Pakistan Journal of Engineering and Technology, Pak JET
Multidisciplinary & Peer Reviewed
Volume: 4, Number: 2, Pages: 49- 55, Year: 2021

Modified Fuzzy Logic MPPT for PV System under Severe Climatic Profiles

Rao Muhammad Asif[1], Muhammad Abu Bakar Siddique[2], Ateeq Ur Rehman[3], Muhammad Tariq Sadiq[4], and Adeel Asad[5]

[1]Faculty of Engineering and Technology, Superior University, Lahore, Pakistan
[2] College of New Energy, China University of Petroleum (East China), Qingdao, China
[3] Department of Electrical Engineering, Government College University, Lahore, Pakistan
[4] Department of Electrical Engineering, The University of Lahore, Lahore, Pakistan
[5] College of Control Science and Engineering, China University of Petroleum (East China), Qingdao, China
Corresponding author: Ateeq Ur Rehman (e-mail: ateeq.rehman@gcu.edu.pk)

Abstract- **Photovoltaic energy is considered highly favorable towards the environment due to its pleasant nature. After analyzing different maximum power point tracking (MPPT) algorithms, an effective control scheme is proposed to obtain stabilized maximum output power throughout the PV system. Therefore, this article presents an efficient control algorithm for the extraction of maximum power through a PV system under severe climatic drifts. The modified fuzzy logic controller sustains the maximum output power of the system by defining fuzzy rules to control the duty cycle appropriately. A DC-DC boost converter is also modeled to stabilize and maintain output power under variant climatic uncertainties. Furthermore, charging management control is also implemented on lead-acid battery bank to store PV energy for backup usage. It defines charging-discharging time and state of charge for keeping the battery bank healthier.**

Index Terms-- **Fuzzy Logic Control, FLC, MPPT, Optimization, Charging Management Control, CMC.**

I. INTRODUCTION

The generation of energy is decaying exponentially as the demand for energy rising day by day all over the world due to the depletion of conventional energy sources and their serious impact on the environment such as global warming i.e greenhouse discharges, air pollution, and ozone depletion [1][2]. The transportation sector has the main contribution to the emissions of carbon dioxide and their effect on global warming which is estimated at nearly 14% [3]. Similarly, the consequences of air pollution are a worldwide concern due to the internal combustion engine (ICE) used in the transportation sector which is polluting our atmosphere [4]. In 2012, 3.7 million people died under 60 and 1.7 million children expired due to environmental air pollution according to the world health organization (WHO) [5][6]. It is not only influencing after birth but also in pregnancy periods. Globally, nearly 18% of premature births are considered due to air pollution, and millions of premature death cases are reported yearly since now [7]. China reported 1.6 million people died due to cardiovascular, respiratory, and brain strokes because of polluted air every year [8]. Therefore, the exploration of natural resources is a need of the hour in today's era. Researchers have found renewable energy sources as environmental-friendly because of their non-polluting nature.

The PV system is considered the most significant and competitive source of renewable energy to fulfill energy demand forever due to downward trends in its prices [9]. It transforms solar energy directly into electrical energy with very low efficiency [10]. Therefore, many kinds of research are being under consideration to implement an algorithm that can increase the conversion efficiency of the PV system [11]. A well-known algorithm regarding maximizing the energy conversion efficiency is the maximum power point technique (MPPT) which regulates the output power of the PV system by chasing MPP under severe and dynamic weather conditions. To attain MPP and obtain the maximum output power of the system, the system impedance and load impedance should be the same [12].

In literature, several MPPT algorithms are implemented on PV systems for extraction of maximum power such as Perturb and Observe (P&O), Sliding Mode Control (SMC), Incremental Conductance (IC), and Fuzzy Logic (FL). Although these algorithms are easy to implement and perform accurately under steady-state conditions but do not respond well under sudden climatic variations. In [13] a dynamic global MPPT technique merged with Perturb and Observe (P&O) methodology is proposed to optimize and track the global peak of the PV system. Another novel self-predictive P&O approach is recommended in [14] using a circular analogy that chases MPP by iterations. It contains three stages i.e trend, dynamics, and analysis to determine the nearest point to the MPP. Although this algorithm provided an appropriate solution regarding MPP tracking under steady-state and dynamic situations, the iterative process takes much time to compute the exact power-point [15]. Additionally, an integral procedure for the SMC technique is presented in [16] for assurance of the desired operation of the PV system. It declares a reference level provided by load and actual weather conditions to track MPP using perturbation and prediction. This technique has a much good response in terms of computations and tracking time but it has some limitations over variable operating frequency of boost converter due to which output power expresses unstable behavior [17]. To cope up with this problem, a double integral SMC algorithm is illustrated in [18] to extract the maximum power of the PV system using a pulse-width modulator. Similarly, [19] presents model predictive control (MPC) technique to transfer maximum available power to the grid utility by adjusting power factor and minimizing the controller cost function. Furthermore, a research study in [20] proposes a residue-based control scheme on classical incremental conductance MPPT algorithm which balances the rate of change of actual PV current to PV voltage. It generates a reference maximum voltage for SMC to compensate for the adaptive gain of the controller. This work presents much handling capability for uncertainty and sudden variations in climatic profiles [21].

A hill-climbing fuzzy logic MPPT approach is proposed in [22] for a micro-grid standalone PV system. Hill-climbing searching methodology is used by introducing 16 fuzzy rules and 4 subsets for inputs and output of the system. Although, control methodology has provided effective and robust simulated results but this approach takes too much time for the translation of many fuzzy rules and fuzzy subsets [23]. To tackle this problem, an optimum design is introduced in [24] which proposes a Fuzzy-MPPT controller having protection abilities. This technique uses a linear model by executing the genetic algorithm (GA) to determine the optimal parameters of the controller [25,26]. This control algorithm expressed good behavior under varying temperatures and irradiance than the conventional approaches. However, due to the execution of the linear model, the proposed technique cannot handle severe climatic variations. An enhanced fuzzy logic algorithm has been used by [27] which reduces inputs and membership functions to increase its computational ability. Furthermore, a boost converter is also deployed to transmit the maximum energy to the grid station using Voltage Source Converter (VSC). This study provides an effective solution by reducing inputs and member functions of the controller to track MPP by using only two rules [28,29]. But due to the compression of member functions, the controller neglects many parameters which results in disorders while tracking MPP under sudden variations in climatic profiles. Similarly, an optimized FLC MPPT algorithm is proposed in [30] which introduced a high degree of freedom in this era. To obtain the design parameters of the controller, Differential Evolution Optimization Algorithm (DEOA) is executed. Although, this algorithm responded quickly and fastly tracked MPP but it will not stabilize output power due to the very fast discrete level track of MPP [31,32]. Similarly, Linear and modified incremental conductance MPPT methodologies are proposed in [33,34], which tracks maximum output power of a grid-connected PV module by incorporating integral regulator with boost converter.

After a study of the background history of different MPPT algorithms, this paper presents a modified FL algorithm implementation on a standalone type PV system for charging the battery bank and supply to grid utility.

II. PHOTOVOLTAIC CELL

Solar cells are considered the fundamental element of a PV system. Electric current generation occurs by the motion of free electrons within the solar cells caused by solar irradiance with a combination of direct and diffused radiations. Both p-type and n-type semiconductors make a PV cell that transforms solar energy into electricity. Solar irradiance occurrence generates electron-hole pairs due to the higher energy band gap than semiconductor material. Figure 1 illustrates the equivalent circuit diagram. These cells can be arranged in the form of strings with different combinations to form the PV module. These modules are connected in series or parallel connections to form a PV array in accordance with the required different current and voltage.

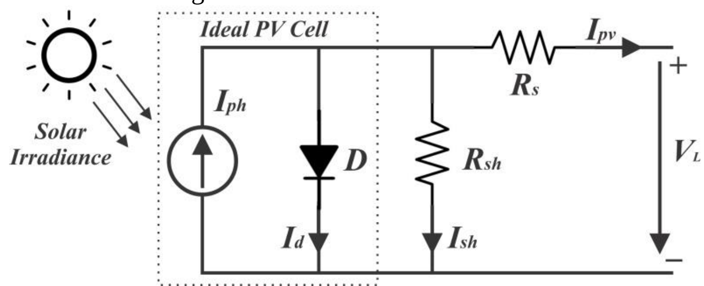

Fig 1: Equivalent circuit diagram of actual PV Cell

In this paper, a 250W Canadian solar panel is considered, which has 59.9V voltage at maximum power, 5.49A current at maximum power under 25°C temperature, and 1000 W/m^2 irradiance level [35]. When solar irradiance occurs on the surface of the PV cell, the photocurrent I_{ph} passes are represented as the current source connected in parallel with diode D to demonstrate the real behavior of the PV cell. Similarly, a shunt R_{sh} and series R_s resistances are used to express power dissipation. The factor including R_{sh} is eliminated due to large value and the output current I_{pv} and V_{pv} are calculated by (1) and (2) respectively which illustrates the mathematical model of an equivalent circuit of PV cell.

$$I_{pv} = N * I_{ph} - N * I_o \left(e^{\frac{q(V_{pv}+I_{pv}R_S)}{akT}} - 1 \right) \quad (1)$$

$$V_{pv} = \frac{nAKT}{q} \ln\left(\frac{I_{ph} + I_o - I_{pv}}{I_o} \right) \quad (2)$$

Where I_{pv} and V_{pv} are the module output current and voltage respectively, K is the Boltzmann's Constant; q_o is the electronic charge and $'a'$ is the ideality factor.

Table I
Characteristics of PV Module [35]

S. No.	Characteristics	Value
1	Max. power of PV module (P_m)	250W
2	PV voltage at P_m	59.9V
3	PV current at P_m	5.49A
4	Diode saturation current I_o	1.1753e-08A
5	Open circuit voltage V_{oc} of PV Cell	51.4V
6	Short circuit current Isc of PV Cell	5.31A
7	Photocurrent I_{ph}	5.32A
8	Shunt resistor R_{sh}	1KΩ
9	Series resistor R_s	27mΩ
10	Cells in PV module	72

The output power of the PV system depends mainly on two main factors current I_{pv} and voltage V_{pv}. Both solar irradiance and temperature affect the power conversion efficiency of the PV system. The solar irradiance is directly proportional and the temperature is inversely proportional to the output power of the system but the temperature has a very minute effect as compared to solar irradiance. The characteristics of the PV module were observed under variant climatic drifts i.e. temperature and irradiance. The parameters of a PV system are defined in Table I. Figure 2 represents PV characteristics under irradiance variations from 250w/m^2 to 1000w/m^2 and Figure 3 illustrates under temperature variations from 25°C to 100°C. On each instant of temperature and irradiance, a unique operating point exists at which the obtained output power of the PV module is maximum, i.e. the maximum power point (MPP). The effect of irradiance and temperature on MPP can be seen in Figures 2 and 3 respectively.

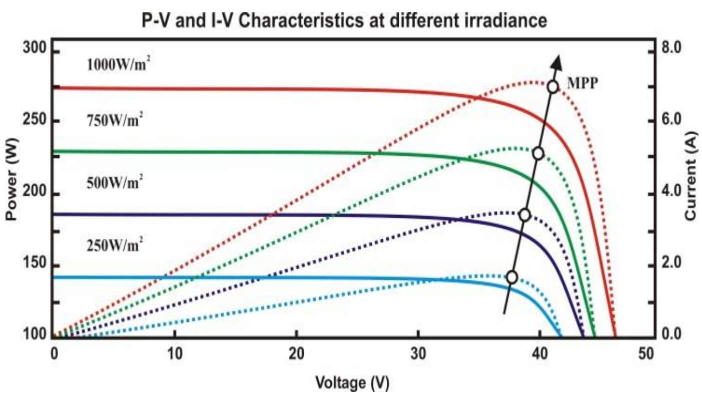

Fig 2: P-V & I-V Characteristics of PV module at various irradiances

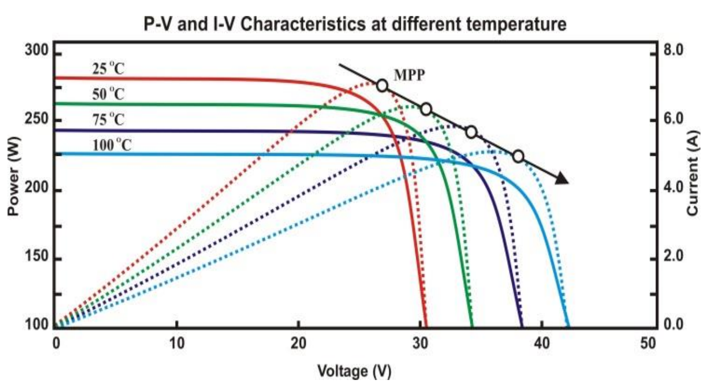

Fig 3: P-V & I-V Characteristics of PV module at various temperatures

III. DC-DC BOOST CONVERTER

A simple configuration of a boost converter with a PV panel is presented in Figure 4. It transfers the extracted power of the PV panel towards the load, when an appropriate duty cycle signal (0<D<1) is applied. It transforms low DC voltages of PV panel into higher DC voltages in accordance with the desired load.

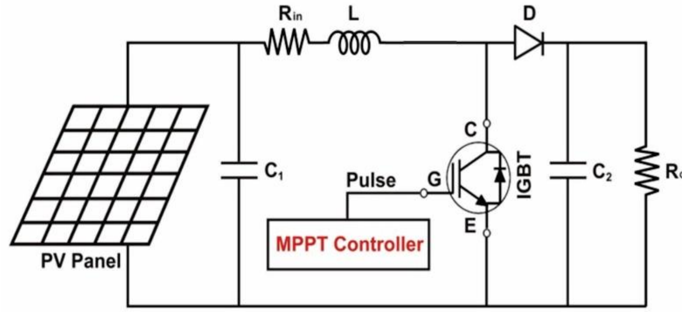

Fig 4: Configuration of Boost Converter with PV Panel

The relationship between input and output of various components of the boost converter is illustrated by (3) and (4) [35].

$$V_{out} = \frac{V_{in}}{1-D} \tag{3}$$

$$I_{out} = I_{in}\,(1-D) \tag{4}$$

The equivalent resistance (R_e) of the boost converter is presented in terms of duty cycle in (5).

$$R_e = R_{in}(1-D)^2 \tag{5}$$

The maximum extracted power of the PV system can only be transferred to the load when the equivalent resistance of the boost converter and output resistance of the PV system is the same. Therefore, the duty cycle (D) can be obtained by using the maximum power transfer theorem is presented in (6).

$$R_{in} = \frac{V_{in}}{I_{in}}$$

$$R_{in} = R_{out}(1-D)^2$$

$$D = 1 - \sqrt{\frac{R_{in}}{R_{out}}} \tag{6}$$

Similarly, (7) and (8) define the functionality of inductor and capacitors [35].

$$L = \frac{(V_{out}-V_{in})V_{in}}{f \times \partial I \times V_{out}} \tag{7}$$

$$C = \frac{(V_{out}-V_{in})I_{out}}{f \times \partial V \times V_{out}} \tag{8}$$

Where f represents the frequency, ∂I and $\partial V$are current and voltage ripples respectively.

The best working region A-B for the boost converter in the P-V & I-V curve of the PV panel is depicted in Figure 5. The variable ∂I is much important factor to be measured by boost converter. Point A on the I-V curve is the MPP point and B is the open circuit position. Therefore, at point A the power transfer efficiency is maximum due to R_{out}=R_{in}.

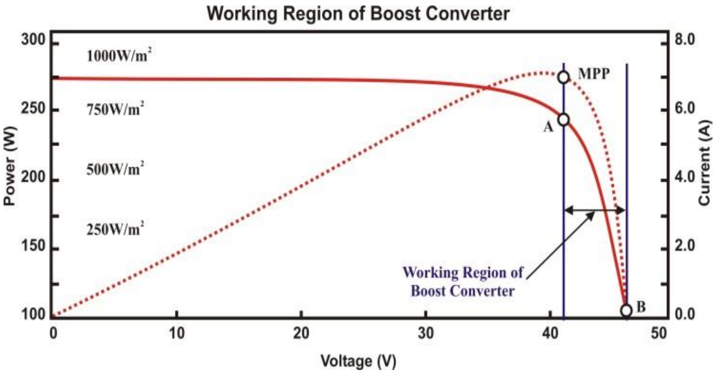

Fig 5: Working region of a boost converter in the P-V & I-V Curve of PV

IV. MODIFIED FUZZY LOGIC ALGORITHM

The proposed FLC algorithm assigns fuzzy sets to the membership function of the PV voltage to determine the output power of the PV system. The block diagram of the proposed methodology is illustrated in figure 6. It takes samples of voltage and current for calculation of power in every instant. Then, it compares the values of calculated power (δP_1) and current (δI_1) with previous instant values for obtaining variations by using the feedback loop system. The corresponding error is calculated by considering the rate of change of power (δP) and current as elaborated by (9). Similarly, to get a change in error (δe), a comparison was held between calculated error and previous error. Both error and change in error as illustrated by (10) are fed to the fuzzy logic controller as inputs of the system.

$$e_1 = \frac{\delta P}{\delta I} = \frac{\delta P_1 - \delta P_0}{\delta I_1 - \delta I_0} \qquad (9)$$

$$\delta e_1 = \delta e_1 - \delta e_0 \qquad (10)$$

After the calculation of the change in power and current, the fuzzification component translates the data into linguistic variables to feed into fuzzy inference. It formulates some decisions by applying fuzzy rules on given input and output. Then defuzzification component reduces the fuzzy set into crisp value for the generation of the duty cycle. Finally, the FLC sets the duty cycle for driving the converter switches. The pulse width modulation (PWM) generator provides the switching pulses to control the duty ratio of FLC. In [35], an efficient fuzzy logic MPPT methodology based on an isolated push-pull boost converter has been utilized to chase the maximum output power of the PV system and introduced its robustness and nonlinear handling capability over other MPPT algorithms. If current power is at point PA which is closer to MPP then a smaller fuzzy step is required for its optimization [36,37]. In another case, if actual power is at P_E which is far away from MPP then the required fuzzy step will be larger as presented in Figure 7-8. The flow chart of the FLC algorithm is presented in Figure 9.

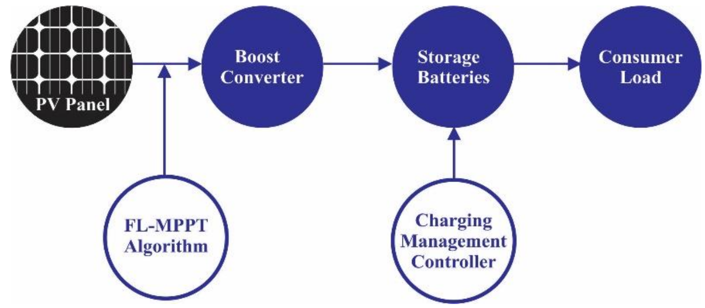

Fig 6: Block diagram of the proposed methodology

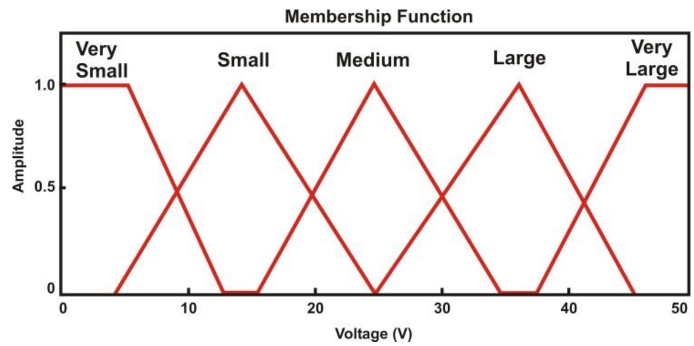

Fig 7: FLC curve illustration with membership function

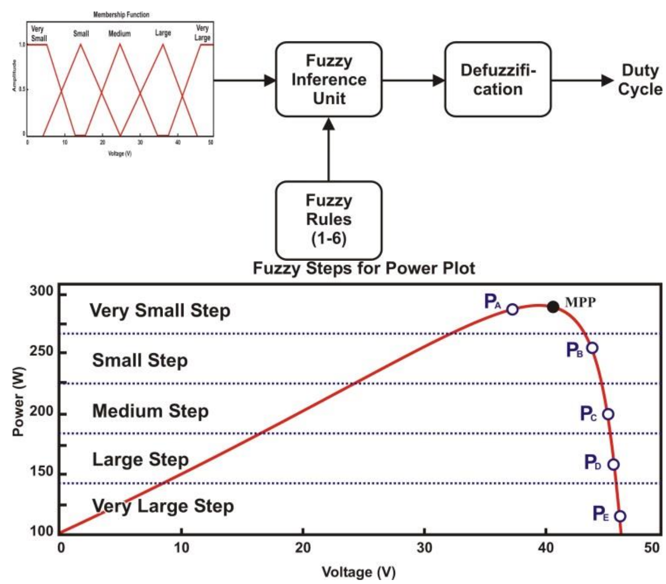

Fig 8: FLC curve illustrations with PV output power plot

FLC algorithm follows the following rules for optimizing the output power by processing the appropriate duty cycle of the boost converter according to the different fuzzy steps regarding Table II such as:

Rule 1: If $\delta P \gg \Delta F$, it means the current output power is far away from the old fuzzy step, therefore, a negative big (NB) signal will be generated to process the duty cycle of the boost converter as ΔD6 as illustrated in Table III.

Rule 2: If still $\delta P > \Delta F$ means the current value of output power has still not reached MPP, now it will process a negative small (NS) signal for the generation of duty cycle ΔD5 as demonstrated in Table III.

Rule 3: If $\delta P = \Delta F$ means current output power reached MPP, then it declares the same zero signal (ZO) to process the same duty cycle as the previous one.

Rule 4: If $\delta P \ll \Delta F$ means current output power is far away from the previous fuzzy step, therefore, a positive big (PB) signal will be generated to process duty cycle ΔD1.

Rule 5: If still $\delta P < \Delta F$ means the current value of output power is still away from MPP, now it will process a positive small (PS) signal for the generation of duty cycle ΔD2.

And so on.

where δP is the instant power and ΔF is the fuzzy step.

Table II
Fuzzy rules to optimize MPP

δP \ ΔF	**Very Small**	**Small**	**Medium**	**Large**	**Very Large**
Very Small	ZO	NS	NS	NB	NB
Small	PS	ZO	NS	NB	NB
Medium	PS	PS	ZO	NS	NB
Large	PB	PB	PS	ZO	NB
Very Large	PB	PB	PS	PS	ZO

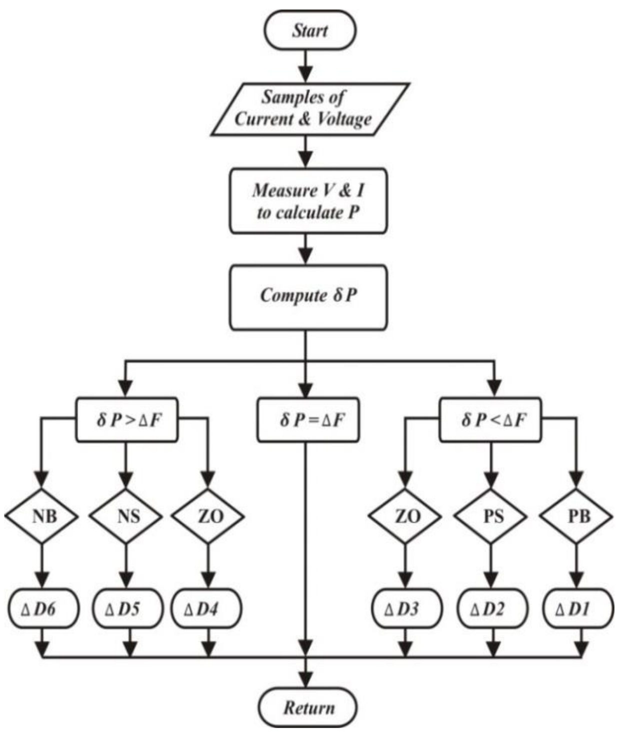

Fig 9: Proposed flow chart of FLC based MPPT algorithm

Table III
The duty cycle of boost converter vs fuzzy rules

Duty Cycle	Value	Fuzzy Rule
ΔD1	D>0.5	PB
ΔD2	0.3<D<0.5	PS
ΔD3	0.1<D<0.3	ZO
ΔD4	-0.1<D<-0.3	ZO
ΔD5	-0.3<D<-0.5	NS
ΔD6	D>-0.5	NB

V. BATTERY BANK

This work proposes lead-acid batteries due to cost-effectiveness, easy availability, and better capacity. The best operating temperature for the lead-acid battery is 25 °C for a long lifetime of the cells [38,39]. The study has shown that a rise in temperature and rapid charging or discharging reduces the lifetime of the battery such as every 8°C increase in temperature halves the battery life [40-41]. Charging and discharging rates of a battery are directed by C-rates. A C-rate of 1Cn and 0.5Cn are considered as 1 hour and 2 hour discharge time of a battery respectively [42]. The lead-acid battery is rated at a 0.2 Cn current for 5-hour and 0.05 Cn current for 20-hour discharge as presented in Figure 10. The capacity of the battery depends on the discharge time such as if discharge time is longer then, the capacity of the battery will be higher [43-46]. The charging and discharging characteristics of the battery are presented in Table IV. The charging time of a lead-acid battery can be calculated by using (11) [47-49].

$$Charging\ T = \frac{Ah\ rating\ of\ the\ battery}{Applied\ Current} \quad (11)$$

The discharging time of the battery bank can be obtained by using (12).

$$Discharging\ T = \frac{Ah\ rating \times Voltage}{Applied\ Load} \quad (12)$$

Table IV
Charging-discharging characteristics of the battery bank

Specifications	Ratings
Battery input	12V-14.7A
Battery output	100 Ah
Charging time	6 hours and 48 mins
Voltage of battery	24 Volts
Applied load	440W
Discharging time	1 hour and 36 mins
Efficiency	82%

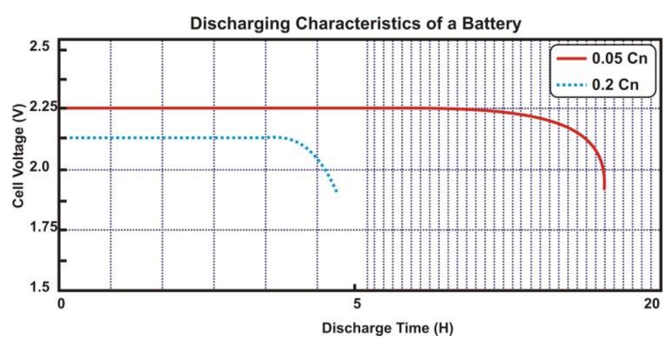

Fig 10: Discharging characteristics of lead-acid cells

VI. CHARGING MANAGEMENT CONTROLLER

The charging management controller (CMC) is implemented on the PV system to maintain the SOC positive by automatically disconnecting the battery if it is going to be empty. It measures voltage level and amperes of battery to process its algorithm as illustrated in Figure 11.

In the first step, the input source feeds the power directly to the CMC, and then it calculates the power of batteries by collecting samples of actual current and voltage.

Case 1: If the power from the source side is in an excessive amount than the load side demand, then it supplies power directly to the load side and extra power is consumed to charge the power bank to sustain its continuous active mode.

Case 2: If the power from the source side is lower than the load side demand, then it supplies power from the battery bank to fulfill the energy needs of the load side.

Furthermore, a safe limit of 60% discharging is also maintained by CMC for keeping batteries in a healthy state. As if the SOC level goes to zero levels then ultimately their strength will be decreased. To maintain the SOC level of the battery bank it works on two conditions as If the power is lesser than 60%, then the SOC level will be considered negative and CMC will ON the charging state and OFF the discharging state. Otherwise, the load side can consume power from the battery bank.

The charging energy Ec required mainly depends on the battery's initial and final state of charge and its capacity as stated in (13) and (14).

$$E_c = \delta(SOC)_B \times C_B \quad (13)$$

$$SOC = SOC(t_o) - \frac{\int_{t_o}^{t} i_b(t)dt}{C_B \times 3600} \quad (14)$$

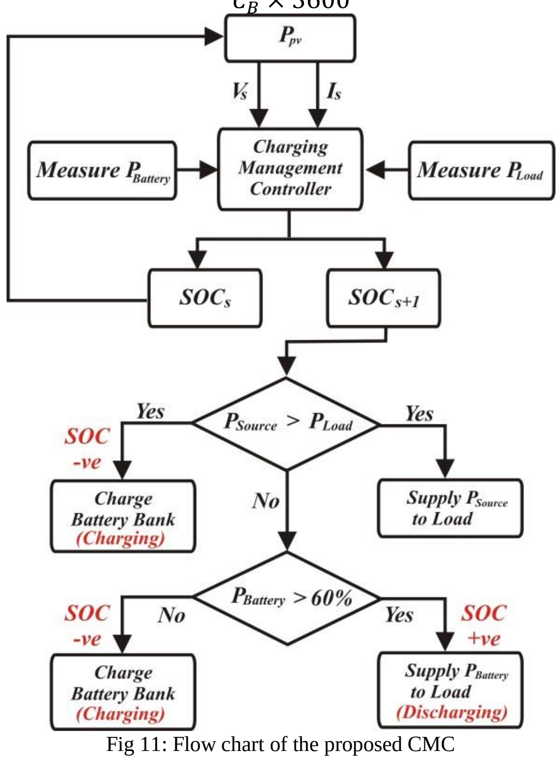

Fig 11: Flow chart of the proposed CMC

VII. CONCLUSION

In this paper, a modified fuzzy logic algorithm is implemented on a PV system for power loss reduction and obtaining maximum power under robust conditions of irradiance and temperature. MPPT has wide consideration in the PV system, therefore, many techniques are proposed by researchers to chase the MPP. Due to the limitations of various MPPT methodologies, this work proposes an effective and efficient modified fuzzy logic MPPT technique for optimization and stable output of the PV system by validating the duty cycle of a DC-DC boost converter. Furthermore, CMC is also deployed on the battery bank to maintain the SOC of the batteries as well as their charging and discharging time is also calculated by using a C-rate scale to keep the battery bank healthier.

REFERENCES

[1] E. Elisabeth, H. Jonas and F. Göran, "Screening potential social impacts of fossil fuels and biofuels for vehicles," Energy Policy. 73. 416–426. 10.1016/j.enpol.2014.05.034.

[2] N. Yilmaz and A. Atmanli, "Sustainable alternative fuels in aviation. Energy," 2017, vol 140, pp 1378-1386, doi:10.1016/j.energy.2017.07.077.

[3] R. M. Asif, A. Yousaf, A. U. Rehman, H. M. Ashraf, "Real time extra economic dispatch for renewable energy uncertainty over IEEE Bus Bar," IEEEP New Horizon Journal 2018, pp 9-16.

[4] B. D. McNicol, D. A. J. Rand, K. R. Williams, "Fuel cells for road transportation purposes - Yes or no?," Journal of Power Sources 2001, vol 100, pp 47-59, doi:10.1016/S0378-7753(01)00882-5.

[5] L. Carlsen, R. Bruggemann, B. Kenessov, "Use of partial order in environmental pollution studies demonstrated by urban BTEX air pollution in 20 major cities worldwide," Science of the Total Environment 2018, 610–611, 234–243, doi:10.1016/j.scitotenv.2017.08.029.

[6] The cost of a polluted environment: 1.7 million child deaths a year, Available online: https://www.who.int/news-room/detail/06-03-2017-the-cost-of-a-polluted-environment-1-7-million-child-deaths-a-year-says-who (accessed on 11 August 2020).

[7] S. Khan, A. Ahmad, F. Ahmad, M. Shafaati Shemami, M. Saad Alam, S. Khateeb, "A Comprehensive Review on Solar Powered Electric Vehicle Charging System," Smart Science 2018, 6, 54–79, doi:10.1080/23080477.2017.1419054.

[8] K. Agbossou, M. Kolhe, J. Hamelin, T. K. Bose, "Performance of a stand-alone renewable energy system based on energy storage as hydrogen," IEEE Transaction Energy Conversion 2004.

[9] A. R. Bhatti, Z. Salam, M. J. B. A. Aziz, K. P. Yee, "A critical review of electric vehicle charging using solar photovoltaic," International Journal of Energy Research 2016, 40, 439–461, doi:10.1002/er.3472.

[10] A. U. Rehman, M. Tariq Sadiq, N. Shabbir and G. Jafri, "Opportunistic Cognitive MAC (OC-MAC) Protocol for Dynamic Spectrum Access in WLAN Environment", International Journal of Computer Science Issues (IJCSI), vol. 10, Issue 6, No. 1, pp. 45-51, 2013.

[11] A. U. Rehman, A. Jiang, A. Rehman, et al. "Identification and role of opinion leaders in information diffusion for online discussion network," J Ambient Intell Human Comput (2020). https://doi.org/10.1007/s12652-019-01623-5.

[12] A. U. Rehman, A. Jiang, A. Rehman and A. Paul, "Weighted Based Trustworthiness Ranking in Social Internet of Things by using Soft Set Theory," 2019 IEEE 5th International Conference on Computer and Communications (ICCC), Chengdu, China, 2019, pp. 1644-1648, doi: 10.1109/ICCC47050.2019.9064242.

[13] S. Mohanty, B. Subudhi, and P. K, Ray, "A Grey Wolf Assisted Perturb & Observe MPPT Algorithm for a PV System," IEEE Transactions on Energy Conversion, 2016.

[14] N. Kumar, I. Hussain, B. Singh, and B. K. Panigrahi, "Framework of Maximum Power Extraction from Solar PV Panel using Self Predictive Perturb and Observe Algorithm," IEEE Transactions on Sustainable Energy, 2017.

[15] A. U. Rehman, R. A. Naqvi, A. Rehman, A. Paul, M. T. Sadiq, and D. Hussain, "A Trustworthy SIoT Aware Mechanism as an Enabler for Citizen Services in Smart Cities," Electronics 2020, 9, 918.

[16] D. G. Montoya, C. A. Ramos-Paja, and R. Giral, "Improved design of sliding mode controllers based on the requirements of MPPT techniques," IEEE Transactions On Power Electronics, 2015.

[17] A. U. Rehman, R. M. Asif, R. Tariq and A. Javed, "Gsm based solar automatic irrigation system using moisture, temperature and humidity sensors," 2017 International Conference on Engineering Technology and Technopreneurship (ICE2T), Kuala Lumpur, 2017, pp. 1-4, doi: 10.1109/ICE2T.2017.8215945.

[18] R. Pradhan and B. Subudhi, “Double Integral Sliding Mode MPPT Control of a Photovoltaic System”, IEEE Transactions on Control Systems Technology, 2016.

[19] S. S. R. Ahmadi, and H. Zargarzadeh, “Extremum Seeking Based Model Predictive MPPT for Grid-tied Z-Source Inverter for Photovoltaic Systems,” IEEE Journal of Emerging and Selected Topics in Power Electronics, 2018.

[20] M. Alsumiri, “Residual Incremental Conductance Based Nonparametric MPPT Control for Solar Photovoltaic Energy Conversion System,” IEEE Access 2019.

[21] J. Arshad, A. Rehman, A. U. Rehman, R. Ullah, S. O. Hwang, “Spectral Efficiency Augmentation in Uplink Massive MIMO Systems by Increasing Transmit Power and Uniform Linear Array Gain,” Sensors 2020, 20, 4982.

[22] M. T. Sadiq et al., "Motor Imagery EEG Signals Classification Based on Mode Amplitude and Frequency Components Using Empirical Wavelet Transform," in IEEE Access, vol. 7, pp. 127678-127692, 2019, doi: 10.1109/ACCESS.2019.2939623.

[23] N. B. Alajmi, H. K. Ahmed, S. J. Finney, and B. W. Williams, “Fuzzy-Logic-Control Approach of a Modified Hill-Climbing Method for Maximum Power Point in Microgrid Standalone Photovoltaic System,” IEEE Transactions on Power Electronics, Vol. 2, No. 4, 2011.

[24] A. A. S. Mohamed, A. Berzoy and O. Mohammed, “Design and Hardware Implementation of FLMPPT Control of PV Systems Based on GA and Small-Signal Analysis,” IEEE Transactions on Sustainable Energy, 2016.

[25] A. M. F. Durrani, A. U. Rehman, A. Farooq, J. A. Meo and M. T. Sadiq, "An Automated Waste Control Management System (AWCMS) by Using Arduino," International Conference on Engineering and Emerging Technologies (ICEET), Lahore, Pakistan, 2019, pp. 1-6, doi: 10.1109/CEET1.2019.8711844.

[26] M. Jamil., U. Rashid, R. Arshad, M. N. Khan, et al., “Robust Repetitive Current Control of Two-Level Utility-Connected Converter using LCL Filter,” Arab J Sci Eng 40, 2653–2670 (2015).

[27] L. Farah, A. Hussain, A. Kerrouche, C. Ieracitano, J. Ahmad and M. Mahmud, “A Highly-Efficient Fuzzy-based Controller with High Reduction Inputs and Membership Functions for a Grid-connected Photovoltaic System,” IEEE Access, 2020.

[28] A. Hassan, A. U. Rehman, N. Shabbir, S. R. Hassan, M. T. Sadiq and J. Arshad, "Impact of Inertial Response for the Variable Speed Wind Turbine," 2019 International Conference on Engineering and Emerging Technologies (ICEET), Lahore, Pakistan, 2019, pp. 1-6, doi: 10.1109/CEET1.2019.8711826.

[29] M. Jamil, R. Arshad, U. Rashid, Y. Ayaz and M. N. Khan, "Design and analysis of repetitive controllers for grid connected inverter considering plant bandwidth for interfacing renewable energy sources," 2014 International Conference on Renewable Energy Research and Application (ICRERA), Milwaukee, WI, USA, 2014, pp. 468-473, doi: 10.1109/ICRERA.2014.7016429.

[30] M. Aly and H. Rezk, “A Differential Evolution-Based Optimized Fuzzy Logic MPPT Method for Enhancing the Maximum Power Extraction of Proton Exchange Membrane Fuel Cells,” IEEE Access, 2020.

[31] F. Khan, M. A. B. Siddiqui, A. U. Rehman, J. Khan, M. T. S. A. Asad and A. Asad, "IoT Based Power Monitoring System for Smart Grid Applications," 2020 International Conference on Engineering and Emerging Technologies (ICEET), Lahore, Pakistan, 2020, pp. 1-5, doi: 10.1109/ICEET48479.2020.9048229.

[32] A. Raza, H. Farooq, M. Ellahi, W. Ali, S. Kaleem, M. Khan, “Design and Implementation of TCSC for 500KV Power Transmission Systems,” 10.17993/3ctecno.2019.specialissue.13.

[33] M. A. B. Siddique, A. Asad, R. M. Asif, A. U. Rehman, M. T. Sadiq, and I. Ullah “Implementation of Incremental Conductance MPPT Algorithm with Integral Regulator by using Boost Converter in Grid Connected PV Array” in IETE Journal of Research, Vol. 67, Issue 1, 2021. DOI: 10.1080/03772063.2021/1920481

[34] M. A. B. Siddique, M. A. Khan, A. Asad, A. U. Rehman, R. M. Asif, S. U. Rehman “Maximum Power Point Tracking with Modified Incremental Conductance Technique in Grid-Connected PV Array” 2020 5th International Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA), Sydney, Australia, 25-27 November 2020, pp. 1-6, DOI: 10.1109/CITISIA50690.2020.9371803

[35] R. M. Asif, A. U. Rehman, S. U. Rehman, J. Arshad, J. Hamid, S. Tariq S. Tahir, “Design and analysis of robust fuzzy logic maximum power point tracking based isolated photovoltaic energy system,” Eng. Reports 2020, doi:10.1002/eng2.12234.

[36] MN Khan, Syed K. Hasnain, Mohsin Jamil, Sameeh Ullah, "Electronic Signals and Systems Analysis, Design and Applications International Edition," in Electronic Signals and Systems Analysis, Design and Applications: International Edition , River Publishers, 2020

[37] Khan, Muhammad Nasir, Hasnain Kashif, and Abdul Rafay. "Performance and optimization of hybrid FSO/RF communication system in varying weather." Photonic Network Communications vol. 41, no. 1, pp. 47- 56, 2021.

[38] Jamil, Mohsin, Muhammad Nasir Khan, Saqib Jamshed Rind, Qasim Awais, and Muhammad Uzair. "Neural network predictive control of vibrations in tall structure: An experimental controlled vision." Computers & Electrical Engineering, vol. 89, pp. 106940, 2021.

[39] Khan, Muhammad Nasir, Mohsin Jamil, Syed Omer Gilani, Ishtiaq Ahmad, Muhammad Uzair, and H. Omer. "Photo detector-based indoor positioning systems variants: A new look." Computers & Electrical Engineering, vol. 83, pp. 106607, 2020.

[40] Kashif, Hasnain, Muhammad Nasir Khan, and Ali Altalbe. "Hybrid optical-radio transmission system link quality: link budget analysis." IEEE Access, vol. 8, pp. 65983-65992, 2020.

[41] Khan, Muhammad Nasir, and Fawad Naseer. "IoT based university garbage monitoring system for healthy environment for students." In 2020 IEEE 14th International Conference on Semantic Computing (ICSC), pp. 354-358. IEEE, 2020.

[42] Uzair, Muhammad, R. O. B. E. R. T. D DONY, Mohsin Jamil, KHAWAJA BILAL AHMAD MAHMOOD, and Muhammad Nasir Khan. "A no-reference framework for evaluating video quality streamed through wireless network." Turkish Journal of Electrical Engineering & Computer Sciences, vol. 27, no. 5, pp. 3383-3399, 2019.

[43] Khan, Muhammad Nasir, Syed Omer Gilani, Mohsin Jamil, Abdul Rafay, Qasim Awais, Bilal A. Khawaja, Muhammad Uzair, and Abdul Waheed Malik. "Maximizing throughput of hybrid FSO-RF communication system: An algorithm." IEEE Access, vol. 6, pp. 30039-30048, 2018.

[44] Khan, Muhammad Nasir, Syed K. Hasnain, and Mohsin Jamil. Digital Signal Processing: A Breadth-first Approach. Stylus Publishing, LLC, 2016.

[45] Khan, Muhammad N. "Importance of noise models in FSO communications." EURASIP Journal on Wireless Communications and Networking vol. 2014, no. 1, pp. 1-10, 2014.H. Arslan, A. U. Rehman, N. Shabbir, S. R. Hassan and I. Haider, "A Three Stage Load Sharing Routing Algorithm to Increase Lifetime of Cognitive Radio Sensor Networks", Journal of Communications, vol. 12, no. 5, pp. 254-260, 2017.

[46] S. R. Hassan, A. U. Rehman, N. Shabbir, and A. Unbreen “Comparative Analysis of Power Quality Monitoring Systems” in NFC-IEFR Journal of Engineering and Scientific Research, Vol. 07, Issue 1, 2019. DOI: 10.24081/nijesr.2019.1.0004

[47] N. Rakshana, “Charging Lead-Acid Batteries. Journal of Electrical and Electronics Systems,” vol 8, pp 8-11, doi:10.4172/2332-0796.1000294.