Power Quality Improvements in Grid Connected PV System Using Hybrid Technology

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***Abstract*—The demand for electricity is rising in the country with an increase in population. To meet the peak load demands renewable energy sources like solar and wind can be used along with conventional sources. Compared to wind power generation the installation cost and the production cost are less in the Photo-Voltaic (PV) energy generation. But due to the widespread use of nonlinear electronic equipment's, the power quality issues are more in grid connected PV systems. The power electronic converters inject harmonics into the system which leads to various power quality issues. So, in this research paper a new hybrid method is introduced for the enhancement of power quality in grid-connected PV systems, which is a combination of both the Adaptive Cuckoo Search Algorithm (ACSA) algorithm with Fuzzy Logic Controller (FLC). ACSA is used to track the maximum power of the PV system. It offers high accuracy and good robustness. FLC provides accurate fast response, high performance and maximum efficiency. Therefore, the combination of these controllers together could improve the MPPT and PV performance. The proposed method reduced the THD compared with traditional Radial Basis Function Neural Network (RBFNN) and Incremental Conductance (IC)-MPPT (Maximum Power Point Tracking) techniques. The proposed method is executed in the MATLAB/Simulink platform to analyze the performance of power quality issues.**

Keywords—Adaptive Cuckoo Search Algorithm, Fuzzy Logic Controller, Incremental Conductance, Maximum Power Point Tracking, Photo-Voltaic, Total Harmonic Distortion.

I. INTRODUCTION

Nowadays, due to the peak demand for energy, renewable energies like PV and wind are better utilized with the grid. Among these renewable sources the PV modules are using widely because of its less manufacturing cost due to the improvement in semiconductor technology. The wide usage of power converters and non-linear loads leads to many power quality issues [1-3]. The power quality issues are due to harmonic current injected to the grid, which causes an increase in harmonic level and voltage fluctuations. The two stages of power conversion in the PV system (DC-DC and DC-AC) lead to the lower effectiveness and dependability of the system. Therefore, to improve the output power quality of the PV organization, the design and control of inverter should be done effectively [4, 5]. In PV systems the inverter control also helps to maintain unity power factor and deliver reactive power provision [6].

Earlier classical controller based control schemes were proposed for the PV systems to inject current with low harmonic distortion to the grid, which failed to remove the high-frequency harmonic contents from the injected current [7]. Later the hysteresis current controllers were used instead of conventional controllers. But, the hysteresis current control cannot give a solution for the shoot through problems [8]. Many researchers proposed new Multi-Level Inverter (MLI) technologies and also try to modify the previous ones for aiming the power quality enhancement in PV systems. But all those methods cannot ensure complete solution for power quality issues [9-11]. The Multilevel Multifunctional Grid Connected Inverters (ML-MFGCI) can ensure reduced switching losses and harmonics. However, the existing ML-MFGCIs are not completely precise because it requires additional functionalities [12, 13]. Some studies with cascaded H-bridge MLI control also possess high THD in some cases [14, 15]. To overcome the above-discussed issues, novel optimization is required, so here, by introducing a hybrid ACSA-FLC based PV system which is connected with the grid to enhance the Power Quality (PQ) features.

II. LITERATURE REVIEW

Many research works are present in the literature for power quality improvement with grid-connected PV systems.. In this literature section, few of them are presented.

Bouazza Fekkak, Mohamed Menaa and Bouziane Boussahoua [16] proposed the modeling and control of transformer less grid connected PV systems. The MPPT control technique based on fractional open circuit voltage algorithm was modified and combined with a boost converter to get good tracking accuracy and fast response. But the system modeling was done without considering the system losses.

Chettibi N, and A. Mellit, [17] presented a control technique for the power quality enhancement of a hybrid system connected to the grid. This grid tied hybrid structure comprises of PV, fuel cells and battery. Using this method the power flow of the system is regulated by neuron fuzzy gain tuners. This method can do power quality improvement, reactive power control and voltage stabilization. But in a few cases, the system is more complex to present.

Abadlia, M. Adjabi, and H. Bouzeria [18] proposed a sliding mode based control technique for the grid-tied hybrid system. This technique helps to make the system more elastic, flexible, well-organized and simple. However, sometimes, this control may cause energy loss, change in dynamics and system instability because of high-frequency oscillations called chattering.

Zheng Zeng et al [19] analyzed the multi-functional grid-connected inverters which are utilized for both the renewable source incorporation and PQ improvement. The Pareto approach is used to derive the optimal solution of the model. This method avoids the use of an extra power quality conditioner in the micro-grid. But the capacity of MFGCI is limited, which will be used more for the real power generation when renewable energy is sufficient and the full compensation cannot be done.

III. OBJECTIVES

In this research, a proposed combination between PSO and FLC methods with boost converter for controlling MPPT of PV array is presented.

The output of this proposed combination generates the maximum value of the duty cycle (D). This value of D is utilized for PWM to produce input for IGBT of a dc-dc boost converter.

The increase or decrease of D should be adjusted to reduce the oscillations of the system, optimize the MPPT operation and reduce the THD.

IV. MODELLING OF PV MODULE

PV arrays are consisting of many series-connected solar cells. The current generated from the PV can be calculated from the equivalent model and specification of the PV array is tabulated in table.1

TABLE I. SPECIFICATION OF PV ARRAY

Parameters	Value
Maximum power	305.226 W
Open circuit voltage V_{OC}	64.2 V
Voltage at maximum power point Vmp	54.7 V
Temperature coefficient of V_{OC}	-0.27269 (%/deg.C)
Cells per module	96 Ncell
Short-circuit current I_{SC}	5.96 A
Current at maximum power point I_{SC}	5.58 A
Temperature coefficient of I_{SC}	0.061745 (%/deg.C)
Light generated current I_L	6.0092 A
Diode saturation current	6.3014 e-12 A
Diode ideality factor	0.94504
Shunt resistance	269.5934 ohms
Series resistance	0.37152 ohms

The I-V characteristic of PV model can be described by the equation (1).

$$_{LO}\, e^{\frac{qV \quad R_S}{KT}\ \frac{qV \quad R_S}{KT}}$$

$$_{LO}\, e^{\frac{qV \ R_s}{KT}} \ 1 \quad \frac{V \quad R_s}{R_{sh}} \qquad (1)$$

Where the I_L represents the photo-generated current, the leakage current is represented by R_{sh} , the total internal and contact resistance of PV cell is represented by R_S and I_O represents the saturation current, which characterize the diode current. The term $\frac{KT}{q}$ in the equation represents the cell junction temperature and V_t represents voltage. The V-I characteristic of PV cell is as shown in the Figure 1.

V. PROPOSED METHOD

A. Block diagram

The general block diagram of a grid-tied PV system is as shown in Figure 1. Basically, two different topologies are available for the grid connected PV systems and among them the two-stage configuration is used. In the dual-stage configuration process, both power conversion stages (DC-DC and DC-AC) are convoluted between PV and grid. The grid tied PV structure comprises of a PV panel, DC-DC converter, DC-AC inverter and the grid. In this proposed method, the boost converter is used for the DC-DC conversion and the three-level inverter is used for the DC-AC conversion.

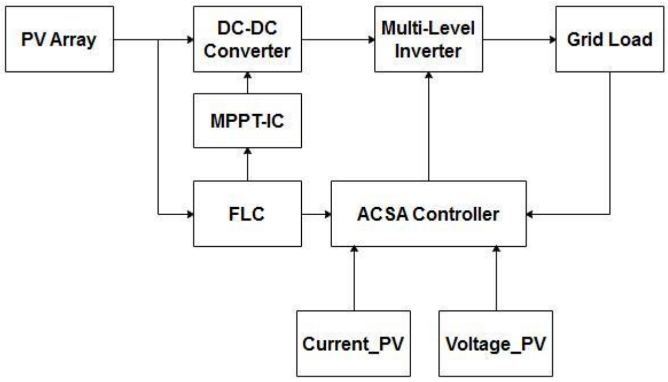

Fig. 1. Block diagram of grid tied PV system

B. IC algorithm

In the literature, the perturb-and-observe (P&O) method is the most frequently used MPPT algorithm. But in this work, IC is applied for the maximum power point tracking, which is expected to give better results than the P&O method. It controls the duty cycle of boost converter to modify the operating point of the PV module. It was developed to overcome the drawbacks of P&O algorithm.

C. FLC Controller

The theory of FLC is depended on the model which is related to the binary logic values (0,1). However, in view of binary logic, any value can either be in a set (having a value of 1) or not in a set (having a value of 0). Things in the binary logic are either black or white. But in fuzzy logic, each value can be considered as a member of a set by a certain percentage (either a low or a high percentage). Thus, the values in fuzzy logic have partial memberships in the set. The results of FLC produces the value of direct duty cycle (D). MPPT is attained when FLC modifies D of PWM to produce proper switching pulses for IGBT device of a boost converter. FLC is a nonlinear controller, which doesn't need exact mathematical modeling.

D. Adaptive Cuckoo search algorithm

A more recent meta-heuristic search algorithm, Adaptive Cuckoo Search Algorithm (ACSA) has been developed by Yang. CSA has two main operators. The high quality eggs (Optimal value) which are more similar to the host bird's eggs have more chance to develop (next generation) and became a mature cuckoo. Unhealthy eggs (not optimal value) are identified by host bird with a probability Pa 0,1 and these eggs are thrown away or the nest is discarded, and the new nest is built at new location. The parameters used in the CSA are number of nests or different solutions n, discovery rate of alien eggs/solutions pa and levy coefficient .

The cuckoo randomly chooses the nest position to lay eggs using equation (2) and (3).

$$X_{pq}^{gen\ 1} \quad X_{pq}^{gen} \qquad S_{pq} \quad Levy \tag{2}$$

$$Levy \quad \left| \frac{1 sin \overline{\ \ 2\ \ }}{\overline{\ \ 2\ \ } S \ 1 \quad 1/2} \right| \tag{3}$$

Where is constant 13 ; is a random number generated between 1,1 ; is gamma function; S > 0, it is step size.

The step size is obtained by using equation (4).

$$S_{pq} X_{pq}^{gen} X_{fq}^{gen} \tag{4}$$

Where p, f 1, 2,...m and q, f1, 2,...D are randomly chosen indexes, f is chosen randomly but its value must be different from p.

The host bird will identify the cuckoo egg and choose the high quality egg with probability of using equation (5).

$$pro_q \frac{0.9 \ fit_q}{max \ fit} \ 0.1 \tag{5}$$

Where fit_q is the fitness value of the solution; q is the proportionality index to the quality of egg in the nest position q .

If the host bird identify the cuckoo egg, then the host bird may throw the egg away or leave that nest and build a new nest using equation (6). Otherwise the egg will grow and is alive for next generation

$$nest_q \ X_{q,min} \quad rand \ 0,1 X_{q,max} \quad X_{q,min} \tag{6}$$

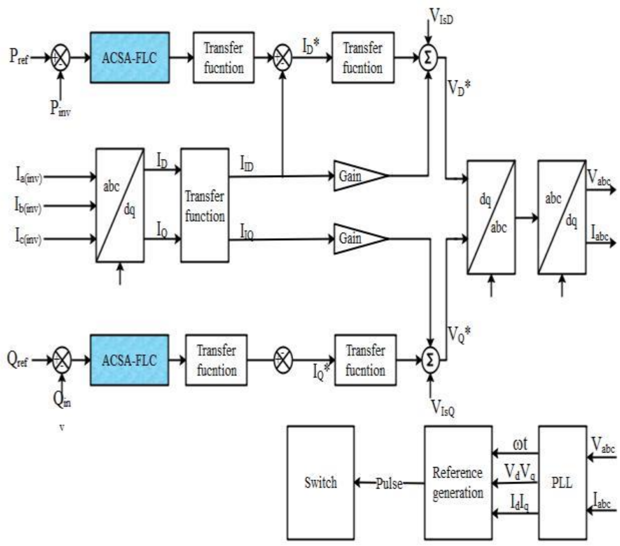

Fig. 2. Control Circuit Diagram

Figure 2 illustrates the control circuit diagram for the proposed method. When utilizing every duty cycle, it's necessary to pause the transient condition to resolve; the higher resultant number of particles will increase the tracking time of the MPP. Another significant factor is a convergence of particle since the duty cycle does not receive some value which is not within the interval [0, 1]. The particles should converge in this particular duration; else, the arrangement can't discover the MPP. To confirm the particle values, the speed parameter has to be controlled which should not exceed the interval.

VI. Simulation results and Discussions

This segment presents the simulation outcomes that is associated to the PV system which is operating with ACSA-FLC. The simulation diagram for the grid connected PV system is shown in Fig.3. Various assessments have been recognized afore relating the PV structure which is associating with some obtained results by means of traditional techniques.

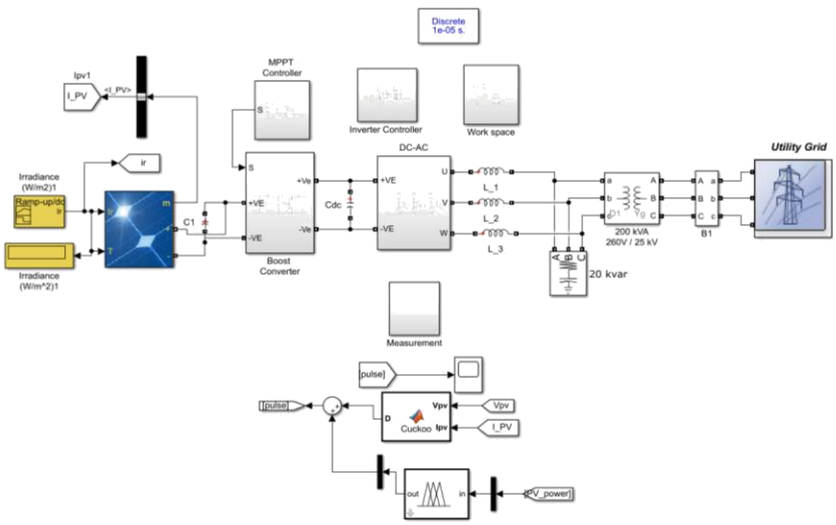

Fig. 3. Grid connected PV system with proposed optimization technique

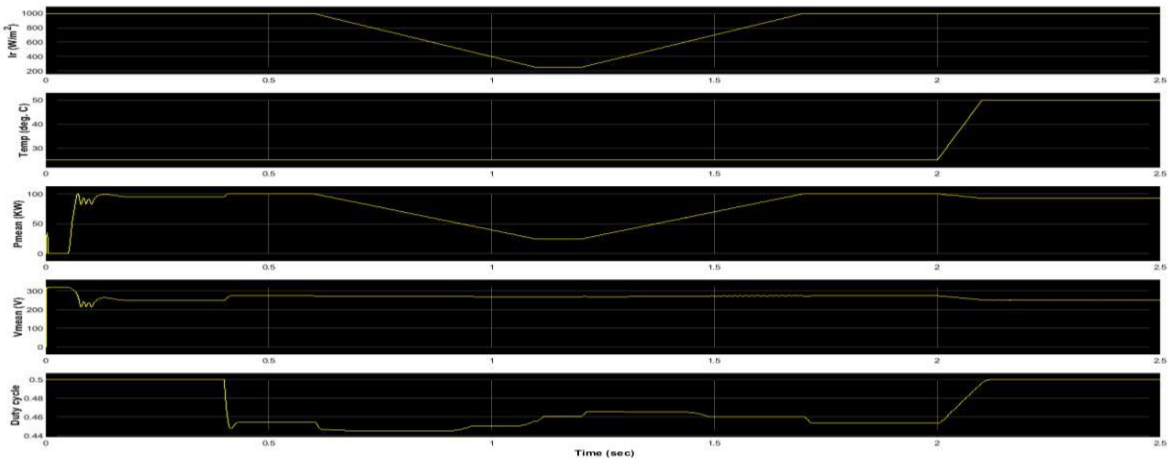

Fig. 4. The duty cycle and PV power at different irradiation and cell temperature

The behavior of the projected technique is examined when the PV irradiation is changed, which is shown in Fig. 4. And also demonstrates the resultant ac power that produced by the modelled PV system for every strategy when varying the solar irradiation level. In this work, a fuzzy controller with a single input and single output was designed. The power from PV is specified as input which is given to FLC and the modulation index is used to control the boost converter which is used to attain the output. For the input PV power and output modulation index, three membership functions were defined. The maximum range of PV power for the modulation index is (0 to 1) and all three fuzzy rules are applied to the controller.

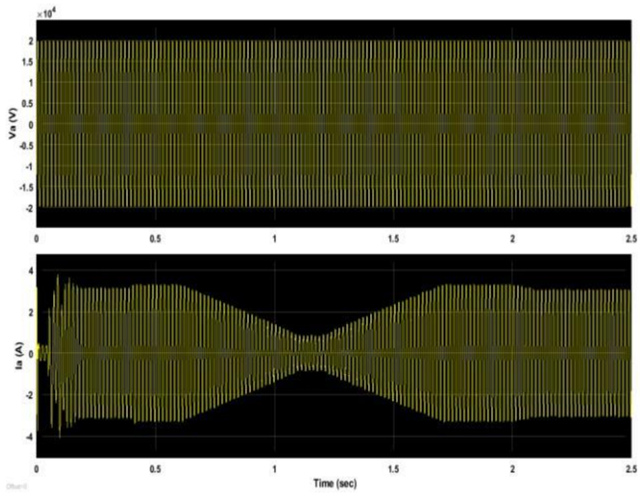

Fig. 5. Grid parameters of voltage and current

The PV power, duty cycle of boost converter and grid parameters are analyzed at different conditions to check the improvement in power quality. The grid parameters like voltage and current is given in Fig 5. PV power alone is shown in Fig 6.

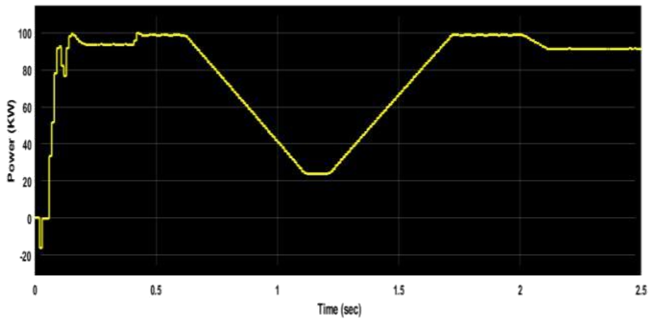

Fig. 6. Extracted PV Power

The harmonic analysis of load side current is done at different conditions and its measurement is given in Fig 12. In the earlier studies, PQ of PV system output was improved using PI controller and ANN-PI controller. The PI controller reduced the THD only up to 11% in grid current and the results from ANN-PI also had 7% THD. The above results concluded that the PSO-FLC based optimization technique is very effective in dynamic weather conditions and gives lesser harmonics compared to other techniques.

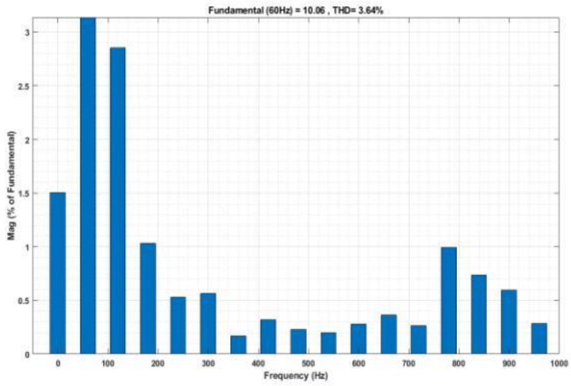

Fig. 7. THD measurement of 3-level MLI

Furthermore, FFT analysis of the inverter output current is given in fig. 12, as seen from this figure THD level of this current is 3.64 %. The presentation of the suggested technique was assessed by means of the comparison analysis with the presented technique. The assessment properties represent that the projected technique could be a favorable solution for PQ improvement of the PV systems under grid side faults, which is proficient over the other conventional techniques which is mentioned in below section.

TABLE II. COMPARISON OF THD ANALYSIS

Solution Techniques [20], [21]	3-level MLI
Without Controller	24.97
PI Controller	12.86
ANN-PI Controller	8.44
RBFNN Controller	4.81
Improved IC-MPPT algorithm	17.95
Proposed (ACSA-FLC) Controller	3.64

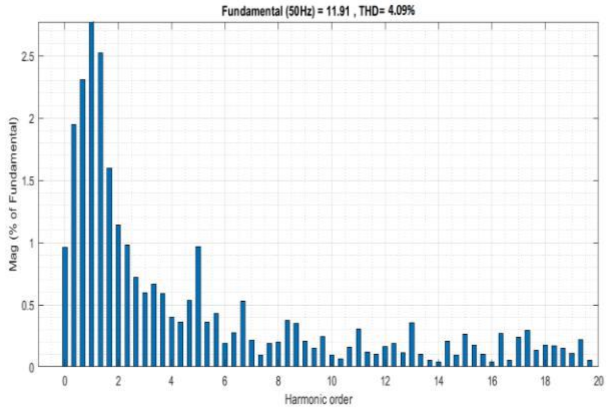

Fig. 8. THD measurement of 5-level MLI.

From the comparison table 2 and 3, it clearly shows that the THD of the proposed controller is much superior over the existing techniques [20] and [21]. It can determine that the projected technique effectively enhances the PQ of the grid-connected PV system compared to the conventional techniques.

TABLE III. COMPARISON OF THD ANALYSIS

Solution Techniques [20], [21]	27-level MLI
PSPWM controller	17.14
PSPWM and Modified SOPWM	6.59
ACSA Controller	6.05
FLC Controller	5.87
Hybrid ACSA-FLC controller	5.62

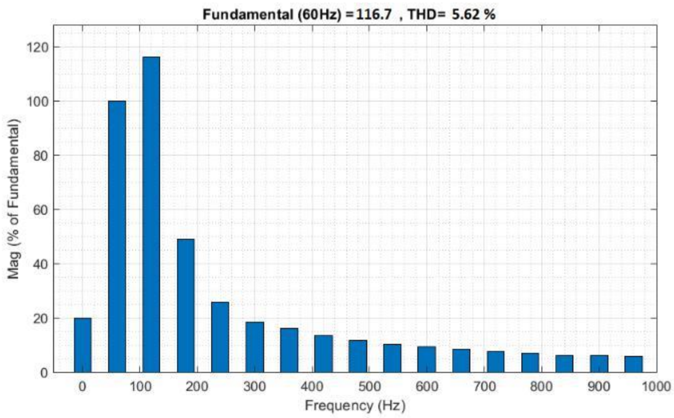

Fig. 9. THD measurement of 27-level MLI.

TABLE IV. COMPARISON OF THD ANALYSIS

Solution Techniques [20], [21]	5-level MLI
Without Controller	24.97
PI Controller	12.86
ANN-PI Controller	8.44
RBFNN Controller	4.81
Improved IC-MPPT algorithm	4.18
Proposed (ACSA-FLC) Controller	4.09

From the figure 7, 8 and 9, it illustrates the THD values for the 3, 5 level and 27-level MLI. From the table II, III and IV, it clearly explains the THD analysis for the various level of MLI with different techniques.

VII. Conclusion

In this paper, FLC is used with the ACSA algorithm in order to enhance the output power quality of the PV system. Both the FLC and ACSA generate a modulation index by considering the PV power and load demand. The modulation indices obtained from both the fuzzy controller and ACSA algorithm to regulate the duty ratio of boost converter and improve the power quality. The results obtained from the conventional methods at THD level is 4.81 %. But the proposed power quality improvement method reduced the THD up to 3.64 %, which is very less compared to the ordinary methods. The obtained results demonstrate the effectiveness of the projected control strategy in terms of THD, PV power, Grid voltage/current. The Proposed method offers superior performance and higher power quality compared to conventional RBFNN and IC-MPPT based control strategies. In the future, this research can be extended by modifying the topology of multi-level inverter or using recent novel optimization technique to enhance the features of PQ.

References

[1] R. Mahalakshmi, and K.C. Sindhu Thampatty, "Grid Connected Multilevel Inverter for Renewable Energy Applications," Elseveir Procedia Technology, vol. 21, pp. 636-642, January 2015.

[2] X. Cao, C. Zhang, Y. Zhang, Z. Gan, H. Li, W. Ni, and J. Wang, "The simulation study of the modulation method for PV grid-connected system," Elseveir Procedia Technology, vol. 145, pp. 122-127, July 2018.

[3] B. Fazlali, and E. Adib, "Quasi-resonant DC-Link transformer-less structures for grid-connected PV systems," International Journal of Electrical Power & Energy Systems, vol. 103, pp. 384-394, December 2018.

[4] D. Xu, W. Wang, W. Yan, and X. Yan, "A novel adaptive command-filtered backstepping sliding mode control for PV grid-connected system with energy storage," Solar Energy, vol. 178, pp. 222-230, January 2019.

[5] R.K. Gatla, W. Chen, G. Zhu, D. Zeng, and R. Nirudi, "Lifetime estimation of modular cascaded H-bridge MLPVI for grid-connected PV systems considering mission profile," Microelectronics Reliability, vol. 88, pp. 1051-1056, September 2018.

[6] M. Lakshmi, and S. Hemamalini, "Coordinated control of MPPT and voltage regulation using single-stage high gain DC–DC converter in a grid-connected PV system," Electric Power Systems Research, vol. 169, pp. 65-73, April 2019.

[7] N. Hamrouni, M. Jraidi, A. Dhouib, and A. Cherif, "Design of a command scheme for grid connected PV systems using classical controllers," Electric Power Systems Research, vol. 143, pp. 503-512, Feburary 2017.

[8] C. Bharatiraja, R. Palanisamy, and S.S. Dash, "Hysteresis current controller based transformerless split inductor-npc-mli for grid connected pv-system," Procedia Engineering, vol. 64, pp. 224-233, January 2013.

[9] V.V. Rajasegharan, L. Premalatha, and R. Rengaraj, "Modelling and controlling of PV connected quasi Z-source cascaded multilevel inverter system: An HACSNN based control approach," Electric Power Systems Research, vol. 162, pp. 10-22, September 2018.

[10] G. Prakash, C. Subramani, C. Bharatiraja, and M. Shabin, "A low cost single phase grid connected reduced switch PV inverter based on Time Frame Switching Scheme," International Journal of Electrical Power & Energy Systems, vol. 77, pp. 100-111, May 2016.

[11] K. Arulkumar, D. Vijayakumar, and K. Palanisamy, "Modeling and control strategy of three phase neutral point clamped multilevel PV inverter connected to the grid," Journal of Building Engineering, vol. 3, pp. 195-202, September 2015.

[12] M.A.N. Doss, R. Naveenkumar, R. Ravichandran, J. Rengaraj, and M. Manikandan, "PV Fed Asymmetrical Switched Diode Multi Level Inverter With Minimum Number of Power Electronic Components," Energy Procedia, vol. 117, pp. 592-599, June 2017.

[13] M.B. Latran, and A. Teke, "Investigation of multilevel multifunctional grid connected inverter topologies and control strategies used in photovoltaic systems," Renewable and Sustainable Energy Reviews, vol. 42, pp. 361-376, Feburary 2015.

[14] D. Umarani, and R. Seyezhai, "Modeling and Control of Quasi Z-source Cascaded H-bridge Multilevel Inverter for Grid Connected Photovoltaic Systems," Energy Procedia, vol. 90, pp. 250-259, December 2016.

[15] V. Sridhar, S. Umashankar, P. Sanjeevikumar, V.K. Ramachandaramurthy, L. Mihet-Popa, and V. Fedák, "Control Architecture for Cascaded H-Bridge Inverters in Large-Scale PV Systems," Energy Procedia, vol. 145, pp. 549-557, July 2018.

[16] S. Patra, N. Kishor, S.R. Mohanty, and P.K. Ray, "Power quality assessment in 3-Φ grid connected PV system with single and dual stage circuits," International Journal of Electrical Power & Energy Systems, vol. 75, pp. 275-288, Feburary 2016.

[17] N. Chettibi, and A. Mellit, "Intelligent control strategy for a grid connected PV/SOFC/BESS energy generation system," Energy, vol. 147, pp. 239-262, March 2018.

[18] I. Abadlia, M. Adjabi, and H. Bouzeria, "Sliding mode based power control of grid-connected photovoltaic-hydrogen hybrid system," International Journal of Hydrogen Energy, vol. 42(47), pp. 28171-28182, November 2017.

[19] Z. Zheng, H. Li, S. Tang, H. Yang, R. Zhao, "Multi-objective control of multi-functional grid-connected inverter for renewable energy integration and power quality service," IET Power Electronics, vol. 9(4), 761-770, March 2016.

[20] B.G. Sujatha, and G. S. Anitha, "Enhancement of PQ in grid connected PV system using hybrid technique," Ain Shams Engineering Journal, vol. 9(4), pp. 869-81, December 2018.

[21] N. Prabaharan, A. Rini Ann Jerin, K. Palanisamy, and S. Umashankar, "Integration of single phase reduced switch multilevel inverter topology for grid connected photovoltaic system," Energy Procedia, vol. 138, pp. 1177-1183, October 2017.