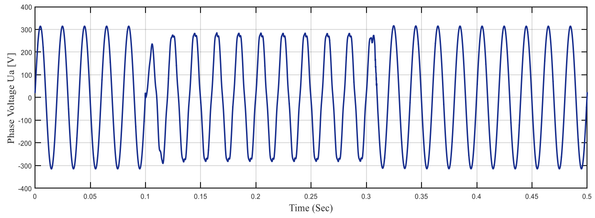

Fig. 9 Phase Voltage for phase 'A' with DSTATCOM

The DSTATCOM, as discussed earlier, absorbs the fluctuations in the voltage level due to any of the reason like change in load or fault etc. From the figure 9 the phase voltages of phase 'A' is shown. From there it is found that there is dip in the voltage between time 0.1 sec to 0.3 sec, when the load is increased. The voltage dips from 310 V to 295 V. This dip is less than 5% as the recommended level.

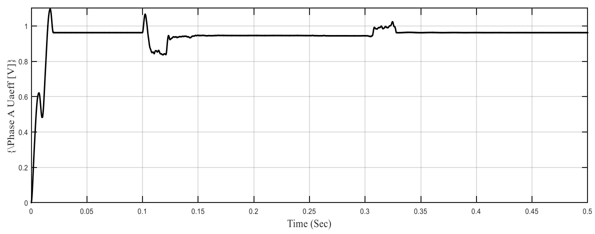

Fig. 10 Dip in voltage level (pu) with DSTATCOM

The pu voltage waveform of system is shown in fig. 10. There is 0.1 pu voltage dip in the voltage as compared to 0.3 pu in case of system without DSTATCOM. When the extra load is released at time 0.3 sec there is momentarily voltage swell. This voltage swell is comparatively less as compared to system without DSTATCOM.

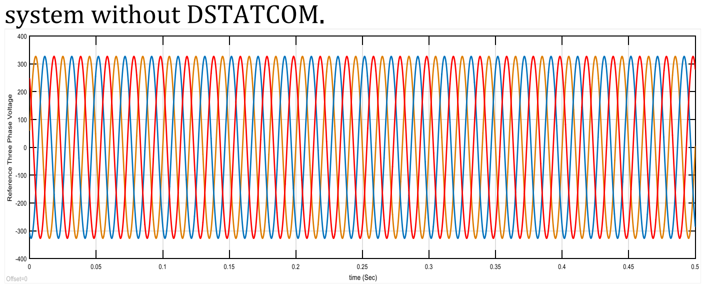

Fig. 11 Three phase voltage waveform with DSTATCOM.

The three phase voltage waveform across the load is shown in the fig. 11. There is no change in the voltage level neither at time of adding the extra load or at removing that load.

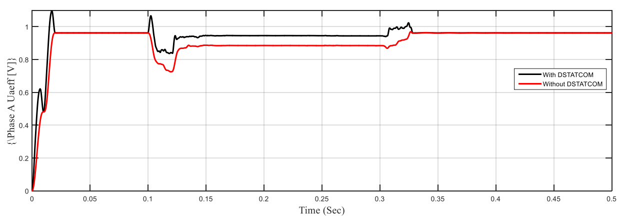

Fig. 12 Comparison in voltages with & without DSTATCOM

Fig 12 clearly shows the difference between voltage waveform with and without DSTATCOM when load is changed. After increasing the value of load at time 0.1 sec the dip occurs and the voltage level reduces throughout the time period when extra load is connected. The voltage resorted to its previous value when DSTATCOM is connected but in case of without DSTATCOM voltage not come back to the value prior to load change. This is the one of the major advantage of DSTATCOM connected to the system.

6. CONCLUSIONS

Nonlinear loads produce harmonic currents that can propagate to other locations in the power system and eventually return back to the source. Therefore, harmonic current propagation produces harmonic voltages throughout the power systems.

Mitigation techniques have been proposed and implemented to maintain the harmonic voltages and currents within recommended levels are harmonic filters (passive, active and hybrid) and custom power device DSTATCOM.

The different sources and occurrences of voltage Sags, swells and interruptions have been presented. The investigation with a Shunt Active Filter for installation on a power distribution system with mainly focus on harmonic reduction and voltage regulation performance has been successfully demonstrated in MATLAB/Simulink.

Simulated results are shown with good dc bus voltage regulation, reduced source harmonic currents and stable operation.

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