D-STATCOM Control using SRFT Method for PQ Improvement in a PV System

Namratha Sampath, P.V.S.S.A Parimala

Abstract*: *The set of restrictions defined for a system's electrical characteristics so that the entire electrical system can function in the intended manner and without losses is known as power quality. Power quality issues such as transients, harmonics, voltage swell, sag, flicker, fluctuations, and power factor difficulties are becoming more common as power electronic devices become more widely used. The usage of a Distribution Static Compensator (D-STATCOM) to mitigate power quality issues is discussed in this study. In this case, D-STATCOM functions as a shunt active power filter to reduce harmonics caused by non-linear loads. The simulation studies on a PV-based Cascaded-H-Bridge Multi-Level Inverter i.e Solar PV and Cascaded H Bridge MLI are integrated using Selective Harmonic Elimination method with D-STATCOM injected at the load side to improve power quality are presented in this project. The Solar PV system is mathematically modelled using Boost regulator and P&O MPPT technique and to the D-STATCOM the controller is designed utilizing Synchronous Reference Frame Theory (SRFT) out of many control strategies for reactive power compensation, harmonic mitigation, and power factor enhancement as it is more accurate. A 2nd order low pass filter is employed at the load side to reduce the harmonics to some extent, and both 5-level and 7-level models are evaluated. MATLAB/SIMULINK is used for simulation.

Keywords*: *Multi-level Inverter (MLI), PV System, Boost converter, P&O (Perturb and Observe) Cascaded H-Bridge (CHB), Selective Harmonic Elimination (SHE), D-STATCOM, Voltage Source Converter (VSC), SRFT, PI controller, Hysteresis Controller, 2nd order low pass filter.

I. INTRODUCTION

Power quality issues now have a significant influence on AC systems that have non-linear loads attached to them. Initially, FACT devices like as D-STATCOM, SSSC, IPFC, and UPFC were added to improve the system's power quality and reliability. D-STATCOM is the most favorable and effective device for harmonics abatement, voltage regulation, reactive power compensation, unity power factor, and other applications. In AC systems with non-linear loads, therefore mentioned issues have been identified. As a result, D-STATCOM is injected into these types of AC systems. It's a gadget that's connected in shunt. The D-STATCOM can be controlled using a variety of control mechanisms. Instantaneous power reactive theory (IRPT), Synchronous Reference frame theory (SRFT), Symmetrical Component (SC), Modified p-q Theory, and others are some examples. The primary goal of this research is to investigate PV-based 5- and 7-level cascaded H-bridge Multilevel Inverters with D-STATCOM injected near the load side to mitigate Power Quality issues. The CHB-MLI employs the Selective Harmonic Elimination (SHE) PWM method. In this study, an SRFT-based D-STATCOM has been constructed, which may be used to filter harmonics, perform power factor correction, compensate for reactive power, and balance source current, among other things. For the management of reactive power, the controller uses the Dqo approach. The power factor is enhanced by managing reactive power. The PI controller is used to keep the voltage constant, whereas the Hysteresis controller is used to keep the current constant. In this paper, parameters such as THD, Reactive power, and Power factor in the PV based 5-Level and 7-Level CHB-MLI to which D-STATCOM is injected are compared to see which is superior. Further prediction is made based on it. In addition, at the load side, a second order low pass filter is utilized to decrease harmonics.

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II. MULTI LEVEL INVERTER TOPOLOGIES

An inverter is a device that converts DC power to AC power at a specific frequency and voltage level. Inverters can be divided into two types: single and multilevel inverters. Multilevel inverters are a high-power, medium-voltage option utilized in commercial applications. Power switching devices and capacitor voltage sources are used in multilevel inverters. The most common multilevel topologies are as follows:

1. Diode Point Clamped or Neutral Clamped
2. Flying capacitor
3. H bridge Cascaded.

Cascaded H Bridge is the best of the three Multilevel inverters since it requires less components in each level. It draws low-distortion input current. It can switch at both a high and a low frequency. By employing this MLI, the harmonics are also minimized. Separate DC sources are used in the cascaded H-bridge. Solar panels can be utilized to power the module instead of DC sources.

CASCADED-H-BRIDGE MULTILEVEL INVERTER:

This is a series of power conversion cells and power that can be scaled simply. H-Bridge refers to the combination of capacitors and switches.

It is made up of H-Bridge cells, each of which may output three different voltages: zero, positive DC, and negative DC. One of the advantages of this sort of MLI is that it requires less components than the Cascaded-H-Bridge topology, which consists of a to the MLIs. The inverter is less expensive and weighs less than two inverters. Cascaded MLIs eliminate the massive transformer required by traditional multi-phase inverters, clamping diodes required by diode clamped MLIs, and flying capacitors required by Flying capacitor MLIs.

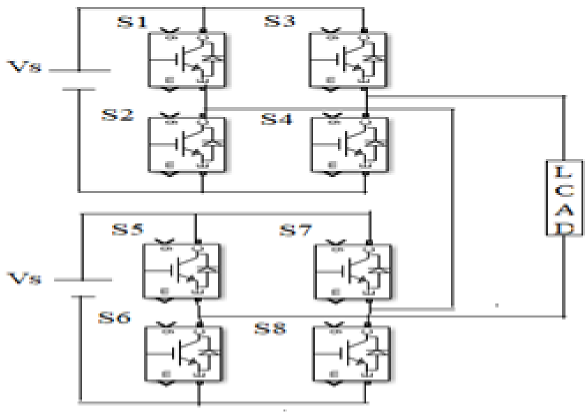

FIG 1. Cascaded MLI in a single phase

Table I CHB MLI switching states

Vo	S1	S2	S3	S4	S5	S6	S7	S8
V1	0	0	0	0	0	0	0	0
V2	0	1	0	0	0	1	1	0
V3	0	1	1	0	0	1	1	0
-V2	1	0	0	0	0	0	0	1
-V3	1	0	0	0	1	0	0	1

III. METHODOLOGY

A. Solar pv Based Chb Mli System:

In India, solar energy capacity installation has increased by 25-30% in the recent few years. In PV systems, MPPT plays a vital function in its applications for increasing efficiency since it records the maximum power from solar irradiation and temperature has a significant impact on the generated voltage from PV systems. In compared to the voltage rating, the voltage obtained by PV arrays is lower. In this project, a DC-DC Boost converter is employed to boost the PV panels' voltage. The Perturb and Observe MPPT technique is used in this research to manage the duty cycle of the boost converter using the MPPT controller. Because AC loads are the most commonly utilized loads nowadays, conversion of the boosted output voltage from the DC-DC boost converter to AC is required for commercial purposes.

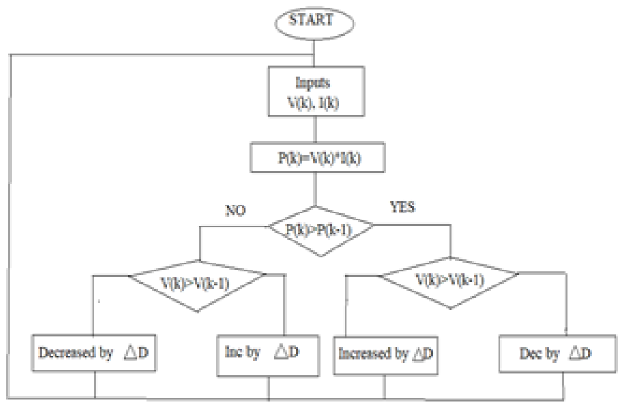

FIG 2. P&O Algorithm flowchart

CHB-MLI is a series of two or more single phase H-Bridge inverters, where H-Bridge refers to a switch configuration that includes MOSFETs, IGBTs, and other components. CHB has the advantage of employing only one converter per panel, which improves the efficiency of each PV module. The voltage regulation of MLIs is done via separate DC lines. As a result, each PV panel can have its own MPPT control. PV panel energy harvesting will be at its peak. The output voltages waveforms, THD percent of 5-Level and 7-Level are presented in the work published in this paper, and the configuration is depicted in the fig CHB-MLI with PV system and DC-DC BOOST converter.

Table II Boost regulator Parameters

Parameters	Rating
Irradiation	1000
Temperature	25
C1	1000UF
R	0.005 ohms
L	5mH
C2	0.1UF

B. Selective Harmonic Elimination (SHE):

To the Cascaded H-Bridge Multi-level inverter, out of many PWM techniques, SHE PWM technique is applied and switching angles at a desired frequency for an MLI are calculated by solving the SHE equations in such a way that the desired voltage is obtained while certain lower order harmonics are removed. To generate multilevel output AC voltage from various DC input levels, semiconductor devices must be switched on and off in such a way that the desired fundamental is obtained with the least amount of harmonic distortion. At fundamental frequency, the SHE method is the most widely used switching approach. Because the CHB is made up of IGBT/MOSFET switches, each one produces harmonics. By sending proper signals to the switches, harmonics are reduced. The sine wave and carrier wave are first compared with the aid of the comparator. The reference and carrier waves will be compared with the help of a comparator.

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The gating pulses are generated by this comparator and are sent to the switches. Selectors are used to turn on and off switches at the same time. The switches are now selected using selectors, and the harmonics at each switch are minimized as a result of this procedure, resulting in 5-Level and 7-Level output.

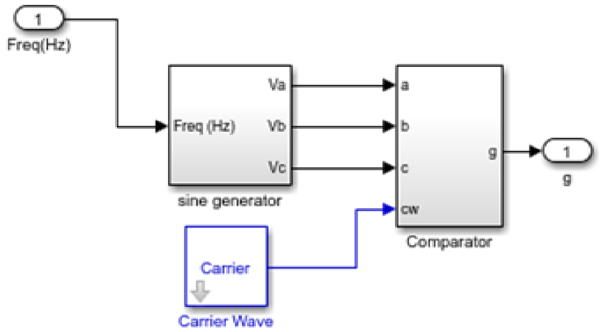

FIG 3. SHE Block

C. Control Strategy of D-Statcom:

Within the distribution system, D-STATCOM has been extensively employed for reactive power compensation, load balancing, and harmonic mitigation. The control algorithm for extracting reference current components has an impact on D-STATCOM performance. Many control algorithms have been reported in the literature for this purpose, including interpretations and modifications of the Instantaneous Reactive Power theory (IRP), Synchronous Reference Frame theory (SRF), symmetrical Component Theory (SC). SRFT control strategy has been chosen in this project. The goal of the control system is to obtain the reference current waveforms that will be injected to achieve the goal. There are a variety of methods for generating reference source currents for controlling the VSC of a three-phase D-STATCOM system, Hysteresis current controller has been used for the generation of pulses.

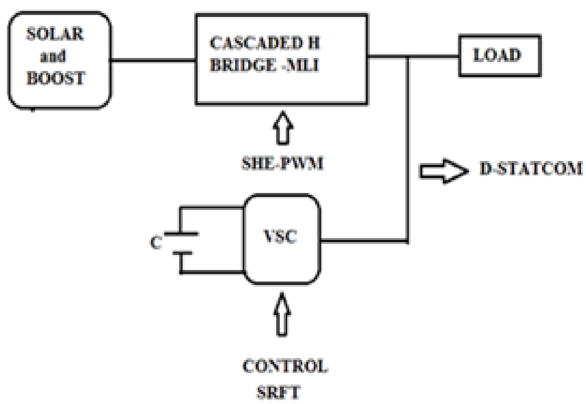

FIG 4. D-STATCOM Block Diagram

Table III

PARAMETERS	RATINGS
Frequency	50Hz
Solar PV	60W
Non-Linear load	R=10ohms L=20Mh
D-STATCOM Inductor Capacitor	1Mh 1000Uf
Vdc	250Volts

SRFT or dqo method:

The load current is clarke and park transformed, as shown in Fig 5. The components are then filtered further, for example, the d component of the load current is high pass filtered to only pass the basic component. Because the source should not provide any reactive power, the q load current component should be 0. The current component of the zero-sequence is left alone. The reference source current is then generated by inverse park and clarke transformations of these current quantities. The load current is subtracted from the reference source current to generate the reference. The pulse generator block is then provided the reference current. The active power current is represented by the d component of current, while the reactive power current is represented by the q component of current. The unbalance in the supply is shown by the o component current. the q component of current. The unbalance in the supply is shown by the o component current.

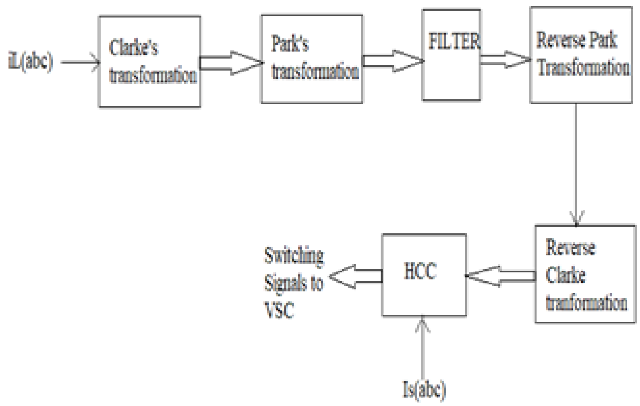

FIG 5. SRFT Block diagram

Hysteresis Controller:

Hysteresis current control is an instantaneous closed loop control approach that makes the inverter's output current I track the command current I while keeping the error within the hysteresis band. Inverters are switched to bring the output current within the error band when the current error (i.e.=i*-i) crosses it. When the output current exceeds the upper band, the inverter leg of the phase considered is brought back within the band by turning on the lower switch and turning off the top switch. As a result, the voltage across the load drops from Vdc to 0 and the current drops accordingly.

When the output current falls below the lower band, the load is connected to Vdc by turning the lower switch off and the higher switch on. As a result, the output voltage across the load rises from 0 to Vdc, and the output current increases. To maintain a balance between output current ripple and switching losses and hence eliminate harmonics, an optimal value of must be chosen. Because each phase is regulated independently in this manner, switching frequency rises unnaturally high, increasing switching losses.

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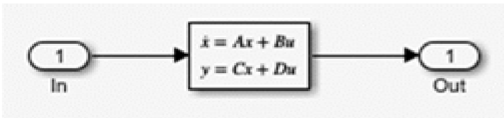
Second Order Filter:

It's occasionally useful to have circuits that can selectively filter one or a range of frequencies from a circuit's mix of frequencies. Filter circuits are circuits that are meant to perform frequency choices. Low-pass, high-pass, band-pass, and notch/band-reject filters are the four primary types of filters, which are active or passive. The low pass filter utilized in this project is a 2nd order filter. This project's 2nd order filter is based on State space realizations. The State space filter is an example of such a filter.



The frequency value and a Zeta value of 0.707, known as the cut-off frequency point, are both present in the 2nd order low pass filter block. The waveform shape changes to sinusoidal and the Harmonics are reduced when the Frequency value is entered. The output voltage of the filter is constant from 0Hz to a cut-off frequency point (Fc) of 1000Hz. The output is three-phase sinusoidal, as seen in the scope, because a three-phase MLI is utilized.

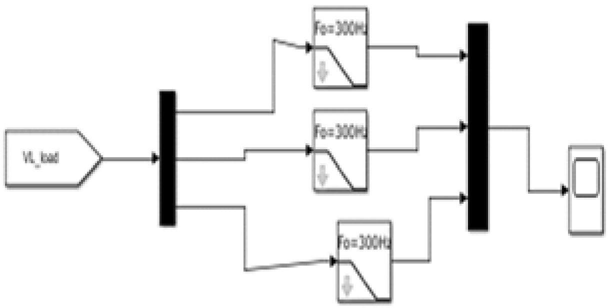


FIG 6. 2[nd] Order Low-pass filter

IV. SIMULATION MODELS AND RESULTS

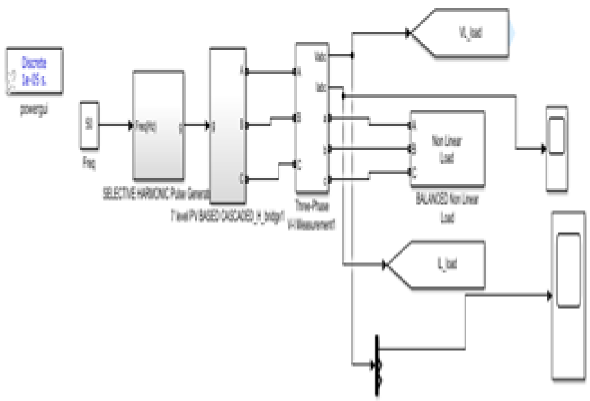


FIG 7. Circuit diagram of three-phase PV based CHB-MLI without D-STATCOM

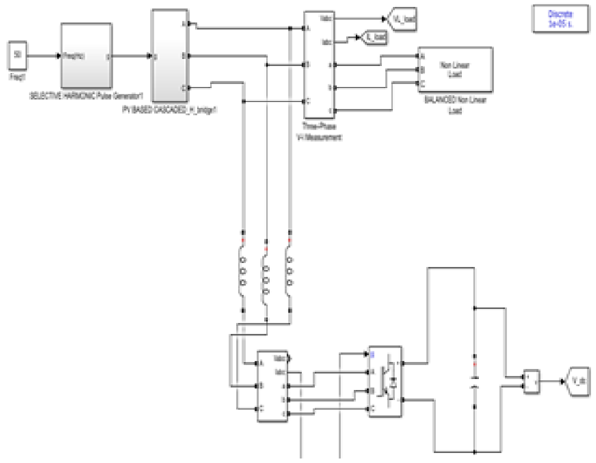


FIG 8. Circuit diagram of three-phase PV based CHB-MLI with D-STATCOM

5-Level without D-STATCOM:

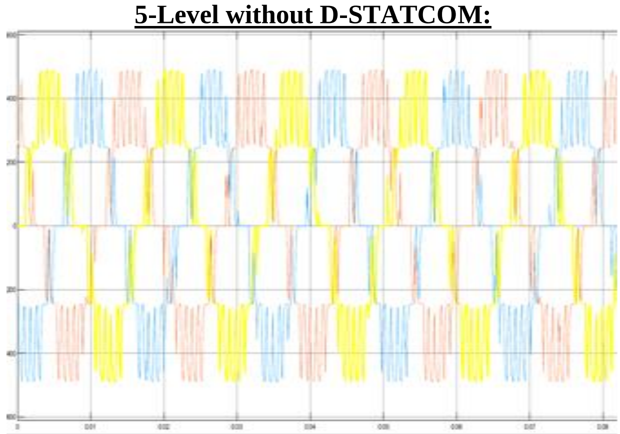


FIG 9. 5-Level CHB MLI Voltage waveform

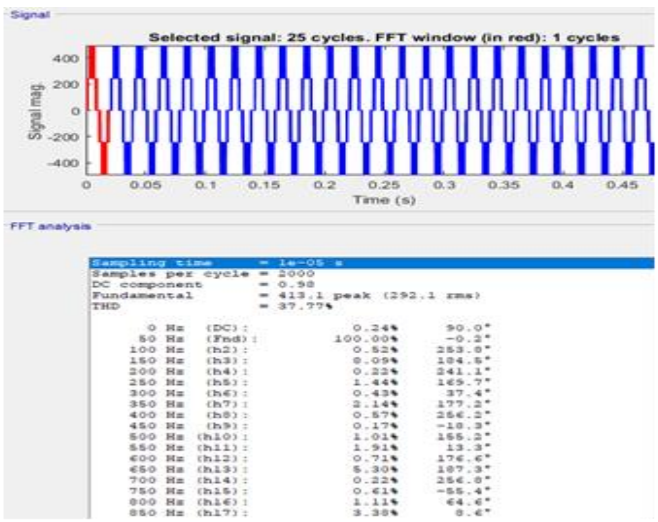


FIG 10. THD%

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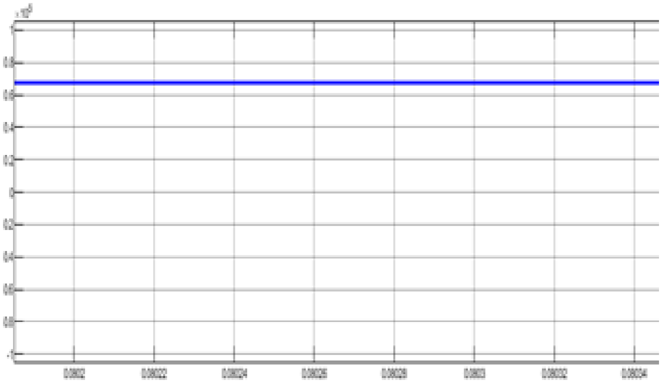

FIG 11. Reactive power

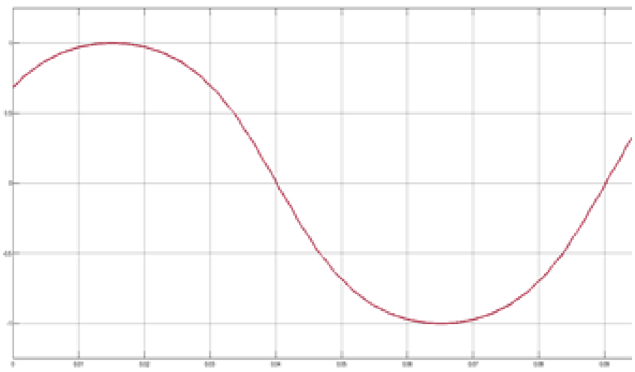

FIG 12. Power factor

5-LEVEL with D-STATCOM:

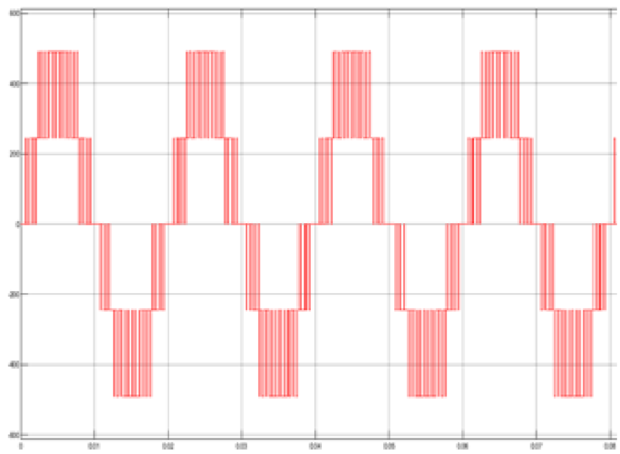

FIG 13 Voltage waveform

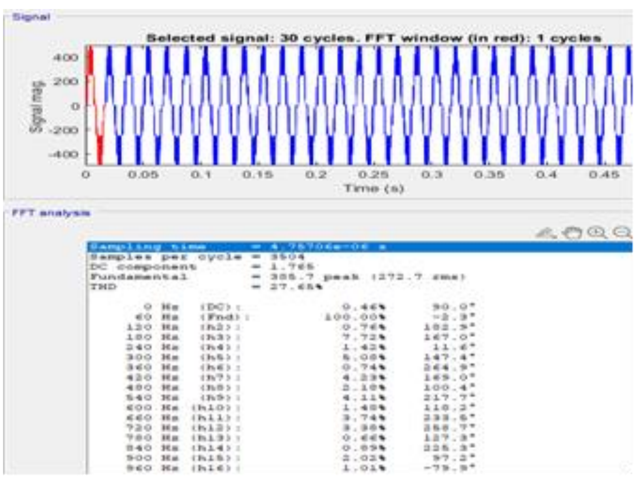

FIG 14. THD%

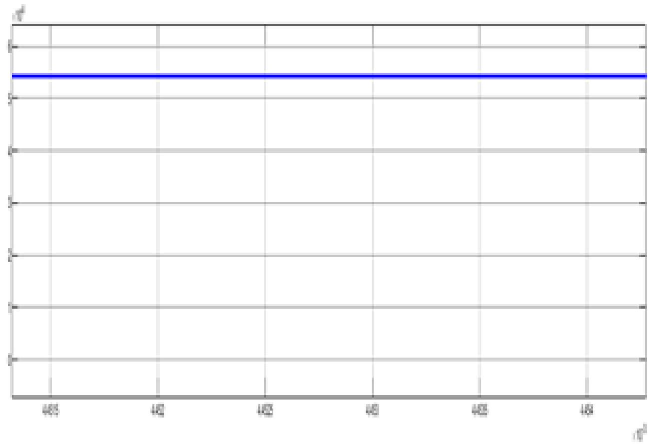

FIG 15. Reactive power

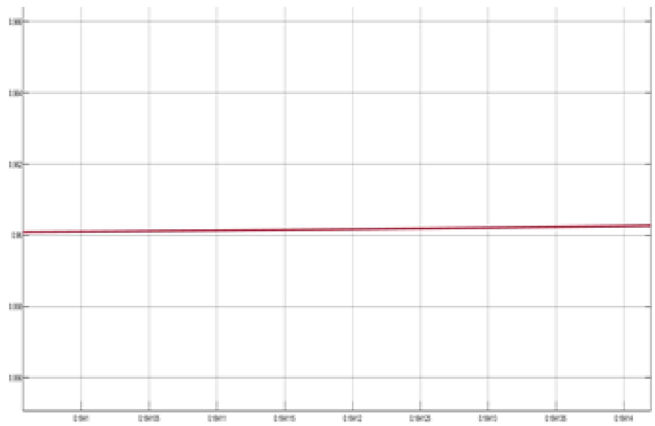

FIG 16. Power factor

Table IV Comparison of 5-Level

PARAMETER	WITHOUT D-STATCOM	WITH D-STATCOM
THD%	37.70%	27.70%
Reactive power	70KW	55KW
Power factor	0.7	0.96

7-Level without D-STATCOM:

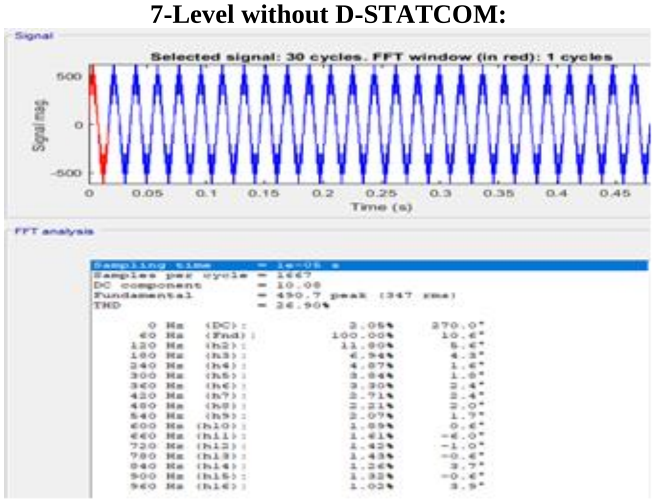

FIG 17. THD%

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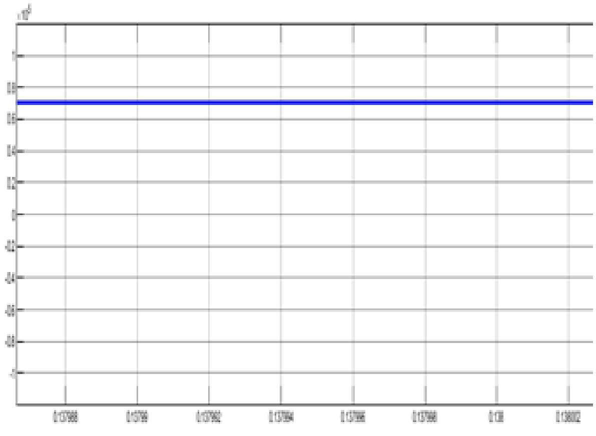

FIG 18. Reactive power

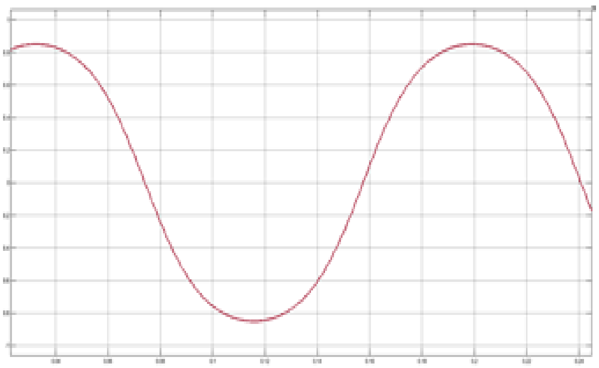

FIG 19. Power factor

7-Level with D-STATCOM:

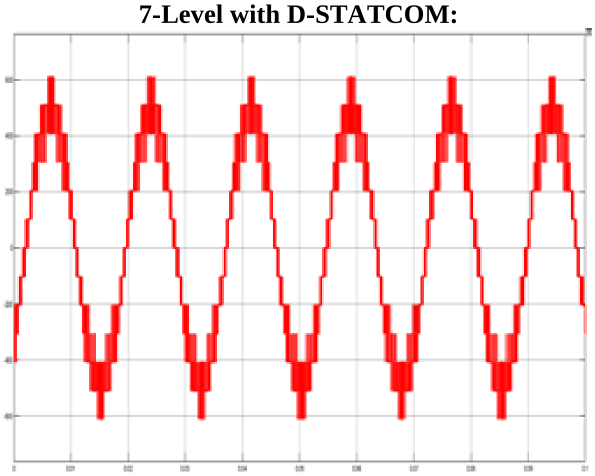

FIG 20. Voltage waveform

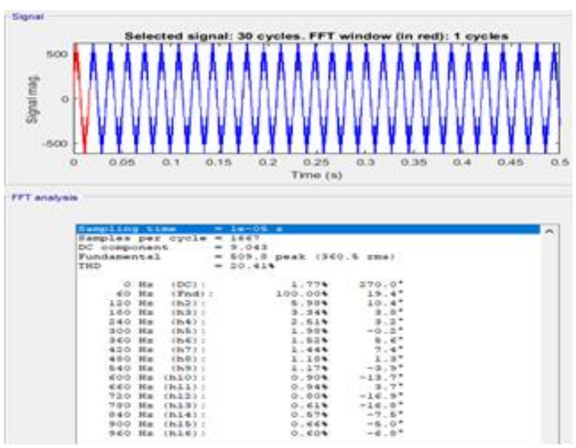

FIG 21. THD%

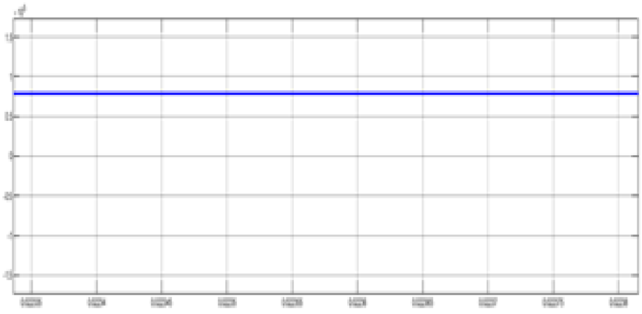

FIG 22. Reactive power

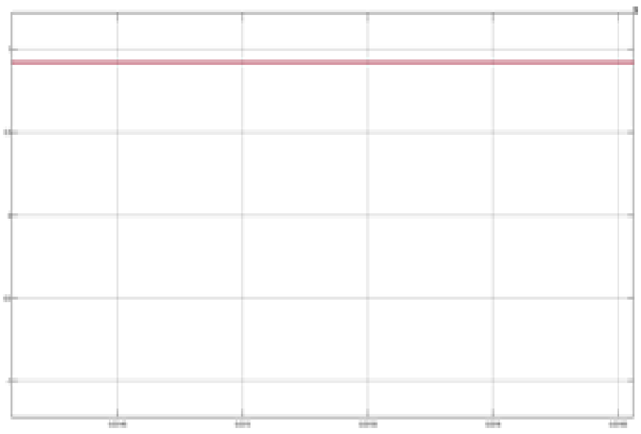

FIG 23. Power factor

Table V Comparison of 7-Level

PARAMETER	WITHOUT D-STATCOM	WITH D-STATCOM
THD%	26.90%	20.40%
Reactive power	70KW	50KW
Power factor	0.8	0.97

Table VI Comparison of 3rd and 5th Harmonics

Model	5	LEVEL	7	LEVEL
Harmonics	3rd	5th	3rd	5th
Without D-STATCOM	8.09%	7.72%	6.94%	3.38%
With D-STATCOM	5.08%	1.44%	3.84%	1.96%

With 2nd order low pass FILTER(5-LEVEL):

FIG 24. Voltage waveform

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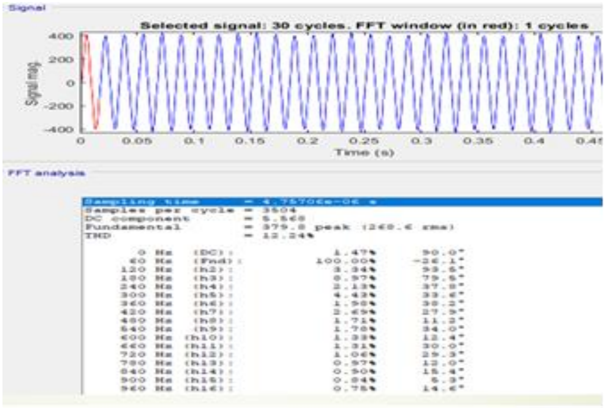

FIG 25. THD%

With 2nd order low pass FILTER(7-LEVEL):

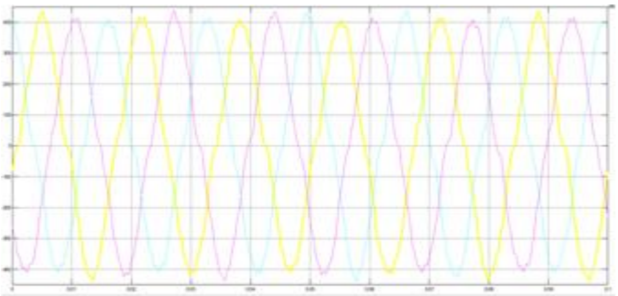

FIG 26. Voltage waveform

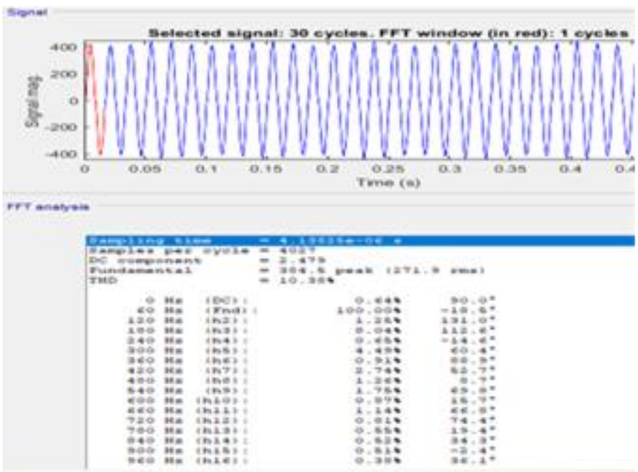

FIG 27. THD%

Table IV Comparison of THD using 2nd order low pass Filter.

Model	THD
5level	**12.24%**
7level	**10.30%**

V. CONCLUSION

This study shows simulation work for a PV-based cascaded H bridge 5-level and 7-level MLI system with D-STATCOM injected at the load side to minimize non-linear load power quality issues. The SRFT control method is injected into D-STATCOM, which compensates for reactive power, eliminates harmonics, and achieves a power factor close to unity. The 3rd and 5th harmonics of 5-level and 7-level are compared and by that we can say for a 7-level, the harmonics are decreased compared to 5-level. A 2nd order low pass filter is also used, which reduces the harmonic percent even more. Based on the comparison of both 5-Level and 7-Level MLIs, it is clear that, as the levels of MLI is increased, the THD decreases. With the SRFT method, we can conclude that for a 7-level the reactive power is compensated in a better way and the power factor is also reached nearly to unity.

FUTURE SCOPE

Power demand is increasing on a daily basis, and with it, power quality issues are becoming more prevalent. As a result, it is necessary to reduce them, and D-STATCOM is the most effective and promising technology for addressing power quality issues. THD can be further reduced by raising the levels of The Multilevel Inverter.

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