A Five Level Modified Cascaded H-Bridge Inverter STATCOM for Power Quality Improvement

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ABSTRACT

Multilevel converters have received serious attention on account of their capability of high voltage operation, high efficiency, and low electromagnetic interference. It has many advantages compared to conventional two-level inverters such as high dc-link voltages, reduced harmonic distortion, fewer voltage stresses, and low electromagnetic interferences. The multilevel converters have been used for STATCOM widely as it can improve the power rating of the compensator to make it suitable for medium or high-voltage high power applications. While deploying multilevel STATCOMs, designer's role is to reduce the number of switching devices since, the total switching losses are proportional to the number of switching devices. The reduction in the count of switching devices also reduces the size and cost. In this paper, a five-level modified cascaded H-bridge inverter STATCOM is proposed for mitigation of harmonics. Modified Five-level CHB configuration is the most suitable as with lesser number of switches, give better performance resulting in a compact system. The PQ theory-based controller is developed for control of STATCOM operation. MATLAB simulation results are presented to demonstrate mitigation of harmonics.

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1. INTRODUCTION

In an electrical power system, the unbalance is observed in voltage and frequency if active and reactive power balance between sending-end and receiving-end is disturbed. Most of the loads today are inductive (induction motors) and non-linear type (rectifier) [1, 2]. The earlier type draws a lagging reactive power and the later type introduces harmonics in the system and thereby deteriorating the power quality. The reactive power demand increases the system losses as well as reduces the deliverable active power. A voltage fluctuation in terms of sag and swell is another major power quality problem. It leads to the power fluctuations and tripping of the circuit breakers. The nonlinear loads like arc furnace, welding machine etc. also contributes to the flickering problems [3].

The STATCOM has been increasing gaining attention at distribution levels on account of constant and consistent capacitive and inductive reactor power compensation capabilities [4]. It is connected across the system to be compensated. It can regulate the voltage at point of common coupling and provide reactive power compensation as well as it can reduce harmonics. A voltage source inverter is the heart of the STATCOM which is often driven with pulse width modulation (PWM) and other control techniques. These control techniques all together regulates PCC voltage, compensates reactive power and mitigates harmonics. The control techniques are often developed to address assorted power quality issues [5].

Multilevel inverters are preferred for efficient power conversion in systems demanding high power and power quality requirements. There often deployed in Renewable Energy applications like wind and solar, industrial power applications and reactive power compensation devices. The multilevel converters have an ability to handle and generate high voltage levels with lower rated semiconductor devices. The hence offer advantages like less dv/dt stress on switching devices, reduced electromagnetic interference, reduced voltage rating of switching devices etc. They can operate at fundamental as well as high PWM switching frequency and hence losses are minimum. Diode clamp (neutral point clamp), flying capacitor and Cascaded H bridge are the basic configurations of multilevel inverters [6]. All the configurations of multilevel inverter support low frequency and high frequency modulation. The popular control techniques include space vector modulation, selective harmonic elimination, sinusoidal and non-sinusoidal PWM control. The switching matrix for five level cascaded H - bridge multilevel inverter is elaborated in [7]. The 5 - level inverter configuration is capable of reducing the lower order harmonics.

A multilevel inverter is the best topology for managing large power with medium voltage sources. It delivers a smoother voltage waveform, generates high voltages using devices with lower ratings, and decreases the stress on switching components. Thus, compared to conventional inverter topologies, the multilevel inverter delivers superior power quality. Diode Clamped, Flying-Capacitor, and Cascaded H-bridge inverters are the three basic topologies of multilevel inverters [7]. When compared to diode clamped and flying capacitor inverters, this form of multi-level inverter has the benefit of requiring fewer components. The inverter is less expensive and heavier than the other two inverters. Some of the new switching techniques enable soft-switching. With the usage of multilevel cascade inverters, it is no longer necessary to use the large transformer required by traditional multi-phase inverters, clamping diodes for diode clamped inverters, or flying capacitors for flying capacitor inverters.

FACT devices are proposed for mitigating issues related to the power quality [8]. A STATCOM is often used for stabilizing the voltage profile of the system [9] The multilevel inverter STATCOM is effective in reactive power compensation in medium voltage high power applications [14]. A cascaded multilevel converter STATCOM is proposed in [10, 11] for improving voltage profile. The control strategy for this STATCOM is effective for maintaining voltage profile for up to 25% voltage sag or swell. The SPWM control [12] is deployed for STATCOM for maintaining voltage profile through compensation of reactive power in the system. The multilevel inverter STATCOM is an effective method for mitigation of harmonics. The two level STATCOM of [13] has reduced THD up to 4.73% whereas, the THD value of five level STATCOM is 2.75%.

The multilevel STATCOM requires careful design of control circuit, switching sequence, career selection and appropriate control scheme of reactive power control [15]. While developing multi-level inverter STATCOM, one of the objectives is to reduce number of switching devices and producing nearly sinusoidal output perform. The converter configuration in [16] can reduce number of switching devices in the converter.

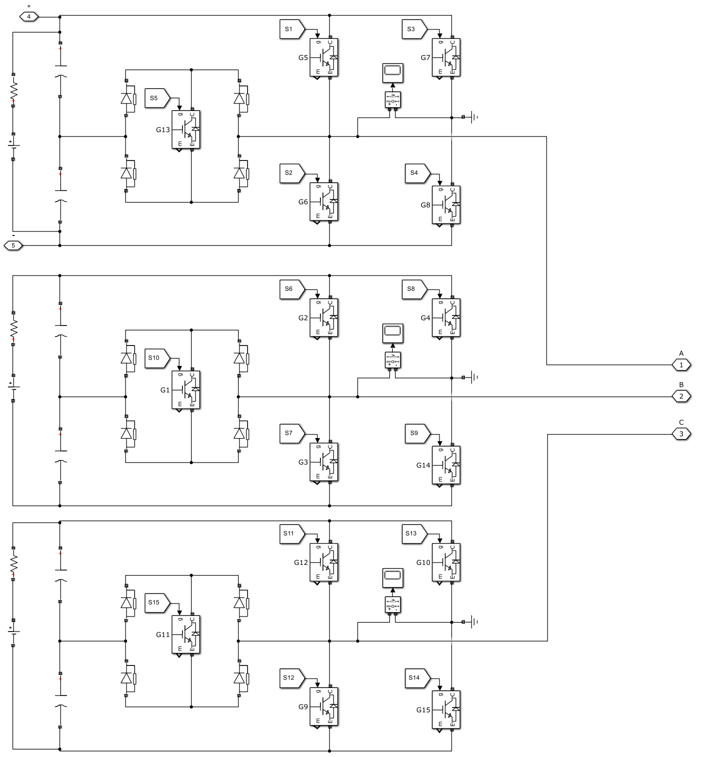

Figure 1. Five level modified CHB inverter configuration

Few researchers have also implemented multi-level CSI fed STATCOM. The modulation technique of [17] has demonstrated less THD in comparison with conventional phase shifted carrier SPWM. The feasibility of deploying modular multilevel converters for STATCOM is explored in [18] with a moto to install high energy capabilities for reactive power compensation with high efficiency and insuring safety and reliability in grid operation. One cycle controller for STATCOM is presented in [19]. Such controller has low steady state error and better dynamic response.

Many more controls schemes and inverter configurations [20 - 23] have been proposed by various researchers with an objective of improving the characteristics of system. The 5-level modified CHB STATCOM of Yamnaz [25] is configured for providing the reactive power compensationa and the harmonics part is left unaddressed. Mengi [26] has repored 4.94% voltage THD and 4.17% current THD with 5-level STATCOM. Some benefits of the five-level Cascaded H-Bridge topology include: The working cycles and power losses are uniformly dispersed, and the modularity is quite high [27]. In this regard, a modified 5-level cascaded H-bridge multilevel inverter configuration as shown in Figure 1 is proposed to reduce number of switching devices in conventional multilevel inverter. This modified CHS multilevel inverter is then configured in STATCOM for mitigating harmonics. The comparison of performance of proposed configuration will be done with state-of-the-art models in the literature.

2. FIVE LEVEL MODIFIED CHB STATCOM

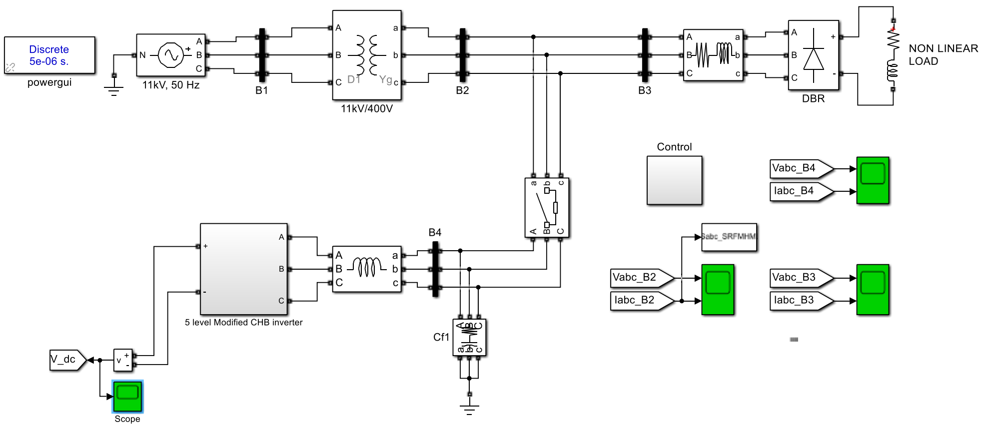

Figure 2. STATCOM configuration

For mitigation of harmonics, a five-level modified cascaded H-bridge STATCOM is developed as shown in Figure 2. The instantaneous reactive power (IRP) theory often called PQ theory is used in the control scheme. The control scheme is shown in Figure 3. The PQ theory is based estimation of active and reactive power from the values of voltage and current. The source voltage Vabc and load current Iabc are measured and Clarke transformation converts three phase abc components into α β components. These α β components are further used to estimate P and Q component. The P component when passed through a low pass filter gives non-oscillatory power. It is added with power loss component which is computed from the DC link voltage controller. The reference currents I_α and I_β are obtained by combining non-oscillatory power and power loss component, estimated Q, V_α and V_β. The reference current α and β components are converted into the form of abc by performing inverse Clarke transform. The sinusoidal abc components are further compared with triangular shaped carrier waveform and triggering pulses for each of the IGBT in the modified cascaded H bridge inverter are generated. All the system specifications are mentioned in Table 1.

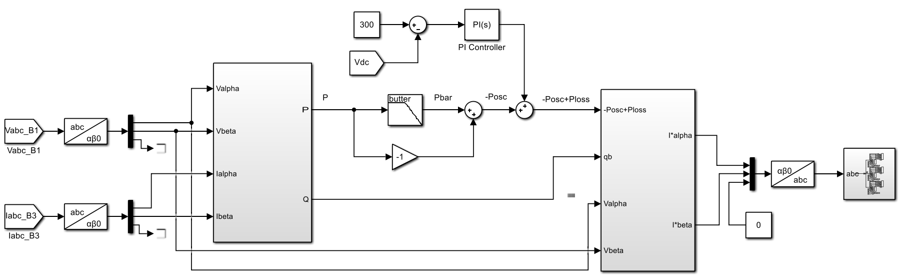

Figure 3. Control scheme of STATCOM

Table 1. Specifications of STATCOM

Source Parameters	Vrms (Ph-Ph) = 11 kV, Frequency = 50 Hz
Transformer Parameters	Winding 2 connection: Star grounded Nominal Power = 20kVA Frequency = 50 Hz V1 Ph-Phv\ (Vrms) = 11 kVV2 Ph-Ph (Vrms) = 400 V
Line & Load Parameters	RL Branch: Resistance R (Ohms) = 0.4, Inductance L (mH) = 3.55 Nonlinear Load: Resistance R (Ohms) = 15, Inductance L (mH) = 60
STATCOM Parameters	DC Link Voltage = 300 V Capacitance (μF), C_1=C_2=C_3=C_4= C_5= C_5= 1000 Switching Frequency (kHz) = 5 LC Filter: Inductance L (mH) = 150, Capacitance, C (μF) = 5000
Three Phase Circuit Breaker	Initial status: Open Switching times (s) = 0.4, Breaker resistance Ron (Ohm) = 0.001

3. RESULTS AND DISCUSSION

The Simulink model is set for execution for a period of 1 second. The STATCOM compensation is activated at the time instance of 0.4 second. During 0 to 0.4 second, the system remains uncompensated. The recording of voltage and current waveforms is noted. The aim of this simulation is to develop a a pulse generation scheme for five level modified cascaded H bridge inverter for STATCOM application and to mitigate the harmonics created by nonlinear load. The THD analysis is carried out for the system during uncompensated time and with active compensation. Figure 4 shows the waveforms of STATCOM voltage and current. The voltage current waveforms are active only for compensation period i.e., from 0.4S onwards. The Figure 5 shows load voltage and load current waveforms. The effect of bringing STATCOM for compensation is reflected in Figure 6. The wave shape becomes much smoother up on compensation with STATCOM.

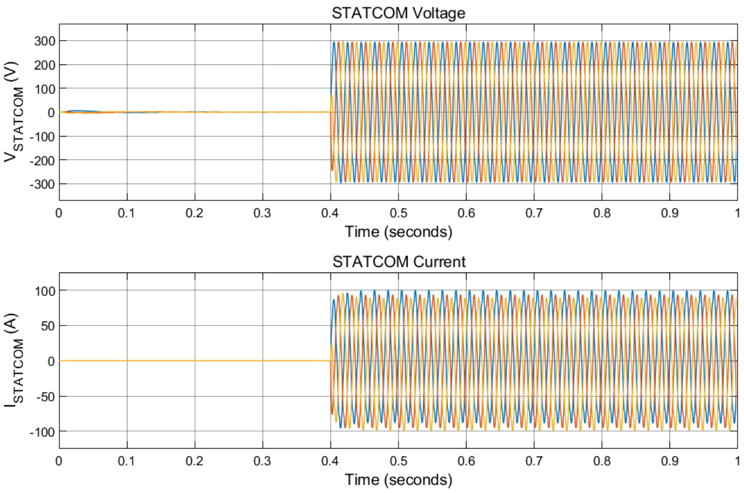

Figure 4. STATCOM voltage and current

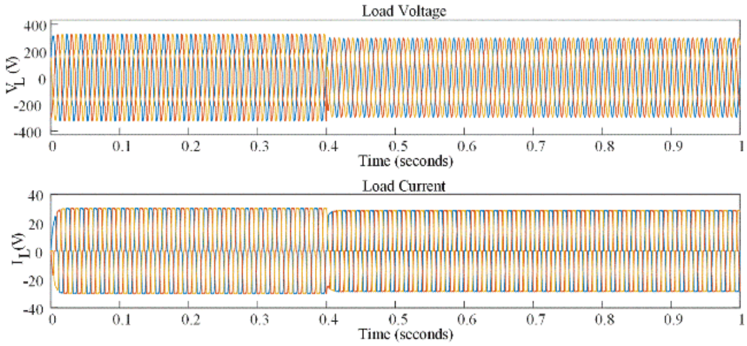

Figure 5. Load voltage and current

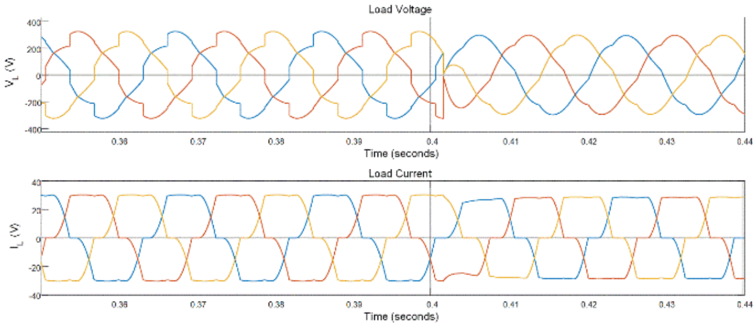

Figure 6. Load voltage and current (Switching instance = 0.4 S)

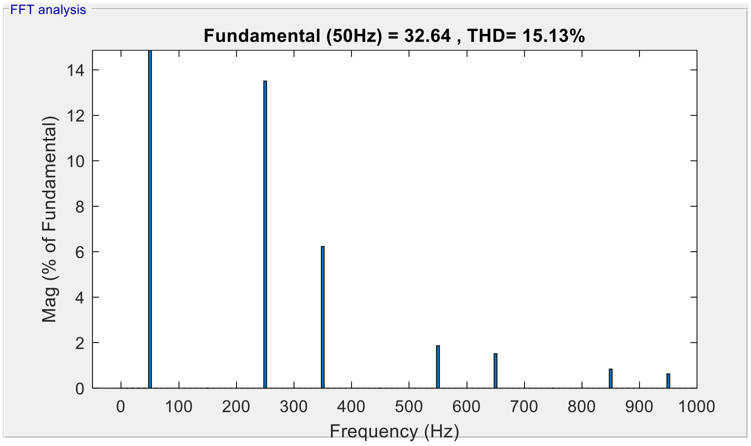

Figure 7. THD without STATCOM

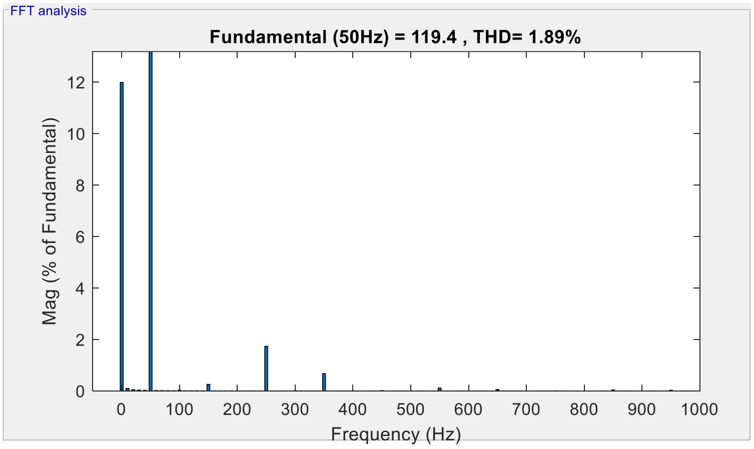

Figure 8. THD with STATCOM

The harmonics measurement of the system is done, the Figure 7 shows harmonics in the system without STATCOM. The nonlinear load is generating 15.13 % harmonics. The Figure 8 shows harmonics with STATCOM compensation. The compensation brings the harmonics down to 1.89 % which is as per the recommendations of IEEE 519 – 2014 standards. In comparison with the statistics of THD reported in literature review, this value is much less than that of Mengi 4.17% [26], kota 3.46% [29] and of Shuvo 3.17% [28]. Table 2 shows comparison of proposed system with those of literature for current THD values.

Table 2. comparison of results

Configuration	Current THD
Proposed 5 level modified CHB	1.89%
5 level CHB [26]	4.17%
5 level CHB [28]	3.17%
5 level diode-clamped [29]	3.46%

4. CONCLUSION

This paper presents a novel modified cascaded H – bridge multilevel inverter based STATCOM for mitigation of harmonics. The STATCOM configuration is built with lesser number of switches and controlled with PQ theory. The improvement in power quality is brough around with reduction of harmonics from 15.13% to 1.89%. Also, it is to be noted that the restoration (response) time taken by the system to compensate the disturbances is less than three cycles. The THD value of modified H – bridge based STATCOM is less that the state-of-the-art models [26, 28, 29].

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REFERENCES

[1] Ankush Sharma, “Review Paper on Applications of D-STATCOM in Distribution System”, International Journal of Science and Modern Engineering (IJISME), Volume-2, Issue-11, October 2014
[2] T. A. Abdul-Hameed, M. F. Akorede, Y. Abdulrahman and O. M. Tijani, “An Investigation of the Harmonic Effects of Nonlinear Loads on Power Distribution Network”, Nigerian Journal of Technology, Vol. 38, No. 2, April 2019, pp. 401 – 405
[3] Viveksheel Verma, Ved Prakash Verma, Harkamaldeep Singh, “THD Analysis of Non-Linear Loads”, International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, Vol. 7, Issue 7, July 2019
[4] Soto, D., Green, T.C. “A comparison of high-power converter topologies for the implementation of FACTS controllers”, IEEE Transactions on Industrial Electronics, 2002
[5] Liu, X., Lv, J., Gao, C., Chen, Z., Chen, S. “A novel STATCOM based on diode-clamped modular multilevel converters”, IEEE Transactions on Power Electronics 2016
[6] Dhal, P.K., Rajan, C.C.A. “Design and comparative analysis of diode clamped multilevel inverter for eliminating total harmonics using high switching frequency techniques”, Power Electronics and Renewable Energy Systems, pp. 665-677, 2015
[7] A. K. Koshti and M. N. Rao, "A brief review on multilevel inverter topologies," 2017 International Conference on Data Management, Analytics and Innovation (ICDMAI), pp. 187-193, 2017
[8] Yahia M. Esmail1, Ali H. Kasem Alaboudy, M. S. Hassan, Gamal M. Dousoky, "Mitigating power quality disturbances in smart grid using FACTS", Indonesian Journal of Electrical Engineering and Computer Science, Vol. 22, No. 3, June 2021, pp. 1223~1235
[9] I. A Ethmane, Ahmed Yahfdhou, A.K. Mahmoud, M. Maaroufi, "STATCOM integration in a power grid to enhance voltage stability", Indonesian Journal of Electrical Engineering and Informatics (IJEEI), Vol. 7, No. 4, pp. 620~627, Dec 2019
[10] Rashmi Sharma, Vijay H. Makwana, "Transformer Less Cascaded Voltage Source Converter Based STATCOM", Indonesian Journal of Electrical Engineering and Informatics (IJEEI), Vol. 10, No. 1, pp. 1~12, March 2022
[11] Y. Ahmad and S. F. Pinto, "Cascade multilevel STATCOM as a solution to improve the voltage profile of a power grid," 2018 International Young Engineers Forum (YEF-ECE), pp. 109-114, 2018
[12] Al-Kharsan, Ibrahim. “Simulated Design of a Multilevel STATCOM for Reactive Power Compensation”, 2013
[13] Rekha K. G. and Jaison Joy, "Power Quality Enhancement Based on Multilevel STATCOM for High Power Applications", International Journal of Engineering Research & Technology (IJERT), Vol. 6 Issue 04, pp. 982 - 987, 2017
[14] T Santosh Tej, V S Prasadarao K, SK Abdul Samadh, M. Naveen Kumar, "Cascaded Multilevel Inverter based STATCOM for High Power Applications", International Journal of Applied Engineering Research, Volume 12, No. 1, 2017
[15] Amal Lazar and Ashwani Kumar Chandel, "Design of STATCOM for reactive power control using multilevel inverter", Journal of Physics: Conference Series, Volume 1706,First International Conference on Advances in Physical Sciences and Materials, August 2020
[16] S. K. and S. Maiti, "A New Multilevel Converter Configuration with Reduced Component Count for Medium Voltage STATCOM Application," 2019 National Power Electronics Conference (NPEC), pp. 1-6, 2019
[17] F. Alskran and M. G. Simões, "Multilevel Current Source Converter-Based STATCOM Suitable for Medium-Voltage Applications," in IEEE Transactions on Power Delivery, vol. 36, no. 2, pp. 1222-1232, April 2021
[18] F. Hahn, L. Camurca and M. Liserre, "Investigation of Modular Multilevel Converters for E-STATCOM Applications," 2020 IEEE 29th International Symposium on Industrial Electronics (ISIE), pp. 1028-1032, 2020
[19] S. Hasanzadeh, H. Shojaeian, M. M. Mohsenzadeh, E. Heydarian-Forushani, H. H. Alhelou and P. Siano, "Power Quality Enhancement of the Distribution Network by Multilevel STATCOM-Compensated Based on Improved One-Cycle Controller," in IEEE Access, vol. 10, pp. 50578-50588, 2022

[20] E. R. Ramos, R. Leyva, G. G. Farivar, H. D. Tafti, C. D. Townsend and J. Pou, "Incremental Passivity Control in Multilevel Cascaded H-Bridge Converters," in IEEE Transactions on Power Electronics, vol. 35, no. 8, pp. 8766-8778, Aug. 2020
[21] F. Abdollahi, Y. Neyshabouri and M. Farhadi-Kangarlu, "Finite Control Set Model Predictive Control for Asymmetric Cross-Switched Multilevel Inverter Based STATCOM," 2022 13th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC) , pp. 374-379, 2022
[22] N. N. V. S. Babu, "Simplified Cluster Balance Control of Cascaded H-Bridge STATCOM under Unbalanced Grid," IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society, pp. 1-6, 2022
[23] Tamer M. Shehata, Mohamed S. Abdul moteleb, Essam Abou El-Zahab, "STATCOM controllers based on fuzzy PI approach", Indonesian Journal of Electrical Engineering and Computer Science, Vol. 18, No. 3, pp. 1138~1147, June 2020
[24] M.Deepika, Mrs.S.M.Padmaja, 2012, Simulation of DSTATCOM Based On 5-level Cascaded H-bridge Inverter, International Journal Of Engineering Research & Technology (IJERT) Volume 01, Issue 05 (July 2012),
[25] Yanmaz, Kenan & Altas, İsmail & Mengi, Onur. (2017). Five level cascaded H-Bridge D-STATCOM using a new fuzzy and PI controllers model for wind energy systems. Advances in Electrical and Computer Engineering.
[26] Onur Ozdal Mengi, “A Five-Level H-Bridge STATCOM for an Off-Grid PV Solar Farm under Two Controllers PI and PIλ -MPC Hybrid”, International Journal of Photoenergy Volume 2018
[27] J. A. Barrena, S. Aurtenechea, J. M. Canales, M. A. Rodriguez and L. Marroyo, "Design, analysis and comparison of multilevel topologies for DSTATCOM applications," 2005 European Conference on Power Electronics and Applications, Dresden, Germany, 2005
[28] S. Shuvo, E. Hossain, T. Islam, A. Akib, S. Padmanaban and M. Z. R. Khan, "Design and Hardware Implementation Considerations of Modified Multilevel Cascaded H-Bridge Inverter for Photovoltaic System," in IEEE Access, vol. 7, pp. 16504-16524, 2019
[29] V. R. Kota and S. Vinnakoti, "Synchronous Reference Frame based control of MLI-STATCOM in power distribution network," IEEE Power and Energy Conference at Illinois (PECI), Urbana, IL, USA, 2016, pp. 1-6 , 2016