Diminish of Power Losses and Reactive Power Compensation and Unbalanced Loads using DSTACOM

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Abstract: This Project proposes an improved hybrid distribution static compensator (DSTATCOM) topology to address some practical issues such as power rating, filter size, compensation performance, and power loss. An LCL filter has been used at the front end of a voltage source inverter (VSI), which provides better switching harmonics elimination while using much smaller value of an inductor as compared with the traditional L filter. A capacitor is used in series with an LCL filter to reduce the dc-link voltage of the DSTATCOM. This consequently reduces the power rating of the VSI. 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 both simulation studies.

Keywords: Distribution Static Compensator (DSTATCOM), Hybrid Topology, Passive Filter, Power Quality (PQ).

I. INTRODUCTION

Traditionally, static capacitors and passive filters have been utilized to improve power quality (PQ) in a distribution system. However, they usually have problems such as fixed compensation, system-parameter-dependent performance, and possible resonance with line reactance. A distribution static compensator (DSTATCOM) has been proposed in the literature to overcome these drawbacks. It injects reactive and harmonics component of load currents to make source currents balanced, sinusoidal, and in phase with the load voltages. However, a traditional DSTATCOM requires a high-power rating voltage source inverter (VSI) for load compensation. The power rating of the DSTATCOM is directly proportional to the current to be compensated and the dc-link voltage. Generally, the dc-link voltage is maintained at much higher value than the maximum value of the phase-to-neutral voltage in a three-phase four-wire system for satisfactory compensation (in a three-phase three-wire system, it is higher than the phase-to-phase voltage). However, a higher dc-link voltage increases the rating of the VSI, makes the VSI heavy, and results in higher voltage rating of insulated gate bipolar transistor (IGBT) switches. It leads to the increase in the cost, size, weight, and power rating of the VSI. In addition, traditional DSTATCOM topologies use an L-type interfacing filter for shaping of the VSI injected currents. The L filter uses a large inductor, has a low slew rate for tracking the reference currents, and produces a large voltage drop across it, which, in turn, requires a higher value of the dc-link voltage for proper compensation. Therefore, the L filter adds in cost, size, and power rating. Some hybrid topologies have been proposed to consider the aforementioned limitations of the traditional DSTATCOM, where a reduced rating active filter is used with the passive components.

Fig.1: Proposed DSTATCOM topology in the distribution system to compensate unbalanced and nonlinear loads.

In hybrid filters for motor drive applications have been proposed. In authors have achieved a reduction in the dc-link voltage for reactive load compensation. This also reduces the cost, weight, and size of the passive component. However, the LCL filter uses a similar dc-link voltage as that of DSTATCOM employing L filter. Hence, disadvantages due to high dc-link voltage are still present when the LCL
filter is used. Another serious issue is resonance damping of the LCL filter, which may push the system toward instability. One solution is to use active damping. This can be achieved using either additional sensors or sensorless schemes. The sensorless active damping scheme is easy to implement by modifying the inverter control structure. It eliminates the need for additional sensors. However, higher order digital filters used in these schemes may require to be tuned for satisfactory performance. Another approach is to go for passive damping. This does not require extra sensor circuitry. However, insertion of a damping resistor in the shunt part of an LCL filter results in extra power loss and reduces the efficiency of the system.

II. PROPOSED DSTATCOM TOPOLOGY

This paper proposes an improved hybrid DSTATCOM topology where the LCL filter followed by the series capacitor is used at the front end of the VSI to address the aforementioned issues. This topology reduces the size of the passive components and the rating of the dc-link voltage and provides good reference tracking performance simultaneously. Along with this, a significant reduction in the damping power loss is achieved, which makes this scheme suitable for industrial applications. The performance of the proposed topology is validated through the extensive simulation and experimental results. A three-phase equivalent circuit diagram of the proposed DSTATCOM topology is shown in Fig. 1. It is realized using a three-phase four-wire two-level neutral-point-clamped VSI. The proposed scheme connects an LCL filter at the front end of the VSI, which is followed by a series capacitor $C_{sc}$. Introduction of the LCL filter significantly reduces the size of the passive component and improves the reference tracking performance. Addition of the series capacitor reduces the dc-link voltage and, therefore, the power rating of the VSI. Here, $R_1$ and $L_1$ represent the resistance and inductance, respectively, at the VSI side; $R_2$ and $L_2$ represent the resistance and inductance, respectively, at the load side; and $C$ is the filter capacitance forming the LCL filter part in all three phases. A damping resistance $R_d$ is used in series with $C$ to damp out resonance and to provide passive damping to the overall system. VSI and filter currents are $i_{f1a}$ and $i_{f2a}$, respectively, in phase-a and similar for other phases. In addition, voltages across and currents through the shunt branch of the LCL filter in phase-a are given by $v_{sha}$ and $i_{sha}$, respectively, and similarly for the other two phases. The voltages maintained across the dc-link capacitors are

$$V_{dc1} = V_{dc2} = V_{dc_{ref}} \quad (1)$$

The DSTATCOM, source, and loads are connected to a common point called the point of common coupling (PCC). Loads used here have both linear and nonlinear elements, which may be balanced or unbalanced. In the traditional DSTATCOM topology considered in this paper, the same VSI is connected to the PCC through an inductor $L_f$. In the LCL filter-based DSTATCOM topology, an LCL filter is connected between the VSI and the PCC.

Fig. 2. Controller block diagram.

here is non-stiff, 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. These currents are given as follows:

$$i_{f2a} = i_{1a} - i_{s2a} = i_{1a} - \frac{v_{f2a}}{\Delta_1} (P_{1avg} + P_{loss}) \quad (2)$$

$$i_{f2b} = i_{1b} - i_{s2b} = i_{1b} - \frac{v_{f2b}}{\Delta_1} (P_{1avg} + P_{loss}) \quad (3)$$

$$i_{f2c} = i_{1c} - i_{s2c} = i_{1c} - \frac{v_{f2c}}{\Delta_1} (P_{1avg} + P_{loss}) \quad (4)$$

IV. SIMULATION RESULTS

A. With DSTATCOM

Fig. 3. Circuit diagram of with DSTATCOM.
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Fig. 3 shown in the above Circuit diagram of with DSTATCOM.

![Circuit Diagram](image)

(a)

(b)

(c)

(d)

Fig. 4. Simulation results for DSTATCOM with the LCL filter. (a) Source currents. (b) PCC voltages. (c) Filter currents. (d) Voltages across the dc link.

Fig. 4 shows the compensation performance for LCL filter based DSTATCOM. The source currents and PCC voltages are balanced and sinusoidal but contain significant switching harmonics ripple. 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.

Fig. 5. The proposed topology with the RC-type nonlinear load.

Fig. 5 shown in the above proposed topology with the RC-type nonlinear load.
The compensation performance of the proposed topology is shown in Fig. 6. The load and source parameters are the same as given in Table I. In Fig. 6. (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. 6.(b) shows the three-phase compensated PCC voltages with reduced switching harmonics. Additionally, source currents are in phase with their respective phase voltages. 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.
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The compensation performance of the proposed DSTACOM topology during dynamic conditions has been shown in Fig.8. The transient is created by connecting and disconnecting the linear load. The Fig.8 shows the waveforms of phase-a source current $i_{sa}$, load current $i_{la}$, injected filter current $i_{f2a}$, and total dc-link voltage $v_{dc1} + v_{dc2}$. The waveforms show the satisfactory performance of the proposed topology during transient conditions.

V. CONCLUSION

In this paper, design and operation of an improved hybrid DSTACOM topology is proposed to compensate reactive and harmonics loads. The hybrid interfacing filter used here consists of an LCL filter followed by a series capacitor. This topology provides improved load current compensation capabilities while using reduced dc-link voltage and interfacing filter inductance. Moreover, the current through the shunt capacitor and the damping power losses are significantly reduced compared with the LCL filter-based DSTACOM topology. These contribute significant reduction in cost, weight, size, and power rating of the traditional DSTACOM topology. Effectiveness of the proposed topology has been validated through extensive computer simulations and experimental studies.

VI. REFERENCES


Fig.8. Experimental results showing the dynamic performance of the proposed topology.