An Improved Dstatcom Topology with Reduced VSI Rating, Dc Link Voltage and Filter Size

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Abstract: This paper proposes an improved hybrid distribution static compensator (DSTATCOM) topology to compensate reactive and nonlinear loads with reduced VSI rating, DC link voltage and filter size. An LCL filter with small value of inductor compared to traditional L filter has been used at the front end of a voltage source inverter (VSI), which provides the elimination of switching harmonics. Voltage of the DSTATCOM can be reduced with capacitor to be connected in series with an LCL filter. Consequently the power rating of the voltage source inverter has been decreased. With reduced dc-link voltage, the voltage across the shunt capacitor of the LCL filter will be also less. It will reduce the power losses in the damping resistor as compared with the traditional LCL filter with passive damping. Therefore, the proposed DSTATCOM topology will have reduced weight, cost, rating, and size with improved efficiency and current compensation capability compared with the traditional topology. A systematic procedure to design the components of the passive filter has been presented. The effectiveness of the proposed DSTATCOM topology over traditional topologies is validated through simulation.

Keywords: Distribution static compensator (DSTATCOM), Hybrid topology, passive filter, power quality (PQ).

1. INTRODUCTION

An electric power distribution system is the final stage in delivery of electrical power; it carries electricity from transmission system to individual consumers. Except in a very few special situations, electrical energy has been generated, transmitted, distributed, and utilized as alternating current (AC). However, alternating current has several distinct disadvantages. One of these is the necessity of supplying reactive power with active power. Due to stored energy in the load and again send back to source, or presence of nonlinear loads that distorts the wave shape of the current drawn from the source, due to this the apparent power will be greater than the real powers, which will effects the power factor. Due to this high currents energy lost in distribution system will increase, further equipment cost will increase. This incremental cost of equipment and wastage of energy causes electrical utilities to charge a higher cost to industries or commercial customers where there is a low power factor. In traditional method, L-type filters with large value of inductance were used to increase the quality of current to be injected. This large value of inductor has low slew rate for tracking the reference currents, and produces large voltage drop across it, intern it requires high value of dc-link voltage for the compensation. Therefore L-filters increases cost, size, and power rating. AN LCL filter is used at the front end of the VSI which will improve the tracking performance, but requires high value of dc-link voltage as that of L filter. In this paper an LCL filter is used to overcome the aforementioned draw backs. Capacitor is used in series with the LCL filter to decrease the voltage of DSTATCOM. This proposed model decreases the size of the passive components, rating of dc-link voltage, rating of VSI. It provides good tracking performance.

2. PRINCIPLE OF DSTATCOM

DSTATCOM is power electronics based power quality improving device, which generates and /or absorbs the reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The DSTATCOM comprises of coupling transformer with internal leakage reactance, a three phase voltage source inverter (VSI) with self-commutating switches (GTO/IGBT), and a DC-link capacitor. Fig.1 shows the basic configuration of DSTATCOM. The VSI converts the dc voltage across the storage device into ac output voltages. These ac voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Inverter is the main component of the DSTATCOM. The objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage. The operation of the DSTATCOM is as follows: The voltage is compared with the AC bus voltage system (Vs). When the magnitude of AC bus voltage is above that of the VSI magnitude (Vc), the AC system considered that, DSTATCOM as inductance connected to its terminals. Otherwise if the voltage magnitude of VSI is above that of the AC bus voltage magnitude, the AC system sees the D-STATCOM as capacitance connected to its terminals. If the VSI voltage magnitude is equal to AC bus voltage magnitude, then the reactive power exchange is zero. Suppose DSTATCOM has a DC active element or energy storage elements or devices on its DC side, it can able to deliver real power to the power system. This can be done by varying the phase angle of the DSTATCOM terminals and the phase shift of the AC power system. When VSI phase angle lags phase angle of the AC power system, the DSTATCOM absorbs the real power from the AC system, if the phase angle of VSI leads phase angle of AC power system, the DSTATCOM supplies real power to AC supply mains. The main feature is governing of bus voltage magnitude by dynamically absorbing or generating reactive power.

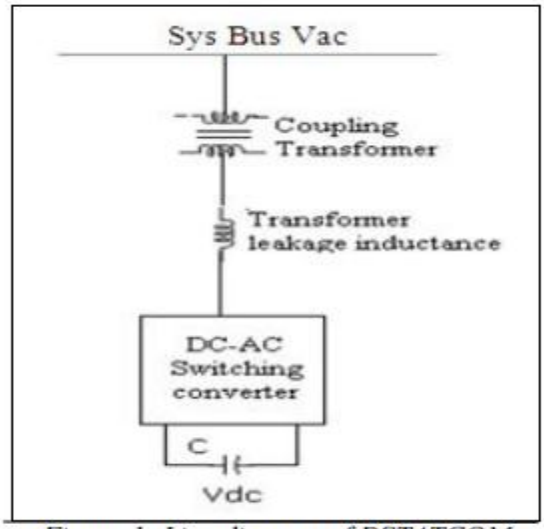

Figure 1: Line diagram of DSTATCOM

3. PROPOSED DSTATCOM WITH LCL-FILTER AND SERIES CAPACITANCE

The proposed DSTATCOM three-phase equivalent circuit diagram is shown below in fig.2.It is realized by using three-phase fourwire two-level neutral-point-clamped VSI. An LCL filter is connected at the front end of voltage source inverter with series capacitance This LCL filter reduces the size of the passive components required and capacitance will reduce the DC-link voltage and hence power rating of voltage source inverter.

Here and represent resistance and inductance at VSI side; and represents inductance and resistance at load end side of the system. C is filter capacitance which forms LCL filter in all three phases. Rd is damping resistance used in series with the capacitance C, provides passive damping of the overall system and damp out the resonance. Here if1a and if2a are filter currents in phase-a and similar in all three phases. vsha is voltage across LCL filter and isha is current through LCL filter, this is similar for other two phases. The voltage across the DC_link capacitors are maintained constant i.e. Vdc1=Vdc2=Vdcref. The source and load of DSTATCOM are connected to a common point called point of common coupling (PCC).

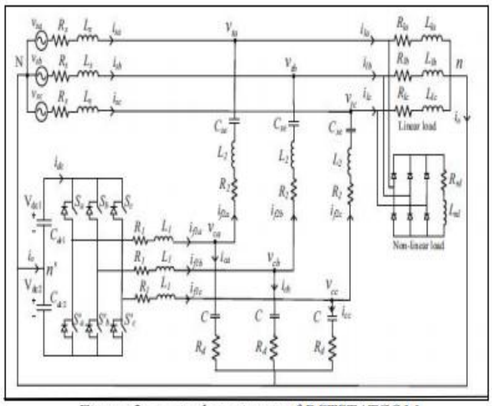

Figure 2: equivalent circuit of DSTSTATCOM

4. CONTROL OF DSTATCOM:

The overall control block diagram is shown in Fig. 3. The DSTATCOM is controlled in such a way that the source currents are balanced, sinusoidal, and in phase with the respective terminal voltages. In addition, average load power and losses in the VSI are supplied by the source. Since the source considered Fig. 3. Controller block diagram. here is nonstiff, the direct use of terminal voltages to calculate reference filter currents will not provide satisfactory compensation. Therefore, the fundamental positive sequence components of three-phase voltages are extracted to generate reference filter currents (i ∗ f2a, i ∗ f2b, and i ∗ f2c) based on the instantaneous symmetrical component theory [27]. These currents are given as follows:

$$i^*_{f2a} = i_{la} - i^*_{sa} = i_{la} - \frac{v^+_{ta1}}{\Delta^+_1}(P_{lavg} + P_{loss})$$
$$i^*_{f2b} = i_{lb} - i^*_{sb} = i_{lb} - \frac{v^+_{tb1}}{\Delta^+_1}(P_{lavg} + P_{loss})$$
$$i^*_{f2c} = i_{lc} - i^*_{sc} = i_{lc} - \frac{v^+_{tc1}}{\Delta^+_1}(P_{lavg} + P_{loss}) \quad (1)$$

where v+ ta1, v+ tb1, and v+ tc1 are fundamental positive sequence voltages at the respective phase load terminal, and Δ+ 1 = (v+ ta1)2 + (v+ tb1)2 + (v+ tc1)2. The terms Plavg and Ploss represent the average load power and the total losses in the VSI, respectively. The average load power is calculated using a moving average filter for better performance during transients and can have a window width of half-cycle or full cycle depending upon the odd or odd and even harmonics, respectively, present in the load currents. At any arbitrary time t1, it is computed as follows:

$$P_{lavg} = \frac{1}{T}\int_{t_1-T}^{t_1} (v_{ta} i_{la} + v_{tb} i_{lb} + v_{tc} i_{lc})\, dt. \qquad (2)$$

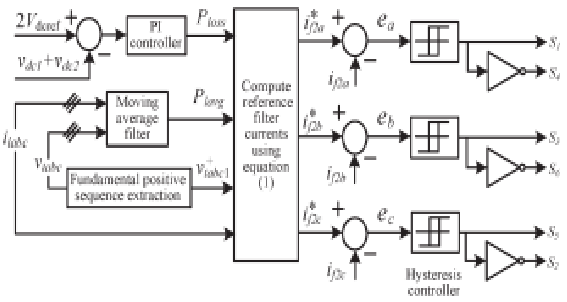

Fig: 3 Controller block diagram.

5. SIMULATION RESULTS:

The advantages of the proposed topology are that it uses a lower rating of the VSI, has a smaller value of the filter inductor, reduces the damping power loss, and provides improved current compensation. All these advantages are verified through MATLAB software. System parameters used to validate the performance are given in Table I. Fig. 4(a) shows the threephase source currents before compensation which are same as load currents. These currents are unbalanced and distorted due to presence of unbalanced linear and nonlinear loads. Three phase PCC voltages, as shown in Fig. 4(b), are unbalanced and distorted due to presence of feeder impedance. The performance of the traditional DSTATCOM topology is presented in Fig. 5. The three-phase source currents, which are balanced and sinusoidal, are shown in Fig. 5(a). Fig. 5(b) shows the three-phase PCC voltages. As seen from waveforms, both the source currents and the PCC voltages contain switching frequency components of the VSI. The three-phase filter currents are shown in Fig. 5(c). The waveforms of voltages across upper and lower dc capacitors, as well as the total dc-link voltage, are presented in Fig. 5(d). The voltage across each capacitor is maintained at 520 V, whereas the total dc-link voltage is maintained at 1040 V using the PI controller. Fig. 6 shows the compensation performance for LCL filterbased DSTATCOM. The source currents and PCC voltages are balanced and sinusoidal but contain significant switching harmonics ripple. Their percentage total harmonic distortions (THDs) are given in Table II. To accommodate power losses in the damping resistor, the source currents are slightly increased compared with the traditional topology. Moreover, the total dc-link voltage is maintained at 1040 V (same as the traditional scheme) to achieve load compensation. The compensation performance of the proposed topology is shown in Fig. 7. The load and source parameters are the same as given in Table I. In Fig. 7(a), the three-phase source current waveforms are shown, which are balanced, sinusoidal, and have negligible switching ripple compared with the traditional topology. In addition, neutral current is nearly zero. Fig. 7(b) shows the three-phase compensated PCC voltages with reduced switching harmonics. Additionally, source currents are in phase with their respective phase voltages.

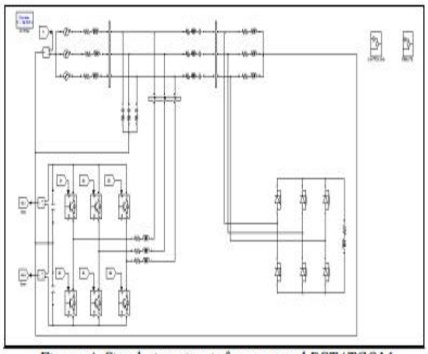

Figure 4: Simulation circuit for proposed DSTATCOM

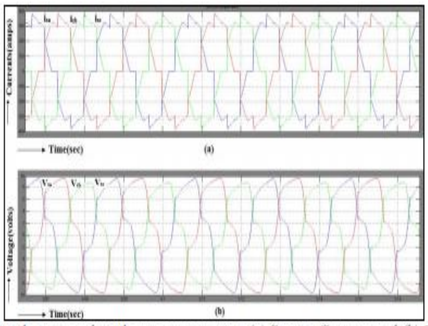

Figure 5: Simulation result without compensation (a) Source Current and (b) PCC voltage

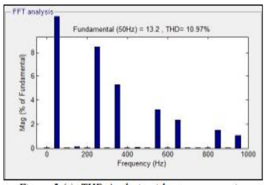

Figure 5 (c): THD Analysis without compensation

Fig 5 (c) shows that total harmonic distortion without compensation the percentage of total harmonic distortion is 10.97%.

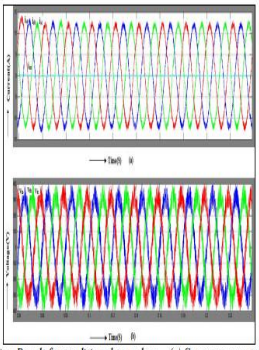

Figure 6: Simulation Result for traditional tropology (a) Source currents (b) PCC Voltages

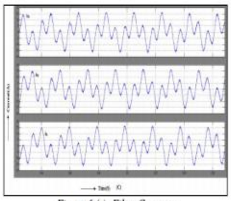
Figure 6 (c): Filter Currents

The filter currents, as shown in Fig. 6(c), have smaller ripples as compared with that of the traditional topology. The voltages across each capacitor and the total dc-link voltage are shown in Fig. 6(d), having maintained at 110 and 220 V, respectively.

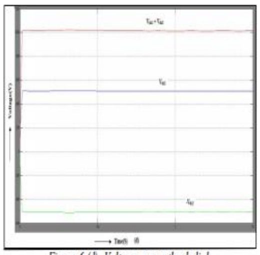
Figure 6 (d): Voltage across the dc link

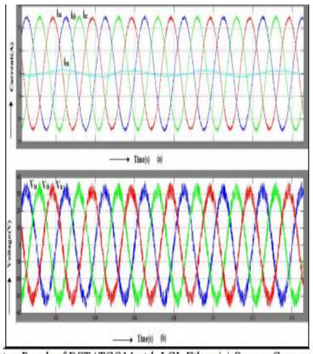
Figure 7: Simulation Result of DSTATCOM with LCL Filter (a) Source Current (b) PCC Voltages

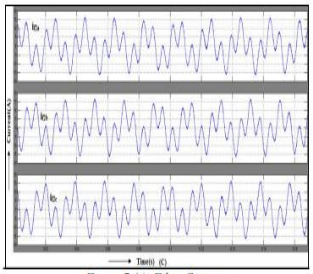
Figure 7 (c): Filter Currents

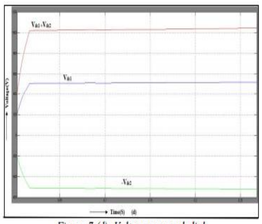
Figure 7 (d): Voltage across dc link

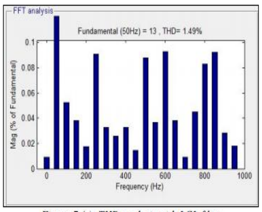

Figure 7 (e): THD analysis with LCL filter

The simulation results with LCL filter is presented in Fig (7). Here source currents, PCC voltages are sinusoidal and balanced, contains switching harmonics. Fig(e) shows the THD result of DSTATCOM with LCL filter and with LCL filter THD is 1.49%.

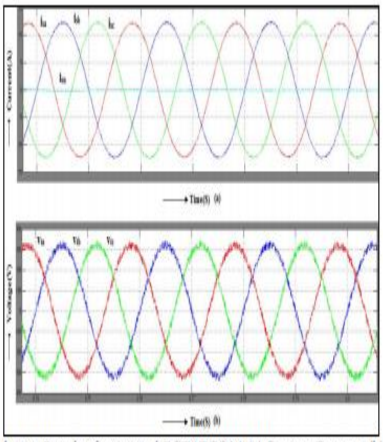
Figure 8: Simulation Result of proposed DSTATCOM (a) Source Current (b) PCC Voltages

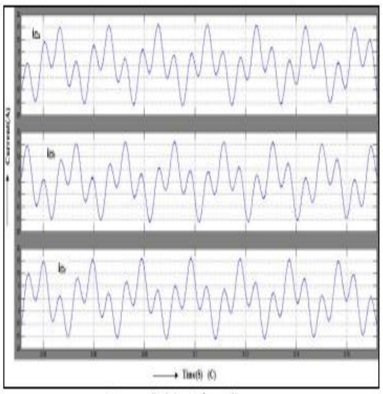
Figure 8 (c): Filter Currents

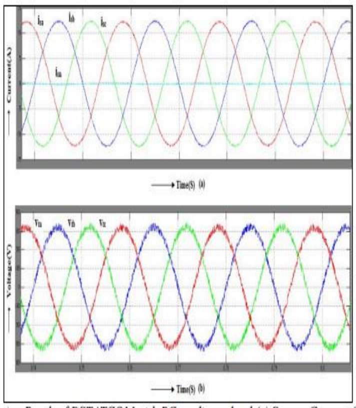
Figure 9: Simulation Result of DSTATCOM with RC nonlinear load (a) Source Current (b) PCC Voltages

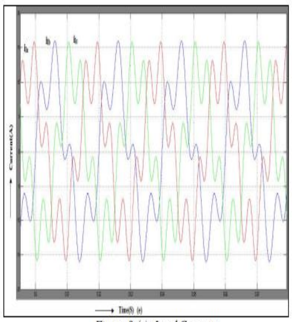
Figure 9 (e): Load Currents

Thus the reduced compensated voltage is sufficient to run the nonlinear RC load. And it is shown in fig 9(e).

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6. CONCLUSION

The simulation results given that reduction of dc-link voltage, filter inductance, current through the shunt capacitor and damping power loss are reduced with DSTATCOM with LCL filter followed by series capacitance. This contribution shows reduction in cost, weight, size, and power rating of the traditional DSTATCOM topology. Effectiveness of the proposed topology has been validated through extensive computer simulation.

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