UPQC based PI, FLC and ANN controllers to Analyze Steady State and Transient State of Grid Connected Solar PV System

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Abstract – Solar Photo voltaic (SPV) is connected to grid through converters. *Unified Power Quality Conditioners (UPQCs) are essential devices used in power distribution systems to improve power quality by mitigating the steady state and transient state of system. This paper presents a comparative study of intelligent control techniques such as Fuzzy Logic Controller (FLC) and Artificial Neural Network (ANN), as applied to UPQC for enhanced performance in mitigating power quality issues with PI conventional method. The FLC and ANN are both employed as control strategies for the UPQC to regulate its compensation actions based on the detected disturbances in the grid. The proposed system is simulated in MATLAB/Simulink software 2018b.*

Key Words: *SPV, UPQC, FLC. ANN.*

1. INTRODUCTION

Unified Power Quality Conditioners (UPQCs) play a vital role in enhancing the performance of grid-connected solar photovoltaic (PV) systems by mitigating power quality issues and ensuring stable operation under varying grid conditions [1-2]. In this introduction, an overview of the application of Proportional-Integral (PI), Fuzzy Logic Controller (FLC), and Artificial Neural Network (ANN) controllers [4] in UPQCs to analyze both steady-state and transient state behaviour of grid-connected solar PV systems is presented. Grid-connected solar PV systems are an increasingly popular renewable energy solution, providing clean and sustainable electricity generation. However, the integration of solar PV into the grid introduces challenges related to power quality, including voltage fluctuations, harmonic distortions, and frequency variations [5]. UPQCs are advanced power electronic devices designed to mitigate power quality issues in electrical distribution systems. They typically consist of series and shunt active power filters that work together to compensate for voltage sags, swells, harmonics, and other disturbances, ensuring stable and high-quality power supply to connected loads. Proportional-Integral (PI), Fuzzy Logic Controller (FLC), and Artificial Neural Network (ANN) controllers are commonly employed in UPQCs to regulate their compensation actions based on detected grid disturbances [6-7]. These controllers analyze input signals, such as voltage and current waveforms, and determine the appropriate compensation signals to maintain power quality within specified limits. Steady-state analysis focuses on the long-term equilibrium of the system under normal operating conditions. PI controllers are commonly used in UPQCs to regulate voltage and current levels, ensuring steady-state stability and optimal power flow in grid-connected solar PV systems [8-9]. FLC controllers offer flexibility and adaptability in handling non-linear and uncertain system dynamics, while ANN controllers provide the ability to learn from historical data and optimize compensation responses for improved steady-state performance [9-10]. Transient state analysis deals with the system's response to sudden disturbances or changes in operating conditions. FLC and ANN controllers in UPQCs can effectively mitigate transient disturbances such as voltage sags, swells, and harmonics by adjusting compensation actions [11-13]. These intelligent control strategies enable UPQCs to rapidly restore system stability and ensure uninterrupted operation of grid-connected solar PV systems during transient events. The objective of this research is to analyze the performance of PI, FLC, and ANN controllers in UPQCs for both steady-state and transient state operation of grid-connected solar PV systems. The study aims to evaluate the effectiveness [14-16], efficiency, and robustness of each control strategy in mitigating power quality issues and enhancing system reliability under various operating conditions. The application of PI, FLC, and ANN controllers in UPQCs offers promising solutions for analyzing and improving both steady-state and transient state behaviour of grid-connected solar PV systems[17-19]. By leveraging intelligent control strategies, UPQCs can ensure stable and high-quality power supply, contributing to the integration of renewable energy sources and the advancement of sustainable power generation technologies [20].

2. Configuration of Solar System Integrated with UPQC

The Configuration of Solar System Integrated with UPQC is shown in figure 1. The Maximum power point algorithm is used to extract the maximum power from using boost converter connected with the multilevel voltage source inverter. The inverter is connected through UPQC to grid.

Control strategies are applied to DC link Voltage of UPQC to maintain the controlled signal.

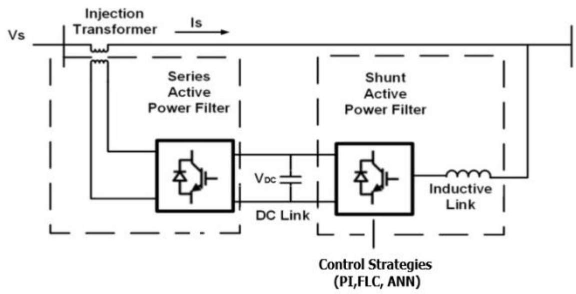


Fig. 1. Configuration of Solar System Integrated with UPQC

UPQCs with DC voltage control capabilities integrate additional control algorithms to regulate DC voltage levels. These UPQCs typically include DC-DC converters and control strategies to manage the flow of power between the DC source/load and the grid, ensuring stable DC voltage levels and enhancing overall power quality. Control strategies employed in UPQCs with DC voltage control capabilities.

2.1 UPQC based PI Controller

PI controllers shown in figure 2 are widely used in UPQCs to regulate compensation actions based on the difference between the desired reference and measured signals. In the context of UPQCs, PI controllers are typically employed to regulate voltage and current levels to maintain stable and high-quality power supply to connected loads. In UPQCs, PI controllers regulate voltage levels by adjusting the compensation voltage injected into the grid. The PI controller continuously compares the measured grid voltage with the reference voltage and calculates the appropriate compensation signal to minimize the error and maintain the desired voltage level.

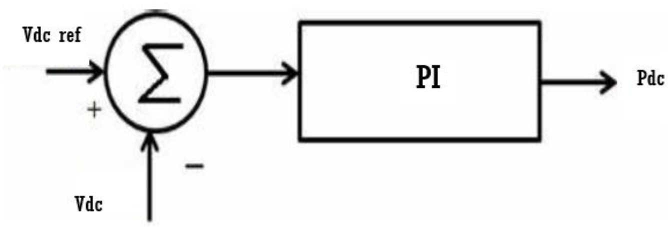


Fig. 2. PI Controller block diagram

2.2 UPQC based FLC Controllers

The measured grid voltage with the reference voltage is compared and error voltage is given as input to FLC. The Mamdani method for fuzzification and centroid method for defuzzification used in FLC . FLC controllers in UPQCs regulate both voltage and current levels to maintain power quality within specified limits. They continuously monitor grid conditions, analyze input signals such as voltage and current waveforms, and determine the appropriate compensation signals to mitigate disturbances and stabilize the system. The fuzzy rule base in UPQC based FLC controllers consists of a set of linguistic rules that describe the relationship between input and output variables. These rules are derived based on expert knowledge, empirical observations, or simulation studies, and they define the behavior of the controller under different operating conditions. Membership functions are used to quantify the degree of membership of input signals to different linguistic variables (e.g., "low," "medium," "high"). These membership functions define the shape and characteristics of the fuzzy sets that represent input and output variables in the FLC controller. FLC controllers shown in figure 3 are integrated into the control system of UPQCs, along with other components. The control system continuously monitors grid conditions, analyzes input signals using the FLC controller, and adjusts the output of the UPQC to mitigate power quality issues.

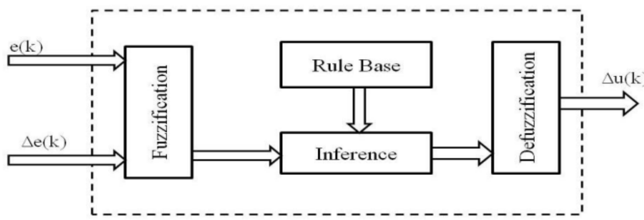


Fig. 3. FLC Controller block diagram

2.3 UPQC based ANN Controllers

Artificial Neural Network (ANN) controllers offer a data-driven approach to control, making them suitable for handling complex and non-linear system dynamics. ANN controllers in UPQCs analyze input signals, such as voltage and current waveforms, and determine the appropriate compensation actions based on learned patterns and historical data.

ANN controllers are trained using given input data and target data to learn the relationship between input signals and desired output actions using the formula.

$$Y_n = \sum W_n I_n$$

Where Yn is controlled voltage output, Wn is weight and In is input voltage. Training algorithms such as feed forward propagation algorithms adjust the parameters of the neural network to minimize prediction errors and optimize control performance. The single layer feedforward network is shown in figure 4. ANN controllers in UPQCs consist of interconnected neurons organized in layers, including input, hidden, and output layers.

The Levenberg-Marquardt algorithm used gives a better solution. In the proposed model the ANN uses three layers namely: two input layer (voltage error and change in voltage error), 100 neurons in hidden layer and one output layer (Power loss) showed in figure 5. The hidden layer computes the assigned input value based on weight matrix and bias value and gives the assigned target value. The output of the hidden layer is compared with the threshold value to generate output. The number of neurons in the hidden layer is selected based on trial and error method.

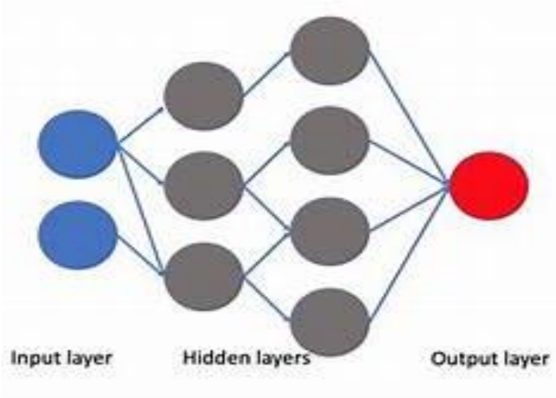


Fig. 4. Single layer feedforward network

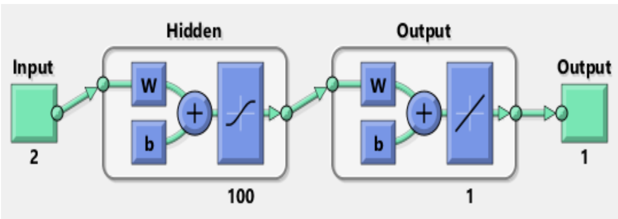


Fig. 5. Neural Network Model of Controller

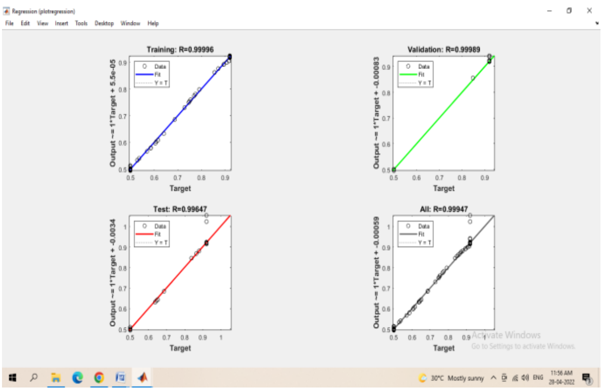


Fig. 6. Regression analysis of Controller

The figure 6 shows regression plots display the network outputs with respect to targets for training, validation, and test sets. For a perfect fit, the data should fall along a 45 degree line, where the network outputs are equal to the targets. Figure 6 show the fit is reasonably good for all data sets, with R values in each case is nearly 1. The Mean Squared Error (MSE) is nearer to zero. Moreover the results of R show ANN controller training is more stable.

3. Simulation, Results and Discussions

The figure 7 shows the solar PV system connected to grid through converters and inverters along with UPQC to improve voltage performance at grid.

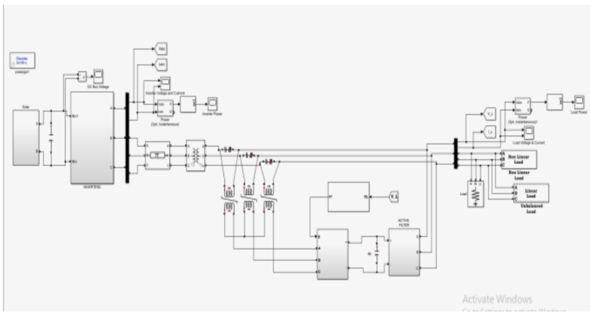
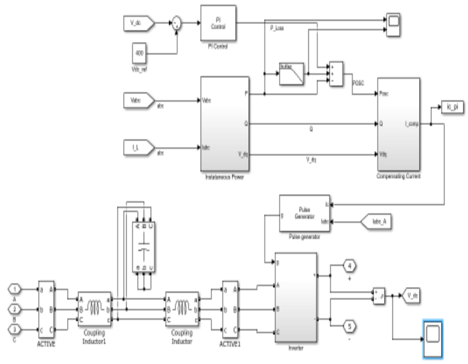
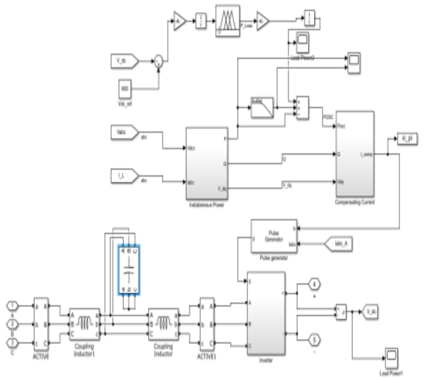


Fig. 7. Basic structure of UPQC based on controllers

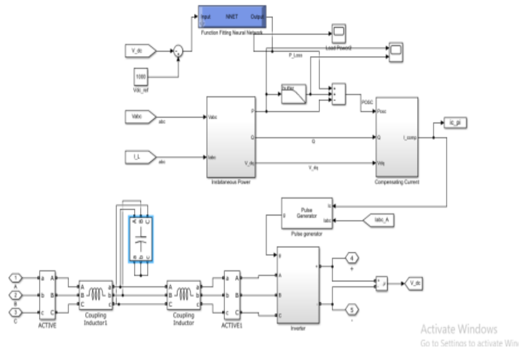
The controllers such as PI, FLC and ANN shown in figure 8 are connected in shunt APC (active power inverter) to get controlled voltage signal. The reference voltage is compared with fixed voltage, which is applied to PI controller to get controlled signal. The output signal is given to current compensating block to get compensated current which is compared with load current to generate error signal passed to hysteresis controller to generate pulse to inverter.



a) UPQC based on PI controller

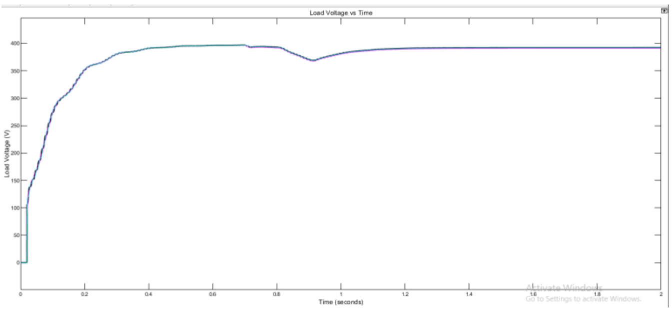


b) UPQC based on Fuzzy controller

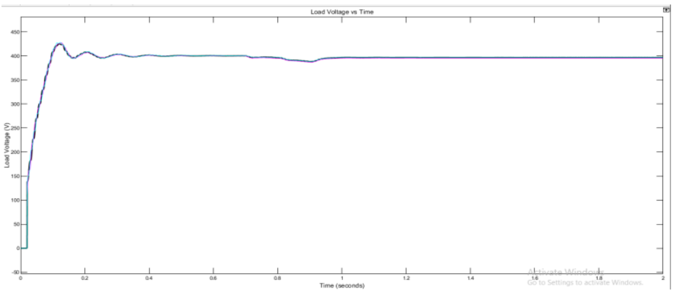


c) UPQC based on ANN controller

Fig. 8. Response of Controllers in UPQC a) UPQC based on PI controller, b) UPQC based on Fuzzy controller and c) UPQC based on ANN controller



(a)



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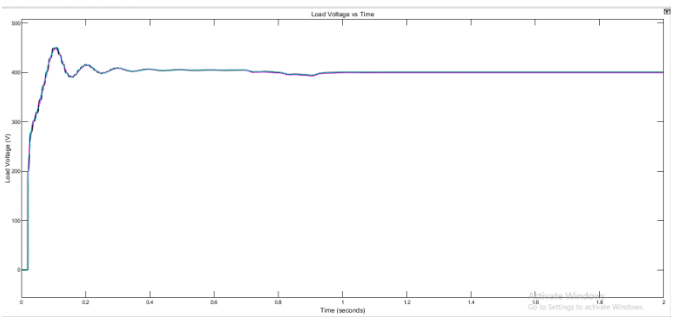


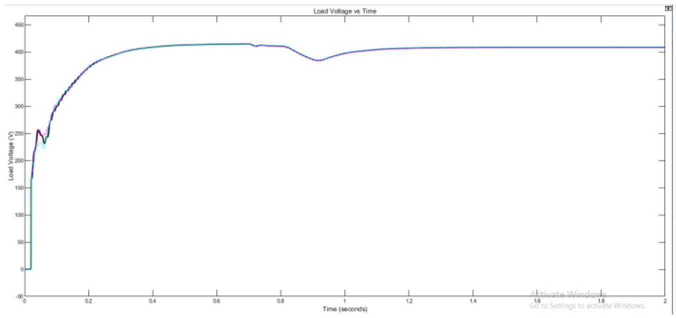
(c)

Fig. 9. Response of UPQC based load voltage for conventional (a) PI controller (b) Fuzzy Controller and (c) ANN Controller

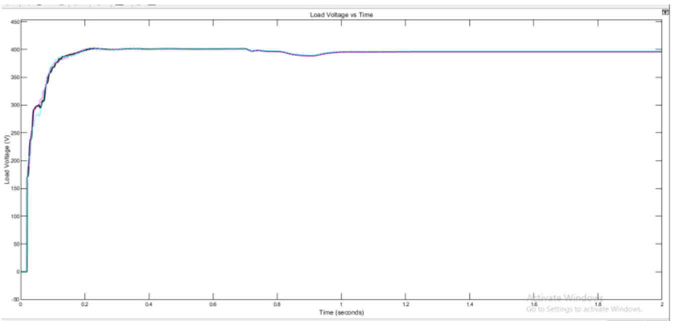
The results of figure 9 are provided in table 1. The rise time and settling time of conventional inverter for PI controller is 0.43s and 1.01s along with load voltage is 392V as such steady state error is more shown in Fig 9(a).

The rise time and settling time of conventional inverter for FLC controller is 0.12s and 0.26s along with load voltage is 395V as such steady state error is slightly reduced compared to PI shown in Fig 9(b).

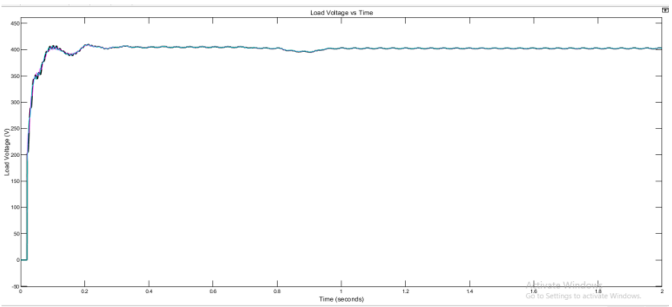
The rise time and settling time of conventional inverter for ANN controller is 0.06s and 0.25s along with load voltage is 399V as such steady state error is nearly stable shown in Fig 9(c).



(a)



(b)



(c)

Fig. 10. Response of UPQC based load voltage performance for Multilevel inverter (five) (a) PI controller (b) Fuzzy Controller and (c) ANN Controller

The rise time and settling time of load voltage using PI controller is 0.18s and 0.442s along with load voltage is 408V as such steady state error is more shown in Fig 10(a).

The rise time and settling time of for FLC controller is 0.09s and 0.23s along with load voltage is 398V as such steady state error is slightly reduced compared to PI shown in Fig 10(b).

The rise time and settling time for ANN controller is 0.06s and 0.21s along with load voltage is 401V as such steady state error is stable shown in figure 10(c).

Table 1: Performance analysis of controller type with VSI

Controller Type	VSI (two level)			
	Load Voltage(V)	Settling Time(s)	Rise Time(s)	Steady state error(V)
PI	392	1.01	0.43	-8
FLC	395	0.26	0.12	-5
ANN	399	0.25	0.06	-1

The Performance analysis of controller type with VSI on steady and transient state is provided in Table 1.

The PI controller provides voltage magnitude of 392V with steady state error of 8V while ANN offers 399V with 1V as error and fuzzy provides 395V.

Table 2: Performance analysis of controller type with MLI

Controller Type	MLI (five level)			
	Load Voltage(V)	Settling Time(s)	Rise Time(s)	Steady state error(V)
PI	408	0.442	0.18	8
FLC	398	0.23	0.09	-2
ANN	401	0.21	0.06	1

The Performance analysis of controller type with MLI on steady and transient state is given in Table 2.

The PI controller provides voltage magnitude of 408V with steady state error of 8V whereas ANN offers 401V with 1V as error and fuzzy provides 398V. The result of MLI with ANN and fuzzy give the better performance compared to PI controller in term of steady state and transient state performance.

4. Conclusion

The settling time and rise time reduces with fuzzy and ANN control compared to PI control. The application of Fuzzy Logic Controller (FLC), and Artificial Neural Network (ANN) controllers in Unified Power Quality Conditioners (UPQCs) offers versatile solutions for analyzing both steady-state and transient state behaviour of grid-connected solar PV systems. Proposed ANN and Fuzzy controller type has its unique advantages and characteristics, contributing to the overall effectiveness and efficiency of power quality mitigation in solar PV systems.

REFERENCES

1. Devi, S.C, Chandrakala, S. Shah, P. Devassy, S. Singh, B. Solar PV array integrated UPQC for power quality improvement based on modified GI. In Proceedings of the 2020 IEEE 9th Power India International Conference (PIICON), Sonepat, India, 2020, pp. 1–6.

2. Mallikarjuna G D, G.S.Sheshadri, Comparison of Solar Energy System Tools: A Case Study, International Research Journal of Engineering and Technology (IRJET) - (ISSN 2395-0056), Vol. 6, Issue. 12, Dec. 2019.

3. Rao, Pragaspathy, S. Enhancement of electric power quality using UPQC with adaptive neural network model predictive control. In Proceedings of the 2022 International Conference on Electronics and Renewable Systems (ICEARS), Tuticorin, India, 16–18 March 2022, pp. 233–238.

4. Mallikarjuna G D, G.S.Sheshadri, Validation of Performance evaluation using Matlab/Simulink Model of a PV Array, International Journal of Advance Science and Engineering (IJASE) – (E-ISSN 2349 5359; P-ISSN 2454 9967), Vol. 6, no. 3, Feb.2020.

5. Kumar, A.S, Rajasekar, S. Raj, Power Quality Profile Enhancement of Utility Connected Microgrid System Using ANFIS-UPQC. Procedia Technol. 2015, 21, pp. 112–119.

6. Mallikarjuna G D, G.S.Sheshadri, Power Quality Improvement Using unified power quality conditioner in PV sourced stand alone micro grid system, International Journal of Creative Research Thoughts (IJCRT), Vol.11, Issue-3, ISSN: 2320-2882, 2023. UGC Approved.

7. Kinhal, V.G, Agarwal, P. Gupta, H.O. Member, Performance Investigation of Neural-Network-

Based Unified Power-Quality Conditioner. IEEE Trans on Power Delivery. 2011, 26, 431–437.

8. Mallikarjuna G D, G.S.Sheshadri, "Power Quality Analysis Using Active NPC Multilevel inverter in PV sourced stand alone micro grid system" paper published in International Research Journal of Engineering and Technology (IRJET), Vol 10, Issue. 10, Oct. 2023, ISSN: 2395-0056.

9. Kaushal, J, Basak, P, Power quality control based on voltage sag/swell, unbalancing, frequency, THD and power factor using artificial neural network in PV integrated AC microgrid. Sustain. Energy Grids Netw. 2020.

10. Mallikarjuna G D, G.S.Sheshadri, Evaluation of 5 Level Multilevel inverters connected to solar sourced stand alone micro grid system, paper published in International Research Journal of Engineering and Technology (IRJET), Vol 02, Issue. 02, Feb. 2024, ISSN: 2395-0056.

11. Khadkikar. V, Enhancing electric power quality using UPQC: A comprehensive overview. IEEE Trans. Power Electron. 2012, 27, 2284–2297.

12. Han, B. Bae, B. Kim, H. Baek, S. Combined operation of unified power-quality conditioner with distributed generation. IEEE Trans on Power Delivery. 2006, 21, 330–338.

13. Vinnakoti, S. Kota, V.R. Implementation of artificial neural network based controller for a five-level converter based UPQC. Alex. Eng. J. 2018, 57, 1475–1488.

14. Kesler, M. Ozdemir, E. Synchronous-reference-frame-based control method for UPQC under unbalanced and distorted load conditions. IEEE Trans on Ind. Electron. 2011, 58, 3967–3975.

15. Lu, Y. Xiao, G. Wang, X. Blaabjerg, F. Lu, D. Control strategy for single-phase transformerless three-leg unified power quality conditioner based on space vector modulation. IEEE Trans. Power Electron. 2016, 31, 2840–2849.

16. Rahmani, B, Li,W. Liu, G. A wavelet-based unified power quality conditioner to eliminate wind turbine non-ideality consequences on grid-connected photovoltaic systems. Energies 2016, 9, 390.

17. Sindhu, S. Sindhu, M.R. Nambiar, T.N.P. An Exponential Composition Algorithm Based UPQC for Power Quality Enhancement. Procedia Technol. 2015, 21, 415–422.

18. Dheeban, S.S, Selvan, N.B.M. ANFIS-based Power Quality Improvement by Photovoltaic Integrated UPQC at Distribution System. IETE J. Res. 2021, 1–19.

19. Shukla, S, Mishra, S, Kumar, S. Implementation of empirical mode decomposition based algorithm for shunt active filter. IEEE Trans. Ind. Appl. 2017, 53, 2392–2400.

20. Aryanezhad, M, Ostadaghaee, E. Robustness of unified power quality conditioner by neural network based on admittance estimation. Appl. Soft Comput. 2021.

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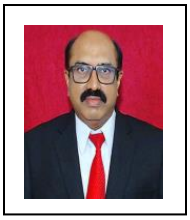

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