PV, Wind powered Electric Vehicle Charging Station with Fuzzy and Perturb & Observe MPPT Control

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Abstract

Electric vehicle charging stations that include renewable energy sources have drawn a lot of interest as a sustainable way to cut greenhouse gas emissions and fulfill the world's expanding energy needs. This paper presents the design and analysis of a hybrid renewable energy-based EV charging station powered by PV and wind energy systems. The proposed system employs a dual MPPT strategy: Fuzzy Logic Controller (FLC) for PV units and the Perturb and Observe (P&O) technique for wind turbines, ensuring optimal power extraction under varying environmental conditions. A detailed performance evaluation highlights the reliability, efficiency, and adaptability of the system. Simulation results demonstrate the system's ability to handle partial shading conditions, wind speed variations, and dynamic EV charging demands. The combination of FLC and P&O significantly enhances tracking accuracy and response time compared to traditional methods. This study underscores the feasibility of renewable energy-powered EV charging stations as a robust, eco-friendly alternative to grid-dependent systems.

Keywords: Electric Vehicle Charging Station (EVCS), Photovoltaic , Wind Energy, Fuzzy Logic Controller MPPT.

I. INTRODUCTION

The rapid acceptance of EVs has emphasized the need for sustainable and effective charging infrastructure. Integrating RES like PV and wind energy into EVCS offers an eco-friendly solution to reduce dependence on fossil fuels. However, the variability of solar irradiance and wind speed poses challenges in ensuring reliable power delivery.

In [1], a PV-powered EV charging station incorporating a fuzzy MPPT algorithm. This work optimized energy conversion from PV panels by adjusting operating points based on environmental conditions, Additionally, the study emphasizes the sustainability of the charging station, achieving a 30% reduction in carbon emissions. It does not consider the integration of additional RES, like wind energy, which could further enhance reliability during low irradiance periods. In [2], Different AC/DC converter for DC fast-charging infrastructure was presented which is suitable for high-power appliances (>20 kW) due to its low ripples, high efficiency and reliability. Although the research successfully illustrates the performance of converter topologies, it focuses mostly on grid-powered systems and ignores the incorporation of renewable energy, which is a key factor for sustainable development objectives.[3] presented a hybrid PV-Wind EV charging station that incorporates a unified MPPT technique for concurrent optimization of both PV and wind schemes. The large-scale design demonstrates superior performance in balancing grid load and maximizing energy utilization. However, the research lacks an economic feasibility analysis for large-scale implementation and does not address the variability of wind and solar energy under extreme weather conditions.

In [4], a multi-objective optimization model solved using a hybrid algorithm (MOPSO-TOPSIS) is presented. The study demonstrated improved cost efficiency and reduced emissions in a case study in Inner Mongolia. However, its reliance on specific regional data limits the generalizability of its conclusions to other geographic areas with different energy profiles.[5] described a PV and wind energy-based EV charging system, focusing on reducing fossil fuel dependency and emissions. MATLAB-Simulink simulations highlighted the system's suitability for providing grid-connected charging. While effective, the study lacks an in-depth analysis of bidirectional energy flow, which is increasingly critical in EV applications, particularly for V2G operations. In [6] investigated off-grid EV charging in rural Indonesia. The study concluded that UNS Lithium Ferro Phosphate batteries provide optimal performance for cost-effective and reliable operations. While promising, the research primarily targets rural areas and does not address scalability or integration with urban charging networks, limiting its broader applicability.[7] investigated the possibility of directly using wind energy to power large-scale EVCS. The study applies a time-slot-based approach to analyze wind turbine output, demonstrating that wind energy can sufficiently supply the power needs of large-scale charging stations. While promising, the research does not consider the integration of power storing devices to handle the uncertainty of wind or the optimization of hybrid energy systems that include solar power, which could further enhance system reliability and efficiency.

In [8], the use of wireless charging for EVs powered by PV and wind energy was explored. Inductive power transfer is used in the suggested system between a secondary coil that is attached to the EV battery and a primary coil that is linked to a battery bank that utilizes renewable energy. Because there is no requirement for physical connections, the study provides users benefits in terms of safety and convenience. The model does not, however, consider the difficulties in expanding this technology for broad commercial use or the possible efficiency losses related to long-distance inductive charging. In [9], a FLC based MPPT method for PV systems integrated with a battery charging controller. The system aims to maximize the efficiency of the PV panels under varying environmental conditions. Although the FLC MPPT method is shown to achieve high accuracy (up to 99.4%), the study does not explore its long-term stability or the impact of integrating this system with other RES, such as wind or storage solutions, for a more robust EV charging station. The study by [10] focuses on optimizing the power distribution between a battery and supercapacitor to handle both steady and transient power demands. However, the research lacks a detailed analysis of the costs and scalability of such systems, particularly for large-scale EV charging networks. Additionally, the integration of grid energy or other renewable sources is not considered in this approach. In [11], a VS-PO MPPT algorithm for WECS, using modular sectors to adjust the step-size centered on the wind speed and power accuracy was introduced. The algorithm improved tracking performance compared to traditional methods, particularly in terms of speed tracking and reducing steady-state fluctuations. However, the study does not assess the algorithm's performance under varying environmental conditions or in hybrid systems that combine wind and solar power for EV charging. The study by [12] uses a P&O MPPT method to obtain maximum power across different wind speeds and load conditions. While the experimental results are promising, the study is limited to resistive loads and does not consider the dynamic nature of EV charging, which could require more complex control strategies to optimize power delivery to multiple charging stations.

This paper proposes a hybrid renewable energy-based EV charging station to address these challenges, employing MPPT techniques for optimal energy utilization. The PV system uses a FLC to dynamically adapt to changing irradiance, while the wind system adopts the P&O algorithm to maximize power output.

II. SYSTEM DESCRIPTION

The block diagram depicted in Figure.1 shows a hybrid renewable energy system designed to power an EVCS by incorporating PV and wind scheme. The PV module generates output voltage and current by transferring irradiance into electrical energy. By dynamically modifying the duty cycle of a linked boost regulator, a FL MPPT controller makes sure the PV system runs at its MPP. The boost regulator improvesthe PV output voltage to a suitable level and transfers it to a common DC Bus. Similarly, the wind energy system generates power from wind turbines, providing rectified voltage and current.

A P&O MPPT controller tracks the MPP of the wind system by incrementally adjusting its operating point based on power variations. The wind system also uses a boost converter to regulate its voltage and feed it into the DC Bus. The DC Bus acts as a central energy hub, combining the outputs of both renewable resources to give a stable power supply to the EV charging station. This integration ensures efficient and reliable energy utilization for charging EVs, promoting a sustainable and eco-friendly transportation solution.

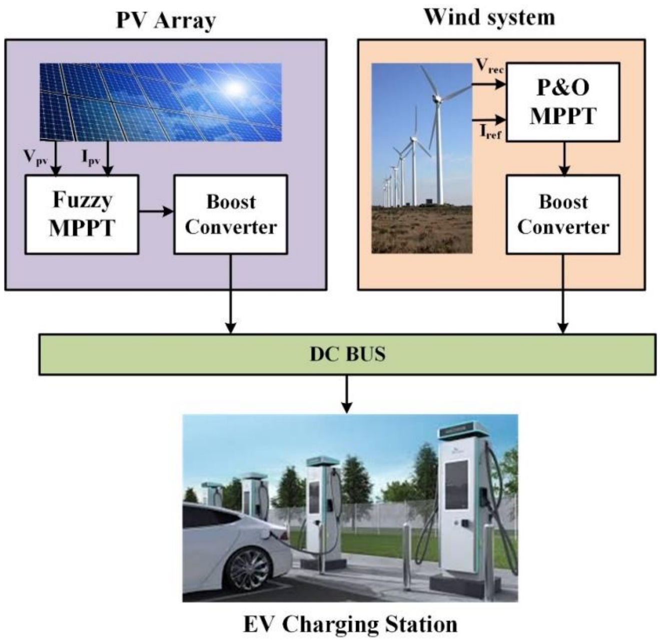

Figure.1 Overall Representation of the Proposed scheme

III. PV CONTROL WITH FUZZY MPPT

A. PV Modeling

The single-diode circuit depicted in Figure 2 is the most often used model since it accurately and simply captures PV behaviour. By optimizing the PV system's power production and facilitating effective MPP tracking, this approach guarantees a steady and sustainable energy supply.

$$I = I_{sc} - I_R\left(e^{\frac{IR_S+V}{KAT}} - 1\right) - \left(\frac{V+IR_S}{R_p}\right) \qquad (1)$$

Boltzmann's constant is represented by K, while the short-circuit current is represented by Isc. A stands for ideality factor, and T for temperature. Reverse saturation current is represented by I_R, while the electron's charge is shown by q. Furthermore, the symbols for the series resistance and parallel resistance are R_s and R_p, respectively. To ensure the smooth integration of renewable energy, which is covered in the following section, the boost regulator effectively controls and optimizes the energy transfer from the PV scheme changing power output.

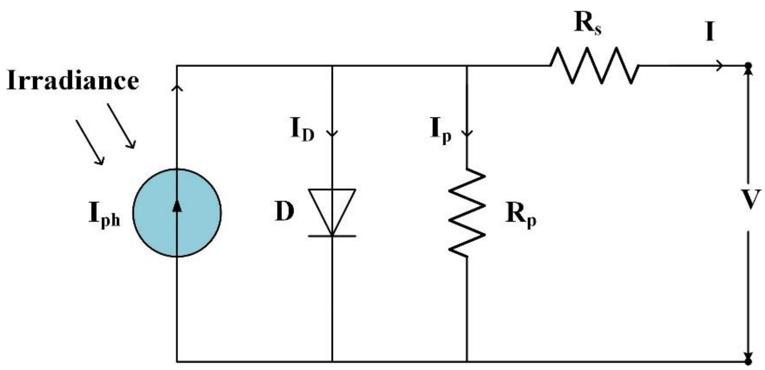

Figure.2 Single diode model of PV cell

B. Fuzzy MPPT

Fuzzy MPPT is a smart control method that maximizes output from a PV scheme under a variety of ecological circumstances, involving temperature and sun irradiance variations. Due to its ability to manage uncertainties and nonlinearities without depending on a mathematical model of the PV scheme.

The fuzzy MPPT controller operates in three primary stages:

1. Fuzzification: Converts numerical inputs into fuzzy linguistic variables using membership functions.
2. Inference: Applies a set of fuzzy rules to decide the output.
3. Defuzzification: Converts the fuzzy output into a competent control signal.

Change in Power (ΔP): Indicates the power variation caused by changes in irradiance or temperature. Change in Voltage (ΔV): Represents the voltage variation of the PV array. The error is specified as the ratio of the change in power to the change in voltage

$$E = \frac{\Delta P}{\Delta V} \qquad (2)$$

The FLC MPPT objective is to trace the MPP by modifying the DC-DC converter's duty cycle.

Fuzzy Rules: The fuzzy controller uses a set of IF-THEN rules based on the linguistic interpretation of E and ΔE

Membership Functions (MF): These define the linguistic terms (e.g., Negative, Zero, Positive) for E and ΔE, typically using triangular or trapezoidal functions.

The outcome of the fuzzy inference system is the variation in duty cycle ΔD for the DC-DC converter. This is calculated as:

$$D_{new} = D_{old} + \Delta D \qquad (3)$$

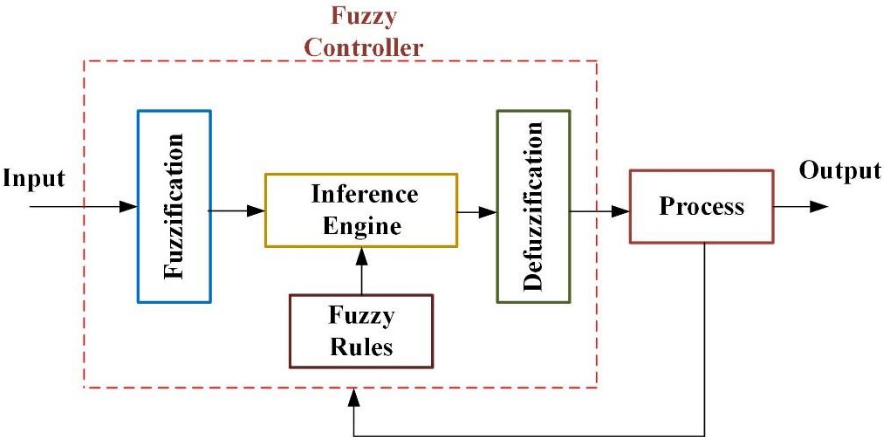

Figure.3 Operation of Fuzzy Control

where D_{old} is the previous duty cycle.

Fuzzy MPPT controllers are highly adaptive and successful for maximizing the output power of solar PV scheme, especially in dynamic environments.

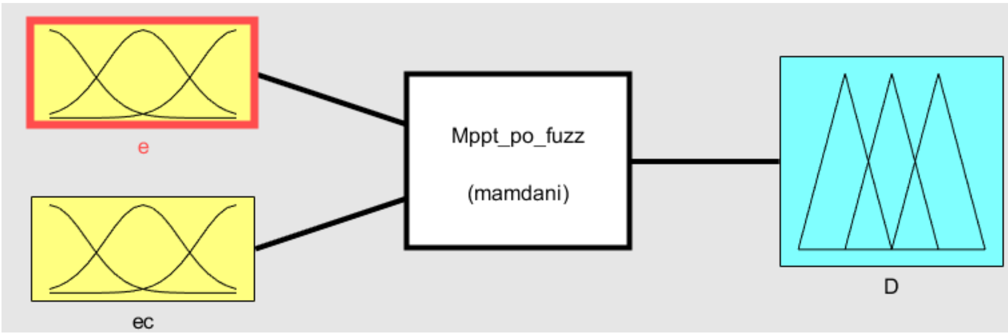

Figure.4 Representation of Fuzzy control with Input & Output MF

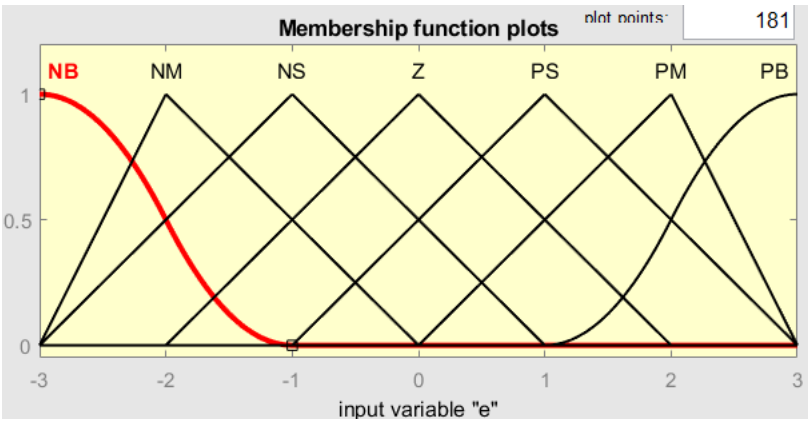

Figure.5 Fuzzy Input MF (e)

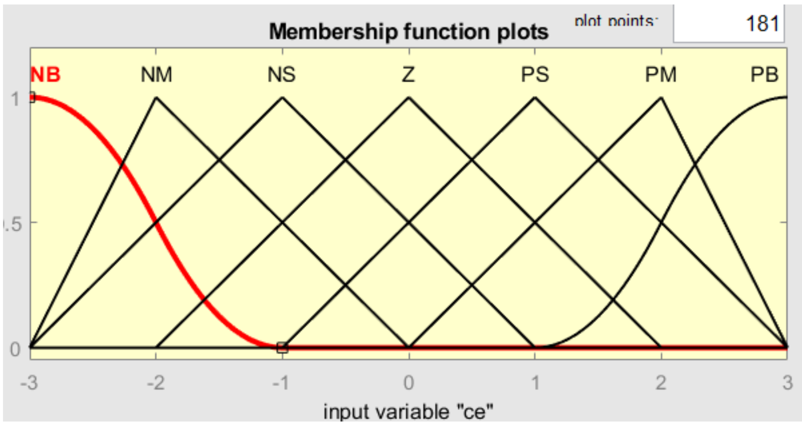

Figure.6 Fuzzy Input MF (ce)

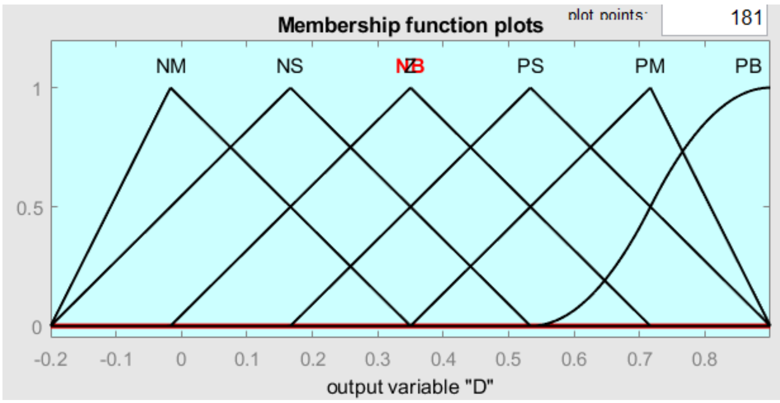

Figure.7 Output MF Duty cycle (D)

The input MF of the fuzzy control is represented in Figures 5 and 6. The output is the duty cycle depicted in Figure 7. Figure 8 represents the representation of the rule based on input and output MF.

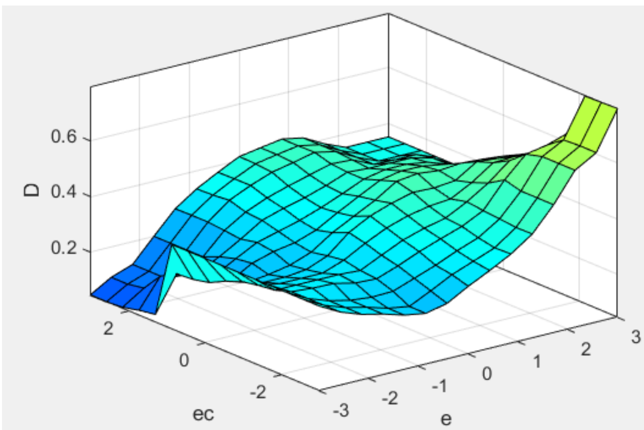

Figure.8 Representation of Rule Base for Input & output MF

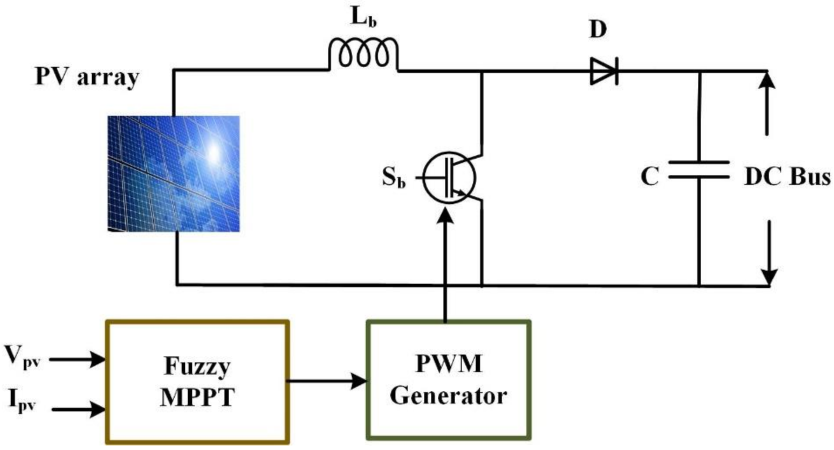

Figure.9 Fuzzy MPPT Control of PV System

Figure.9 signifies the control logic for a PV scheme designed to integrate with a DC bus. The PV module generates a voltage and current based on the PV irradiance and temperature conditions. These outputs are fed into an FLC MPPT controller, which dynamically determines the optimal operating point to obtain MPP from the PV module. The Fuzzy MPPT generates a duty cycle signal based on the input voltage and current sent to a PWM generator. The PWM generator produces switching pulses to control the operation of the boost regulator. The boost regulator, consisting of an inductor, diode, capacitor and switch, improves the PV array voltage to match the needed DC bus voltage. While the diode stops reverse current flow, the inductor retains energy during the switch's ON and releases it during its OFF periods. The capacitor ensures dependable power transmission for connected loads or systems by stabilizing the output voltage and supplying a steady DC voltage to the DC bus. This control logic efficiently confirms that the PV module drives at its MPP while providing a stable DC output for energy utilization or further integration into a hybrid energy system.

IV. WIND CONTROL WITH PO MPPT

WT is used in WECS to transform wind kinetic power into mechanical power. The WT's input wind power Pw may be written as

$$P_w = \frac{1}{2}\rho\pi R^2 V_w^3 \qquad (4)$$

where R is the radius of WT (m), V_ω is the speed of wind(m/s), and ρ is the air density (kg/m3). C_P is turbine's power coefficient , which determines how much mechanical power is collected from the wind. The mechanical power output is provided by

$$P_m = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta) V_w^3 \qquad (5)$$

where $C_p(\lambda,\beta)$ is the coefficient function, λ is the tip speed ratio, β is the pitch angle of blade.

A. P&O MPPT

The P&O procedure is often employed when controlling the PV scheme using the MPPT method. It has a straightforward structure, is inexpensive, simple to use, has fewer parameters, allows for the introduction of enhancements, and might lead to extremely high efficiency.

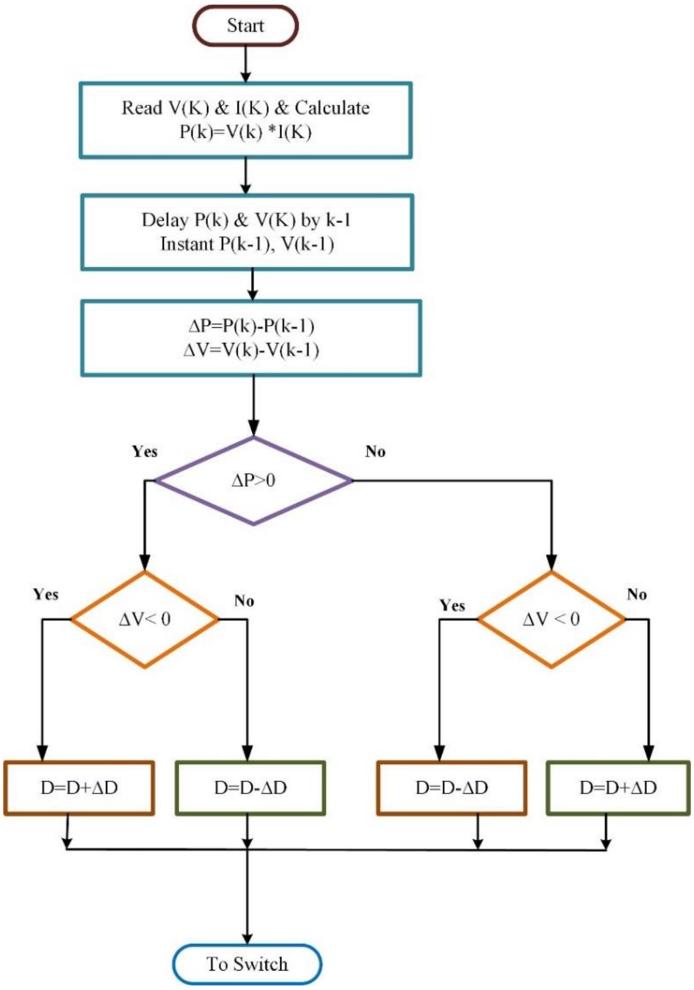

Figure.10 Flow diagram of PO MPPT

Examining the relationship among PV module's output power and voltage is the input of this approach. When the PV unit working point is on the left side of the curve ($\Delta P/\Delta V$ is +ve), indicating a rise in the PV output power, If the PV working point was on the right side of the curve ($\Delta P/\Delta V$ is -ve), the perturbation of the PV array voltage will decrease near the MPP. Figure 10 presents the flow diagram of the PO approach. The real-time parameters of the PV array are obtained. The voltage is then multiplied by the current to find the PV array's actual power. It will then ascertain whether $\Delta P = 0$. If this criterion is satisfied, the MPP is the working point. It begins by verifying the condition $\Delta P > 0$ (change in power). If this statement is not met, it checks whether $\Delta V > 0$ (change in voltage). If $\Delta V > 0$, it indicates that the working point is on the left side of the MPP, and further adjustments are needed to reach the MPP. Conversely, if $\Delta V > 0$ is not satisfied, the Working point is on the right side of the MPP. The algorithm repeatedly performs these checks and adjusts the operating point until the MPP is reached. This iterative process ensures efficient power extraction while balancing the sampling rate and step size to optimize performance.

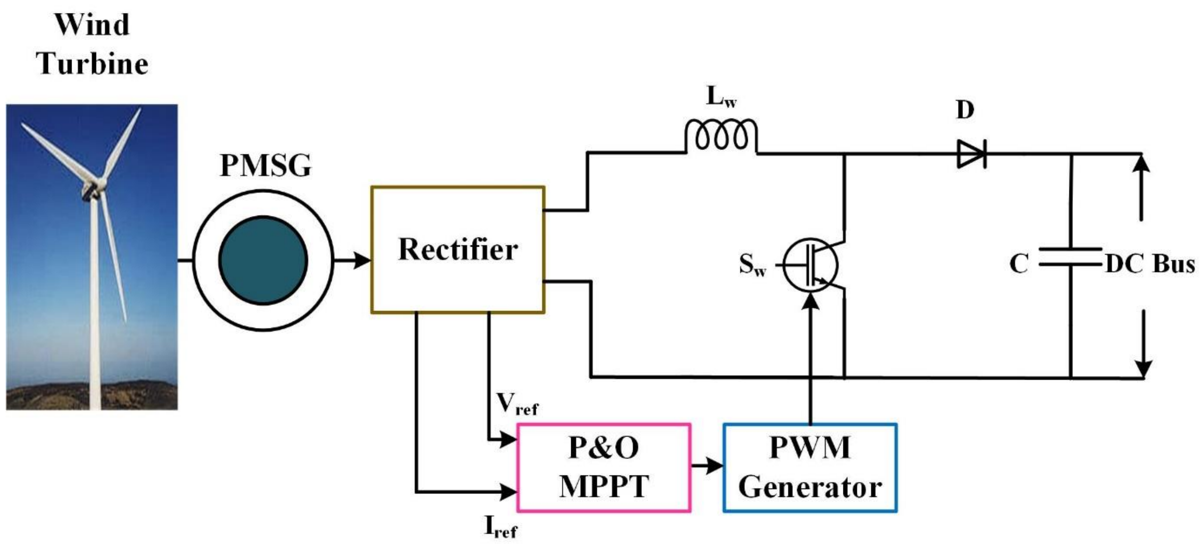

Figure.11 Wind control with PO MPPT

Figure.11 represents a WECS where a WT drives a PMSG to deliver electrical energy. The generated AC power is converted to DC using a rectifier and regulated by a DC-DC converter with a switching device S_w controlled via PWM. A capacitor stabilizes the DC potential and feeds it into the DC bus for energy delivery to a load or grid. The PO MPPT algorithm ensures maximum power extraction by adjusting reference voltage V_{ref} and current I_{ref} inputs to the PWM generator, which controls the converter's operation. This setup optimizes power transfer from the wind turbine while maintaining system stability.

B. EV Battery

The integration of PV with EV batteries also enhances grid resilience by enabling decentralized energy generation and storage. Surplus solar energy can be stored in the EV battery during peak sunlight hours and utilized when sunlight is unavailable, ensuring continuous energy availability. In this work, Lithium-ion battery relates to a nominal voltage of 400V with a capacity of 48 Ah & initial state of charge of 50%.

V. RESULTS & DISCUSSION

The working of the proposed scheme is performed in MATLAB/SIMULINK. The PV irradiance is reduced from 1000 W/m2 to o from 0 to 0.6s, then the irradiance is gradually increased. The PV parameters are represented in Figure 12. A 2 kW PV panel is considered in the simulation. The Theoretical power of the PV is 2001.64 W, When the PV irradiance is 1000 W/m2, the power attained is 1992 W with the efficiency of 99.5 using Fuzzy MPPT, when the irradiance is reduced to 500 W/m2 the power attained is 995 W & the efficiency obtained is 99.9%, Hence the FLC MPPT effectively tracks the MPP irrespective of the change in irradiation condition.

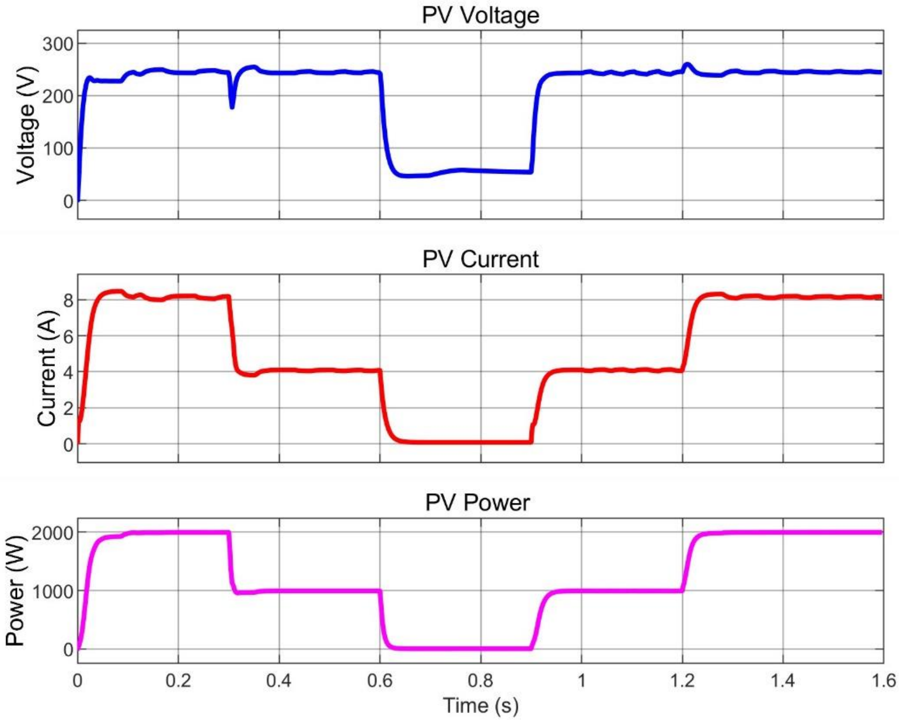

Figure.12 Voltage, Current & power of PV

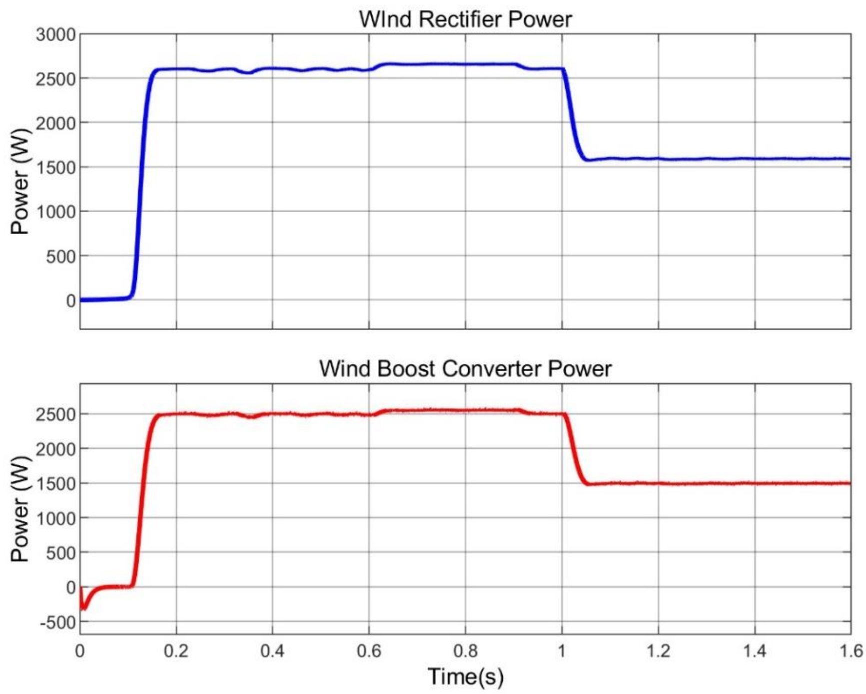

Figure.13 Voltage, Current & power of PV

A 2.5 kW wind turbine is employed in this system, Here the WT is operate with the velocity of 12 m/s from 0 to 1s & it is reduce to 10.8 m/s, In the both the operating condition the WT obtained maximum power using PO MPPT, The power obtained is represented in the Figure.13.

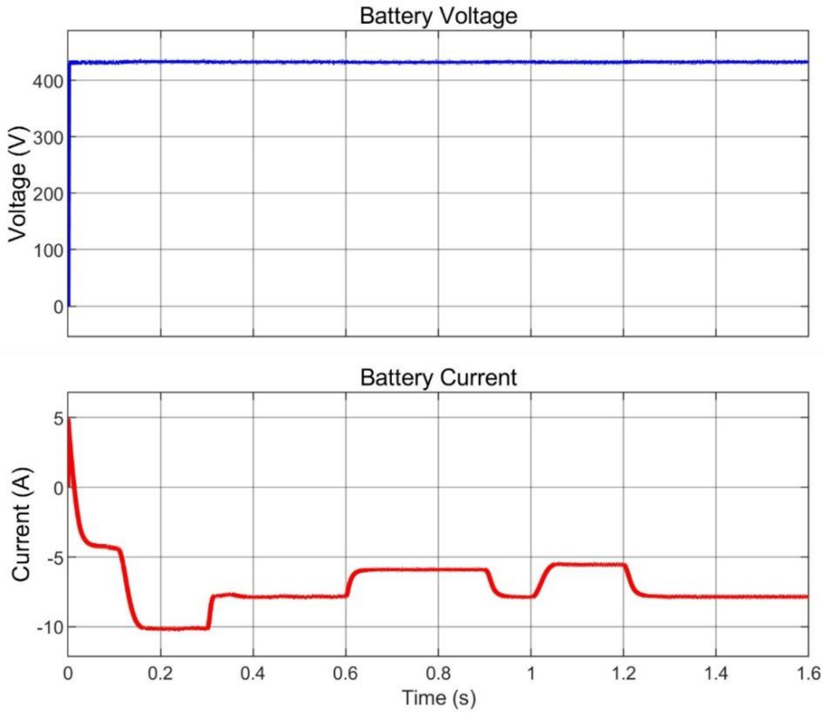

Figure.14 Voltage & Current of battery

The Voltage & current of the battery are represented in Figure 14, here the battery charging current is varied according to the change in the input power of PV & Wind. The variation in the battery SOC is denoted in Figure.15.

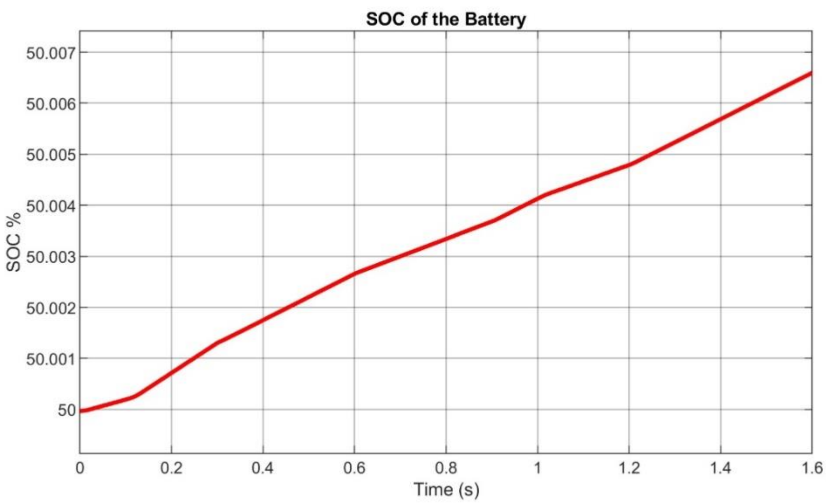

Figure.15 SOC of the battery

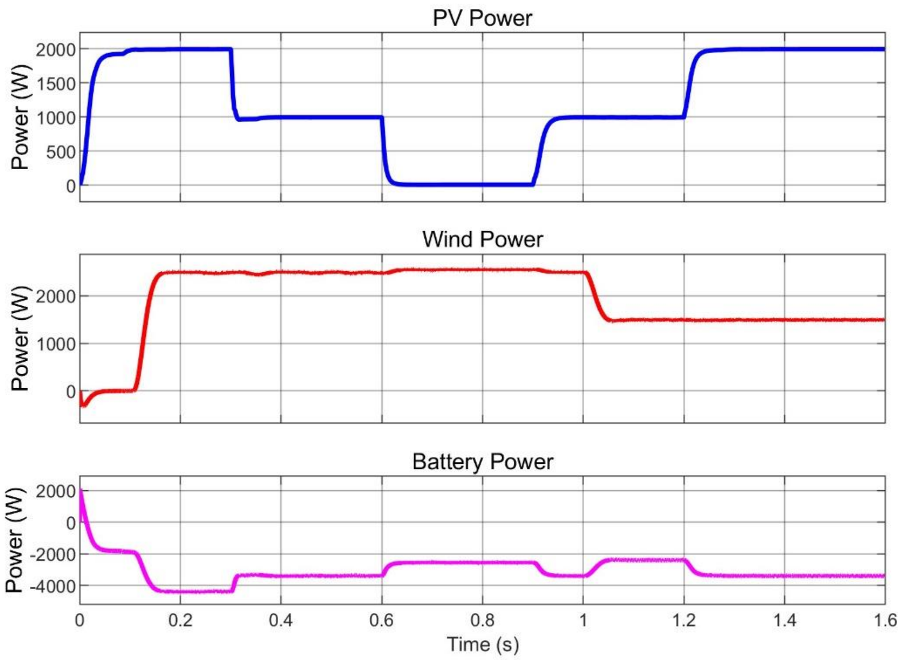

Figure.16 Power of PV Wind & Battery

The power of PV, wind, and battery is depicted in Figure 16. Here the battery charging power depends on the PV and wind; even in the interruptions of PV and wind, the battery receives stable power without any interruption. Hence both the fuzzy and PO MPPT employed in the PV and wind are very efficient in extracting maximum power from the sources. Hence, this proposed scheme is useful for the EV charging station installations.

VI. CONCLUSION

The addition of RES like PV and wind energy into EVCS presents a sustainable and eco-friendly solution to decrease dependency on fossil fuels and reduce GHG releases. The proposed hybrid renewable energy-based EVCS, incorporating a FLC for PV modules and the P&O technique for wind turbines, demonstrates efficient and reliable power extraction under varying environmental conditions, ensuring optimal energy utilization for charging electric vehicles. The FLC MPPT controller effectively tracks the MPP of the PV scheme, with a demonstrated efficiency of up to 99.9% under reduced irradiance conditions, showcasing its adaptability to dynamic environmental factors. Similarly, the PO MPPT algorithm enables the wind system to achieve maximum power output, highlighting its effectiveness in harnessing wind energy. Additionally, the integration of EV batteries enhances grid resilience by enabling decentralized energy generation and storage, ensuring continuous energy availability even during interruptions in PV and wind power. Moreover, the proposed scheme's simulation results in MATLAB/SIMULINK validate the effectiveness of the FLC and PO MPPT controllers in extracting maximum power from PV and wind sources, making it a promising and practical solution for EV charging station installations. This comprehensive analysis underscores the feasibility and potential of renewable energy-powered EVCS as a robust and sustainable alternative to grid-dependent systems, contributing to the advancement of eco-friendly transportation infrastructure.

References

1. Razzaq, M. I. (2021, October). Solar Powered Electric Vehicle Charging Station with Fuzzy Logic Controller. In *2021 International Conference on Engineering and Emerging Technologies (ICEET)* (pp. 1-6). IEEE.
2. Rajendran, G., Vaithilingam, C. A., Naidu, K., & Oruganti, K. S. P. (2020). Energy-efficient converters for electric vehicle charging stations. SN Applied Sciences, 2, 1-15.
3. Fathabadi, H. (2017). Novel grid-connected solar/wind powered electric vehicle charging station with vehicle-to-grid technology. *Energy*, *132*, 1-11.
4. Sun, B. (2021). A multi-objective optimization model for fast electric vehicle charging stations with wind, PV power and energy storage. *Journal of Cleaner Production*, *288*, 125564.
5. Chellaswamy, C., Nagaraju, V., & Muthammal, R. (2018). Solar and wind energy based charging station for electric vehicles. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, *7*(1), 313-324.
6. Nizam, M., & Wicaksono, F. R. (2018, October). Design and optimization of solar, wind, and distributed energy resource (DER) hybrid power plant for electric vehicle (EV) charging station in rural area. In *2018 5th International conference on electric vehicular technology (ICEVT)* (pp. 41-45). IEEE.
7. Noman, F., Alkahtani, A. A., Agelidis, V., Tiong, K. S., Alkawsi, G., & Ekanayake, J. (2020). Wind-energy-powered electric vehicle charging stations: Resource availability data analysis. *Applied Sciences*, *10*(16), 5654.
8. Nethra, K., Bairwa, B., Kiran GS, S., & Gowda KB, T. (2022, August). Modeling and simulation of wireless electric vehicle charging using solar and wind energy. In *AIP Conference Proceedings* (Vol. 2461, No. 1). AIP Publishing.
9. Yilmaz, U., Kircay, A., & Borekci, S. (2018). PV system fuzzy logic MPPT method and PI control as a charge controller. *Renewable and Sustainable Energy Reviews*, *81*, 994-1001.
10. Boda, N., & Tiwari, P. K. (2024, June). Efficient Energy Management for Grid-Connected PV and EV Charging Stations with HES System Using Fuzzy Logic-Based MPPT Control. In *2024 IEEE Students Conference on Engineering and Systems (SCES)* (pp. 1-6). IEEE.
11. Mousa, H. H., Youssef, A. R., & Mohamed, E. E. (2019). Variable step size P&O MPPT algorithm for optimal power extraction of multi-phase PMSG based wind generation system. *International Journal of Electrical Power & Energy Systems*, *108*, 218-231.
12. Lahfaoui, B., Zouggar, S., Elhafyani, M. L., & Seddik, M. (2015, December). Experimental study of P&O MPPT control for wind PMSG turbine. In *2015 3rd International renewable and sustainable energy conference (IRSEC)* (pp. 1-6). IEEE..