SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I3P104

Volume 10 Issue 3, 35-43, March 2023

Original Article

Fuzzy-based Multilevel Inverter with STATCOM in Distributed Generation

G. Geethamahalakshmi[1], Geetha Ramadas[2], S. Vijayalakshmi[3], D. Nageswari[4]

[1]*Department of EEE, Easwari Engineering College, India*
[2, 3, 4] *Department of EEE, R.M.K.College of Engineering and Technology, Thiruvallur, India*

[1]*Corresponding Author : gitatinky@gmail.com*

Received: 13 January 2023 Revised: 28 February 2023 Accepted: 12 March 2023 Published: 29 March 2023

Abstract *- Introducing a new concept for improving power quality in the distributed power generation sectors based on an inverter technology using Distribution STATCOM (DSTATCOM) power quality conditioner using the fuzzy logic controller. A five-level inverter is designed with Space Vector Modulation (SVM) and a fuzzy-based controller for the improvement of the power factor. It enhances the stability of the power system. Also, this concept describes various mitigation methodologies for improving power quality. Simulation results and laboratory-validated results are shown to compare the performances.*

Keywords *- Distributed Generation (DG), Power Quality (PQ), DSTATCOM, Space vector modulation, Fuzzy Based Controller (FBC), Multilevel inverter, Power factor, Reactive power compensation.*

1. Introduction

Electrical energy production can be increased by introducing renewables into the power grid. Distributed Generation is the method of generating electricity from available sources like solar and wind etc., Energy from Solar PV need an inverter for dc to ac conversion. Power quality problems are common if power electronic converters are used. DG interconnection requires inverters and converters, which introduces major power quality issues like harmonic content, voltage instability, reactive power and power factor issues. Electrical energy generation from solar and wind is inconsistent, so it can be integrated with the existing grid to enhance production.

The electrical energy requirement is increasing at a rapid rate nowadays, but the production of electrical energy from fossil fuels is adversely affecting the environment. This can be minimized by introducing renewables into the power grid. Renewable resources are abundant in nature, by using which green energy can be produced. Distributed Generation is the method of generating electricity from available sources like solar and wind etc., Energy from Solar PV need an inverter for dc to ac conversion. Power quality problems are common if power electronic converters are used. DG interconnection requires inverters and converters, which introduces major power quality issues like harmonic content, voltage instability, reactive power and power factor. Electrical energy generation from solar and wind is inconsistent, so it can be integrated with the existing grid to enhance production.

The sinusoidal nature of the alternating voltage and current is very much affected by nonlinear loads, which results in harmonics. Harmonics is a major power quality issue when renewables are integrated with the grid. Inverters used in photovoltaic systems are the major cause of the harmonics in voltage and current waveforms. The harmonic current flow is capable of producing communication interference. The output generated from an inverter will be a square waveform, not a sinusoidal waveform. If the equipment is connected to the inverter, feeding non-sinusoidal output results in increased heating, firing issues in variable speed drives and producing pulsations in electric motors. It is very challenging to maintain the shape of the output of the inverters.

While DG may be relied on to produce electricity, the quality of that electricity is not always guaranteed. Every utility's distribution system aims to ensure that all customers are supplied with uninterrupted power at the appropriate voltage and frequency in a smooth, sinusoidal waveform. The nonlinear loads present in a power system with distribution networks greatly impact the power quality. Other than nonlinear loads, switching of the capacitor, motor starting, and unexpected failures are all variables that might affect Power Quality (PQ). The trouble with Power Quality (PQ) is the consequence of frequency variation caused by voltage and current, which ultimately causes the failure or malfunction of the loads. Voltage dips and spikes are becoming more common in industrial operations as a result of this PQ issue.

Power companies have been struggling in recent years, but new research shows that old approaches-such as employing force-commutated power electronics with fast-controlled devices-can effectively lower PQ. PQ compensators may be broken down into two distinct categories, each using a different strategy to mitigate PQ issues. The first approach is to use a shunt-connected compensating device to get rid of harmonic issues to lower PQ effectively.

In this case, the FACTS devices known as STATCOM are used in a distributed network known as Distribution STATCOM (DSTATCOM) with minor modifications by using the same configuration of STATCOM, which has advantages over shunt type for rectifying distorted system side voltages and power transmission system faults like voltage sag etc. Both the reactive and active power components may be exchanged with the distribution system to alter the converter voltages' amplitude and phase angle relative to the line terminal voltage. The conventional technique known as a multilevel inverter is utilized, enhanced by the addition of voltage levels, to reduce the device voltage and the output characteristics, among them harmonics.

The three primary approaches to multilevel inverters are the (1) cascading H-bridge circuit, (2) the neutral point clamped converter circuit, and (3) the flying capacitor converter circuit. When choosing among these architectures, CHB inverters are the most common due to their compatibility and simplicity. CHB inverters may use several modulation techniques. In a CHB inverter, increasing the number of R-bridges quickly and simply increases the number of available output voltage levels. This work discusses the usage of a proportional integral controller (PI controller) based CHB multilevel inverter with a Fuzzy logic controller to mitigate nonlinear load harmonics and lower the reactive power content. These techniques have widely been used in PQ applications because of their many benefits, including improved voltage regulation, lower switching losses, enhanced electromagnetic compatibility in hybrid filters, and the complete absence of higher-order harmonics.

Developing a Fuzzy Logic (FL) controller is very useful for developing better control systems; it reduces the complexity of the systems. Many applications are making use of fuzzy logic control, and there is tremendous growth in the number of applications. Over the decades, we have witnessed rapid growth in the application of fuzzy logic control. The various applications are consumer products, medical instruments, industrial applications and decision support systems. Fuzzy logic means the relative accuracy and precision parameters. It has two methods of context; in a limited sense, it has a logic system extended with numerous valued logic, but in a broader view of FL controller, also it has a fuzzy set theory and logic controller.

A fuzzy logic controller can be modelled in nonlinear systems to design and analyze the system parameters. The method of the traditional control system is normally based on the analytical model of the system; if a good mathematical prototype is made available with known parameters, it can be examined.

For example, the controller can be designed for the required performances using various stability analysis methods named bode plots or nyquist plots. However, these stability methods may require longer processing and system performance identification. FL controller has flexible features. The flexible features contain powerful performance, which is the unpredictability of various frameworks and load side disturbances-FL controller explicitly the various operational logics and laws in linguistics terms instead of analytical equations.

Most system models are too complex to model accurately and preciously, although with complex analytical equations; therefore, traditional technique implies more achievable in the various systems. FL controller provides a convenient technique for describing the operational features of such systems.

2. Literature Survey

In this paper [1], the author discussed the realization of DSTATCOM is used in a three-phase bridge inverter circuit along with two neutral-clamped DC storage capacitors. Three filter capacitors are connected one by one like a parallel connection with DSTATCOM to reduce various switching components in high-frequency circuits. In order to maintain the AC bus voltage, a dead-beat controller is used to control the voltage across the filter capacitor. A nominal value of 1.0 p.u. is chosen as the magnitude of the bus voltage, and its phase angle is found as a feedback loop which maintains the voltage across the DC storage capacitors.

The author in paper [2] deals with the algorithm to intensify the transient performance of static synchronous compensator (STATCOM) by integrating a new reactive current reference. A multilevel inverter of cascaded multilevel inverter with separated DC capacitors is used and operated by the carrier-based pulse width modulation to implement the STATCOM.

In this paper [3], the author deals with the five-level cascaded H-bridge (CHB) inverter and DSTATCOM to compensate for the reactive power and harmonics of the power system. Low harmonic distortion, reduced number of switches, and elimination of switching losses are the various advantages of using CHB inverters. Also, the DSTATCOM helps to enhance the power factor and eradicate the total harmonic distortion (THD) drawn from a Nonlinear diode rectifier load.

The author of this paper [4] proposes the closed-loop model for a static compensator (STATCOM). The controller used in this technique is PI and PD controllers, in which the PD controller is found to have better performance to eliminate the harmonics. This model also concerns the load current's instantaneous active fundamental component.

In this paper [27], the author used a diode-clamped multilevel inverter in the static compensator. The author proposes the multilevel inverter switching strategy and output voltage model. In this, various issues like voltage balancing and circuit solutions were discussed, and finally, STATCOM/BESS was used. The system is simulated using the diode-clamped multilevel inverter to reduce the harmonics and the total harmonic distortion.

A 7-level cascaded H-bridge inverter is proposed for designing a multilevel STATCOM by the author in the article [6]. (M-STATCOM). Numerous analyses have been done on steady-state performance, dynamic MSTATCOM behavior, and capacitor voltage regulation and balancing. The fundamental frequency switching (FSS) approach with pulse rotation and the pulse width modulation (PWM) methodology are two of the suggested switching techniques in this research. In order to lower the system's harmonics, MATLAB is used to model the system and performs a number of analyses.

Universal STATCOM (USTATCOM) and cascade multilevel inverter with delta connection are proposed in this study [7]. Due to imbalanced loads, a negative sequence current is produced, and this USTATCOM is used to cancel out that current. We simulate the suggested system in MATLAB and explore the resulting findings for filtering out harmonics.

This article [8] discusses a wide range of specialized power devices that enhance power quality. We analyze the many factors that contribute to poor power quality and come to the conclusion that installing a STATCOM will help reduce voltage fluctuations and spikes. In this paper [9], the effects of increasing nonlinear loads in industries are discussed, and a 11-level cascaded multilevel inverter-based DSTATCOM is implemented to reduce harmonic content. Comparison of proposed scheme and hybrid filter results are compared.

This paper [10] discusses using custom power devices in power quality compensation. The features of different types of STATCOM are discussed. A 3-dimensional Space vector modulation technique is implemented with a four-leg DSTATCOM, and using a power quality analyzer, total harmonic distortion of various voltages and currents is measured.

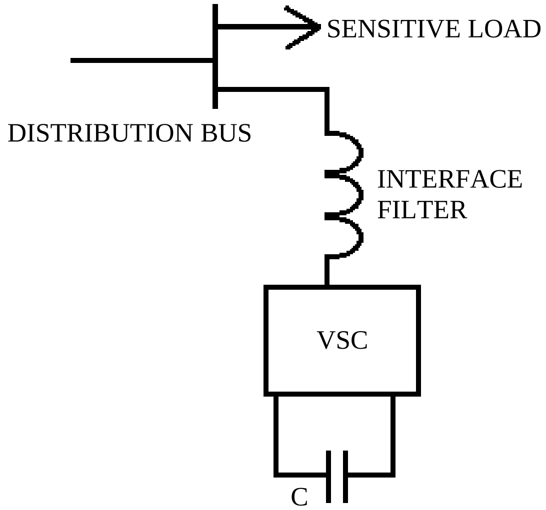

Fig. 1 Basic structure of DSTATCOM

3. System Description

3.1. Principle of DSTATCOM

The DC-amount capacitor circuit, the VSC, and the inductive coupling device comprise a Distribution Static Compensator (DSTATCOM), as illustrated in simplified form in Figure 1. The direct current component is transformed to three-phase alternating current before being sent to distribution line systems through the leakage inductance of a coupling transformer. Figure 1 displays the fundamentals of a DSTATCOM; if the voltage at the AC terminals and the voltage at the VSC output is the same, no reactive power is given to the system. If the DSTATCOM output voltage is greater than the terminal voltage on the AC side, the device enters capacitive mode; otherwise, it enters inductive mode. The reactive power flow in the system is proportional to the difference between the two voltages.

The system's reactive power is compensated, and the voltage side of the system is controlled at the point of common coupling by managing the magnitude of VSC, i.e., the voltage in the output side (PCC).

The VSC connected in shunt along with the AC system implement a multifunctional (various network) topology which can be used for the following advantages: 1) Regulation Voltage and reactive power compensation, 2) Power factor correction and improvement, 3) Reduction of harmonics in current levels.

3.2. Reactive Power Compensation

The major cause for compensation of reactive power in a system is: 1) Regulation on the voltage side, 2) Improved system stability, 3) Effective utilization of the system, which is connected to the machines, 4) reduced system losses, and 5) to restrict the voltage sag and voltage collapse in the system [11-12,19].

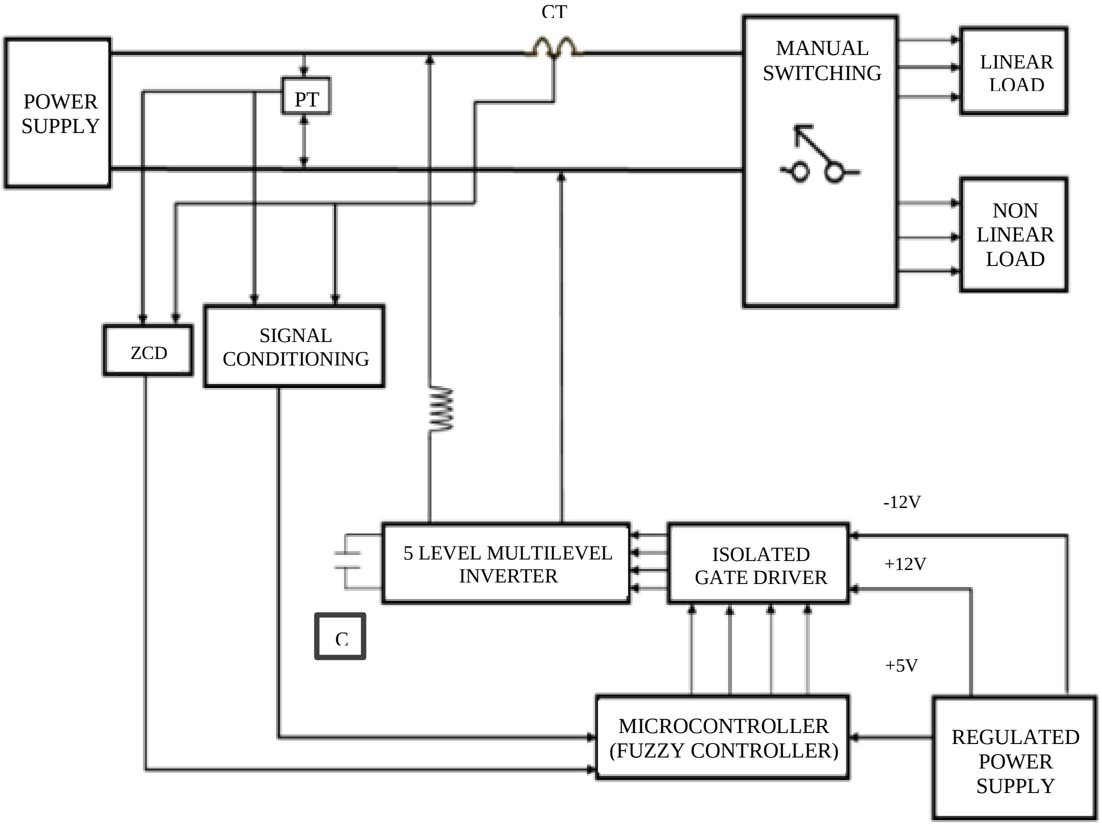

Fig. 2 Block diagram of proposed system - multilevel inverter and DSTATCOM

The impedance parameters of transmission lines and the necessity for VAR lagging result in the utilization of reactive power, which is affected by the stability limits of the system. Redundant voltage drops lead to higher losses which need to be supplied by the source, leading to the line's outages. Hence, the compensation of reactive power is necessary to rectify the abovementioned parameters and better transient response to faults and disturbances [13, 28]. In a distribution substation or in a transmission substation, the shunt compensation can be installed near the load [14-16].

3.3. Harmonic Compensation

In order to eliminate the harmonics, the multilevel inverter is proposed as CHB multilevel inverter. These CHB multilevel inverters have several advantages,

1) It contains common mode voltage, which reduces pressure and stain of the motor and will not harm the motor.
2) These multilevel inverters can depict the input current with low distortion.
3) The multilevel inverter can work at fundamental switching frequencies of both the components that improvise the switching frequency and decrease the switching frequency.
4) It lowers the total harmonic distortion in the output waveform without implementing any filter circuit.

4. Existing and Proposed System

The problems identified by using a normal system are,

1) Mitigation of sag and swell is limited
2) Supply to the inverter is obtained from the line where the level of harmonic content is more.
3) Challenging to get pure sine wave
4) By using a normal inverter, the harmonic content is more; due to this, there will be an increase in the usage of filter design.

In order to overcome these difficulties, the following system was proposed. Figure 2 shows the proposed system's block diagram along with the Multilevel inverter usage.

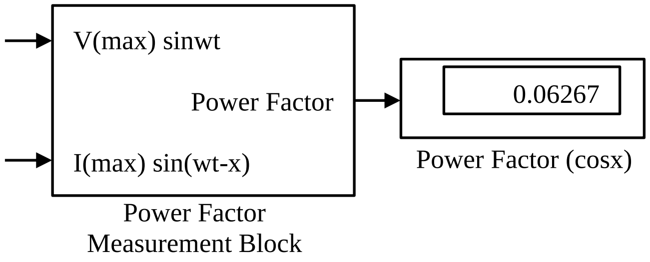

Fig. 3 Power factor of the uncompensated system

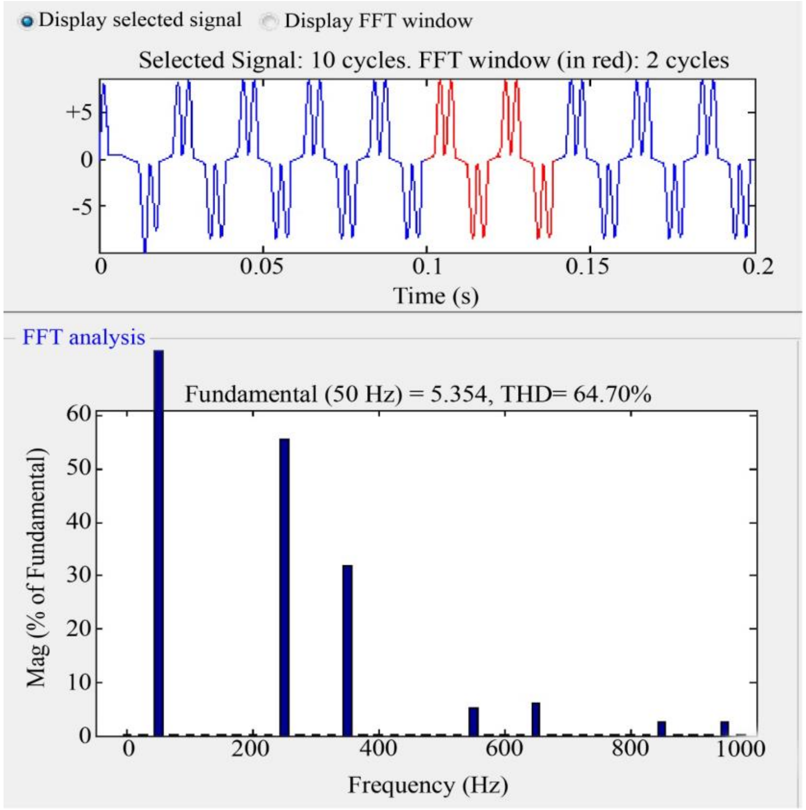

Fig. 4 Load current THD of the uncompensated system

Table 1. Comparative analysis of various parameters - system without compensation

Configuration	Parameters	
	Power factor	THD (%)
System without compensation	0.6267	64.7

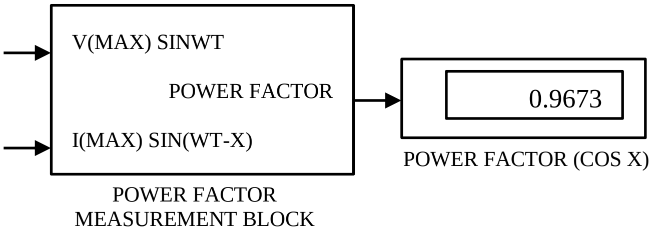

Fig. 5 Matlab simulink diagram for proposed work power factor calculation

The various advantages of the proposed system are,

1) Additional high step-up voltage multiplier is designed.
2) Utilization of Green energy
3) Good response for both balance and unbalanced load conditions.
4) Achievement of the pure sine wave.

The methodology used here is DSTATCOM, along with a proportional integral controller (PI controller) based CRB multilevel inverter with a Fuzzy logic controller [17, 18, 29].

5. Simulation and Results

With modern technology, the power system made vital changes in the aspects of the distribution system. The key role of the power systems includes stability, compensation, harmonics analysis, voltage control and power quality. Among all these, power quality (PQ) are the major requirement in the field of the power system as well as power electronics. Analysis like power factor, total harmonic distortion etc., can be done in the power quality aspects with the usage of power electronic components. Using the power electronic components tends to draw the harmonics and reactive power from the source, leading to the disturbance and distortions in the voltage and current waveform [20-24].

Figure 3 and Figure 4 show the system without compensation, voltage and current waveform, observation of power factor parameter and THD for Load current analysis. Before compensation, the system gets distorted, and the voltage and current waveform also gets distorted.

The power factor is observed as 0.6267, and its total harmonic distortion for Load current is observed as 64.7%. Drastic distortion is observed by using this configuration. Table 1 shows the comparative analysis of various parameters using without compensation system. Before compensation, the power quality issues like more harmonic distortion and less power factor are observed.

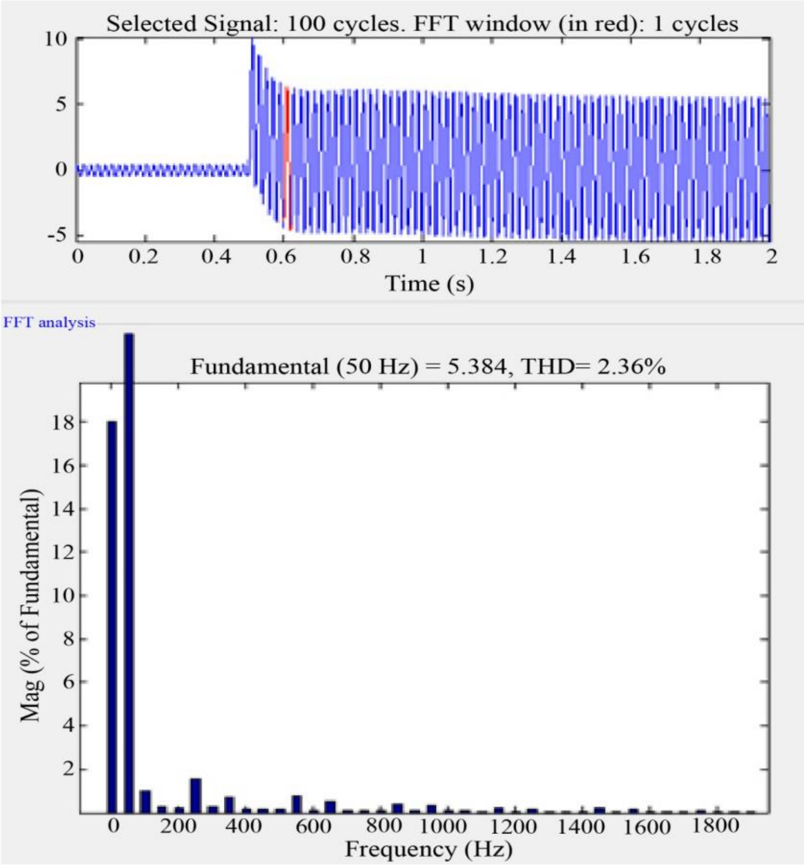

Fig. 6 Load the current THD of the proposed system with a DSTATCOM-based CHB multilevel inverter

Table 2. Comparative analysis of various parameters – system with compensation

Configuration	Parameters	
	Power factor	THD (%)
System without compensation	0.9673	2.36

Table 3. Comparative analysis of various parameters without and with compensation

Configuration	Parameters	
	Power factor	THD (%)
System without compensation	0.6267	64.7
System with compensation	0.9673	2.36

Hence, it is required to compensate the system using a multilevel inverter along with reactive power compensation like D-STATCOM, and the controller used here is the fuzzy logic controller. Figure 5 shows the Matlab simulink diagram for the proposed work Power factor calculation.

Cascaded - H - Bridge multilevel inverter is the most popular inverter because of the medium-voltage high-power inverter. It requires isolating the transformer with each isolated power source in individual cells. By proper switching arrangements, the inverter's output voltage will get 2Vab. Because of the advantages of switching redundancy and simple packaging structure, the cascaded multilevel inverter is used in this proposed system in Figure 6.

To improve the PQ issues, like increasing the power factor and reducing the THD, MLI used a reactive power compensation called D-STATCOM at the point of common coupling (PCC) [25]. Inverter is used to supplies the required reactive current to the compensator with the help of controller with the help of controller called a Fuzzy Logic Controller (FLC). It compensates for the reactive power and enhances the power quality by improving the power factor and reducing the THD.

With the help of MATLAB/Simulink tool, the performance parameters will be analyzed and compared the results by using without and with compensation techniques: Figure 7 and Figure 8 show power factor analysis and THD for the load current. The improved power factor and reduced THD were shown in the simulated results, and the hardware prototype of the D-STATCOM network, along with MLI, was built. The results were tested and verified with the simulated results. The comparative analysis of various parameters is shown in Tables 2 and Table 3.

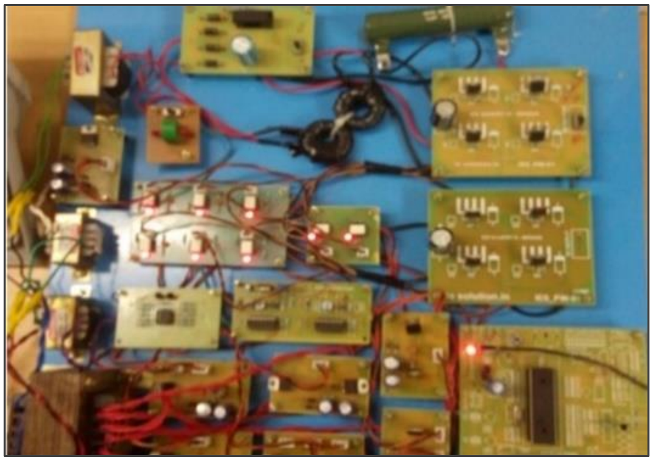

Fig. 7 Experimental setup of D-STATCOM-based inverter

6. Experimental Setup of STATCOM-based System

6.1. D-Statcom based Inverter

Figure 7 shows the experimental setup of D-STATCOM Based Inverter. The proposed method is carried out for RL-Load of simulation results, and the harmonic levels were eliminated using fuzzy controllers[26].

The performances of the proposed inverter were tested experimentally by using STATCOM compensation. The inverter is enacted as STATCOM to compensate for the reactive load power. The reactive power injection is into the system of PCC, and the voltage stability is maintained. The compensation is done for both linear and nonlinear loads.

Figure 8 shows the power factor at linear loads. At time t = 2ms, the magnitude of linear load changes and the steady state time is achieved gradually at time t = 5ms. Figure 9 shows the power factor at Nonlinear Load; at time t = 2.2ms, the output gets the distorted waveform, and the results show that the settling time is very high, which is not appreciable for the active results.

Figure 10 shows power factor after injection. In this waveform, At time t=1.5ms, the input voltage seems to be lesser and the increase in the inverter voltage which regulates the load. The maximum magnitude of inverter voltage is obtained, injects the harmonics, regulates the load, and gives accurate results.

Figure 11 shows the zero cross detector output, and finally, the next waveform is Figure 12. It Shows the inverter output. At time t=0.5ms and at the voltage of 5V, the inverter output voltage performs better. It injects the reactive power to attain the regulated output power, which in turn reduces the total harmonic distortion. The input parameters of the experimental setup are shown in Table 4.

6.2. Power Factor at Linear Load

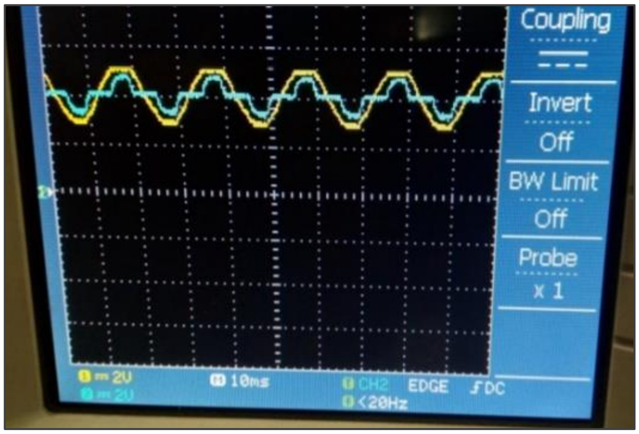

Fig. 8 Power factor at linear load

6.3. Power Factor at Nonlinear Load

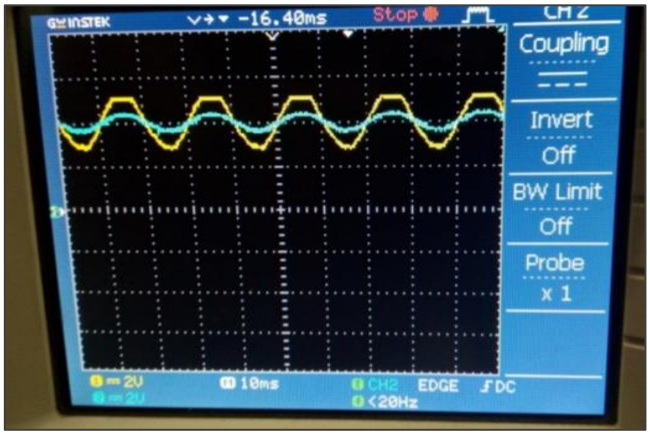

Fig. 9 Power factor at nonlinear load

6.4. Power Factor after Injection

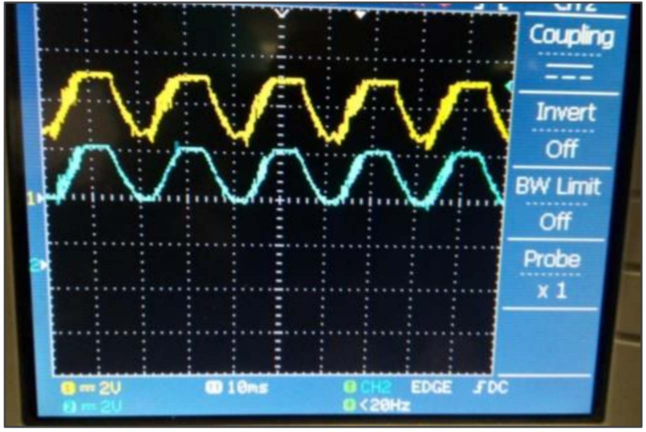

Fig. 10 Power factor after injection

6.5. Zero Cross-Detector Output

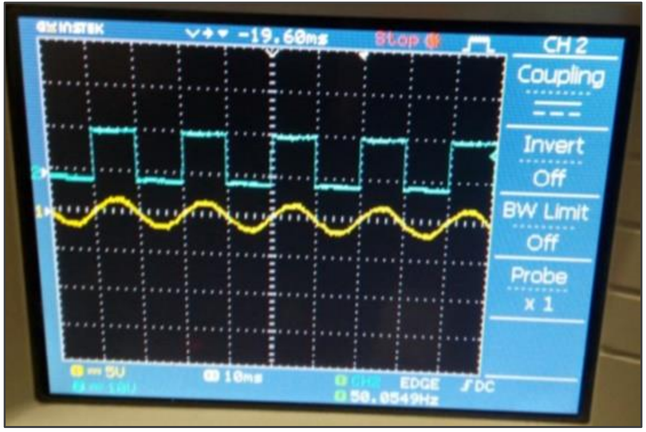

Fig. 11 Zero cross detector output

6.6. Inverter Output

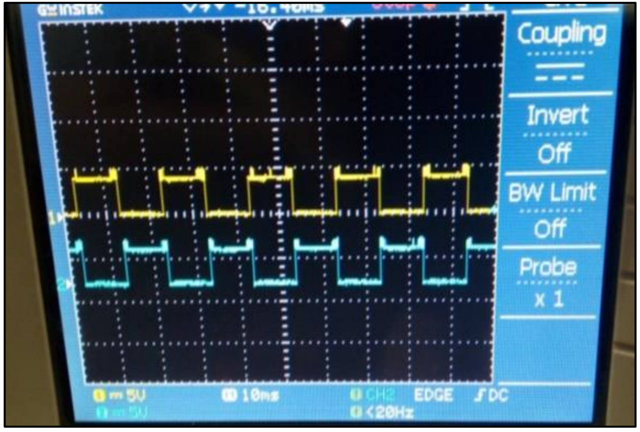

Fig. 12 Inverter output

Table 4. Simulation parameters

Parameters	Different values
Input DC voltage magnitude	100 V, 200V
Load	R = 25 Ω, L = 20mH
Rating of Power MOSFET	500V, 20A, 0.3Ω
Rating of Power Diode	200V, 20A

7. Conclusion

To better the power quality parameters, this research covers both the theoretical principles of study and the simulation of fuzzy logic controllers using a DSTATCOM-based multilevel inverter. Switching pulses are generated with the help of a five-level multilevel inverter that is accomplished with the help of synchronous voltage modulation. Because it relies on human expertise rather than mathematical calculations, the FL controller utilized here is a departure from the usual when it comes to controller approaches. Fuzzy controllers, fuzzy rules, and laws underpin the control operator's design, allowing maximum flexibility. The suggested fuzzy-based controller demonstrated that the performance of a conventional controller might be significantly enhanced via the use of this novel approach. All of the design methods have been shown successful via MATLAB simulations. It also improves the reliability and management of the electrical grid. The simulation results for DSTATCOM reveal that the FL controller is the optimal replacement for the traditional controller.

References

[1] M. K. Mishra, A. Ghosh, and A. Joshi, "Operation of a DSTATCOM in Voltage Control Mode," *IEEE Transactions Power Delivery*, vol. 18, no. 1, pp. 258–264, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[2] Law Kah Haw, Mohamed S. A. Dahidah, and Haider A. F. Almurib, "A New Reactive Current Reference Algorithm for the STATCOM System based on Cascaded Multilevel Inverters," *IEEE Transactions on Power Electronics*, vol. 30, no. 7, pp. 3577–3588, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[3] B. Jegajothi et al., "Combination BFPSO Tuned Intelligent Controller for Maximum Power Point Tracking in Solar Photovoltaic Farm Interconnected to Grid Supply," *Control and Measurement Applications for Smart Grid*, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[4] K. K. Mahapatra, A. Ghosh, and S. R. Doradla, "Simplified Model for Control Design of STATCOM using Three-level Inverter," *Proceedings of IEEE TENCON '98. IEEE Region 10 International Confrence on Global Connectivity in Energy, Computer, Communication and Control*, 1998. [CrossRef] [Google Scholar] [Publisher Link]

[5] M. Usharani et al., "An Optimized Deep Learning Model Based PV Fault Classification for Reliable Power Generation," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 9, no. 9, pp. 23-31, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[6] H. K. Al-Hadidi, and R. W. Menzies, "Investigation of a Cascade Multilevel Inverter as an STATCOM," *2003 IEEE Power Engineering Society General Meeting*, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[7] F. Z. Peng, and Jin Wang, "A Universal STATCOM with Delta-connected Cascade Multilevel Inverter," *2004 IEEE 35th Annual Power Electronics Specialists Conference*, vol. 5, pp. 3529–3533, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[8] Eklas Hossain et al., "Analysis and Mitigation of Power Quality Issues in Distributed Generation Systems Using Custom Power Devices," *IEEE Access*, vol. 6, pp. 16816–16833, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[9] Tejinder Singh Saggu, Lakhwinder Singh, and Balbir Gill, “Harmonics Mitigation in a Steel Industry Using 11-Level Cascaded Multilevel Inverter-Based DSTATCOM,” *Canadian Journal of Electrical and Computer Engineering*, vol. 40, no. 2, pp. 110–115, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[10] Alladi Pranay Kumar, Ganjikunta Siva Kumar, and Dharmavarapu Sreenivasarao, “Model Predictive Control with Constant Switching Frequency for four-leg DSTATCOM using Three-dimensional Space Vector Modulation,” *IET Generation, Transmission and Distribution*, vol. 14, no. 17, pp. 3571–3581, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] G Geethamahalakshmi, N Kalaiarasi, and D Nageswari, “Fuzzy Based MPPT and Solar Power Forecasting using Artificial Intelligence,” *Intelligent Automation and Soft Computing*, vol. 32, no. 3, pp. 1667-1685, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[12] D Nageswari, N Kalaiarasi, and G Geethamahalakshmi, “Optimal Placement and Sizing of Distributed Generation using Metaheuristic Algorithm,” *Computer Systems Science and Engineering*, vol. 41, no. 2, pp.493-509, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[13] Deepak Pandey, Manish Khemariya, and Anand Singh, “Performance Analysis of Hybrid Renewable Source RSC-MLC Module Integrated D-STATCOM with PQ Controller,” *International Journal of Engineering Trends and Technology*, vol. 70, no. 7, pp. 471-478, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] Milad Sadoughi et al., “PSO-optimized SHE-PWM Technique in a Cascaded H-bridge Multilevel Inverter for Variable Output Voltage Applications,” *IEEE Transactions on Power Electronics*, vol. 37, no. 7, pp. 8065-8075, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Kourosh Khalaj Monfared et al., “Optimal Switching-sequence-Based Model Predictive Control for a Hybrid Multilevel STATCOM,” *IEEE Transactions on Industrial Electronics*, vol. 69, no. 10, pp. 9952-9960, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[16] Milad Sadoughi et al., “PSO-optimized SHE-PWM Technique in a Cascaded H-bridge Multilevel Inverter for Variable Output Voltage Applications,” *IEEE Transactions on Power Electronics*, vol. 37, no. 7, pp. 8065-8075, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[17] K. Ranjith Kumar, M. Venkatesan, and R. Saravanan, “A Hybrid Control Topology for Cascaded Multilevel Inverter with Hybrid Renewable Energy Generation Subsystem,” *Solar Energy*, vol. 242, pp. 323-334, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[18] Xiaoqiang Guo et al., “Improved Modulation Strategy for Singe-phase Cascaded H-bridge Multilevel Inverter,” *IEEE Transactions on Power Electronics*, vol. 37, no. 3, pp. 2470-2474, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] J. Shirisha et al., “Deep Learning-Based Image Processing Approach for Irradiance Estimation in MPPT Control of Photovoltaic Applications,” *SSRG International Journal of Electrical and Electronics Engineering*, vol. 9, no. 9, pp. 32-37, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[20] Tetali Swathi et al., “Design of Cascaded Modular Multilevel Converter for Grid Connected PV System,” *SSRG International Journal of Electrical and Electronics Engineering*, vol. 6, no. 4, pp. 13-21, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[21] Vo Thanh Ha, Pham Thi Giang, and Phuong Vu, “Multilevel Inverter Application for Railway Traction Motor Control,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 4, pp. 1855-1866, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Yuan Li, and Muhammad Humayun, “Analysis of Cross-connected Half-bridges Multilevel Inverter for STATCOM Application,” *Electronics*, vol. 9, no. 11, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] Bi Liu et al., “Performance Improvement of DC Capacitor Voltage Balancing Control for Cascaded H-bridge Multilevel Converters,” *IEEE Transactions on Power Electronics*, vol. 36, no. 3, pp. 3354-3366, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[24] Renner Sartorio Camargo et al., “A Novel Cascaded Multilevel Converter Topology Based on Three-Phase Cells with Model Predictive Control,” *2020 IEEE 29th International Symposium on Industrial Electronics (ISIE)*, pp. 1161-1166, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[25] Zhongxi Li et al., “A Reduced Series/Parallel Module for Cascade Multilevel Static Compensators Supporting Sensorless Balancing,” *IEEE Transactions on Industrial Electronics*, vol. 68, no. 1, pp. 15-24, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[26] M. Infenshirley et al., “Design of Fuzzy Controller for PV Solar Plant as STATCOM (PV-STATCOM) to Mitigate SSR,” *International Journal of Engineering Trends and Technology*, vol. 70, no. 4, pp. 389-402, 2022. [CrossRef] [Publisher Link]

[27] Ying Cheng, and M. L. Crow, “A Diode-clamped Multi-level Inverter for the StatCom/BESS,” *2002 IEEE Power Engineering Society Winter Meeting*, vol. 1, pp. 470–475, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[28] Akhil Gupta, “Power Quality Evaluation of Photovoltaic Grid Interfaced Cascaded H-bridge Nine-level Multilevel Inverter Systems Using D-STATCOM and UPQC,” *Energy*, vol. 238, p. 121707, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[29] Mohsen Asoodar et al., “A Condition Monitoring Scheme for Semiconductor Devices in Modular Multilevel Converters with Cascaded H-bridge Submodules,” *2022 24th European Conference on Power Electronics and Applications (EPE'22 ECCE Europe*, pp. 1-9, 2022. [Google Scholar] [Publisher Link]