An Improved Hybrid DSTATCOM Topology with an Integrated PV to Compensate Reactive and Nonlinear Loads

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Abstract- This paper we proposes an improved hybrid distribution static compensator (DSTATCOM) with an integrated PV load which helps us in increasing the power rating of the system and to increase the load compensation. 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, proposed DSTATCOM topology will have reduced weight, cost, rating, and size with improved efficiency and current compensation capabilities by using PV cell. Simulation and experimental results validate the usefulness of the DSTATCOM topology over traditional topologies.

KEYWORDS-DSTATCOM, load

compensation, SERIES COMPENSATION

I. INTRODUCTION

static capacitors and passive filters have been utilized to improve power quality (PQ) in a distribution system. However, these usually have problems such as fixed compensation, system-parameter-dependent performance, and possible resonance with line reactance [1]. A distribution static compensator (DSTATCOM) has been proposed in the literature to overcome these drawbacks [2]–[8]. 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-powerrating 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 [9]. Generally, the dc-link voltage is maintained at much higher value than the maximum value of the phase-to-neutral voltage n 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) [2], [10]–[12]. 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 [13], [14]. 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 [15]–[21]. In [15] and [16], hybrid filters for motor drive applications have been proposed. In [17], authors have achieved a reduction in the dc-link voltage for reactive load compensation. However, the reduction in voltage is limited due to the use of an L-type interfacing filter. This also makes the filter bigger in size and has a lower slew rate for reference tracking. An LCL filter has been proposed as the front end of the VSI in the literature to overcome the limitations of an L filter [22]–[25]. It provides better reference tracking performance while using much lower value of passive components. 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 an 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 [26]. 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 resultextra power loss and reduces the efficiency of the system.

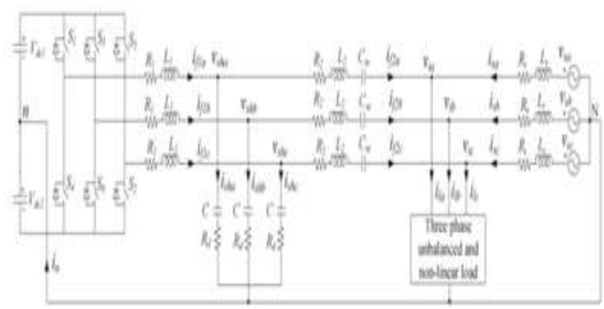

Figure 1 Proposed DSTATCOM topology in the distribution system to compensate unbalanced and nonlinear loads

II. PROPOSED DSTATCOM TOPOLOGY

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 Cse. 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, R1 and L1 represent the resistance and inductance, respectively, at the VSI side; R2 and L2 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 Rd is used in series with C to damp out resonance and to provide passive damping to the overall system. VSI and filter currents are if1a and if2a, 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 $V_{dc1} = V_{dc2} = V_{dcref}$. 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 [27]. In the LCL filter-based DSTATCOM topology, an LCL filter is connected between the VSI and the PCC we have also added the PV to control the threshold levels .

Working ofDSTATCOM

Basically, the DSTATCOM system is comprised of three main parts: a Voltage Source Converter (VSC), a set of coupling reactors and a controller. The basic principle of a DSTATCOM installed in a power system is the generation of a controllable ac voltage source by a voltage source inverter (VSI) connected to a dc capacitor (energy storage device). The ac voltage source, in general, appears behind a transformer leakage reactance. The active and reactive power transfer between the power system and the DSTATCOM is caused by the voltage difference across this reactance. The DSTATCOM is connected to the power networks where the voltage-quality problem is a concern. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches (IGBT's, which are used at the distribution level) of the power converter accordingly.

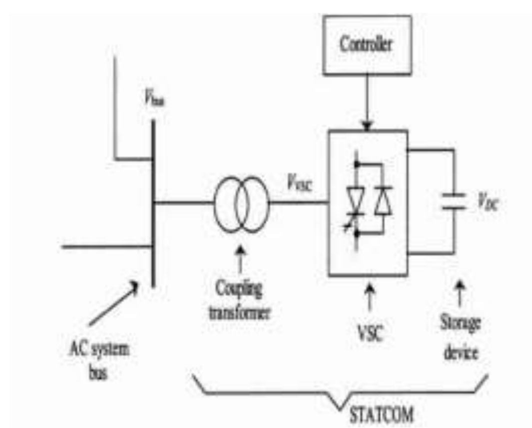

Figure 1 Basic blockdiagram of a DSTATCOM

The AC voltage control is achieved by firing angle control. Ideally the output voltage of the VSI is in phase with the bus (where the DSTATCOM is connected.) voltage. In steady state, the dc side capacitance is maintained at a fixed voltage and there is no real power exchange, except for losses. The DSTATCOM differs from other reactive power generating devices (such as shunt Capacitors, Static VAR Compensators etc.) in the sense that the ability for energy storage is not a rigid necessity but is only required for System unbalance or harmonic absorption. There are two control objectives implemented in the DSTATCOM. One is the ac voltage regulation of the power system at the bus where the DSTATCOM is connected. And the other is dc voltage control across the capacitor inside the DSTATCOM. It is widely known that shunt reactive power injection can be used to control the bus voltage. In conventional control scheme, there are two voltage regulators designed for these purposes. AC voltage regulator for bus voltage control and dc voltage regulator for capacitor voltage control. In the simplest strategy, both the regulators are proportional integral (PI) type controllers.

DESIGN OF DSTATCOM

A Distribution level static Synchronous compensator (DSTATCOM) is a shunt connected flexible AC transmission system (FACTS) controller used for improving the power quality in the distribution level or at the medium voltage level. Figure 2.1 shows a DSTATCOM configuration which consists of a Voltage Source Converter (VSC) or an inverter, a DC-link capacitor and a coupling inductor. The design of the DSTATCOM means the selection of appropriate values of coupling inductor or choke, determining the capacitor value and its operating voltage level and selecting the appropriate operating voltage and current ratings for the power electronic switches. In general, for medium voltage applications, Insulated Gate Bipolar Junction Transistors (IGBTs) are used as power electronic switches.

PROBLEM FORMULATION

A Distribution STATCOM (DSTATCOM) is a shunt compensation device used for reactive power compensation. It can be used either in the power factor correction mode or in the voltage regulation mode. The major problem associated with the design of the controller for the DSTATCOM is the selection of appropriate circuit components. The second major problem is to understand the proper working of the controller and control algorithms. It is necessary to understand the design of hardware components and the controller

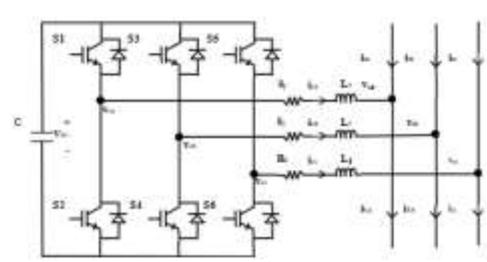

Figure 2 DSTATCOM configuration

DESIGN OF CAPACITORS

The DC-bus capacitor for a DSTATCOM is selected based on the following maximum ratings.The working voltage of the capacitor, which specifies the maximum DC voltage that the capacitor can withstand for a sustained period.Ripple current of the capacitor, whichspecifies the maximum AC current that can flow through the capacitor without exceeding its internal temperature.

III. PHOTO VOLTAIC CELL

A photovoltaic cell is made of semiconductor materials that absorb the photons emitted by the sun and generate a flow of electrons. Photons are elementary particles that carry solar radiation at a speed of 300,000 kilometers per second. In the 1920s, Albert Einstein referred to them as "grains of light". When the photons strike a semiconductor material like silicon , they release the electrons from its atoms, leaving behind a vacant space. The stray electrons move around randomly looking for another "hole" to fill.

To produce an electric current,however, the electrons need to flow in the same direction. This is achieved using two types of silicon. The silicon layer that is exposed to the sun is doped with atoms of phosphorus, which has one more electron than silicon, while the other side is doped with atoms of boron , which has one less electron. The resulting sandwich works much like a battery: the layer that has surplus electrons becomes the negative terminal (n) and the side that has a deficit of electrons becomes the positive terminal (p). An electric field is created at the junction between the two layers.

When the electrons are excited by the photons, they are swept to the n-side by an electric field, while the holes drift to the p-side. The electrons and holes are directed to the electrical contacts applied to both sides before flowing to the external circuit in the form of electrical energy. This produces direct current. An anti-reflective coating is added to the top of the cell to minimize photon loss due to surface reflection.

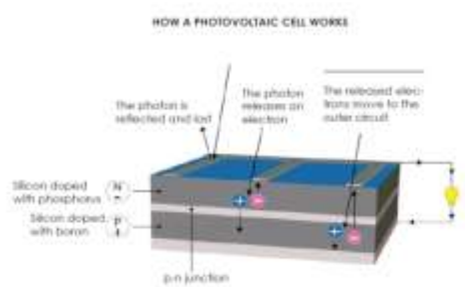

Figure 3 Photo voltaic cell

IV. SIMULATION RESULTS

Advantages of hybrid DSTATCOM topology with an integrated PV are that it uses lower rating of the VSI , smaller value of inductor , reduces damping power loss and provides improved current compensation.

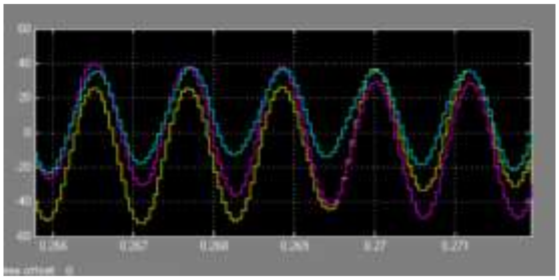

Fig (a)Three phase source currents

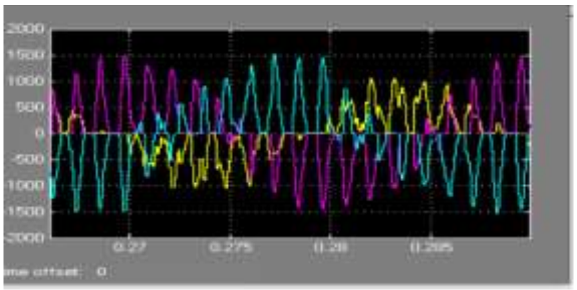

Fig (b) Three phase filter currents

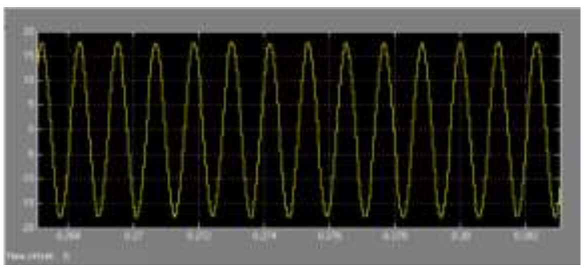

Fig (c) Total dc link voltage

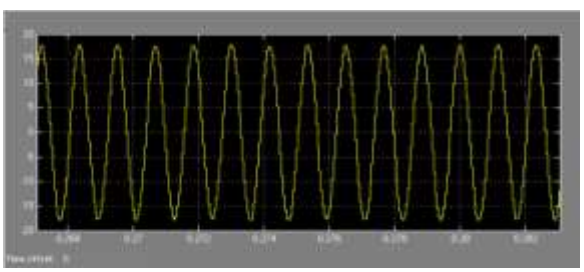

Fig (d) dc link voltage (vdc1)

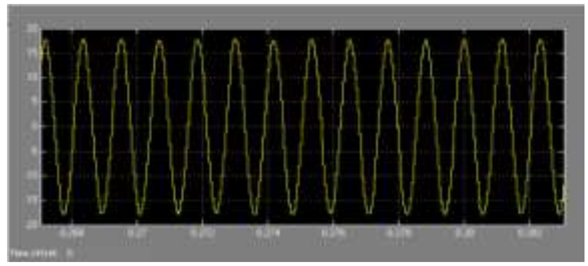

Fig (e) dc link voltage (vdc2)

Fig (a) shows the three phase source currents , which are balanced and sinusoidal. As seen from waveforms source contain switching frequency components of the VSI.

Fig (b) shows the three phase filter currents.

Fig (c), (d), (e) total dc link voltage , vdc1, vdc2. The waveforms of voltages across upper and lower dc capacitors as well as dc link voltage presented in above figures. Voltage across the each capacitor is maintained at 520V, whereas total dc link voltage is maintained at 1040 V using the PI controller.

V. Conclusion

The design and operation of an improved hybrid DSTATCOM topology with an Integrated PV 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 DSTATCOM topology. These contribute significant reduction in cost, weight, size, and power rating of the traditional DSTATCOM topology. Effectiveness of the proposed topology has been validated through extensive computer simulations and experimental studies.

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