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Power quality improvement in the distribution system by interconnecting PV using hybrid DSTATCOM

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Abstract
Integration of renewable energy source is one of the major goals in smart grid technology. This paper proposes a pure wave distribution static compensator (PW-DSTATCOM) for achieving the grid interconnection of solar power without deteriorating the quality of power. This PW-DSTATCOM is a reactive power compensating device that improves the power quality of the distribution system. It reduces voltage sag, surge and flicker caused by rapidly varying reactive power demand. This paper presents the idea of incorporating a seven-level inverter as voltage source inverter (VSI) and inductor capacitor inductor (LCL) filter instead of inductor capacitor (LC) filter in PW-DSTATCOM. This seven-level inverter is used for solar energy conversion to make distortion less sinusoidal waveform and LCL filter is proposed for active damping. This arrangement reduces the total harmonic distortion (THD) as per IEEE 519 standard. The simulation results show that the THD of voltage is 3.00% and the current is 2.26% with the proposed method. It also enhances the system voltage stability due to ultra-fast response time. The costing and sizing of the filter is reduced considerably by using a seven-level inverter. MATLAB Simulation software is used to develop and simulate the proposed system.

Keywords
DSTATCOM, Harmonic analysis, LCL filter, Multilevel inverter, Power quality.

1.Introduction
In our day-to-day life, the integration of solar energy into the electric grid has many daunting challenges [1−6]. The use of adjustable speed drives, switched mode power supplies, rectifiers, and other types of semiconductor-based devices produce non-sinusoidal current in the distribution system. The use of these devices also produces a hot spot while integrating the photovoltaic (PV) energy into the grid [7]. The recent advancement and innovation in digital technologies lead to the increased usage of nonlinear loads in the user end. These non-linear loads are considered as a source of harmonic current in the modern power system [8]. There are many mitigation techniques developed by the researchers.

One of the techniques is the use of active filters to mitigate the power quality disturbance developed by the nonlinear loads.

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The digital control technique of active filters extends an added advantage to the mitigation of distribution side power quality problems [9]. The various power quality issues in the distribution system include transients, long-duration voltage variation, short-duration voltage variation, voltage unbalance, waveform distortion and fluctuation. The waveform distortion includes power quality harmonic issue. This harmonic distortion is considered as the major distortion event in the distribution system which affects the quality of power [10]. To mitigate harmonic distortion, many types of harmonic filters are used.

The inductor capacitor inductor (LCL) filter is a device that is designed to reduce the harmonics. They are constructed using a series-parallel combination of inductors and capacitors to reduce the current harmonics. Conventionally, inductor (L) filters are commonly used for the purpose of grid connected systems. Inductor capacitor (LC) filters are used for standalone systems. The LCL filters are also a common type of filter used for grid connected systems [11].

Multilevel inverters are widely used for diverse applications. But when the stages are increased, the efficiency is reduced and the harmonics are increased significantly. Also, the transformer less methodology is not appropriate for high power applications due to increased switching losses [12].

The seven-level inverter with the least number of switches and its gate triggering system helps to minimize the switching losses. It also helps to reduce the sizing and the installation cost of the proposed system. Thus, the seven-level inverter is suitably used for PV based systems [13].

Power quality is a term that refers to a quality of sinusoidal voltage and current waveform at certain magnitude and frequency. It signifies the reliability of service. High harmonics in the distribution system is one of the power qualities challenges that concerns the quality of the power distribution system. The performance of sensitive loads is affected due to poor power quality. Hence, it is very important to maintain the standard as per IEEE-519. This standard defines the harmonic distortion criteria for voltage and current in the distribution system. The waveform distortion goals for both voltage and current are established in this standard [14, 15].

This research article is organized as follows. Section 1 gives an overview about the problem scenario. Section 2 presents the ideas and outcomes of various researchers who had contributed to the problem analysis. Section 3 describes the methodology used for the problem observed. It discusses about the design of multilevel voltage source inverter (MVSI) with LCL filter used to mitigate the power quality problem. Section 4 details the results obtained through MATLAB simulation and validation of the results compared with the existing methods. Section 5 presents the novelty of the research work carried out and its key elements. Section 6 concludes with the future scope of the research problem.

2.Literature review

Intensive research has been done to integrate PV system into the grid with the drastic growth in the usage of PV system, power electronic inverter, power conditioning system and interfacing system. Although PV integration seems to add more benefits with green energy, it also has associated challenges. The most common challenges are harmonics and voltage fluctuations [16]. The current harmonics and voltage harmonics are taken into consideration for the power quality study. The current harmonic limits vary with load size and direct current (DC) offset [17]. The increase in the usage of non-linear loads in a distribution side, enables the harmonic currents to flow in the system. The inductive reactance increases as the frequency increases and the capacitive reactance decreases as the frequency decreases [18]. However, it is essential to create awareness of recent technological growth and impact because of the harmonic emissions emanating from renewable energy generation and energy cost saving electronic products such as light emitting diode (LED) lighting, home appliances and electric vehicle chargers violates IEEE STD 519 [19].

Compensators are used in the power system to compensate these power quality issues in the power distribution system. The distribution static synchronous compensator (DSTATCOM) is a custom power device linked in parallel with the load to regulate the voltage waveform in the distribution network. Generally, the direct current link voltage shall be greater than the phase voltage or line voltage of the electrical grid for the compensation [20]. The high specification of the voltage source inverter (VSI) makes it expensive, bulk and heavy in weight [21]. Moreover, the L-type filter is normally used for shaping VSI injected currents [22]. The L filter has its own drawback such as low slew rate, large voltage drops. This limitation of the L filter is reduced by replacing it with LCL filter in front of the VSI in DSTATCOM. An active power filter (APF) with a direct current-space-vector control based on a three-level neutral-point-clamped voltage-source inverter is proposed use real-time fast Fourier transform to generate the compensation current [23]. An LCL filter has been proposed to use in the VSI that enables to provide better harmonics elimination results instead of using an inductor rather than the traditional L filter. A capacitor in series with an LCL filter helps to reduce the DC-link voltage of the DSTATCOM. This may decrease the power rating of the VSI. The voltage of the shunt capacitor in the LCL filter also decreases with a decrease in DC-link voltage. Hence power across the damping resistor is also reduced as compared with the traditional LCL filter with passive damping [24]. Multilevel neutral point clamped (NPC) inverter systems are one of the commonly used devices in load compensation applications. However, the challenges associated with these load compensators is the voltage imbalances and drift due to usage of DC components in the zero-sequence current, resulting in deprivation of its performance [25]. The high DC link voltage still persists, even when the LCL filter is used, and resonance damping (instability) arises when the L filter is replaced by the LCL filter [26]. Thus, active damping is required in order to maintain the stability of the system. Hence, it is better, if the LCL filter is followed by the series pass capacitor in front of VSI to mitigate the challenges. This arrangement makes the system small with low DC link voltage and incorporates good stability [27]. It is expensive to renewable energy as a source of large-scale power generation. This challenge is overridden by distributed generation at the end used side that is based on the divide & conquer method [28].

Recent research exploits the usage of multilevel grid connected inverters for large scale solar photovoltaic (SPV) installations has been investigated [29]. This investigation elaborates various control strategies for the power quality control. Also, the impact of parameter variations on power quality variations is explained.

Several control strategies such as coordination, control strategy, optimal predictive scheme, frequency adaptive disturbance observer, fuzzy proportional derivative and integral control are reported in the literature [30]. Some of them are applicable to unbalanced and distorted voltage conditions and some of them needs additional filters and phase locked systems. Simple pulse width modulation (PWM) technique is developed to bring down the cost, size and complexity of the system.

Z-Source network based unified power quality conditioner (UPQC) topology is used to improve the quality of power distribution [31]. Here the UPQC synchronize SPV system with the distribution system and helps to develop the stability of the distribution system. The author reveals that most research does not include LCL filter, battery energy storage systems, D-STATCOM and UPQC. Traditionally, grid connected system uses PV system. Hence appropriate devices are used for better enhancement.

Techno economic and environmental benefits of electric power distribution system are analyzed using photovoltaic distributed generation and DSTATCOM [32]. The author has presented an optimal integration procedure of distributed generation based on photovoltaic system and DSTATCOM.

The literature deals in detail about the problems faced while integrating the renewable to the existing grid. On integration, the problem of harmonic generation and the deterioration of power quality becomes the major issue. Compensators are normally used to enhance the power quality. Filters are also used to eliminate harmonics. In our proposed system a compensator along with filter is employed to remove harmonics and enhance power quality.

3.Methodology

The proposed hybrid DSTATCOM replaces the VSI by MVSI in the conventional system. MVSI has the advantage of reducing the stress on the system when compared to the number of levels. Hence, the multilevel inverter is capable of handling higher voltages [33−35]. The L filter is replaced by an LCL filter to maintain the stability of the system. This is followed by a capacitor to mitigate the power quality issues in the system. Thus, the structural model of the proposed system is obtained by replacing VSI by MVSI and L filter by LCL filter. Specifically, seven level VSI is used.

The basic working principle is that the pure wave DSTATCOM produces a variable voltage that is in phase with the voltage source. If the voltage from the source is greater than the desired voltage, current through the inductor lags the source voltage by 90° due to the inductance of the coupling transformer and filter. Then, the pure wave DSTATCOM acts as a generator and generates a leading reactive current which is inductive. Similarly, if the source voltage is less than the desired voltage, current through the inductor leads by 90°. Now, the pure wave DSTATCOM generates lagging reactive power that is capacitive. The desired voltage is accomplished by integrating solar energy into the electrical grid [36−38]. The performance of the proposed system is simulated and confirmed with the help of MATLAB simulation results.

The proposed system is configured with a solar energy generation system connected to the DC-DC boost converter as shown in *Figure 1.*

It is also coupled with the DC link. The pure wave distribution static compensator (PW-DSTATCOM) plays a vital role and it is the key element of the distributed generation system as it interfaces the solar energy to the grid. Normally, the PV energy sources produce power that is low and intermittent. Thus, a power conditioning device is required, which is performed by a DC-DC boost converter. The DC-

Link capacitor dissociates the solar photovoltaic from the grid, thereby providing separate control over the converters on both ends.

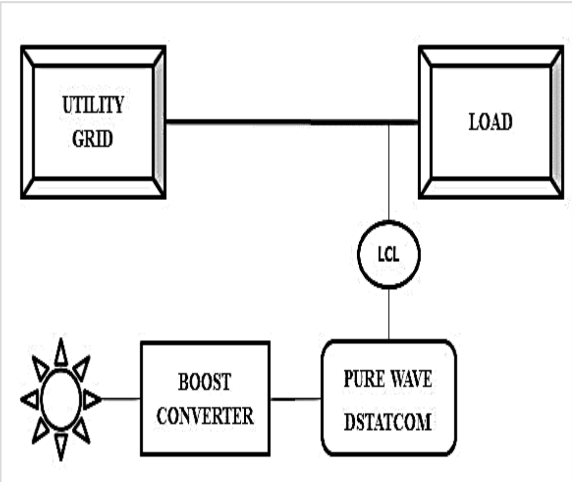

Figure 1 Block diagram of the proposed system

This DC-Link act as the source of PW-DSTATCOM, the VSI of DSTATCOM is modified as PW-DSTATCOM by upgrading VSI to seven-level cascaded multilevel VSI. It is then connected to the high voltage source directly without any transformers as shown in *Figure 2*. Thus, it results in the reduction of implementation costs. The solar energy system with a boost converter connected to the multilevel inverter based DSTATCOM makes it hybrid. The filter to make the output smoother follows the multilevel inverter. In order to provide active damping, an LCL filter with a series pass capacitor is proposed for better performance.

The Simulink diagram for the interconnection of the grid with solar and hybrid DSTATCOM of the proposed system is shown in *Figure 3*. The solar power is utilized for powering the DC link of the hybrid DSTATCOM. The output of hybrid D-STATCOM is enhanced with an LCL filter.

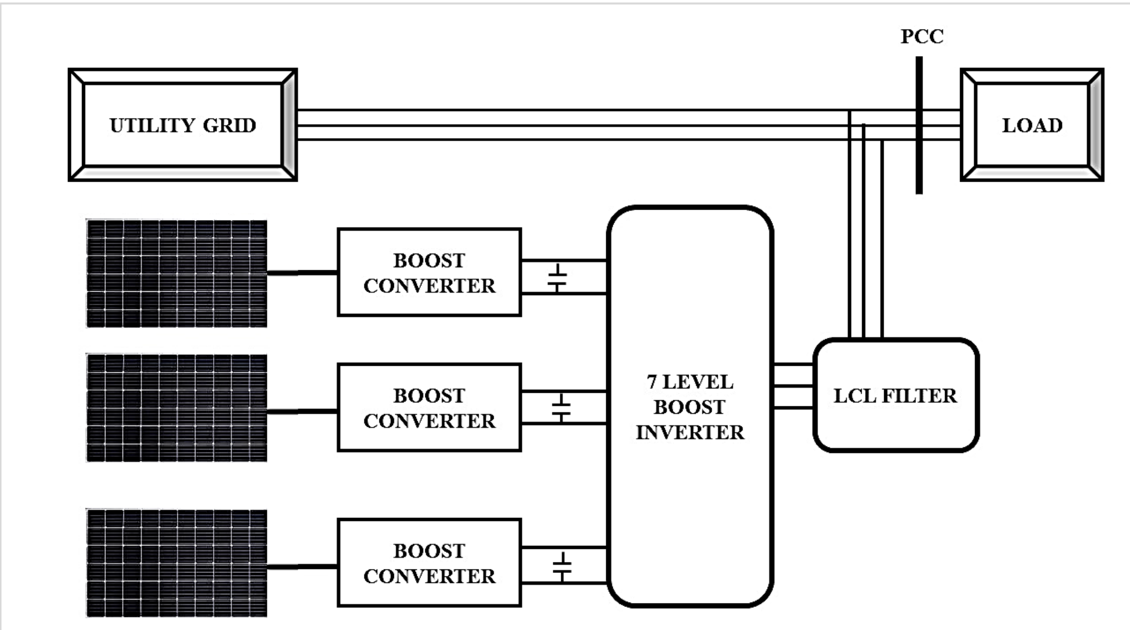

Figure 2 Schematic diagram of proposed PW-DSTATCOM

3.1Multilevel voltage source inverter

MVSI is widely applicable to modernize the existing electric grid. The MVSI is most commonly used to produce a sine voltage waveform with respect to various levels of voltage. There are three main multilevel inverter topologies (a) Diode-Clamped Multilevel Inverter (b) flying-capacitor multilevel inverter (FCMI) (c) Modular Structured Multilevel Inverters. Among these topologies, the cascaded multilevel inverter (*Figure 4*) requires a smaller number of components, thereby reducing the weight and cost of the inverter. It also eliminates the use of a bulky transformer. It is suitably applicable for interfacing renewable energy sources.

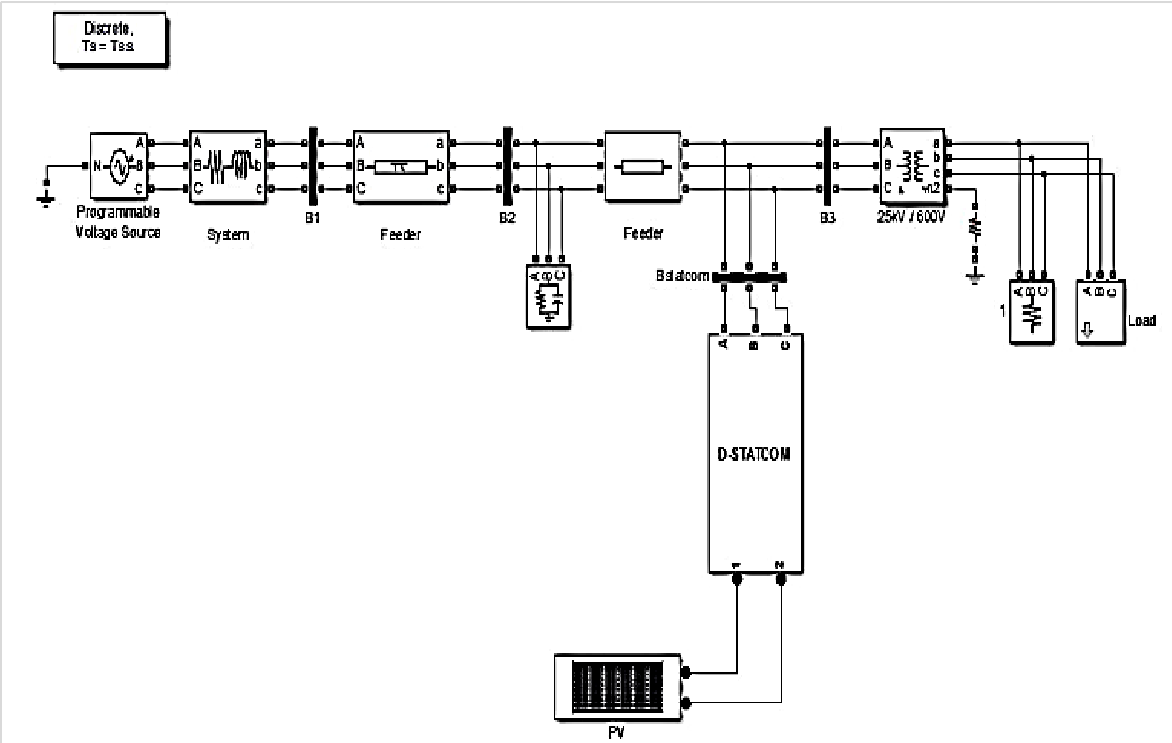

Figure 3 Simulink diagram for proposed PW-DSTATCOM

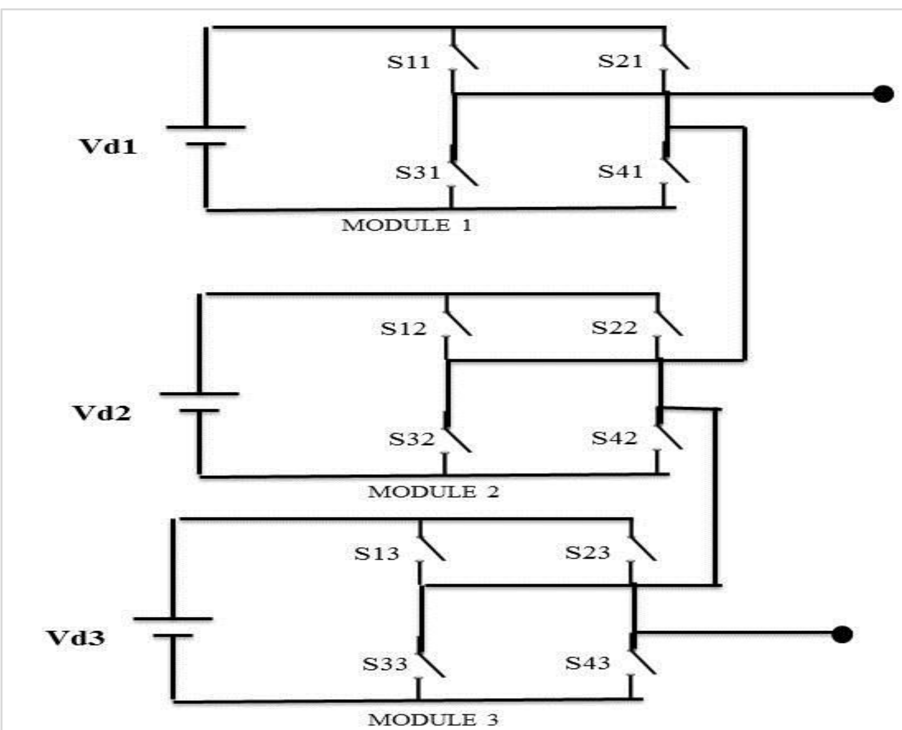

Figure 4 Schematic diagram of 7 level multilevel inverter

Consider three modules of the PV system, in which each photovoltaic module is associated with proposed inverter configuration. The voltage of photovoltaic module is linked in series with the terminal to generate the required outcome. Because of the series connection, the output is just added together. i.e., $V_0=V_{d1}+V_{d2}+V_{d3}$. By varying, the combination of the switches S_1, S_2, S_3 and S_4, each module generates corresponding output voltages. Since the proposed topology is a seven-level cascaded H Bridge inverter, the total number of sources required is calculated as shown in Equation 1.

$$M = \frac{N-1}{2} \quad (1)$$

Where,
N – Number of Levels
M – Total number of modules

In order to get the staircase waveform, there are many possible switching combinations. The number of switching combinations is proportionate to the number of levels (N). The relation between the number of levels (N) and the switching combinations are calculated and the possible switching combinations used in the seven-level cascaded H bridge VSI is listed in *Table 1*.

Table 1 Switching strategy for seven-level inverter

Voltage (V_0)	**+3 (V_d)**	**+2 (V_d)**	**+V_d**	**0**	**-V_d**	**-2 (V_d)**	**-3 (V_d)**
S_{11}	1	1	1	1	0	0	0
S_{12}	0	0	0	1	1	1	1
S_{13}	0	0	0	0	1	1	1
S_{14}	1	1	1	0	0	0	0
S_{21}	1	1	1	1	0	0	0
S_{22}	0	0	1	1	0	1	1
S_{23}	0	0	0	0	1	1	1
S_{24}	1	1	0	0	1	0	0
S_{31}	1	1	1	1	0	0	0
S_{32}	0	1	1	1	0	0	1
S_{33}	0	0	0	0	1	1	1
S_{34}	1	0	0	0	1	1	0

3.2Modulation scheme

The proposed modulation structure with unipolar pulse width modulation switching is shown in *Figure 5*. In this modulation scheme, the triangular carrier signal (T_c) is compared with the modulation signals (M_c) which are the functions of the electric grid. These modulation signals are modified to get a modified modulation signal that has the same frequency and amplitude for grid synchronization.

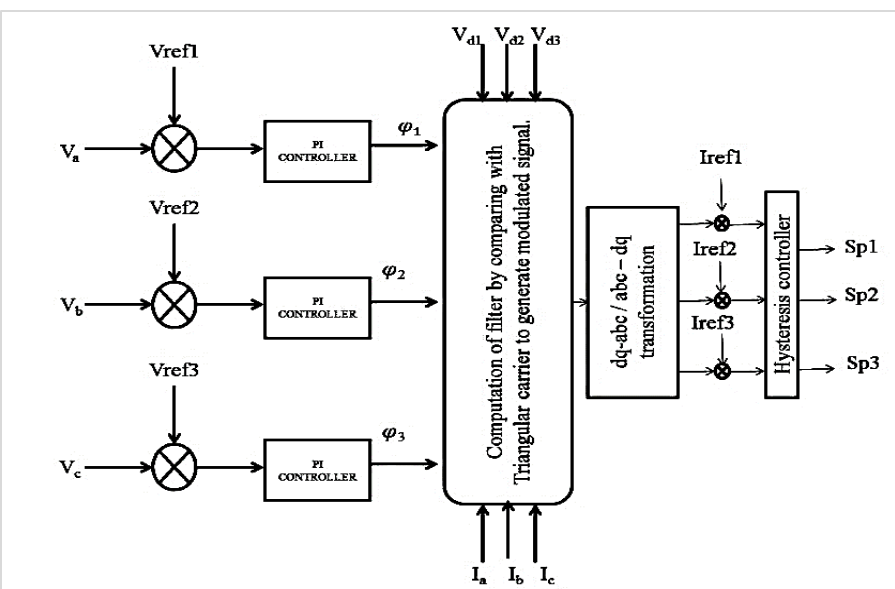

Figure 5 Control logic for generating pulses Sp1, Sp2, Sp3

The required number of modulation signals depends on the number of solar modules. The modulation index, mi for the N-level inverter with M number of modules is given in the Equation 2.

$$m_i = \frac{A_m}{\frac{(N-1)A_c}{2}} = \frac{A_m}{MA_c} \qquad (2)$$

Hence, for a seven-level inverter, it is calculated as per the Equation 3.

$$m_i = \frac{A_m}{3A_c} = 0.33\frac{A_m}{A_c} \qquad (3)$$

where A_c is 1p.u and m_i = 0 to 1, also A_m = 0 to M. From control logic, switching schemes for the seven-level cascaded H-Bridge multilevel inverter is generated as shown in *Table 2.*

Table 2 Switching logic

S_{11}=S_{p1}	S_{12}=S_{11}	S_{31}=S_{33}’
S_{21}= - S_{11}	S_{22}=S_{p2}	S_{32}=S_{p3}
S_{31} = S_{11}’	S_{32}=S_{12}’	S_{33}=S_{31}’
S_{41}=S_{21}’	S_{42}=S_{22}’	S_{43}=S_{23}’

For this proposed topology, the DC bus voltage and the parameters of the proposed filter are chosen as same as the requirements of the design. The electrical diagram of the LCL filter considered for the design is shown in *Figure 6*.

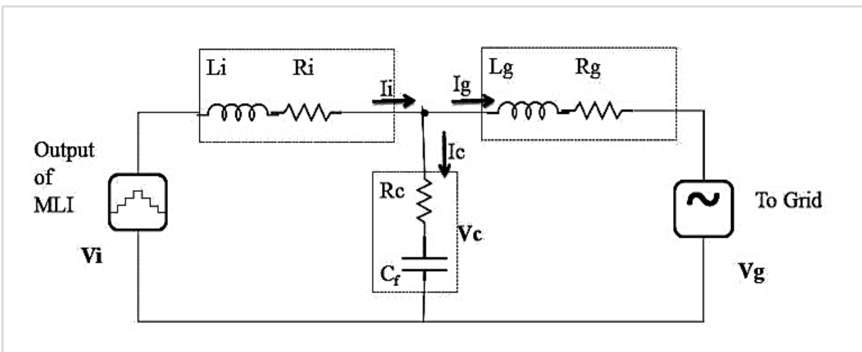

Figure 6 One phase electrical circuit for LCL filter

By basic laws it is shown by Equation 4-7.

$$I_i - I_c - I_g = 0 \qquad (4)$$

$$V_i - V_c = I_i(sL_i + R_i) \qquad (5)$$

$$V_c - V_g = I_g(sL_g + R_g) \qquad (6)$$

$$V_c = I_c\left(\frac{1}{sC_f} + R_i\right) \qquad (7)$$

The notations involved in the design of LCL filter is
V_i – Inverter Voltage
I_i – Inverter Current
V_c – Voltage drop on filter capacitance
I_c – Current through filter capacitance
V_g – Grid Voltage
I_g – Grid Current
L_i – Filter Inductance on Inverter side
R_i – Inverter side parasitic Resistance
C_f – Filter Capacitance
R_c – Filter capacitor side parasitic resistance
L_g – Filter inductance in grid side
R_g – Grid side parasitic resistance

The Functional block diagram of LCL filter can be drawn as shown in *Figure 7.*

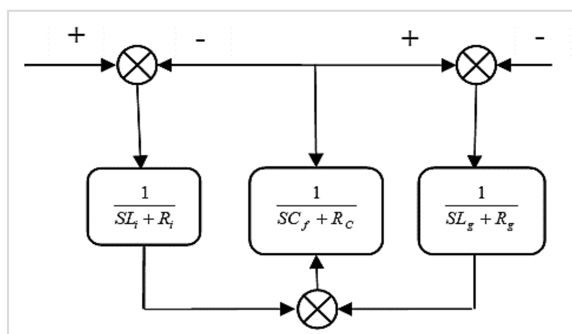

Figure 7 Representation of LCL filter

The Transfer function of the filter is derived as shown in Equation 8.

$$H_f = \frac{I_g}{V_i} \qquad (8)$$

The voltage at the grid is assumed as an ideal voltage and is represented as a short circuit for harmonic frequencies. Thus, for the analysis of filter $V_g = 0$. It is shown in Equation 9 and 10.

$$I_g(sL_g + R_g) = I_c\left(\frac{1}{sC_f} + R_i\right) \qquad (9)$$

$I_c = I_g \frac{s^2 C_f L_g + s C_f R_g}{s C_f R_g + 1}$ (10)

It can be represented as shown in Equation 11.

$V_i = V_c + I_i(sL_i + R_i)$ (11)

By using the above relations, the inverter voltage is written as Equation 12, 13 and 14.

$V_i = I_g(sL_g + R_g) + (I_g + I_c)(sL_i + R_i)$ (12)

$V_i = I_g(sL_g + R_g) + (I_g + I_g \frac{s^2 C_f L_g + s C_f R_g}{s C_f R_g + 1})(sL_i + R_i)$ (13)

$V_i = I_g(sL_g + R_g + sL_i + R_i + \frac{(sL_i + R_i) s^2 C_f R_g}{s C_f R_g + 1})$ (14)

By solving these equations, the transfer function of the filter is calculated accordingly.

4.Results

The proposed topology is validated using the MATLAB simulation software. The solar panel for the distribution system has the specification with 300 watts maximum power, 50.6 volts, 5.9 amps, with open-circuit voltage of 63.2 volts and a short circuit current of 6.5 amps. The simulated output of PV produces a voltage of approximately 51 volts as shown in *Figure 8*.

A boost converter increases the output voltage of the PV. Normally, twice the generated voltage is achieved as shown in *Figure 9*. Since PV is intermittent in nature, a suitable regulation is necessary.

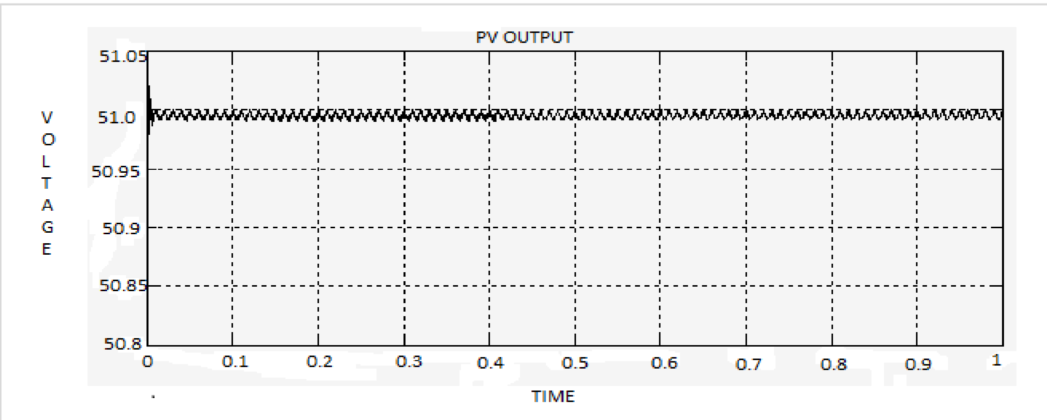

Figure 8 Output voltage from the solar module

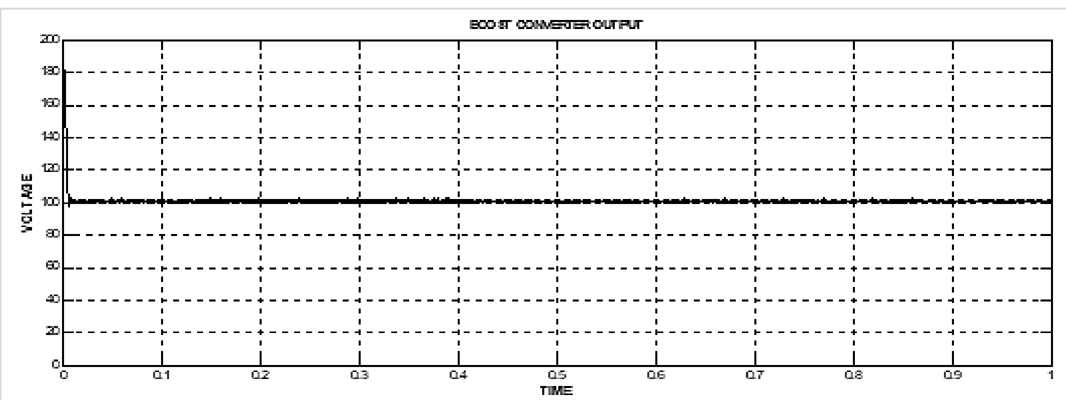

Figure 9 Output voltage of the boost converter

A boost regulator does this voltage regulation. The simulated output of the boost regulator is nearly 100V. This output of the boost converter act as the DC source of DSTATCOM. The VSI of the DSTATCOM is modified as a seven-level cascaded H-bridge MVSI and makes the DSTATCOM as PW-DSTATCOM. From the waveform shown in *Figure 10*, it is possible to say that the conventional square wave changes to a sinusoidal wave by increasing the steps, thereby making the filter less weight and cheaper comparatively. The output waveform of the VSI is shown in *Figure 11*.

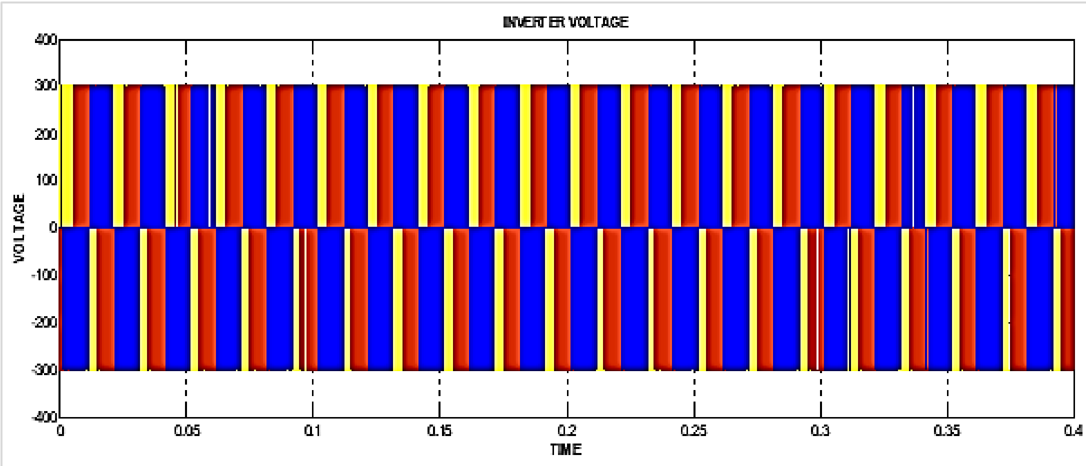

Figure 10 Conventional outputs from the inverter

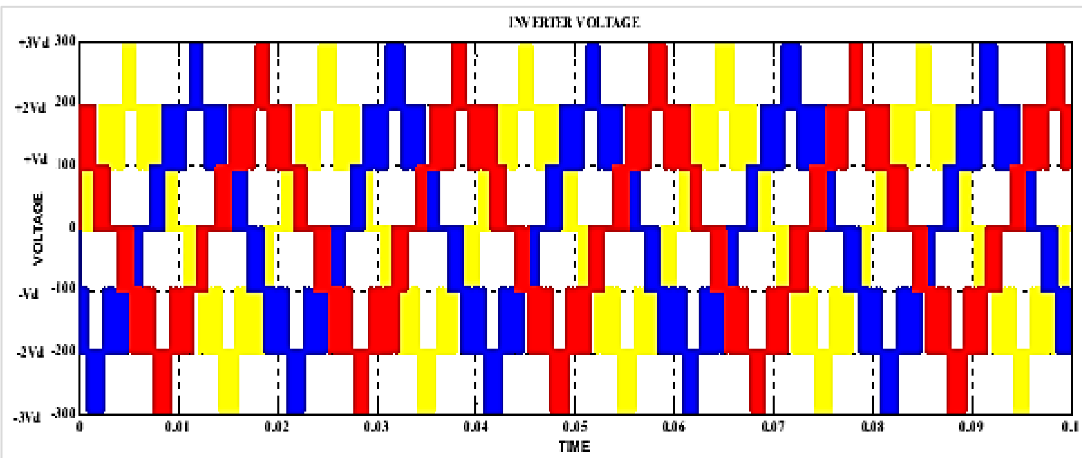

Figure 11 Seven level output from multilevel inverter

The output of a seven-level cascaded H-Bridge multilevel inverter, then passes through the LCL filter where the waveform gets smoothen out to supply a pure sinusoidal wave. *Figure 12 and Figure 13* shows the grid voltage at the point of common coupling (PCC) and their total harmonic distortion (THD) without and with compensator.

Figure 14 and *Figure 15* shows the waveform of grid voltage at the PCC without and with Compensator respectively.

Table 3 shows the comparison of grid voltage by using a conventional inverter, seven-level inverters without LCL filter, and the proposed seven-level inverter with an LCL filter. *Figure 16* and *Figure 17* shows the grid current at PCC, with and without compensator. It is seen that the THD is reduced by using the proposed method. *Figure 18* and *Figure 19* shows the waveform of grid current at PCC with and without PW-DSTATCOM. When Compensator is connected, harmonics are eliminated and the THD is maintained well within the limit as per IEEE519. It is to be noted that the recent advancement in the grid interconnection using renewable energy sources by means of hybrid DSTATCOM enhances the quality of power, which focuses on the day-to-day concern over the smart grid.

Table 4 shows the comparison of grid current by using a conventional inverter, a seven-level inverter without an LCL filter, and the proposed seven-level inverter with an LCL filter. The output of a conventional inverter is a square wave, hence the filter becomes heavy and expensive. The proposed method reduces the size & cost of the filter.

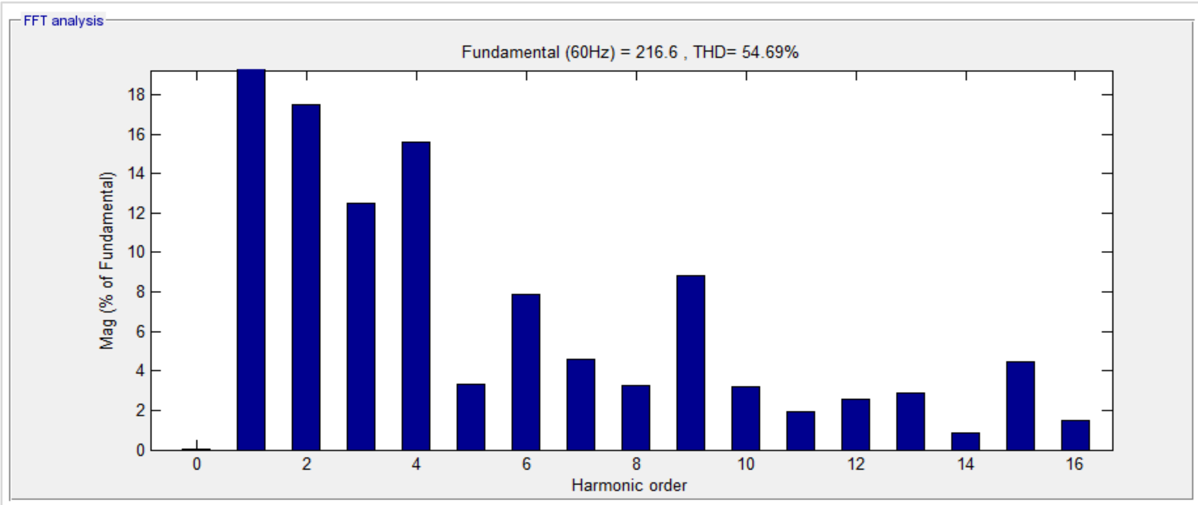

Figure 12 Voltage at PCC for phase A without compensator

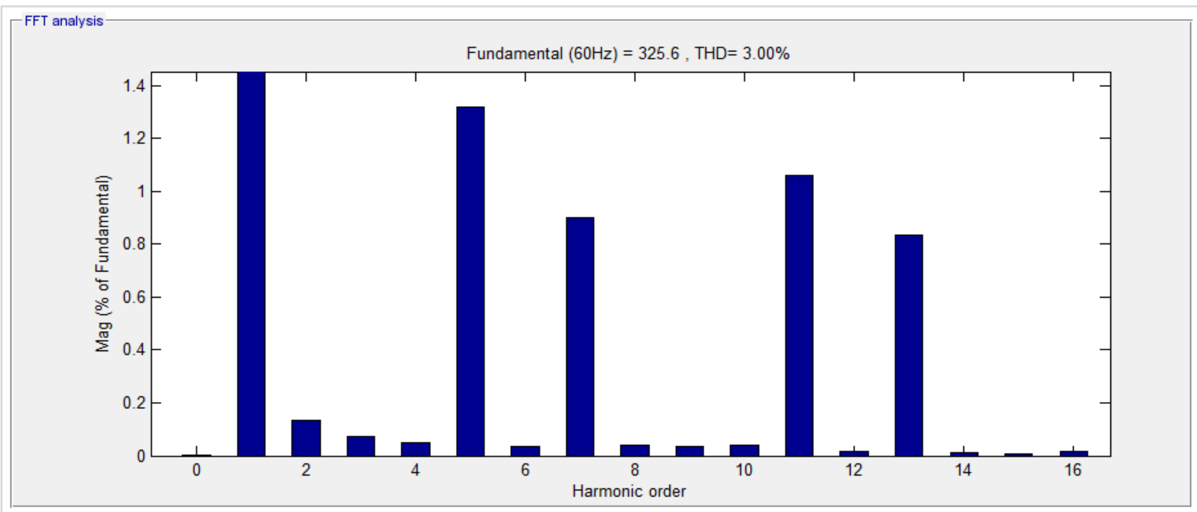

Figure 13 Voltage at PCC for phase A by PW-DSTATCOM with compensator

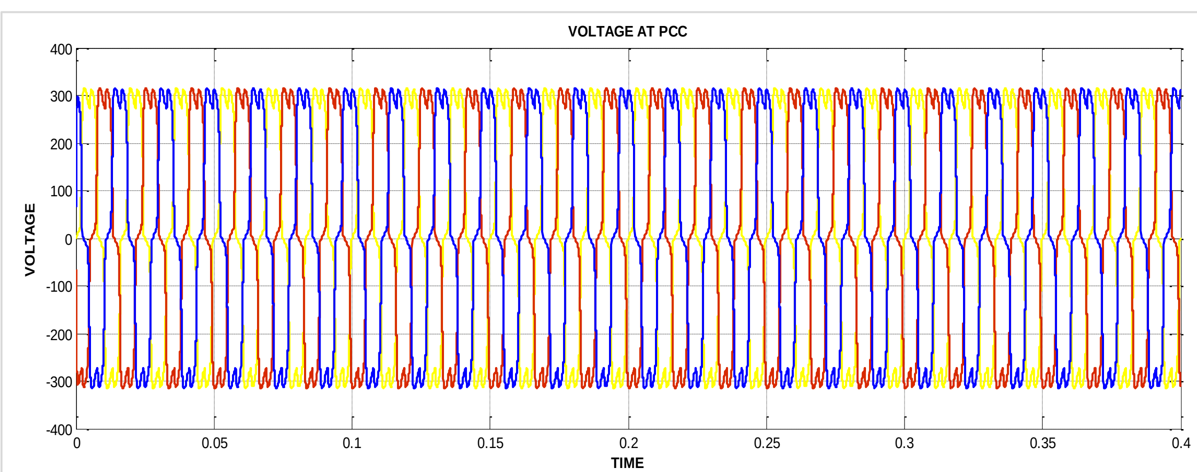

Figure 14 Grid voltage at PCC without PW-DSTATCOM

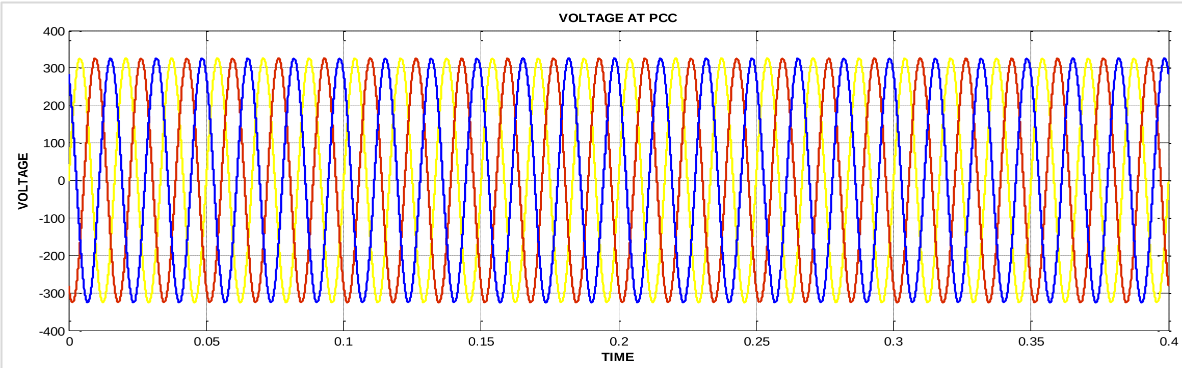

Figure 15 Grid voltage at PCC with PW-DSTATCOM

Table 3 GRID voltage at PCC

Voltage	Conventional system		Proposed system without LCL filter		Proposed system with LCL filter	
	THD	Fundamental voltage	THD	Fundamental voltage	THD	Fundamental voltage
V_a	54.69	216.6	38.26	275.8	3	325.6
V_b	49.16	189.9	32.05	243.6	3.02	325.4
Vc	51.27	188.1	29.50	245	3	325.3

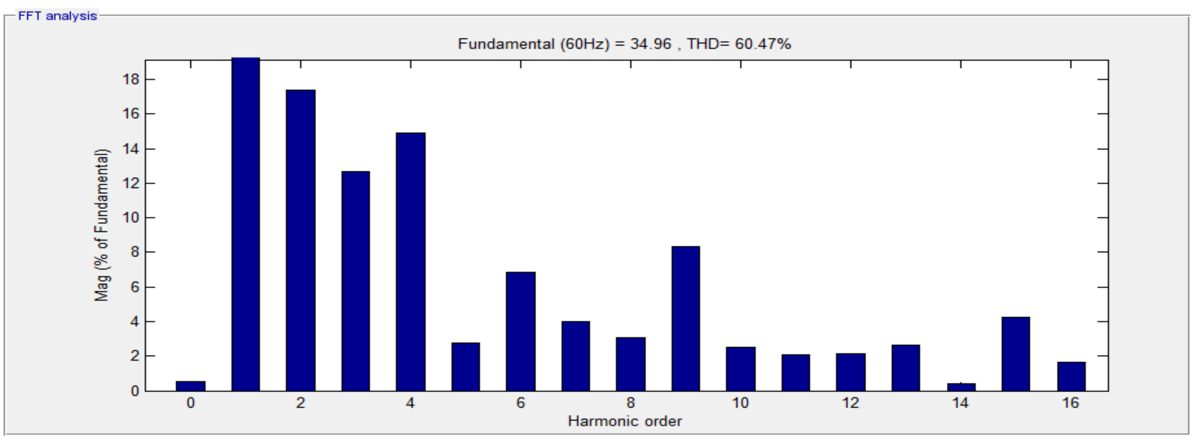

Figure 16 Current at PCC for phase A without PW-DSTATCOM

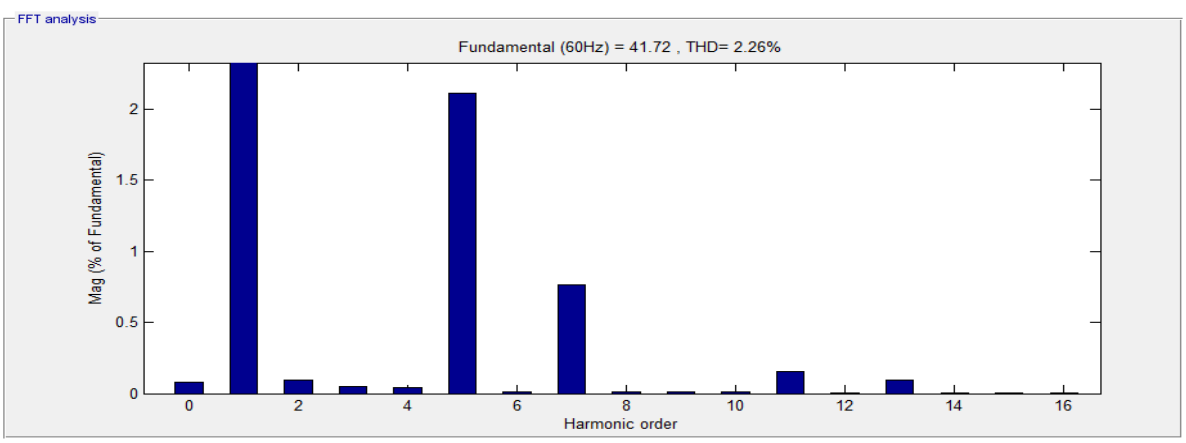

Figure 17 Current at PCC for Phase A with PW-DSTATCOM

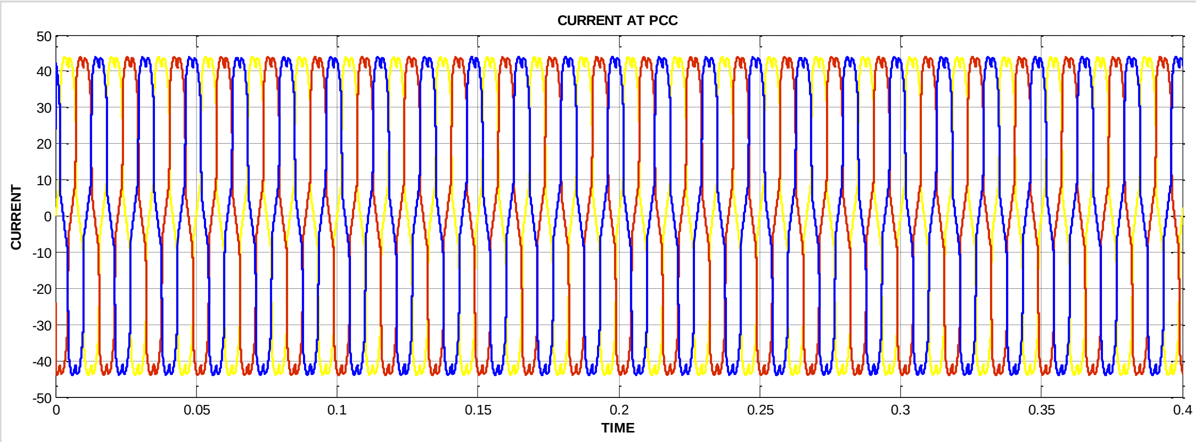

Figure 18 Grid current at PCC without PW-DSTATCOM

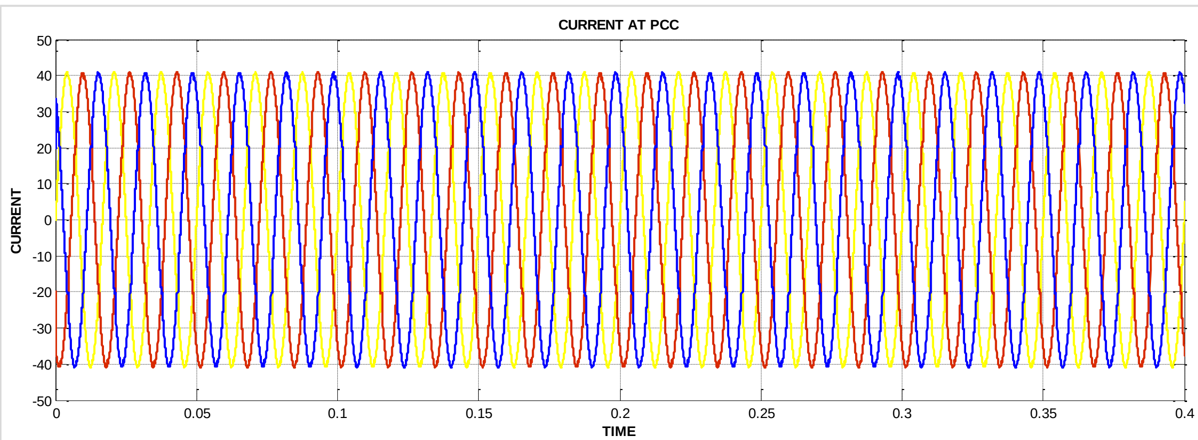

Figure 19 Grid current at PCC with PW-DSTATCOM

Table 4 Grid current at PCC

Current	Conventional system		Proposed system without LCL filter		Proposed system with LCL filter	
	THD	Fundamental current	THD	Fundamental current	THD	Fundamental current
I_a	60.47	34.96	17.97	46.63	2.26	41.72
I_b	56.26	30.5	18.02	46.59	2.26	41.75
I_c	58.27	30.38	18.01	46.59	2.29	41.72

It also shows the grid current at PCC shows better performance. It is seen that the THD is well within the limit as per IEEE 519.

Figure 20 shows the comparative recovery voltage with and without DSTATCOM. It is essential for the per unit voltage to recover quickly after contingency events in order to avoid power losses and faults. Hence the recovery time must be as quick as possible. Conventional recovery time happens more than a second, which is not acceptable. Hence DSTATCOM based system is adopted and found that the recovery time is quick, that is acceptable. This ultimately enhances the stability of the system. It can be seen that per unit voltage is reached at t = 1.47 s. Whereas the per unit voltage PW-DSTATCOM (S&C) is reached at t=0.46 s. Thus, without DSTATCOM, it normally takes three times as that PW-DSTATCOM.

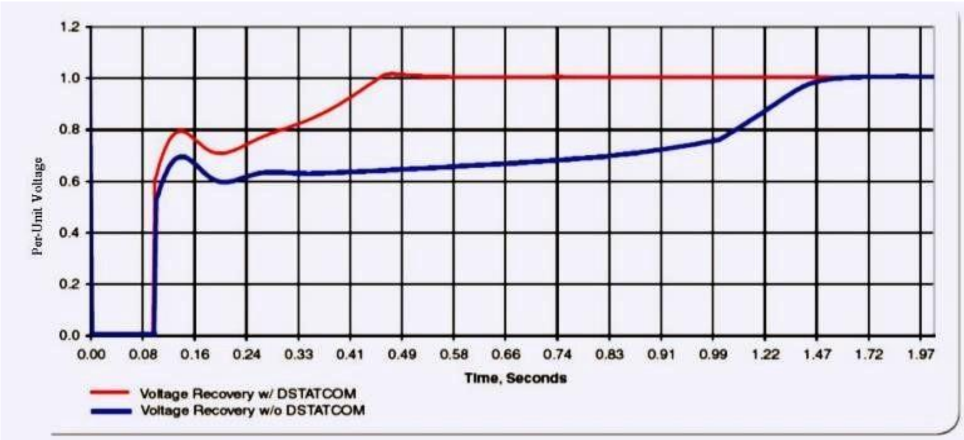

Figure 20 Voltage recovery of PW_DSTATCOM with fast response time

Table 5 gives the system parameters used in the simulation to obtain the tabulated results.

Table 5 System parameters

Grid voltage	**400V**
Grid frequency	60Hz
Grid series resistance	0.1325 ohm
Grid series reactance	0.45mH
Inverter filter inductance	1.5mH
Inverter filter capacitance	0.5mF
Active power of linear load	40KW

5.Discussion

THD is the measurement tool for measuring the power quality. The measurement is done at the PCC to record the voltage harmonics and it is seen that the maximum THD of voltage is 54.69% in 'a' phase which is undesirable. This THD is reduced to 3% with the help of the compensator. Thus, achieving acceptable power quality within the standard. The LCL filter plays a vital role in achieving the standard in addition with the control strategy. The current harmonics is also measured suitably. The maximum THD of current is 60.47 in 'a' Phase that is undesirable. This THD is reduced to 2.26 using proposed methodology.

The key finding of this paper is that the combination of LCL filter with MVSI provides better power quality improvement. The comparative analysis shows that MVSI without LCL helps to minimize THD but not within the standard, whereas adding LCL mitigates the THD well within the standard.

By means of this proposed method, the filter size is reduced from 26mH to about 2mH. Also, the DC link voltage reduces from 1100 volts to 300 volts. Moreover, the stored energy is also considerably reduced. Hence the proposed method is effective in size and cost involved in the implementation of the filter. This paper uses MATLAB simulation software for analysis and shall be extended for experimental verification suitably. Real time load variation for various geographical location shall be collected for better analysis. A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future scope

In this research article, the hybrid interfacing filter consisting of LCL reduces DC link voltage and filter inductance. The introduction of a seven-level inverter as a VSI improves the quality of inverter output and designing an LCL filter instead of L, LC filter in PW-DSTATCOM improves the power quality. The integration of solar energy system ultimately improves the stability of the system. The boost converter regulates the voltage level of the solar module and acts as a protection circuit. The effectiveness of the proposed system is developed using MATLAB, Simulink tool and validated with IEEE 519 standard. The simulation results show that the proposed system improves the quality of power under suitable constraints and the THD is well within the standard limit. The response of the system is also rapid when compared to the conventional system. The voltage recovery of the system is three times faster and makes the system efficient, reliable and stable.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Authors contribution statement

S. Rajalingam: Conceptualization, manuscript drafting, design and analysis. **N. Karuppiah:** Data collection, manuscript drafting, interpretation of results. **S. Muthubalaji:** Data collection, review and editing, statistical analysis. **J. Shanmugapriyan:** Investigation on limitations, supervision, review and editing.

References

[1] Nwaigwe KN, Mutabilwa P, Dintwa E. An overview of solar power (PV systems) integration into electricity grids. Materials Science for Energy Technologies. 2019; 2(3):629-33.

[2] Dumlao SM, Ishihara KN. Dynamic cost-optimal assessment of complementary diurnal electricity storage capacity in high PV penetration grid. Energies. 2021; 14(15):1-23.

[3] Kumar V, Pandey AS, Sinha SK. Grid integration and power quality issues of wind and solar energy system: a review. In international conference on emerging trends in electrical electronics & sustainable energy systems 2016 (pp. 71-80). IEEE.

[4] Panigrahi R, Mishra SK, Srivastava SC. Grid integration of small-scale photovoltaic systems-a review. In industry applications society annual meeting 2018 (pp. 1-8). IEEE.

[5] Natarajan K, Bala PK, Sampath V. Fault detection of solar PV system using SVM and thermal image processing. International Journal of Renewable Energy Research. 2020; 10(2):967-77.

[6] Meenakshi SB, Manikandan BV, Praveen KB, Prince WD. Combination of novel converter topology and improved MPPT algorithm for harnessing maximum power from grid connected solar PV systems. Journal of Electrical Engineering & Technology. 2019; 14(2):733-46.

[7] Winston DP, Kumaravel S, Kumar BP, Devakirubakaran S. Performance improvement of solar PV array topologies during various partial shading conditions. Solar Energy. 2020; 196:228-42.

[8] Rao GS, Rahul M, Teja VN. Reactive power compensation using fuzzy based D-STATCOM. International Journal of Applied Engineering Research. 2017; 12(1):485-91.

[9] Jacobs J, Detjen D, Karipidis CU, De DRW. Rapid prototyping tools for power electronic systems: demonstration with shunt active power filters. IEEE Transactions on Power Electronics. 2004; 19(2):500-7.

[10] Ravivarman S, Natarajan K, Gopal RB. Non-isolated modified quadratic boost converter with midpoint output for solar photovoltaic applications. In E3S web of conferences 2019 (pp. 1-8). EDP Sciences.

[11] Christabel SC, Srinivasan A, Winston DP, Kumar BP. Reconfiguration solution for extracting maximum power in the aged solar PV systems. Journal of Electrical Engineering. 2016; 16(3):440-6.

[12] Kumar BP, Winston DP, Christabel SC, Venkatanarayanan S. Implementation of a switched PV technique for rooftop 2 kW solar PV to enhance power during unavoidable partial shading conditions. Journal of Power Electronics. 2017; 17(6):1600-10.

[13] Umashankar S, Sreedevi TS, Nithya VG, Vijayakumar D. A new 7-level symmetric multilevel inverter with minimum number of switches. International Scholarly Research Notices. 2013.

[14] Prince WD, Ganesan K, Samithas D, Baladhanautham CB. Experimental investigation on output power enhancement of partial shaded solar photovoltaic system. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2020:1-7.

[15] Winston DP, Kumar BP, Christabel SC, Chamkha AJ, Sathyamurthy R. Maximum power extraction in solar renewable power system-a bypass diode scanning approach. Computers & Electrical Engineering. 2018; 70:122-36.

[16] Akagi H, Watanabe EH, Aredes M. Instantaneous power theory and applications to power conditioning. John Wiley & Sons; 2017.

[17] Blooming TM, Carnovale DJ. Application of IEEE Std 519-1992 harmonic limits. In conference record of 2006 annual pulp and paper industry technical conference 2006 (pp. 1-9). IEEE.

[18] Carnovale DJ, Dionise TJ, Blooming TM. Price and performance considerations for harmonic solutions. In power qaulity conference and exhibition 2003 (pp. 4-6).

[19] Dang MD, Waleed M. Harmonics from today's emergent technology. In international conference on smart energy grid engineering 2019 (pp. 240-5). IEEE.

[20] Swetha K, Sivachidambaranathan V. A review on different control techniques using DSTATCOM for distribution system studies. International Journal of Power Electronics and Drive System. 2019; 10(2):813-21.

[21] Gupta R. Generalized frequency domain formulation of the switching frequency for hysteresis current controlled VSI used for load compensation. IEEE Transactions on Power Electronics. 2011; 27(5):2526-35.

[22] Kanjiya P, Khadkikar V, Zeineldin HH. A noniterative optimized algorithm for shunt active power filter under distorted and unbalanced supply voltages. IEEE Transactions on Industrial Electronics. 2012; 60(12):5376-90.

[23] Vodyakho O, Mi CC. Three-level inverter-based shunt active power filter in three-phase three-wire and four-wire systems. IEEE Transactions on Power Electronics. 2009; 24(5):1350-63.

[24] Kumar C, Mishra MK. An improved hybrid DSTATCOM topology to compensate reactive and nonlinear loads. IEEE Transactions on Industrial Electronics. 2014; 61(12):6517-27.

[25] Srikanthan S, Mishra MK. DC capacitor voltage equalization in neutral clamped inverters for DSTATCOM application. IEEE Transactions on Industrial Electronics. 2009; 57(8):2768-75.

[26] Massing JR, Stefanello M, Grundling HA, Pinheiro H. Adaptive current control for grid-connected converters

with LCL filter. IEEE Transactions on Industrial Electronics. 2011; 59(12):4681-93.
[27] Bina MT, Pashajavid E. An efficient procedure to design passive LCL-filters for active power filters. Electric Power Systems Research. 2009; 79(4):606-14.
[28] Rajalingam S, Malathi V. Augmented current controller with SHC technique for grid current compensation in the distribution system. In international conference on swarm, evolutionary, and memetic computing 2014 (pp. 328-38). Springer, Cham.
[29] Gupta A. Power quality evaluation of photovoltaic grid interfaced cascaded H-bridge nine-level multilevel inverter systems using D-STATCOM and UPQC. Energy. 2022.
[30] Badoni M, Singh A, Singh B, Saxena H. Real-time implementation of active shunt compensator with adaptive SRLMMN control technique for power quality improvement in the distribution system. IET Generation, Transmission & Distribution. 2020; 14(8):1598-606.
[31] Raja A, Vijaya KM, Karthikeyan C. Solar photovoltaic interconnected ZSI-unified power quality conditioner to enhance power quality. Bulletin of the Polish Academy of Sciences Technical Sciences. 2022.
[32] Zellagui M, Lasmari A, Settoul S, El-sehiemy RA, El-bayeh CZ, Chenni R. Simultaneous allocation of photovoltaic DG and DSTATCOM for techno-economic and environmental benefits in electrical distribution systems at different loading conditions using novel hybrid optimization algorithms. International Transactions on Electrical Energy Systems. 2021; 31(8).
[33] Lai JS, Peng FZ. Multilevel converters-a new breed of power converters. IEEE Transactions on Industry Applications. 1996; 32(3):509-17.
[34] Mcgrath BP, Holmes DG. A comparison of multicarrier PWM strategies for cascaded and neutral point clamped multilevel inverters. In 31st annual power electronics specialists conference 2000 (pp. 674-9). IEEE.
[35] Meenalochani K, Shanthi B, Balamurugan CR. Performance analysis on bipolar PWM strategies for single phase quasi-Z-source fed seven level modified cascaded H-bridge inverter with asymmetric switched-inductor cell. International Journal of Engineering & Technology. 2018; 7(2.8):583-7.
[36] Mahela OP, Shaik AG. Power quality improvement in distribution network using DSTATCOM with battery energy storage system. International Journal of Electrical Power & Energy Systems. 2016; 83:229-40.
[37] Ray PK, Mishra S, Beng GH, Kollimalla SK. Improvement of power quality using an average model of a new hybrid PV-DSTATCOM. In international conference on industrial technology 2017 (pp. 440-5). IEEE.
[38] Sreenivasarao D, Agarwal P, Das B. Performance enhancement of a reduced rating hybrid D-STATCOM for three-phase, four-wire system. Electric Power Systems Research. 2013; 97:158-71.

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Appendix I

S. No.	Abbreviation	Description
1	APF	Active Power Filter
2	DSTATCOM	Distribution Static Synchronous Compensator
3	FCMI	Flying Capacitor Multi level Inverter
4	LC	Inductor Capacitor
5	LCL	Inductor Capacitor Inductor
6	LED	Light Emitting Diode
7	MVSI	Multilevel Voltage Source Inverter
8	NPC	Neutral Point Clamped
9	PCC	Point of Common Coupling
10	PV	Photo Voltaic
11	PW – DSTATCOM	Pure Wave Distribution Static Compensator
12	SPS	Sim Power System
13	SPV	Solar Photo Voltaic
14	THD	Total Harmonic Distortion
15	UPQC	Unified Power Quality Conditioner
16	VSI	Voltage Source Inverter