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Fuzzy proportional-integral controlled unified power quality conditioner for electric vehicle charging grids

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ABSTRACT

In power system one of the major concerns is the power quality (PQ) issues due to the presence of non-linear loads. At present electric vehicles (EV's) are highly desired for mobility but it has challenges related to power quality. EVs are primarily charged either from the grid or renewable sources like photovoltaic (PV) cells, which function as direct current (DC) grids. However, the growing number of EV's can introduce disturbances in voltage and harmonics in current. This has necessitated a user-friendly method to rectify these imbalances. The uniqueness of this work is that, the investigations are carried out to prove the effectiveness of the PV powered unified power quality conditioner (UPQC) in resolving the disturbance created by EV charger and dynamic load both in grid connected as well as in off grid mode of operation in standard IEEE 14-bus microgrid model distribution system. The approach of intelligent fuzzy-proportional-integral (fuzzy-PI) controller in regulating the performance of the PV powered UPQC is another novel approach. Case studies based on the performance of UPQC is done for various scenarios of EV charger and its performance is compared with conventional PI controller. Simulations are carried out in MATLAB2017b software package.

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1. INTRODUCTION

In recent years, power quality (PQ) has become a critical concern due to the wide spread use of power electronics-based appliances. This necessitates to develop a customer-friendly device that mitigates the inequalities in voltage as well as in current. Unified power quality conditioner (UPQC) is one among the custom power device which addresses the inequalities of both voltage and current. A discussion of the UPQC-based topologies, their reimbursement, operation, and ideal location in the distribution system is explored in [1], [2]. The future trend in the transportation sector is the replacement of conventional vehicles with electric vehicle (EV). These EV's have major influence on grid as well as on distribution systems. Basically, EV chargers are power electronic converter alike to variable load, its characteristics not only disturbs the voltage profile of the system but also initiates harmonics in the current. To support this many research articles have been published. Concerning to this climate change, it is necessary to minimize the amount of production electrical energy by burning fossil fuel from 70% to below 20% by 2050 [3]–[6].

Comprehensive review of PV panels based on its static and dynamic characteristics is discussed [7]. Distinctive characteristics of the AC and DC chargers, power system operations using renewables such as solar and wind for EV charging, detailed survey on different topologies for EV charging using two-way power transmission and enhancing the power quality (PQ) of the network various topologies are presented in the literature [8]. The main motivation behind the evolution of microgrid (MG) in the United States (US) is its capability to resume from a problem and the availability of service at every point in time. DC MG is more advantageous compared to the conventional AC grid. In this context, hybrid AC/DC architecture of MG emerges as the most promising configuration in research which not only ensures reliability but also helps in improving the system efficiency. At present, most of appliances such as remote controllers, mobiles, electric vehicles and laptop are operating on DC supply. Even though conventional grid is AC these DC loads are connected with conventional AC system through AC-DC converter. Due to the nonlinear nature of these electronic devices causes power quality issues [9]–[14]. A decisive review has been carried out on several converter topologies for DC and hybrid microgrid [15]–[17]. The act of conventional proportional integral (PI) controller is not satisfactory especially in presence of nonlinear load, and during the integration of non-renewables to resolve these limitations, it is necessary to tune the PI controller with the aid of imaginative strategies like adaptive network based fuzzy interference system (ANFIS) and fuzzy [18]. Role of fuzzy logic controller (FLC) in eliminating the voltage disturbances and harmonics in power system are discussed in [19]–[21]. Comparative analysis of UPQC in stabilizing DC link voltage is carried with ANFIS, fuzzy-PI and neural network. It is expected that FLC helps to bring out refinement in the hybrid micro-grid version than the elementary PI controller [22]. The conclusion arrived from the review is that challenges related to PQ in hybrid AC/DC MG due to nonlinear load is still an area of research. In order to achieve this effective custom power device and control algorithm is necessary to tune the conventional PI controller. The main contribution of this work involves, i) modelling of standard IEEE hybrid AC/DC microgrid test system, ii) integration of PV powered UPQC in between bus 2 and 5, iii) alleviating power reliability issues attributed to EV chargers in integrated microgrid environment, and iv) validation in both Grid connected and islanded mode without using extra converters and controllers.

2. METHOD

The objective of this research lies in analyzing the performance of PV powered UPQC in enhancing the PQ problems due to the penetration of EV charger and dynamic load in standard IEEE 14 bus microgrid based distribution system. The approach of intelligent fuzzy-PI controller in regulating the effectiveness of the PV powered UPQC is another novel approach in this work. To achieve this, selected IEEE14 bus system detailed specification of is illustrated in Figure 2. The one-line diagram of the standard IEEE 14 bus MG distribution system with the interconnection of PV powered UPQC, EV charger and the dynamic load is shown in Figure 1. In this test model the MG is coupled to the common connection point to a 69 kV utility grid of base 100 MVA with an impedance ratio of 10. The two voltage distribution levels are: 13.8 kV medium voltage (MV) lines represented in blue color and 220 V low voltage (LV) lines indicated in green color. The following bus numbers 14, 13, 12, 11, 10, 9, 8, 7, 6 in the test model represents 13.8 kV voltage level and the bus numbers 1, 2, 3, 4, 5 represents the voltage level of 220 V. In addition to this the test case, it also consists of generators, AC loads on each bus, solar PV subsystem, battery energy storage systems (BESS), AC/AC voltage source converters, transformers and three Sub MGs in which two are AC MG's and one is DC MG. The operating frequency of AC grid is 60 Hz. This work aims to identify the power quality issues at the distribution side therefore PV powered UPQC which is placed between bus 2 and 5, whose voltage level are 220 V. Three single phase EV charger with 16 A and 24 kWh Li-Ion battery is developed and connected at bus 2, along with EV charger a dynamic load pattern of 45 kW is connected at bus 2. The maximum current of EV charger is 16 A and the minimum current is 6 A chosen as per IEC 61851 standard. In dynamic load pattern six loads are considered and each load is switch by $1/6^{th}$ time. At initial the $1/6^{th}$ of 45 kW is connected. Then the $2/6^{th}$ time the $2/6^{th}$ of the load is connected. The conception is based on (1) [23].

$$P_{load}(i) = \left(\frac{i}{6}\right) * P \tag{1}$$

here $I = 1,2 \ldots 6;\ P = 45\ kW$. The hybrid AC/DC microgrid based standard IEEE 14 bus distribution system is simulated in MATLAB 2017b software package.

The complete Simulink model of suggested hybrid AC/DC microgrid with the integration of PV powered UPQC is as shown in Figure 2. PQ problems of EV charger and dynamic load are analyzed based on the three case studies of UPQC and four scenarios of EV charger in grid coupled as well as off grid mode functioning of the hybrid AC/DC MG. Cases are discussed as follows [24], [25]:

Case 1: The system is associated with grid, along with EV charger positioned at the load side in the absence of UPQC.

Case 2: In this case, the system works under grid integrated mode with EV charger at the transient load end and the UPQC is attached to the system.

Case 3: In this case, the UPQC is coupled to the system with EV charger at the load side and the system works under islanded mode, In the island mode DC grid is supplies power to the AC load and charger.

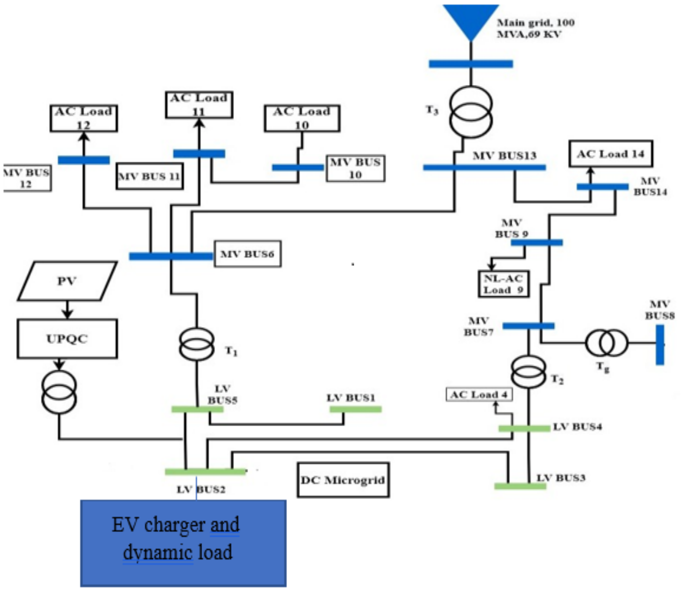


Figure 1. Single line diagram of integration of solar PV powered UPQC and EV charger in IEEE 14 bus test case

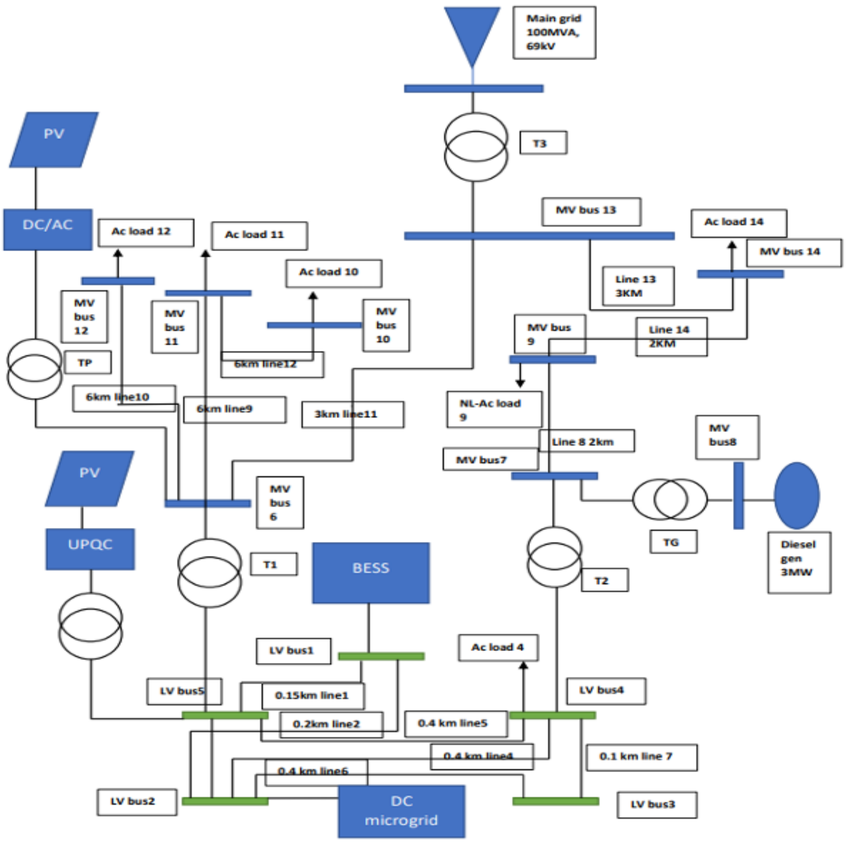


Figure 2. Proposed IEEE 14 bus benchmark [25]

2.1. Scenarios (SCN's) based on EV charger action

These scenarios verify the performance of UPQC under unbalanced condition.

- Scenario 1 (SCN 1): The EV charger is connected at load side and its charging action is in OFF condition.
- Scenario 2 (SCN 2): The EV charger is connected at load side in all the three phases, under charging condition with minimal charging current of 6A.
- Scenario 3 (SCN 3): The EV charger is under charging condition but is connected with two phases only at load side.
- Scenario 4 (SCN 4): The EV charger is connected with only single phase under charging condition.

2.2. Control strategy

The preferred hybrid AC/DC distribution test system operates under grid-connected as well as in off grid mode. The UPQC behaves as the grid connected inverter to transfer the power to the load from the PV powered DC grid, which is coupled to the step-up converter. This is intern linked to the backup battery; this configuration contributes the consistent DC bus voltage. This constant DC voltage is the source for UPQC which improves the power quality of hybrid AC/DC microgrid both in grid connected and isolated means of operation.

To refine the performance of UPQC tuning the conventional PI controller often in presence of nonlinear load results in parameter variations above or below the desired value. This necessitates the fuzzy logic based intelligent control approach which tunes the coefficients of PI controller for various unbalance conditions which exists in the system. The PI parameters are tuned by using Sugeno fuzzy inference model, its performance is analyzed with linear subsequent rules for different power quality issues. The Simulink model of DC link voltage controller using fuzzy logic controller (FLC) is shown in Figure 3. In this work Sugeno based fuzzy controller is chosen, to make the DC bus voltage more optimum. To enhance the PQ in hybrid AC/DC microgrid integrated with PV powered UPQC it is necessary to manage the DC link voltage constant. The input variables of intelligent fuzzy-PI controller are defined as a set of three set of linguistic variables of triangular membership function namely, N–Negative; P–Positive and Z–Zero. The membership function of output variables is also same as the input: N–Negative; P–Positive and Z–Zero. To obtain the desired output, fuzzy rules are framed for each combination of the input variables to tune the parameter of PI controller. As there are three membership functions for input E and ΔE, 9 rules are framed for tuning the PI controller and it is composed as shown in Table 1, where each cell represents the output membership function of a control rule with two input membership functions. Error and change in error are modelled as (2):

$$e(k) = V_{dc\,ref} - V_{dc} \text{ and } \Delta e(k) = e(k) - e(k-1) \quad (2)$$

where $e(k)$ = the error; $\Delta e(k)$ = change in error; $V_{dc\,ref}$ = the reference voltage; V_{dc} = the actual voltage.

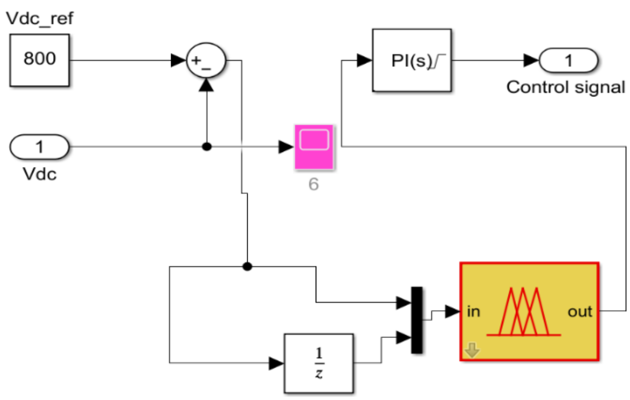


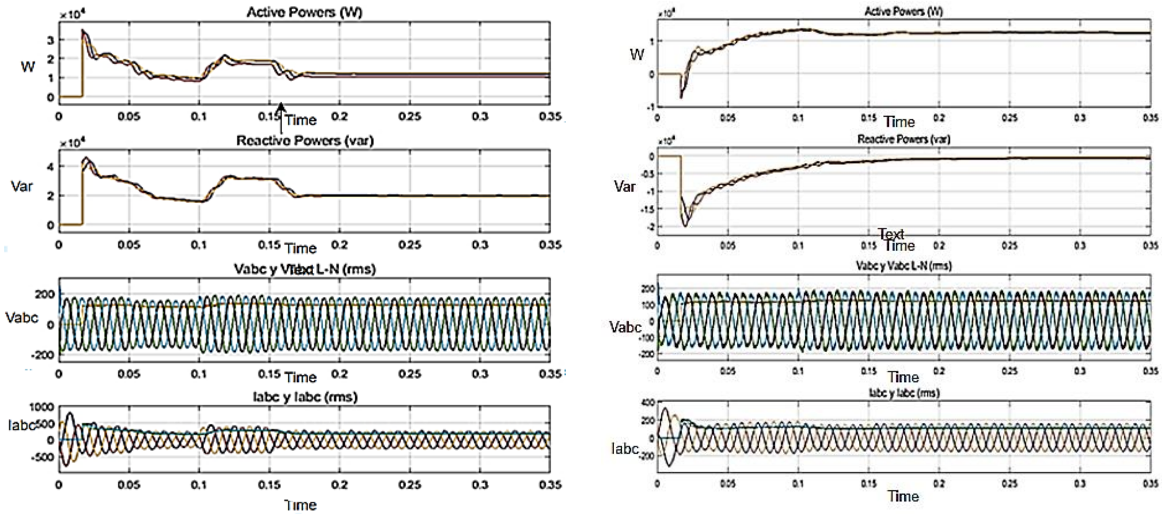
Figure 3. DC link voltage controller using fuzzy logic PI controller

Table 1. Rule for PLC

E/ΔE	N	Z	P
N	Z	P	Z
Z	Z	Z	Z
P	P	Z	Z

3. RESULTS AND DISCUSSION: validation of UPQC

The power quality issues at bus 2 are observed before connecting the PV powered UPQC over the time 1 sec. The Figure 4(a) shows the bus 2 real power, reactive power, voltage and current values prior connecting UPQC. From the graph it is evident that the real and reactive power are disturbed due to the sag and swell creation at 0.05 and 0.1 secs respectively. Figure 4(b) shows the real power, reactive power, voltage and current values of bus 2 after connecting UPQC. It can be seen that the reactive power is neutralized. So, the current amplitude is reduced drastically. The voltage sag and swell are compensated well. So, the solar PV assisted UPQC is performing better in standard IEEE 14 bus MG model distribution network. Hence the desired PV powered UPQC is validated.



(a) (b)

Figure 4. Bus 2 real power, reactive power, voltage and current values (a) before and (b) after connecting UPQC

Following the assessment of PV-driven UPQC in the presence of PI and intelligent fuzzy-PI controller for three cases and four scenarios:

Case 1: In the absence of UPQC (*i.e.* controller action is also absent) the voltage values in scenario 1 is below 100 V, current and voltage THD's are slightly exceeding the desired value in scenario1 compared to remaining three scenarios. The values of EV current and power factor are tabulated in Table 2 along with system voltage and harmonics.

Case 2: When UPQC is attached to the system in all the scenarios of EV charger better voltage stability is achieved in presence of fuzzy-PI controller compared to traditional PI controller. The waveform of scenario 1 of case 2 is represented in Figure 5. All parameters' values are tabulated in Table 3. From the Table 3 it is evident that in presence of UPQC and fuzzy-PI controller there is an improvement in system voltage and harmonics. It is observed from the waveform as shown in Figure 5, that disturbance in the voltage waveform of Figure 5(a) is reduced and better settling time is achieved in Figure 5(b) compared to conventional PI controller.

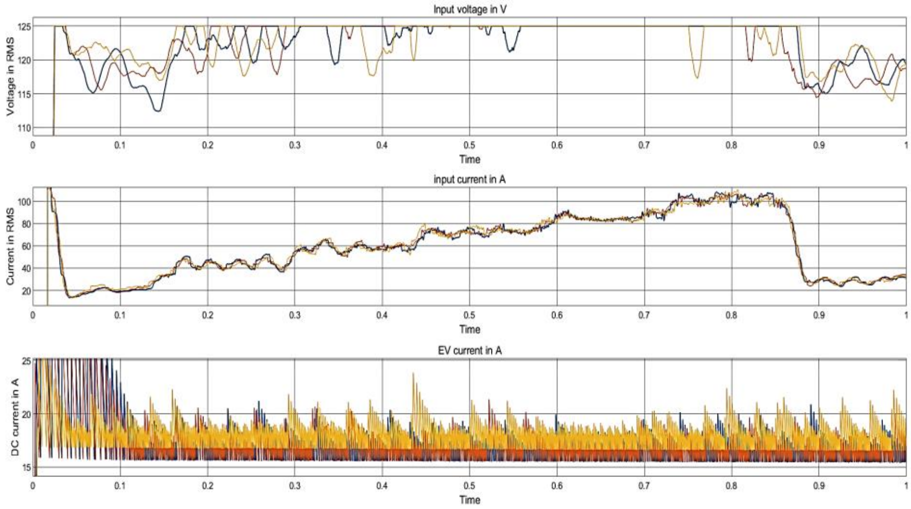
Case 3: When UPQC is brought into action and the system is decoupled from the main grid (*i.e.* island mode), In this case also PV powered UPQC maintains the system voltage and the harmonics of current and voltage at its desired value in all scenarios of EV charger in presence of both the controller. Outcomes are much better in presence of fuzzy-PI controller. Same thing is tabulated in Table 4.

Table 2. All scenarios of case 1 (In the absence of UPQC)

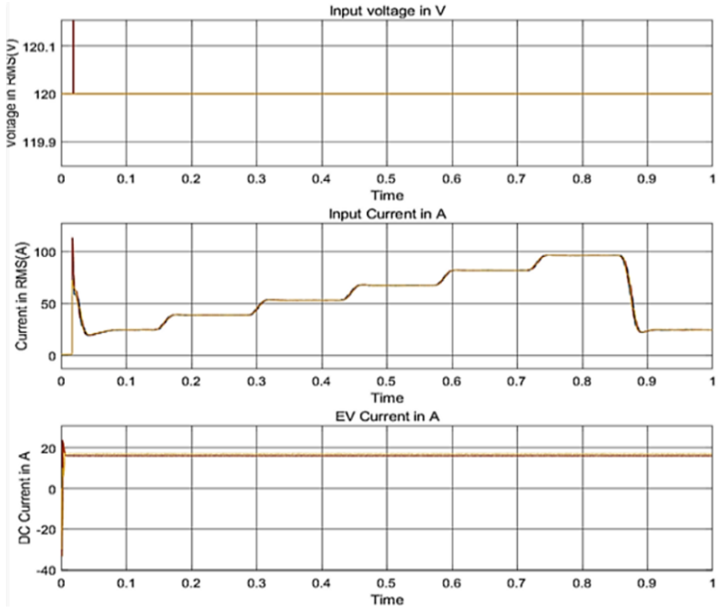
Parameters	Scenario-1	Scenario-2	Scenario-3	Scenario-4
Grid voltage in V(min)	88	106	104	104
Gridcurrent in A(max)	97	103	98	100
Voltage harmonics in %	11.58	4.91	4.6	4.6
Current harmonics in %	4.43	2.39	4.64	2.39
EVcurrent in A(min)	16	6	6	6

Table 3. All scenarios of case 2 (in presence of UPQC grid connected mode)

Parameters	Scenario-1		Scenario-2		Scenario-3		Scenario-4	
	PI	F-PI	PI	F-PI	PI	F-PI	PI	F-PI
Grid voltage in V(min)	125	120	127	120	127	120	125	120
Grid current in A(max)	100	96	100	96	80	70	50	50
Voltage harmonics in %	4.78	0.32	1.91	0.88	3.85	0.5	2.25	0.10
Current harmonics in %	2.15	0.3	5.55	0.29	4.02	4.38	6.07	1.52
EV current in A(min)	17	15	16	16	16	3	16	3



(a)



(b)

Figure 5. RMS value of voltage, current and EV current in SCN1, case 2 (a) with PI controller and (b) with fuzzy–PI

Table 4. All scenarios of case 3 (in presence of UPQC off grid mode)

Parameters	Scenario-1		Scenario-2		Scenario-3		Scenario-4	
	PI	F-PI	PI	F-PI	PI	F-PI	PI	F-PI
Grid voltage in V (min)	121	120	121	120	123	120	121	120
Gridcurrent in A (max)	10	85	10	85	20	55	46	85
Voltage harmonics in %	1.77	4.34	4.58	3.51	9.44	3.15	4.27	3.57
Current harmonics in %	4.88	3.38	3.52	3.13	4.58	2.87	6.4	2.86
EVcurrent in A (min)	16	12	16	12	16	12	12	12

4. CONCLUSION

The main significance of this work is to provide a unique solution for the enhancement of power quality through PV powered UPQC which not only compensates voltage related PQ issues but also compensates issues related to current in hybrid AC/DC microgrid. The novel approach in this work is the addition of EV charger as a load along with dynamic load. Comparative analysis of PV driven UPQC in presence of conventional PI controller and intelligent fuzzy-PI controller is performed through simulation in standard test bench. From the result it is evident that in case 1 (*i.e.* in the absence of UPQC) scenario1 the voltage harmonics is 11.58 in (%) which is above the standard threshold level and the grid voltages are below the desired value *i.e.* 120 V in all the scenarios as tabulated in Table 2. It is evident from Table 3 in case 2 that the grid voltage and harmonics levels are slightly above the standard limit in presence of PI controller, but remains at its desired limit in presence of intelligent fuzzy-PI controller. In case 3 *i.e.* (off grid mode) PV powered UPQC provides the better solution in enhancing the voltage quality as well as maintains the harmonics related to voltage and current within its standard limit in presence of fuzzy-PI controller than traditional PI controller. Also, harmonic distortions reduced in presence of intelligent fuzzy-PI. Therefore, it is evident from the Tables 3 and 4 that the performance of PV powered UPQC is much better in mitigating the PQ issues with the application of intelligent fuzzy-PI controller.

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AUTHOR CONTRIBUTIONS STATEMENT

This paper uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Tanuja H		✓						✓	✓	✓	✓	✓		
Supriya J	✓		✓	✓						✓	✓		✓	
Shruthi R Gunaga		✓						✓	✓	✓	✓	✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] S. Gade, R. Agrawal, and R. Munje, "Recent trends in power quality improvement: review of the unified power quality conditioner," *ECTI Transactions on Electrical Engineering, Electronics, and Communications*, vol. 19, no. 3, pp. 268–288, Oct. 2021, doi: 10.37936/ecti-eec.2021193.244936.

[2] R. Padmavathi, V. Devadoss, R. Kalaivani, P. S. Maheswari, and C. B. Venkatramanan, "Mitigation and power quality enhancement using UPQC: a recent study," in *Research and Developments in Engineering Research Vol. 3*, B P International (a part of SCIENCEDOMAIN International), 2023, pp. 153–167. doi: 10.9734/bpi/rader/v3/18943D.

[3] A. Mousaei, "Analyzing locational inequalities in the placement of electric vehicle charging stations using machine learning: A

case study in Glasgow," *Next Research*, vol. 2, no. 1, p. 100123, Mar. 2025, doi: 10.1016/j.nexres.2024.100123.
[4] A. Alyakhni, L. Boulon, J.-M. Vinassa, and O. Briat, "A comprehensive review on energy management strategies for electric vehicles considering degradation using aging models," *IEEE Access*, vol. 9, pp. 143922–143940, 2021, doi: 10.1109/ACCESS.2021.3120563.
[5] M. Bilal and M. Rizwan, "Electric vehicles in a smart grid: a comprehensive survey on optimal location of charging station," *IET Smart Grid*, vol. 3, no. 3, pp. 267–279, Jun. 2020, doi: 10.1049/iet-stg.2019.0220.
[6] K. K. Nandini, N. S. Jayalakshmi, and V. K. Jadoun, "An overview of DC microgrid with DC distribution system for DC loads," *Materials Today: Proceedings*, vol. 51, pp. 635–639, 2022, doi: 10.1016/j.matpr.2021.06.093.
[7] T. N. Olayiwola, S.-H. Hyun, and S.-J. Choi, "Photovoltaic modeling: a comprehensive analysis of the I–V characteristic curve," *Sustainability*, vol. 16, no. 1, p. 432, Jan. 2024, doi: 10.3390/su16010432.
[8] G. F. Savari *et al.*, "Assessment of charging technologies, infrastructure and charging station recommendation schemes of electric vehicles: A review," *Ain Shams Engineering Journal*, vol. 14, no. 4, p. 101938, Apr. 2023, doi: 10.1016/j.asej.2022.101938.
[9] G. Sharma, V. K. Sood, M. S. Alam, and S. M. Shariff, "Comparison of common DC and AC bus architectures for EV fast charging stations and impact on power quality," *eTransportation*, vol. 5, p. 100066, Aug. 2020, doi: 10.1016/j.etran.2020.100066.
[10] Z. Li, H. He, L. Wang, L. Gao, M. Zhang, and R. Fan, "A comprehensive evaluation method of DC voltage sag in medium–low voltage DC distribution system," *Energy Reports*, vol. 8, pp. 345–356, Nov. 2022, doi: 10.1016/j.egyr.2022.10.140.
[11] P. Karami, M. Baharizadeh, M. S. Golsorkhi, and M. H. Ershadi, "A coordinated control of hybrid AC/DC microgrids based on master–slave method," *Electrical Engineering*, vol. 104, no. 5, pp. 3619–3629, Oct. 2022, doi: 10.1007/s00202-022-01573-w.
[12] A. Mousaei, Y. Naderi, and I. S. Bayram, "Advancing state of charge management in electric vehicles with machine learning: a technological review," *IEEE Access*, vol. 12, pp. 43255–43283, 2024, doi: 10.1109/ACCESS.2024.3378527.
[13] M. Ahmed, L. Meegahapola, M. Datta, and A. Vahidnia, "A novel hybrid AC/DC microgrid architecture with a central energy storage system," *IEEE Transactions on Power Delivery*, vol. 37, no. 3, pp. 2060–2070, Jun. 2022, doi: 10.1109/TPWRD.2021.3103742.
[14] J.-W. Chang, S. Chae, and G.-S. Lee, "Distributed optimal power sharing strategy in an islanded hybrid AC/DC microgrid to improve efficiency," *IEEE Transactions on Power Delivery*, vol. 38, no. 1, pp. 724–737, Feb. 2023, doi: 10.1109/TPWRD.2022.3197434.
[15] Y. Yang and P. Yang, "A novel strategy for improving power quality of islanded hybrid AC/DC microgrid using parallel-operated interlinking converters," *International Journal of Electrical Power & Energy Systems*, vol. 138, p. 107961, Jun. 2022, doi: 10.1016/j.ijepes.2022.107961.
[16] J. Khodabakhsh and G. Moschopoulos, "Simplified hybrid AC–DC microgrid with a novel interlinking converter," *IEEE Transactions on Industry Applications*, vol. 56, no. 5, pp. 5023–5034, Sep. 2020, doi: 10.1109/TIA.2020.2996537.
[17] M. Biglarahmadi, A. Ketabi, H. Reza Baghaee, and J. M. Guerrero, "Integrated nonlinear hierarchical control and management of hybrid AC/DC microgrids," *IEEE Systems Journal*, vol. 16, no. 1, pp. 902–913, Mar. 2022, doi: 10.1109/JSYST.2021.3050334.
[18] T. Ravi, K. S. Kumar, C. Dhanamjayulu, B. Khan, and K. Rajalakshmi, "Analysis and mitigation of PQ disturbances in grid connected system using fuzzy logic based IUPQC," *Scientific Reports*, vol. 13, no. 1, p. 22425, Dec. 2023, doi: 10.1038/s41598-023-49042-z.
[19] M. S. Ahmed, D. Y. Mahmood, and A. H. Numan, "Power quality improvement of grid-connected photovoltaic systems using PI-fuzzy controller," *International Journal of Applied Power Engineering (IJAPE)*, vol. 11, no. 2, p. 120, Jun. 2022, doi: 10.11591/ijape.v11.i2.pp120-133.
[20] R. Simhachalam and A. Das Goswami, "Fuzzy induced controller for optimal power quality improvement with PVA connected UPQC," *Energy Harvesting and Systems*, vol. 11, no. 1, Jan. 2024, doi: 10.1515/ehs-2022-0146.
[21] A. Miron, A. C. Cziker, and H. G. Beleiu, "Fuzzy control systems for power quality improvement—a systematic review exploring their efficacy and efficiency," *Applied Sciences*, vol. 14, no. 11, p. 4468, May 2024, doi: 10.3390/app14114468.
[22] R. Boddepalli, P. Raju, and A. Tirupathi, "Comparision of pi, fuzzy & neuro-fuzzy controller based multi converter unified power quality conditioner," *International Journal of Electrical Engineering & technology*, vol. 4, pp. 136–154, 2020.
[23] A. Mousaei, N. Rostami, and M. B. Bannae Sharifian, "Design a robust and optimal fuzzy logic controller to stabilize the speed of an electric vehicle in the presence of uncertainties and external disturbances," *Transactions of the Institute of Measurement and Control*, vol. 46, no. 3, pp. 482–500, Feb. 2024, doi: 10.1177/01423312231178169.
[24] S. Sumana and R. Dhanalakshmi, "Investigations and validation of PV-powered unified power quality conditioner for electric vehicle smart charger in standard AC/DC hybrid microgrid test system," in *Renewable Power for Sustainable Growth. ICRP 2023*, 2024, pp. 45–60. doi: 10.1007/978-981-99-6749-0_3.
[25] S. Sumana, R. Dhanalakshmi, and S. Dhamodharan, "Validation of photovoltaics powered UPQC using ANFIS controller in a standard microgrid test environment," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 1, p. 92, Feb. 2022, doi: 10.11591/ijece.v12i1.pp92-101.

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