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Review on DSTATCOM with L-C-L filter to compensate reactive and non-linear loads

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ABSTRACT: *This paper gives an introduction about an improved hybrid distribution static compensator (DSTATCOM) methodology to compensate reactive and nonlinear loads with reduced VSI rating, DC link (capacitor) voltage and filter size. An LCL filter with low value of inductor compared to old L filter is used at the front end of a voltage source inverter (VSI), which givesthe mitigation of switching harmonics. Voltage of the DSTATCOM can be reduced with capacitor to be connected in series with an LCL filter. The power rating of the voltage source inverter (VSI) has also been decreased. With reduced dc-link voltage, the voltage across the capacitor connected in parallel with the LCL filter will be also less. It will minimize the power losses in the damping resistor as compared with the old LCL filter with passive damping. Therefore, the given DSTATCOM methodology will have reduced cost, rating, and size with improved efficiency and current compensation technique compared with the old fashioned methodology. A systematic procedure of DSTATCOM controlling and filter designing has been presented. The advantages of the proposed DSTATCOM methodology over oldmethodologies is validated through simulation.*

(I) KEY WORDS: *DSTATCOM, STATCOM, VSI, PQ, PE, LCL etc.*

(II) INTRODUCTION:

Modern power systems are of complex and complicated networks, where number of generating stations and number of load centers are connected to each other through long power transmission lines and distribution networks. Even though the power generation is fairly reliable, the quality of power is not always so reliable. Power distribution system should provide with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency to their customers. PS especially distribution systems, have numerous nonlinear loads, which significantly affect the quality of power.

Apart from nonlinear loads, events like capacitor switching, motor starting and unusual faults could also inflict power quality (PQ) problems. PQ problem is defined as any manifested problem in voltage /current or leading to frequency deviations that result in failure or mal operation of customer equipment. Voltage sags and swells are among the many PQ problems the industrial processes have to face. Voltage sags are more severe. During the past few decades, power industries have proved that the adverse impacts on the PQ can be mitigated or avoided by conventional means, and that techniques using fast controlled force commutated power electronics (PE) are even more effective.

The STATCOM used in distribution systems is called DSTACOM (Distribution-STACOM) and its configuration is the same, but with small modifications. It can exchange both active and reactive power with the distribution system by varying the amplitude and phase angle of the converter voltage with respect to the line terminal voltage. A multilevel inverter can reduce the device voltage and the output harmonics by increasing the number of output voltage levels.

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.

(III) PRINCIPLE OF DSTATCOM:

A DSTATCOM (Distribution Static Compensator), which is schematically depicted in Figure:1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. 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. Such configuration allows the device to absorb or generate controllable active and reactive power.

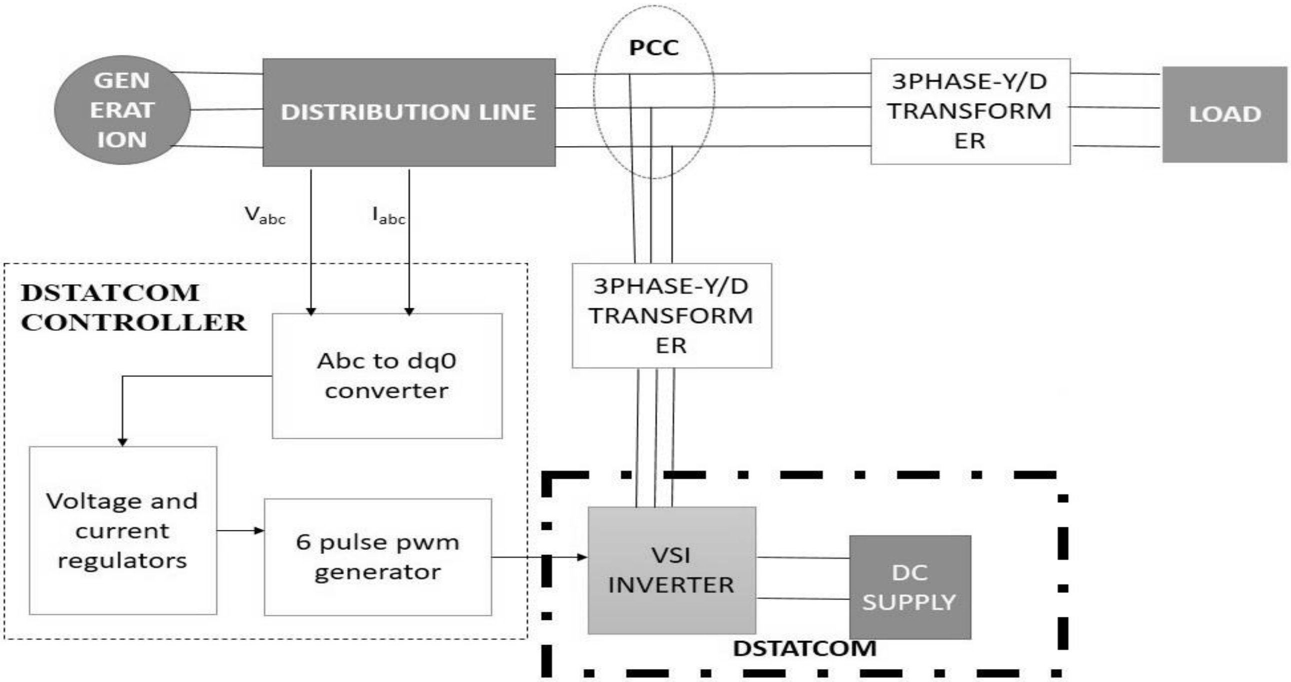

Figure 1: Schematic Diagram of a D-STATCOM

(IV) DSTATCOM WITH LCL FILTER:

The IMPROVED HYBRID DSTATCOM three-phase equivalent circuit diagram is shown below in figure 2. It is obtained by using three-phase four-wire two-level neutral-point-clamped VSI inverter. 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 L_1, L_2 and L_3 inductance are used at VSI side, C_1, R_1 C_2, R_2 and C_3, R_3 are the filter and resistence component of the filter connected in series with VSI inverter. Resistance is series with capacitors are used for providing damping for overall system and damp out the resonance. Here I_{f1a} and I_{f2a} are filter currents in phase-a and similar in all three phases. V_{sha} is voltage across LCL filter and I_{sha} is current through LCL filter, this is similar for other two phases. The voltage across the DC_link capacitors are maintained constant i.e. $V_{dc1}=V_{dc2}$. The source and load of DSTATCOM are connected to a common point called point of common coupling (PCC).

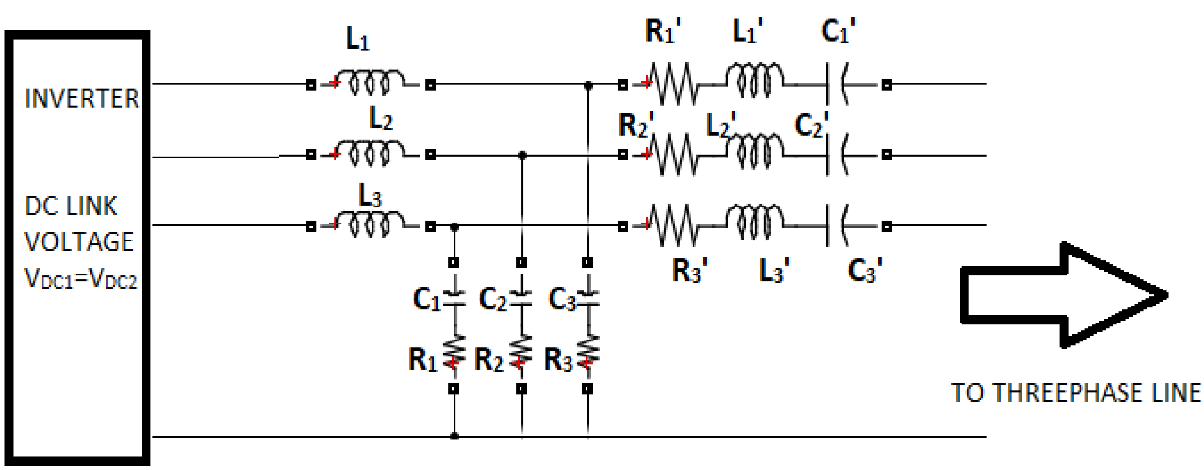

Figure 2: Equivalent circuit of DSTATCOM(with LCL filter)

(IV) DSTATCOM CONTROLLER:

The use of power electronics based apparatus in electrical power systems, at various voltage levels, is becoming increasingly widespread due to the rapid progress of power electronic technology. The STATCOM is one such apparatus that can potentially be used in the context of flexible AC transmission systems (FACTS) at the transmission level (Garica-Gonzalez & Garcia-Cerrada 2000, SenSarma et al 2000 and Rao et al 2000). The Distribution STATCOM (DSTATCOM) is a custom power device working on the STATCOM principle at the distribution level. This device can also be used at the end users' electrical installations Potential applications at the distribution level include voltage regulation, power factor correction, load balancing, and harmonic filtering.

The DSTATCOM has a voltage source converter (VSC) at its core that can be used for different application by appropriate control algorithms. The DSTATCOM is simulated for voltage regulation application using the PI controlled SPWM algorithm and the SVPWM algorithm. In this simulation study, a two-level VSC is used to realize the DSTATCOM. The bus voltage is regulated either by absorbing or by supplying reactive power to the bus. The performance of the DSTATCOM is studied for the SPWM and the SVPWM algorithms for voltage regulation application. Figure 3 represents the distribution system where the DSTATCOM is connected in shunt to the system through a star-delta transformer at the PCC. The distribution bus is represented by a Thevinin's equivalent voltage G and a Thevinin's equivalent impedance and is connected to the distribution line. Three different loads are connected to the system through a transformer at bus B4.

The required voltage at the PCC is 1 pu as per the grid requirement (IEEE standard 519, 1992). The voltage profile at the PCC is affected by rapid changes in the load. The voltage at the PCC is maintained at 1 pu by appropriate control of the DSTATCOM. To mitigate the effects of the voltage sag or swell, a synchronous frame based PI controller is used to control a two-level VSC. The system is simulated in MATLAB using Simulink power system block set.

The DSTATCOM consists of a VSC unit, a DC capacitor and a coupling inductor or transformers. The VSC in the DSTATCOM converts the voltage across the capacitor into a set of three-phase voltages. These voltages are in phase with the AC system voltage and the DSTATCOM is coupled with the AC distribution system through the leakage reactance of the coupling transformer.

The variations of the load and the source voltage also affect the bus voltages, which in turn affect sensitive loads connected to the bus. The performance of the DSTATCOM for the regulation of bus voltage due to the source voltage variation using SPWM method is described in the literature. A PI controller can be used in the cascade control mode to regulate the AC bus voltages and the DC capacitor voltage. The VSC based DSTATCOM, connected in shunt with the AC system, can be used for voltage regulation or power factor correction or elimination of current harmonics.

The cascade controller for the voltage regulation application is shown in Figure 3. For voltage regulation, two voltages are controlled in the DSTATCOM. One is the AC voltage of the power system at the bus, where the DSTATCOM is connected, and the other is the DC link voltage across the capacitor. Both the regulators are of the proportional integral (PI) type. The output current from the VSC is converted into the d-axis and the q-axis components using the Park's transformation technique. Which is given as,

$$\begin{bmatrix} d \\ q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \times \begin{bmatrix} \alpha \\ \beta \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} d \\ q \end{bmatrix} = [park\ matrix] \times \begin{bmatrix} \alpha \\ \beta \end{bmatrix} \quad (2)$$

The error or the difference between V_{dc_ref} and V_{dc} is regulated through a PI controller to get I_{d_ref}. The I_{q_ref} is obtained by regulating the error due to V_{rms_ref} (pu) and V_{rms} (pu) signals by another PI controller. These reference currents are then regulated by comparing the d and q components of currents with their respective components of reference current in another set of PI regulators, whose outputs are the d-axis and q-axis control voltages for the DSTATCOM. The voltage magnitude and phase angle are computed from V_d and V_q as given in Equations 3 and 4. The computed voltage magnitude and phase angle are used to generate the three-phase sinusoidal reference signals, without the use of inverse Park's transformation, to reduce the computation time.

Magnitude: $$|V| = \sqrt{(V_d^2 + V_q^2)} \quad (3)$$

Angle: $$\emptyset = \tan^{-1}(\frac{V_d}{V_q}) \quad (4)$$

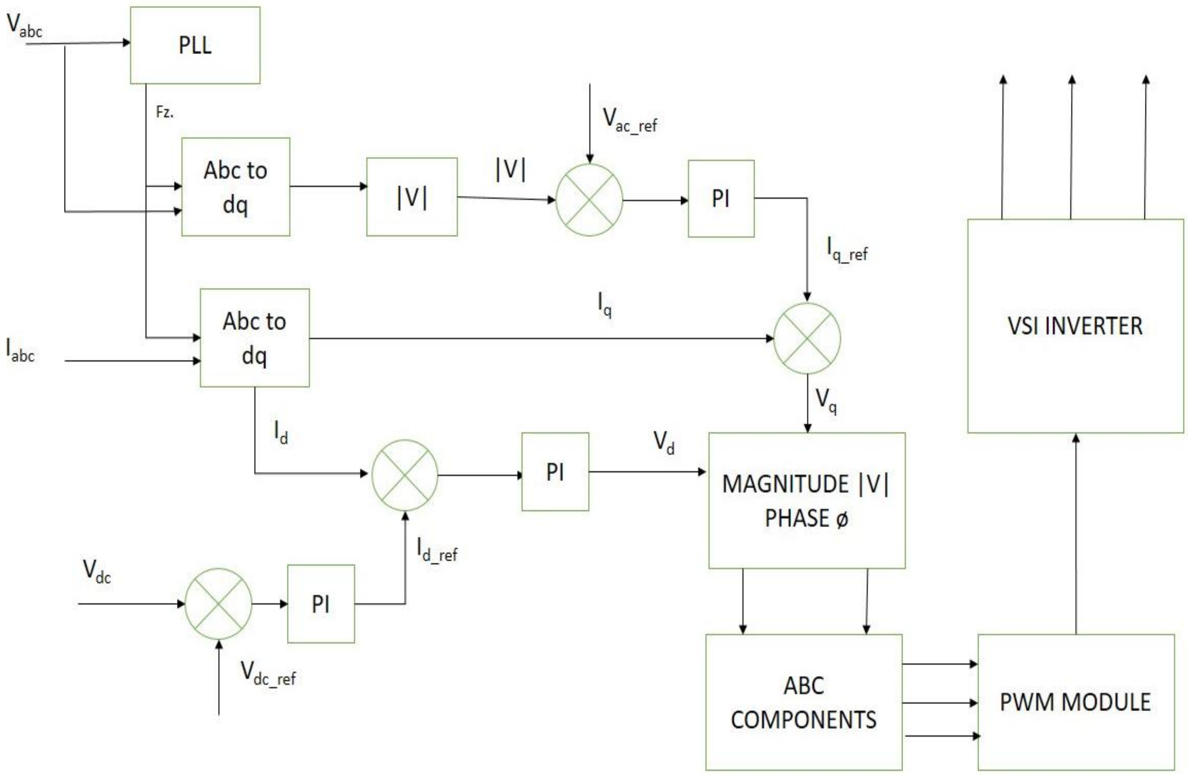

Figure 3: Block Diagram of complete control of DSTATCOM

(VI) DESIGN OF LCL FILTER:

The LCL-filters are beneficial in prices and their dynamic performance as small values of inductors are usually compared to L-filters to realize damping of the switching harmonics. However, LCL-filter design is complex and requires several constraints, like current ripple via inductors, total filter resistance, reactive power absorbed by capacitors used in filters.
The LCL filter which is used is of second order, and that is why there exists a peak amplitude response at the resonant frequency of the LCL-filter. This needs a lot of careful designing of the LCL-filter parameters and current management strategiesfor system stability since the filters tends to oscillate with the filter resonance frequency. This most famous methodology needs to insert a damping electrical element within the capacitance shunt branch of the required filter.
With appropriate values of LCL filter elements,constraints like the cost of inductance, resonance frequency (f_{res}), selection of damping resistance Rd, and attenuation at switch frequency (f_{sw})have to be decided. Considering L1, the value of L1 is chosen such that it provides a high switching frequency and a sufficient rate of change of the filter current. Taking these into consideration the formula for calculating L1 is given by,

$$L_1 = \frac{Vdcref}{(2ha)(2fmax)} = \frac{Vdcref}{4hafmax} \quad (5)$$

Where 2ha is allowable ripple in the current, and f_{max} is the maximum switching frequency achieved by the HCC.
If the ripple current is large then the losses will be less. However, it can be seen from that the smaller ripple current results in higher inductance and, thus, more core losses. Therefore, a ripple current of 20% is taken while compromising the ripple and inductor size, therefore substituting the values of the ripple current and reference dc-link voltage. The expression for resonance frequency will be,

$$F_{res} = \frac{1}{2\pi}\sqrt{\frac{1+a}{kL1C1}} \quad (6)$$

Where a=L2/L1
Selection of L2 > L1 (i.e., a> 1) will reduce the capability of L1 to attenuate lower order harmonics. Therefore, lower order harmonics will be also attenuated by inductor L2 to achieve satisfactory compensation performance. Usually, the magnitude of the lower order harmonics in the LCL filter is used to be more as compared with the higher order harmonics. Hence, the current through the shunt capacitor and the inductor L1 will increase for a>1. This will increase the damping power losses, the reactive power loss in inductor L1,and the inverter current.

As the damping power loss is extracted from the source, the source current increases that results in more losses and cost. Therefore for less cost and losses, 'a' should be lower. For the best choice to provide effective attenuation the value of C1 is chosen.

The equivalent impedance of the LCL filter approaches to zero at the resonance frequency F_{res}, and the system may become unstable. However, the system can be made stable by inserting a resistance R1 in series with the capacitor. Usually, it is chosen in proportion to the capacitive reactance at F_{res}, i.e., X_{cre}, such that the damping losses are less while assuring system stability. The capacitive reactance at resonance will be

$$X_{cre} = \frac{1}{2\pi fresC} \quad (7)$$

In the LCL filter-based DSTATCOM method, the major advantages of the given scheme is that the current through the shunt part of the LCL filter is very much reduced. This reduction in the shunt current correspondingly reduces the damping power losses. Therefore reduction in reactive power of nonlinear load is a prime concern while designing a damping resistor in the proposed method.

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