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# MODELING AND ANALYSIS OF HYBRID DSTATCOM FOR NON LINEAR LOADS

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***Abstract:-***

***Traditionally, 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-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 [9]. 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) [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 results in extra power loss and reduces the efficiency of the system [26].***

***This project focused on 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 results. The proposed control algorithm is implemented using a Matlab/Simulink.*** **INTRODUCTION**

The distribution system is relatively perceived as an interface between the bulk and the custom powers, whose control objective is to strike a balance between the two for maintaining continuous healthy operation of the system. A good distribution control system is therefore expected to enhance the overall system efficiency through loss reduction and power quality control. Presently, distribution system equipment such as the tap changing transformers, synchronous machines, capacitor banks, static volt ampere-reactive compensators (SVCs), and many other flexible ac transmission systems (FACTS) controllers at device level, including DSTATCOM are being applied for such control. However, there are numerous challenges facing the area at the moment in terms of the smart-grid de-centralizing functionality which include: voltage and reactive power compensation (now known as Volt-VAR optimization); distribution system automation (DSA); power factor correction (PF); phase current balancing; integrate-able low loss transformers (to improve efficiency), distributed resources (typically, between 1kW - 50MW), and dispersed energy storage facilities (normally sited at consumer loads), which call for radical change in the type of controllers designed in these equipment for general system power quality improvement.

This is a challenge for economic reasons from the manufacturer's perspective, in that DSTATCOM ratings should be based on voltage deviations at the point of common coupling (PCC) rather than on the magnitude of the load. Equipment manufacturers often include a mismatch between equipment rating and the actual plant rating, so that compensation devices (i.e. DSTATCOM) would have to do extra amount of work to perform some mitigation functions. Consequently, control system designers can reverse this challenge through innovative control designs by trying to improve the ride-through capabilities of DSTATCOM.

Self harmonic contribution nature of the DSTATCOM poses the other challenge. Modular design approaches have been successful in the past at the expense of space and cost to tackle this challenge. Similarly, the use of H-bridge and multilevel converters has also been used to manage the effect of total harmonic distortion (THD) and improve PQ control to considerable levels. However, they are disadvantaged mostly for their on-line implementation involving dedicated simulation studies based solely on approximated linear models. In order to reflect real-time characteristics of a distribution system, serious consideration of nonlinear model simulations has to be made, which must also include reasonable choice of a modulation index (M) that could substantially counter the switching effect of the commutative IGBT switches. As a known fact, a high value (M~1) is normally recommended since it produces smooth output response which means law internal harmonics, but at the same time increases the system gain which causes overshoot. Therefore, there has to be some careful trade-offs while making the control decisions. Substantial reduction of the THD content must remain within the 5% allowed by the IEEE 519 standard.

## LITERATURE SURVEY:

Traditionally, 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 voltage source inverter (VSI) with a high-power rating 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 in a 3-phase 4-wire system for satisfactory compensation (in a 3-phase 3-wire system, and 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 an Insulated Gate Bipolar Transistor 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 larger value of inductor, has a small slew rate for following the currents of reference values, and produces a huge voltage drop across it, which, in turn, requires upper 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.

**DISTRIBUTION STATIC COMPENSATOR**

D-STATCOM consists of three main components that are Voltage Source Converter (VSC), Energy Storage Circuit, and it Controller system. Each one of this component play an important role to ensure that D-STATCOM can operate wisely without have any problems.

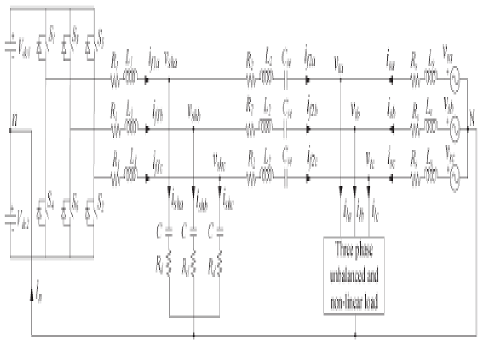


Fig. 1. Proposed DSTATCOM topology in the distribution system to compensate unbalanced and nonlinear loads.

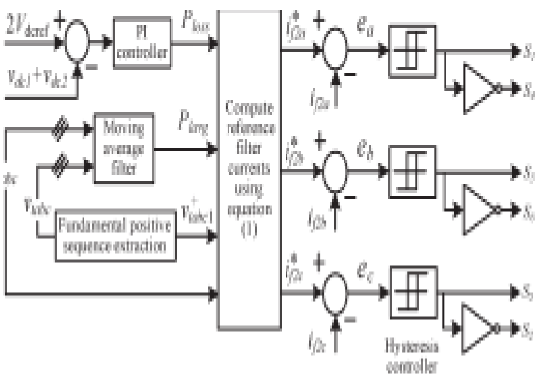


Fig. 2. Controller block diagram.

The dc bus voltage and interfacing filter values of the traditional DSTATCOM are calculated based on the procedure outlined in [28]. For a supply voltage of 230 V, a load rating of 10 kVA, a maximum switching frequency of 10 kHz, and a ripple current of 1 A (5% of the rated current), the dc-link voltage and interfacing inductor values are ound to be 520 V and 26 mH, respectively. For the *LCL* filter based DSTATCOM topology, the dc bus voltage and filter parameters are chosen for the same set of design requirements.The single-phase equivalent circuit diagram of the passive filter of the proposed scheme connected to the PCC is shown in Fig. 3. The term *uV*dc represents the inverter pole voltage with *u* as a switching variable having a value of +1 r −1 depending upon the switching states. The procedure to design the filter parameters is given here in detail.

*1) Reference DC-Link Voltage V*dcref *:* The voltage across the dc capacitor is a source of energy and is selected to achieve good tracking performance. Here, the use of a series capacitor and a small filter inductor has enabled a significant reduction in the dc-link voltage. In present case, a dc-link voltage of 110 V is chosen, which is found to provide satisfactory compensation.

*2) Design of LCL Filter Parameters:* While designing suitable

values of *LCL* filter components, constraints such as cost of inductor, resonance frequency *f*res, choice of damping resistor *Rd*, and attenuation at switching frequency *f*sw should be considered

To inject reactive current from the compensator to the PCC, the fundamental rms voltage per phase available at the VSI terminal (i.e., dc-link voltage) must be much greater than the terminal voltage. Otherwise,

the compensation performance will not be satisfactory. In the traditional topology where the series capacitor is absent, the maximum injected current only depends upon the dc-link voltage (since *Vt*1 and *Xf*12 are fixed). Therefore, the dc voltage is maintained at a much higher value as compared with the terminal voltage. Insertion of the capacitor in series with the interfacing *LCL* filter results in the reduction of the total impedance provided by the compensator, which is also evident from (14). Therefore, the dc-link voltage can be reduced from its reference value for the same reactive current injection.

Hence, the value of the series capacitor depends upon the maximum reactive filter current and to the extent that the decrease in the dc-link voltage is required. The maximum reactive current that a compensator can supply must be the same as that of the maximum load reactive current to achieve unity power factor at the load terminal.

### Voltage Source Converter (VSC)

Voltage Source Converter (VSC) is one of the power electronic devices. VSC is the most important component in D-STATCOM and it can generate a sinusoidal voltage waveform with any required magnitude, with any required phase angle and also with any required frequency. Usually VSC is mostly used in Adjustable Speed Drive but it also can be used to mitigate the voltage sags. VSC is used to replace the voltage or to inject the 'missing voltage'. The missing voltage can be defined as the difference between the actual voltage and the nominal voltage. Normally, the converter is based on some kind of energy storage which will get the supply from the DC voltage. This converter is used the switching based on a sinusoidal PWM method [15]. The PWM offers simplicity and good response. The device that used for the switching is an IGBT power electronic device.

### Energy Storage Circuit

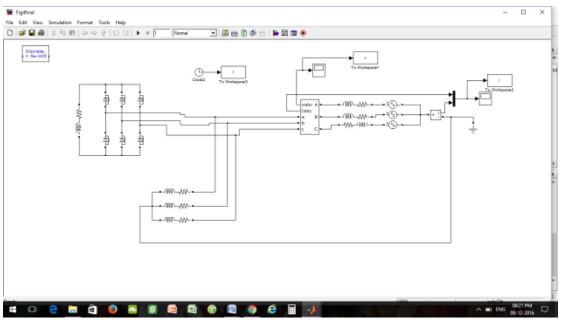
In energy storage circuit, the DC source was connected in parallel with the DC capacitor. DC source is act as a battery that will supply a power meanwhile the DC capacitor is the main reactive energy storage element. It carries the input ripple current of the converter. To charged the DC capacitor, it could be used either a battery source or it could be recharged by the converter itself.

### Controller System

The aim of the controller system is to maintain the constant voltage magnitude at the point where a sensitive load is connected under system disturbances. The control system element can only measured the RMS voltage magnitude that measured at the load point. For the controller system there is no requirements of the reactive power measurements.

The input for the controller system is an error signal. This error signal is obtained from the reference signal measured at the terminal voltage and RMS voltage magnitude that measured at the load point. First of all, this error signal will enter to the sequence analyzer block which is functioning to measure the harmonic level in that signal. Then, the PI controller will process this error signal and come out with the output in term of the angle, $\partial$. This angle can drive the error to zero. Next, this angle will be summed with the phase angle of the supply voltage which is assumed to be 120° to produce the suitable synchronizing signal, required to operate the PWM generator [16]. Then, this angle will be submitted to the PWM signal generator. PWM generator will generate the sinusoidal PWM waveform or signal.

### SIMULATION RESULT ANALYSIS



**Main circuit diagram**

Fig. 3(a) shows the three phase 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.

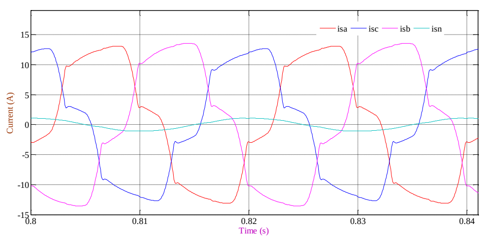



Fig. (a) Source currents

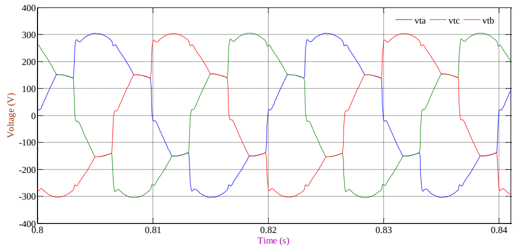



Fig. (b) PCC Voltages

Fig.3: Simulation results without compensation

Three- phase PCC voltages, as shown in Fig. 3b), are unbalanced and distorted due to presence of feeder impedance.

The performance of the traditional DSTATCOM topology is presented in Fig. 4. The three-phase source currents, which are balanced and sinusoidal, are shown in Fig. 4 (a). Fig. 4 (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. 4(c). The waveforms of voltages across upper and lower dc capacitors, as well as the total dc-link voltage, are presented in Fig. 4 (d). The voltage across each capacitor is maintained at 520V, whereas the total dc-link voltage is maintained at 1040 V.

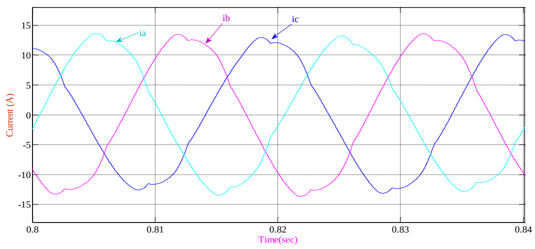



Fig. (a) Source currents

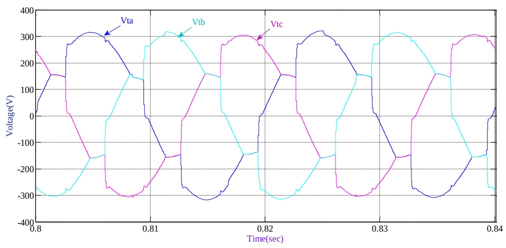



Fig.(b) PCC voltages

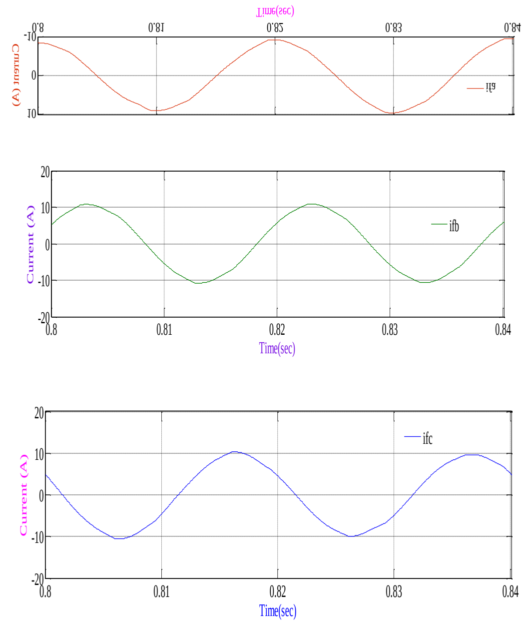



Fig. (c) Filter currents

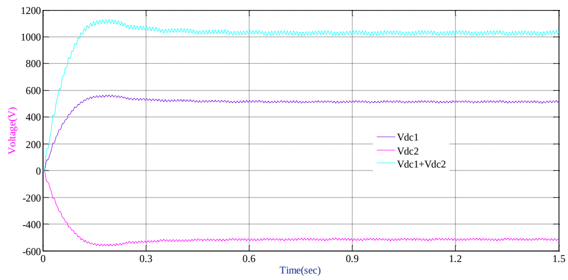



Fig. (d) Voltages across the dc link

Fig.4: Simulation results for traditional topology

Fig. 5 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. Their percentage total harmonic distortions (THDs) are given in Table 5.1. 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.

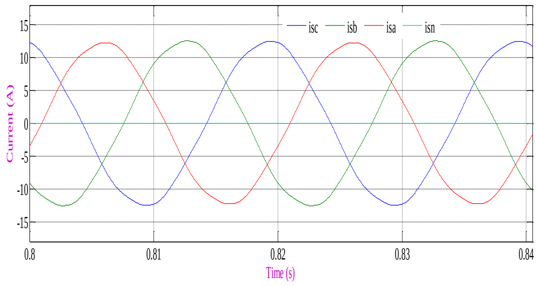



Fig.(a) Source currents

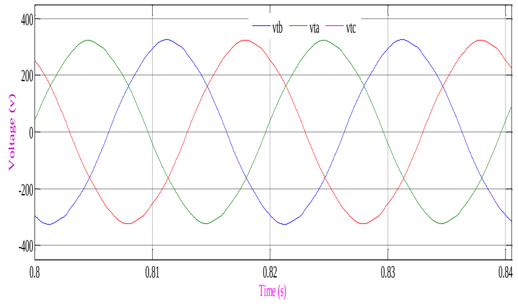



Fig.(b) PCC voltages

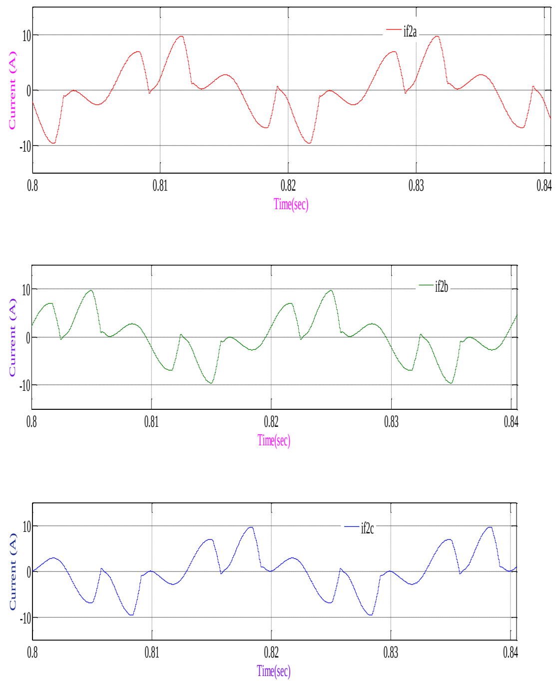



Fig. (c) Filter currents

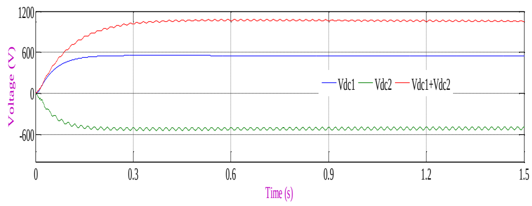



Fig.(d) Voltages across the dc link

Fig. 5: Simulation results for DSTATACOM with the LCL filter

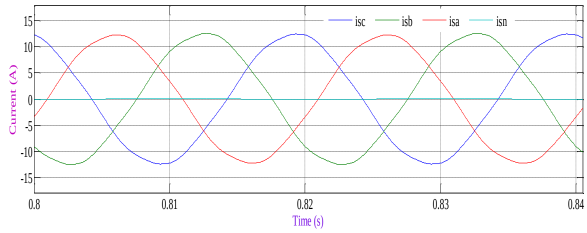



Fig.(a) Source currents

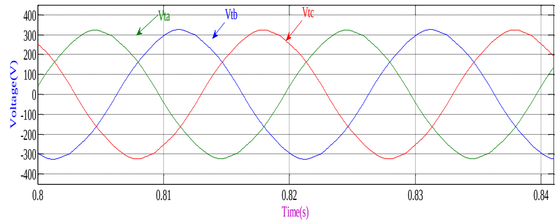
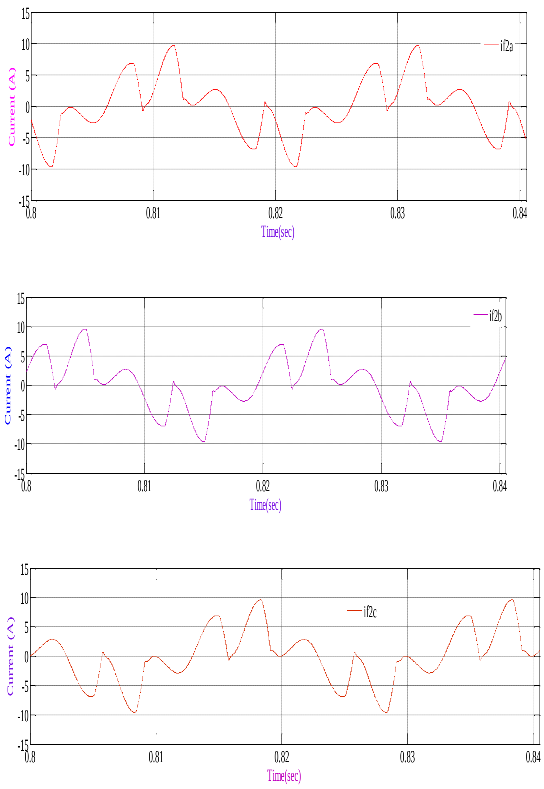
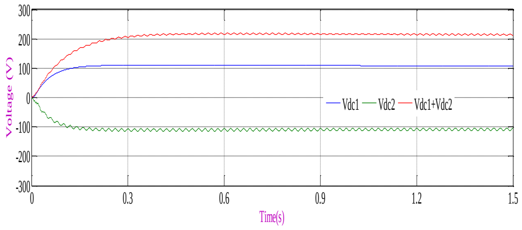



Fig. (b) PCC Voltages




(c) Filter currents




(d) Voltages across the dc link

Fig. 6: Simulation results for the proposed topology

The compensation performance of the proposed topology is shown in Fig. 6. 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. The performance of the proposed topology is compared with traditional DSTATCOM topologies, and corresponding percentage THDs in voltages and currents are illustrated in Table 5.1. It is clear from Table II that the percentage THDs in three-phase source currents and in PCC voltages are considerably lesser in the proposed topology. Moreover, these confirm that the reduced dc-link voltage is sufficient for the DSTATCOM to achieve its current compensation performance.

The PCC voltages are also balanced and sinusoidal with a small ripple component. Again, the total dc-link voltage is maintained at 220 V (110 V across each capacitor). This confirms that the reduced dc-link voltage is sufficient to compensate the RC-type nonlinear load effectively.

The dc bus voltage requirement has been decreased from 520 to 110 V. The term $I_{f1}$ represents the rms current supplied by the IGBT switch. In the traditional DSTATCOM topology, the rms value of $I_{f1}$ will be the same as that of the rms reactive and harmonics component of the load current. In the following section, it can be seen that the current drawn by the shunt branch of the LCL filter is not much. Hence, the current rating of the IGBT switch in both topologies will be approximately the same.

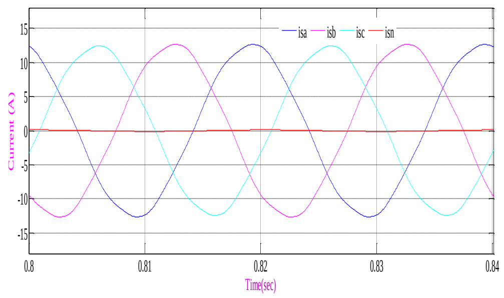
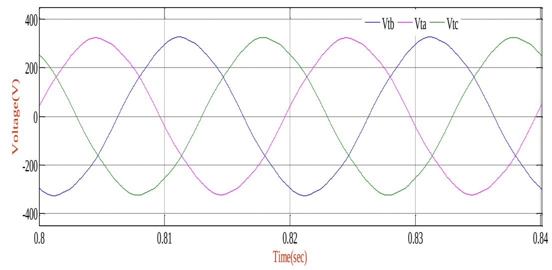
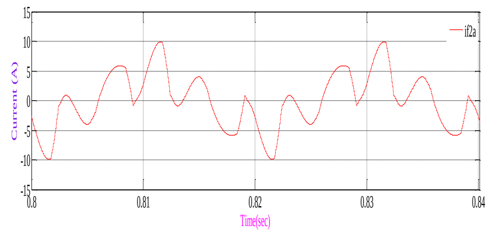
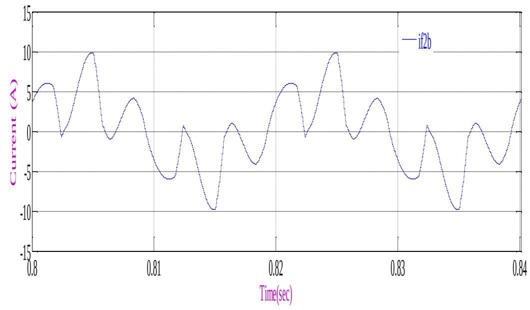



Fig.(a) Source currents



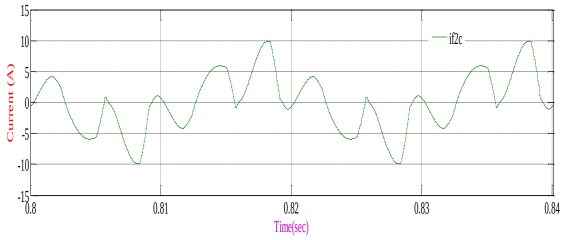



Fig. (c) Filter currents

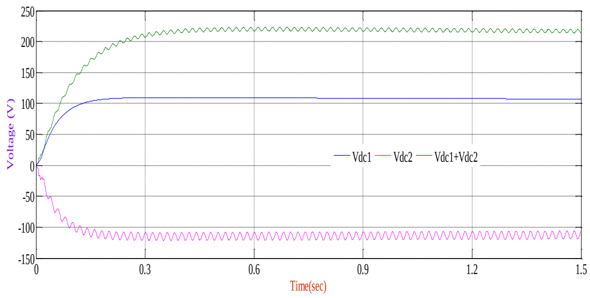



Fig.(d) Voltages across the dc link

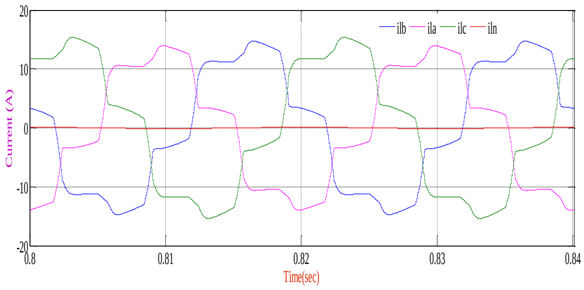



Fig.(e) Load currents

Fig.7: Simulation results for the proposed topology with the RC-type nonlinear load.

Fig. 8(a) shows the filter current in phase-a when only LCL filter-based DSTATCOM is used. Fig. 8(b) shows the current through the damping resistor in the proposed DSTATCOM topology. The effect of reduced dc-link voltage (110 V in this case) can be clearly seen from the steady-state rms damping current.

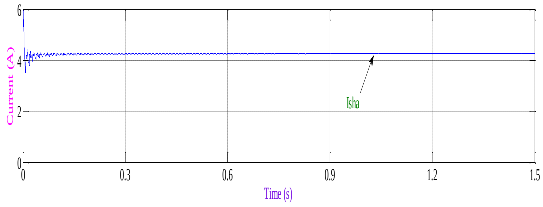



Fig.(a) With the LCL filter

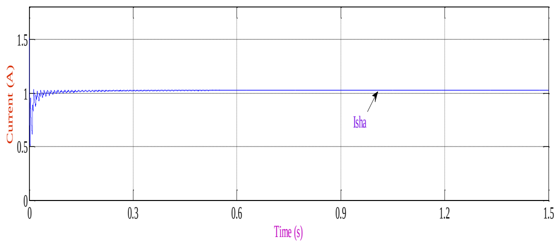



Fig. (b) Proposed topology

Fig.8: Damping rms current

## CONCLUSION

In this project, design and operation of an improved hybrid DSTATCOM 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 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 simulation studies.

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