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Five level modified CHB D-STATCOM for harmonic mitigation of EV charging station

Prashant Kedarnath Magadum,[1,2*] Sangamesh G Sakri[3]

[1]Visvesvaraya Technological University, Belagavi, Karnataka, India. [2]Electrical Engineering Department, Brahmdevdada Mane Institute of Technology, Solapur, India. [3]Electrical Engineering Department, Poojya Dodappa Appa College of Engineering Kalburgi, India.

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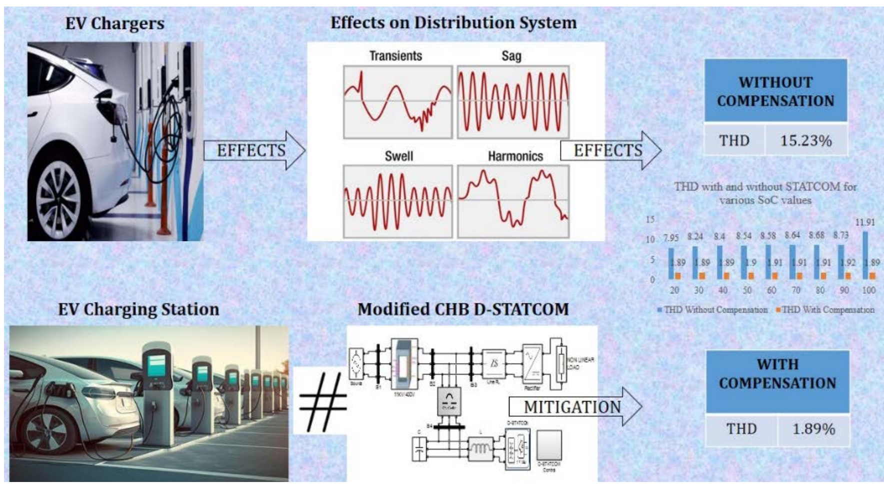
Article

ABSTRACT



An electric vehicle (EV) charging station can be considered a non-linear load because it typically uses power electronics in the forms of rectifiers or inverters to form the necessary interface required for EV charging. These power electronics devices introduce nonlinearities in the current draw from the grid. Non-linear loads draw non-sinusoidal current thus resulting in harmonics. In the case of an EV charging station, the power electronics devices can cause harmonic distortion due to their switching action. This harmonic distortion can affect the power quality of the electrical system. The STATCOM (Static Synchronous Compensator) is an emerging solution for mitigating harmonics. Multilevel converters have found extensive utilization in STATCOM applications due to their capacity to enhance the compensator's power rating, rendering it appropriate for medium or high-voltage situations requiring substantial power output. This results in improved efficiency and reduced electromagnetic interference. The modified cascaded H-bridge topology of multilevel inverters allows for increased voltage levels and reduced harmonic distortion, while the DQ theory provides a robust and efficient control strategy. This paper presents a five level modified cascaded H-bridge (MCHB) D-STATCOM controlled with SRF theory to improve harmonic profile of the EV charging station. The performance is evaluated through MATLAB/Simulink simulation and the results show its effectiveness in improving power quality under different operating conditions. The proposed system offers several advantages over existing approaches, including increased voltage levels, reduced harmonic distortion, and improved control performance.

Keywords: Power quality, harmonics, Cascaded H-bridge, DSTATCOM, DQ theory

INTRODUCTION

The widespread use of EV battery chargers in electric networks would pose a risk to the quality of the electrical power. Grid connected EV chargers are rectifier based non-linear devices that introduce current harmonic and degrade the quality of the electrical power ref[1]. Fast charging stations have high charging loads, which results in higher demand for peak loads, smaller reserve margins, voltage fluctuations, and reliability problems. The location of charging stations poses a potential impact on the effectiveness of the entire system, both positively and negatively. As a result, the positioning of expanding charging stations must take Voltage stability, Reliability, and Power loss index into consideration[2]. Distributed systems are impacted by harmonics and overloads from EV charging. The impact is seen on transformers, distribution cables, circuit breakers and fuses at the micro level. According to simulation studies, the harmonics content is between 25 to 40% [3,4].

*Corresponding Author: Prashant Kedarnath Magadum, Research Scholar, VTU, Belagavi and Assistant Professor, Electrical Engineering Department, Brahmdevdada Mane Institute of Technology, Solapur
Email: magadumpk@gmail.com

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EV chargers also result in DC offset and an imbalanced load in addition to harmonics-related problems. The impact of EV charge controllers on the distribution system may be predicted using nonlinear load modelling[5]. Numerous case studies analyzing how EV charging solutions affect power quality have shown various harmonics problems with the distribution system. The profile of EV charger waveforms can be improved by active rectification employing power electronics switching devices[6,7,8]. The researcher have proposed a numerous remedial actions for resolving power quality problems.

At the distribution levels, the D-STATCOM has been identified as a reliable device for compensating reactive power[9]. The D-STATCOM can be configured in variety of ways as it can mitigate harmonics, compensate reactive power and regulate the voltage at point of common coupling. The heart of the STATCOM is a voltage source inverter that is often controlled with PWM or some advanced PWM control techniques. The control strategies are developed for various functions like reactive power compensation, harmonics mitigation or voltage regulation and hence various power quality problems are addressed[10].

Multilevel inverters are used in systems with high power quality requirements for efficient power conversion. They are often deployed in reactive power compensation devices of industrial power applications and renewable energy applications. The multilevel converters can operate at high voltage levels using semiconductors devices with lower ratings. As a result, they provide benefits such as decreased electromagnetic interference, lower voltage rating of switching devices and decreased dv/dt stress on switching devices. Multilevel inverters are basically configured as the diode clamped, flying capacitor and cascaded H-bridge[11]. Low frequency and high frequency modulation are supported by all the different configurations of multilevel inverters. The commonly used control methods encompass space vector modulation, selective harmonic elimination, as well as sinusoidal and non-sinusoidal PWM control techniques. The operational approach for the switching arrangement of a five-level cascaded H-bridge multilevel inverter is detailed in ref[12]. The CHB multi-level inverters have the advantage of requiring fewer parts than diode clamped and flying capacitor inverters. In contrast to the other two types of inverters, this inverter configuration boasts lower costs and is easy to implement. With the adoption of multilevel cascade inverters, the need for a sizable transformer, which is essential for conventional multi-phase inverters, clamping diodes in diode-clamped inverters, or flying capacitors in flying capacitor inverters is eliminated.

The compensation of reactive power in high power medium voltage applications is successfully accomplished by the multilevel inverter D-STATCOM[13]. A cascaded H-bridge multilevel D-STATCOM is proposed in ref[14] for voltage regulation. The D-STATCOM control strategy for voltage regulation can make up for up to 25% dip or swell in voltage value. The SPWM[15] is also used in D-STATCOM for maintaining voltage accomplished by compensating reactive power. The utilization of the multilevel inverter D-STATCOM proves to be a successful approach in addressing harmonic issues. In the case of the multi-level D-STATCOM of ref[16], a decrease in THD up to 4.73% was achieved. Meanwhile, the THD value after compensation for the five-level STATCOM was even lower, reaching 2.75%.

The multilevel D-STATCOM necessitates careful control circuit design, switching order, career selection, and suitable reactive power control method[17]. The primary objectives in the development of the multi-level inverter STATCOM is to use fewer switching devices and provide output that is almost sinusoidal. The inerter configuration in ref[18] can decrease the number of switching components. The modulation approach outlined in ref[19] has proven to exhibit lower total harmonic distortion (THD) in contrast with the conventional method of phase-shifted carrier space vector pulse width modulation (SPWM). Reference[20] delves into investigating the viability of implementing modular multilevel converters for D-STATCOM. The objective is to enhance reactive power compensation with high efficiency, while ensuring grid operation safety and reliability, alongside the integration of elevated energy capabilities. Additionally, a single-cycle controller proposed in ref[21] showcases notable benefits such as minimal steady-state error and improved dynamic responsiveness.

With an objective of improving the performance of multilevel inverter, numerous control techniques are developed by researchers and designers[22-25]. For minimizing the number of switching devices in a standard 5 level CHB inverter, a modified CHB multilevel inverter configuration[26-28], as of figure 1 is considered for development of D-STATCOM for harmonics mitigation of EV charging station.

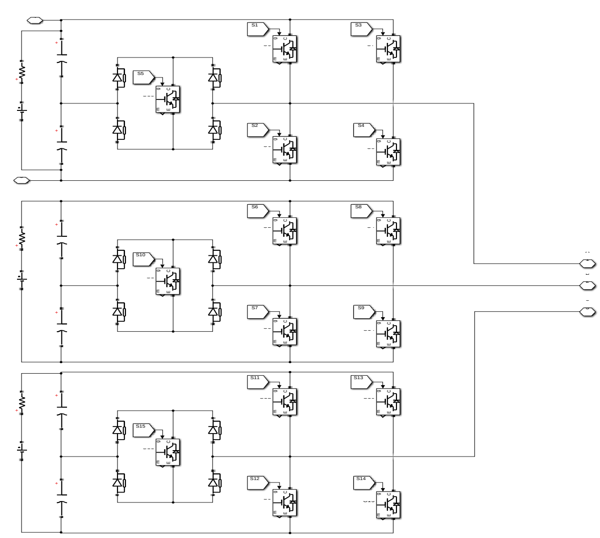

Figure 1. Five Level Modified Cascaded H- Bridge

Five Levels Modified CHB D-STATCOM for EV Charging Station

The control scheme for power quality improvement with D-STATCOM is shown in figure 3. At the top of the block diagram a PI controller is used to regulate the DC link voltage of the STATCOM. The DC link voltage is regulated to 300V. The output of the PI controller is referred as reference direct current. At the bottom of the control scheme, the grid voltage controller takes input from actual grid voltage is compared with reference value the error signal is given to a PI controller which generated reference quadrature current. To perform the Park's transformation, the required direct and quadrature components are generated from the grid voltage. The load current is given as input to the Park's transformation block and the abc reference frame is converted into dq0 reference frame. The reference direct current is added with direct current obtained from Park's transformation of load current and reference quadrature current is subtracted from the quadrature current obtained from Park's transformation of load current. Inverse Park's transformation is performed on the resultant direct and quadrature components to generate the three phase reference frame. This reference waveform is used to generate the gate pulses for the inverter switches with sinusoidal pulse width modulation (SPWM).

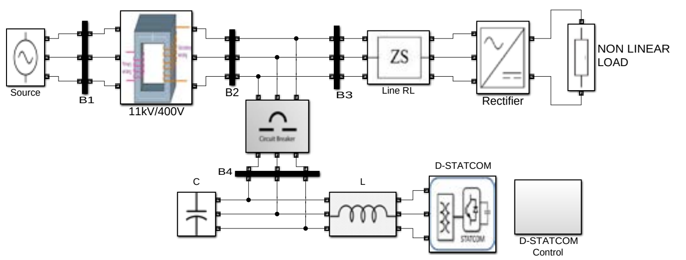

Figure 2. Simulink model of 5 level modified CHB STATCOM compensated EV charging station

Table 1. System Specifications

Source	11 kV, 50 Hz
Distribution Transformer	20kVA, 50 Hz, 11 kV / 400 V
Line & Load	Line Resistance = 0.4 Ω Line Inductance = 3.55mH **Non-Linear Load:** Active power = 10KW Reactive power = 10KVAR
D-STATCOM	DC Link Voltage = 300V Capacitor = 1000µF Switching Frequency = 5 KHz Filter Inductance = 20mH Filter Capacitance = 5mF

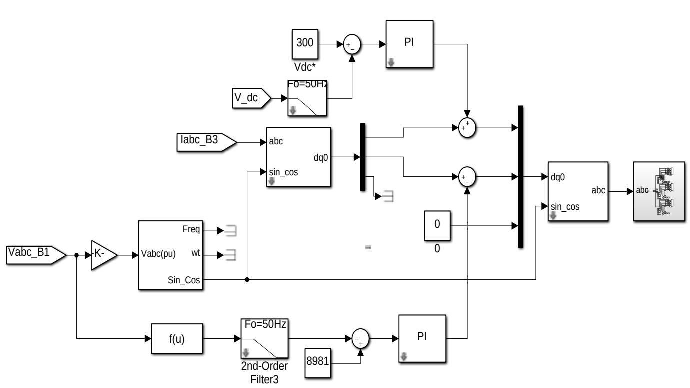

Figure 3. Conrol Scheme

SIMULATION RESULTS AND DISCUSSION

The objective of this simulation is to devise a strategy for generating pulses in a modified five-level cascaded H-bridge (CHB) D-STATCOM. The goal is to alleviate the harmonics produced by an electric vehicle (EV) charging station. The Simulink model is executed over a span of 1 second. The activation of STATCOM compensation commences at the 0.3-second mark. From 0 to 0.3 seconds, the system operates without compensation. Measurements are taken for both voltage and current waveforms. Total harmonic distortion (THD) analysis is conducted for the system during the uncompensated period and with active compensation. In Figure 4, the waveforms of the source voltage and current, specifically the point of common coupling (PCC) voltage and current, are depicted. The impact of introducing STATCOM compensation becomes evident from the 0.3-second point onward. With STATCOM intervention, the waveforms exhibit a notably smoother shape. The source voltage and source current is seen in figure 4 and figure 5 shows load voltage and load current waveforms. The wave shapes are indicated to have clear understanding at pre-compensation and post compensation levels.

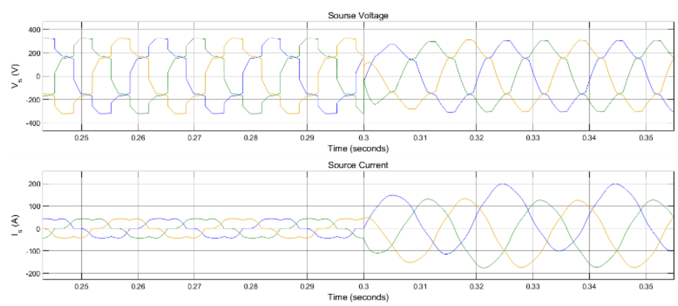

Figure 4. Voltage and current waveforms of source

The harmonics analysis of the system is done in two parts. In the first part THD values are monitored for nonlinear load and later the analysis is done for EV charging load. With nonlinear load, the current THD without compensation is observed to be 15.23% and that with STATCOM compensation is seen to be 1.89% as seen in figure 6 and 7 respectively.

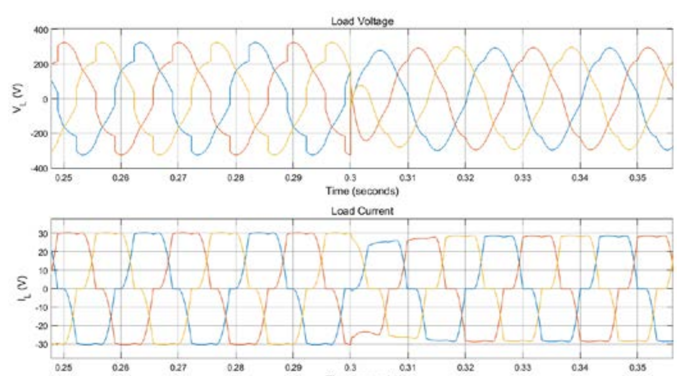

Figure 5. Load Voltage and Current

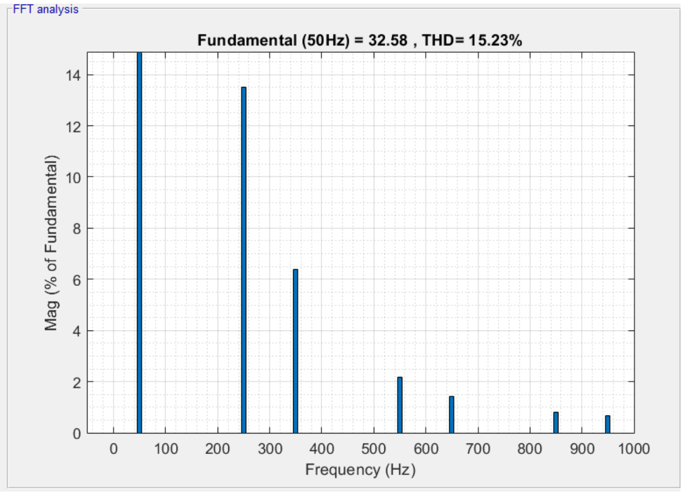

Figure 6. THD without STATCOM

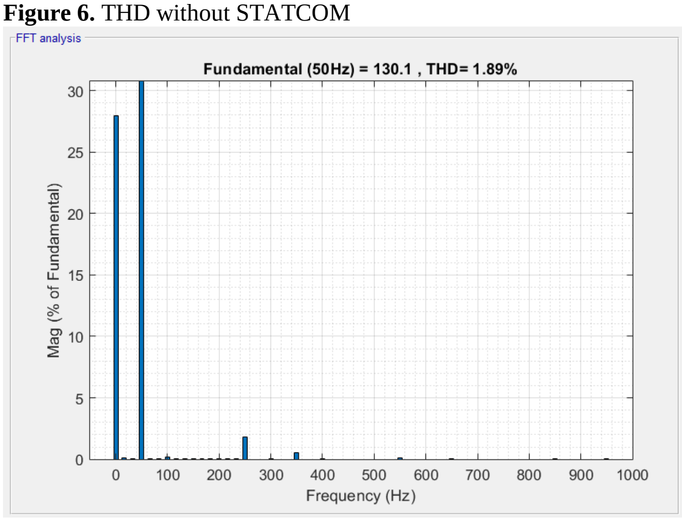

Figure 7. THD with STATCOM

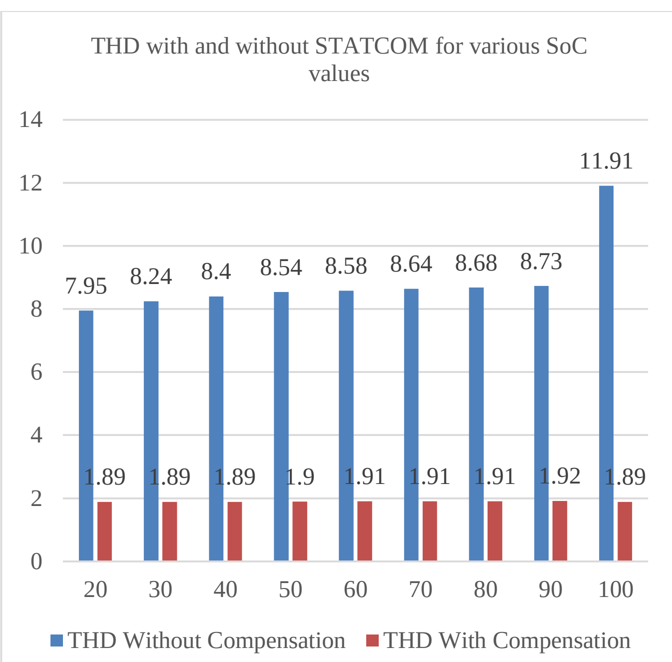

Figure 8. THD of EV charging system with and without STATCOM

For electric vehicle charging station, the system analysis is done by considering the SoC of the battery. As we know that the charging current of the battery reduces with increase in the charging level (SoC) of the battery. Hence, THD values are noted for various values of SoC of the EV battery. The figure 8 shows summary of THD analysis of the system with and without STATCOM. It is seen that the STATCOM compensation is capable of mitigating the harmonics of the nonlinear load to a safe value. In case of the EV charging load combined with nonlinear load, the THD value without compensation is seen to be increasing with increase in SoC. This is particularly due to the decrease in fundamental current which decreases with increase in SoC of the battery. The average THD post STATCOM compensation is 1.89%. In comparison with the state of the art models Rekha [16] reported THD of 2.75% and Mengi [26] report THD of 4.73%, the proposed five level modified cascaded H-bridge STATCOM give better compensation than state of the art models.

Conclusion

This paper presents a 5 level modified CHB inverter based D-STATCOM deployed to mitigate the harmonics arising due to EV charging station. The modified 5 level CHB configuration has only five switching device per leg as compared to 8 devices in conventional 5 level CHB inverter. The DQ theory based controller is developed for controlling the D-STATCOM. The enhancement of power quality is evident with reduction of harmonics from 15.13% to 1.89%. Graph of THD compensation versus state of the charge indicates that the developed compensation system is efficient in mitigating harmonics at any conditions of charging state in the EV charging station. The D-STATCOM response time to compensate the disturbances is less than two cycles.

Conflict of Interest Statements

Authors declared no conflict of intrest is there for the work.

References

1. L. Sainz, J. Balcells. Experimental measurements about harmonic current mitigation of electric vehicle battery chargers. *Renew. Energy Power Qual. J.* **2011**, 1 (9), 407–412.
2. S. Deb, K. Tammi, K. Kalita, P. Mahanta. Impact of electric vehicle charging station load on distribution network. *Energies* **2018**, 11 (1).
3. J.C. Gómez, M.M. Morcos. Impact of EV battery chargers on the power quality of distribution systems. *IEEE Trans. Power Deliv.* **2003**, 18 (3), 975–981.
4. V.A. Katić, M. Pecelj, I.M. Todorović. Effects of Individual Battery Charger Station on Power Quality. *X Int. Symp. Ind. Electron. - INDEL* **2014**, 224–228.
5. S.S. Kamble, A.M. Mulla. Effects of EV Battery Charger on Power Quality. In *Renewable Resources and Energy Management*; **2023**; pp 378–384.
6. T. Thiringer, S. Haghbin. Power quality issues of a battery fast charging station for a fully-electric public transport system in gothenburg city. *Batteries* **2015**, 1 (1), 22–33.
7. V. Monteiro, H. Gonçalves, J.L. Afonso. Impact of electric vehicles on power quality in a Smart Grid context. In *Proceeding of the International Conference on Electrical Power Quality and Utilisation, EPQU*; **2011**; pp 660–665.
8. L.S. Zhao, H.M. Yuan. The impact of quick charge on power quality of high-voltage grid. In *IOP Conference Series: Materials Science and Engineering*; **2018**; Vol. 366, pp 1 – 6.
9. Y. Ahmad, S.F. Pinto. Cascade multilevel STATCOM as a solution to improve the voltage profile of a power grid. In *Proceedings - 2018 International Young Engineers Forum, YEF-ECE 2018*; **2018**; pp 109–114.

10. I.H.M. Salih, D.R. MSushama. Simulated Design of a Multilevel STATCOM for Reactive Power Compensation. *Int. J. Sci. Eng. Technol. Res.* **2013**, 2 (10), 978–983.
11. A. Lazar, A.K. Chandel. Design of STATCOM for reactive power control using multilevel inverter. *J. Phys. Conf. Ser.* **2020**, 1706 (1).
12. A.K. Koshti, M.N. Rao. A brief review on multilevel inverter topologies. In *2017 International Conference on Data Management, Analytics and Innovation, ICDMAI 2017*; **2017**; pp 187–193.
13. T. Santosh Tej, V.S. Prasadarao K., S.K. Abdul Samadh, M. Naveen Kumar. Cascaded multilevel inverter based STATCOM for high power applications. *Int. J. Appl. Eng. Res.* **2017**, 12 (1), 472–476.
14. R. Sharma, V.H. Makwana. Transformer Less Cascaded Voltage Source Converter Based STATCOM. *Indones. J. Electr. Eng. Informatics* **2022**, 10 (1), 1–12.
15. M. Nazmul Haque, A.M. Saleque. Impacts of electric vehicle charging on distribution grid; Electrical and Computer Engineering Publications and Presentations, Portland State University, **2019**; Vol. 18.
16. Rekha. K. G, Jaison Joy. Power Quality Enhancement Based on Multilevel STATCOM for High Power Applications. *Int. J. Eng. Res.* **2017**, V6 (04), 982 – 987.
17. R. Kamble, G.M. Karve, A. Chakradeo, G. Vaidya. Optimal sizing of Battery Energy Storage System in Microgrid by using Particle Swarm Optimization Technique. *J. Integr. Sci. Technol.* **2018**, 6 (1), 6–12.
18. K. Sreekesh, S. Maiti. A New Multilevel Converter Configuration with Reduced Component Count for Medium Voltage STATCOM Application. In *2019 National Power Electronics Conference, NPEC 2019*; **2019**; pp 1–6.
19. F. Alskran, M.G. Simoes. Multilevel current source converter-based STATCOM suitable for medium-voltage applications. *IEEE Trans. Power Deliv.* **2021**, 36 (2), 1222–1232.
20. F. Hahn, L. Camurca, M. Liserre. Investigation of Modular Multilevel Converters for E-STATCOM Applications. In *IEEE International Symposium on Industrial Electronics*; **2020**; Vol. 2020-June, pp 1028–1032.
21. B. Arthi, R. Thamizharasan, M.P. Mohandass, R.L.R. Singh. Power Quality Enhancement of the Distribution Network by Multilevel STATCOM. *Proc. 2023 2nd Int. Conf. Electron. Renew. Syst. ICEARS 2023* **2023**, 10, 124–130.
22. E.R. Ramos, R. Leyva, G.G. Farivar, et al. Incremental Passivity Control in Multilevel Cascaded H-Bridge Converters. *IEEE Trans. Power Electron.* **2020**, 35 (8), 8766–8778.
23. F. Abdollahi, Y. Neyshabouri, M. Farhadi-Kangarlu. Finite Control Set Model Predictive Control for Asymmetric Cross-Switched Multilevel Inverter Based STATCOM. In *2022 13th Power Electronics, Drive Systems, and Technologies Conference, PEDSTC 2022*; **2022**; pp 374–379.
24. N.N.V.S. Babu. Simplified Cluster Balance Control of Cascaded H-Bridge STATCOM under Unbalanced Grid. In *IECON Proceedings (Industrial Electronics Conference)*; **2022**; Vol. 2022-October, pp 1–6,.
25. T.M. Shehata, M.S. Abdul moteleb, E.A. El-Zahab. STATCOM controllers based on fuzzy PI approach. *Indones. J. Electr. Eng. Comput. Sci.* **2020**, 18 (3), 1138–1147.
26. O.O. Mengi. A five-level H-Bridge STATCOM for an off-grid PV solar farm under two controllers PI and PIλ-MPC hybrid. *Int. J. Photoenergy* **2018**, 2018, 1 – 14.
27. G.K. Srinivasan, M. Rivera, V. Loganathan, D. Ravikumar, B. Mohan. Trends and challenges in multi-level inverter with reduced switches. *Electron.* **2021**, 10 (4), 1–23.
28. A. Singh, S. Bhandari, J. Kumar. A Comparative Study on Multilevel Inverters with Reduced Number of Components - A Review. In *2022 1st International Conference on Sustainable Technology for Power and Energy Systems, STPES 2022*; SRINAGAR, India, **2022**; pp 1–6.