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Wireless Power Transfer for Electric Vehicles with ANFIS Based MPPT for Solar System

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ABSTRACT: Wireless Power Transfer (WPT) for Electric Vehicles (EVs) represents an new approach to convenient and efficient EV charging. Integrating WPT with a PV powered charging system can further enhance sustainability by reducing dependency on conventional energy sources. This paper presents a solar-based wireless charging system using an Adaptive Neuro-Fuzzy Inference System (ANFIS) for MPPT to optimize energy harvested from PV panels. ANFIS-based MPPT enables the system to dynamically adjust to changing irradiance conditions, maximizing energy transfer efficiency. The proposed scheme uses ANFIS to optimize PV panel power supply, ensuring a steady and reliable wireless charging output even in the varying environmental conditions. The results of the simulation show that this approach performs better than conventional MPPT methods, producing more efficiency and preserving ideal charging conditions. EVs may now obtain clean energy without physical connections thanks to the invention of this smart charging technology, which has potential uses in both off-grid and urban environments. Future research will concentrate on real-time deployment and investigating how environmental variables affect charging efficiency in various contexts.

KEYWORDS: Wireless Power Transfer, Electric Vehicles, ANFIS, Maximum Power Point Tracking, Solar PV System

1. INTRODUCTION

The rapid acceptance of EVs has intensified the requirement for efficient, accessible, and sustainable charging solutions. Conventional plug-in charging methods pose limitations, such as infrastructure requirements and user inconvenience. WPT technology has arosed as a hopeful alternative, allowing EVs to charge without physical connectors, which improves ease of use and minimizes maintenance. Combining WPT with renewable energy sources, specifically solar power, can further reduce environmental impact by leveraging clean, inexhaustible energy for EV charging.

In [1], an ANN MPPT is presented for PV scheme. The scheme is designed to adapt energy storage, wireless transmission, and efficient power generation. The efficiency of energy conversion from RES is much increased by the ANN-based MPPT, as the authors show, which improves performance in EV charging scenarios. Potential challenges in wireless energy transmission efficiency are not thoroughly explored in this work. An optimal synergetic control strategy using a chaotic dragonfly algorithm combined with ANFIS is implemented in [2] for ultrafast EV charging. The RES is shown to enhance charging speed and efficiency, making it suitable for modern EV applications. The results indicated that this approach surpassed old MPPT techniques in terms of response time and energy utilization. The complexity of the chaotic dragonfly algorithm may hinder practical implementation. The study not considered the effect of varying environmental circumstances on system performance.

In [3], modelling and design for wireless EV battery charging are presented. It contrasted several control strategies, emphasizing how well they maximize charging efficiency and reduce energy losses. The authors suggested a layout that enhances EV wireless charging devices' overall functionality. The comparison of control techniques might be limited to specific scenarios, reducing generalizability. The economic feasibility of the proposed designs is not addressed. The study by [4] implemented various control strategies, including PI, Fuzzy Logic, and ANFIS controllers, for a charging station powered by PV and wind energy sources. The findings suggest that the ANFIS controller offers exceptional functioning in terms of stability and response time compared to conventional controllers. The simulation results may not fully capture the complexities of real-world charging station operations. The study does not explore the integration of other renewable sources or hybrid systems. The long-term performance and maintenance requirements of the controllers are not discussed. An ANFIS-driven control for resonant converters in optimizing the charging schemes of electric vehicle batteries was presented in [5]. The ANFIS controller enhanced the efficiency of the charging process, leading to reduced charging times and improved battery life. The research not considered the effects of battery chemistry variations on charging efficiency. The implementation of resonant converters in practical scenarios is not thoroughly examined. In [6], an EV charging stations that integrates PV, standby batteries, and grid are presented. Different control mechanisms are explained to enhance the resilience and efficiency of the charging stations, ensuring reliable energy supply even during grid outages. The study primarily focuses on simulation results, which may not fully capture real-world operational challenges and dynamics.[7] discussed the implementation of smart control strategies to enhance the stability of DC microgrids used in EV charging ecosystems. The control methods enhanced load balancing and voltage regulation, both of which are essential for preserving system stability during periods of high charging. Case studies that illustrate the efficacy of the control techniques were included in the research. The control algorithms' intricacy might make them difficult to apply in practice and necessitate more simplification before they can be widely used.

In [8], a learning methodology for managing the transition and protection of PV driven EV charging stations was presented. This utilizes ML procedures to predict and manage energy flows, improving the consistency and efficiency of the charging process. This work did not explore the economic implications of implementing such intelligent systems in existing charging infrastructures. A microwave-relied WPT system that utilizes PV for efficient energy transfer is presented in [9]. This system is designed to minimize energy losses during transmission, making it a potential solution for remote or off-grid applications. The outcomes demonstrated the feasibility and efficiency of the system in transmitting power without Wires. The technology's scalability and practicality for widespread use in EV charging remain uncertain and require further investigation.[10] developed an ANFIS MPPT controller for solar PV schemes. The ANFIS controller is shown to outperform traditional MPPT methods in terms of tracking efficiency and response time under varying environmental conditions. The study included simulations that justify the effectiveness of the control in optimizing energy extraction from solar PV systems.

An overview of the current state of research on wireless charging systems for EV powered by PV was discussed in [11]. It discussed various technologies and methodologies employed in WPT systems, including inductive and resonant coupling. The authors highlighted the benefits of integrating solar energy with WPT, like sustainability and reduced reliance on grid electricity. The review did not explore the most recent advancements in wireless charging technologies.

In [12], a self-contained PV-driven inductive power transfer (IPT) scheme designed for wireless EV charging. The authors demonstrated the system's feasibility through simulations and prototype testing, showcasing its efficiency. The incorporation of PV modules with the IPT system allows for a sustainable charging solution that can operate independently of the grid. The prototype's performance vary under different environmental conditions, which is not extensively tested in the study.[13] explored the concept of integrating magnetic induction WPT within PV roads to facilitate EV charging. The experimental case project demonstrated the viability of this approach, highlighting the potential for infrastructure to serve dual purposes. Results indicated that the system can effectively charge EVs while providing renewable energy through solar panels embedded in the road. In [14], the design for a WPT charger for EVs that utilizes PV. The authors discussed the design parameters, efficiency metrics, and potential applications of the system. In order to improve charging efficiency and lower energy losses, the study underlined the need of improving the WPT system. Its feasibility may be impacted by the failure to meet the planned system's long-term durability and maintenance needs.

In [15], a PV-powered WPT system for charging EV is discussed. The authors presented a detailed analysis of the system's design, including power electronics and control strategies to optimize charging efficiency. The outcomes suggest that the proposed system can significantly reduce charging time compared to traditional methods. The economic analysis of the system's implementation and its competitiveness with existing charging solutions is not thoroughly explored. Achieving efficient energy transfer from solar PV systems to WPT setups requires advanced control strategies due to the variable nature of solar irradiance. MPPT techniques are employed to maximize the output of PV systems under fluctuating conditions. In this study, an ANFIS-based MPPT algorithm is proposed to enhance solar energy utilization for WPT. ANFIS leverages both learning and adaptability to manage dynamic environmental changes, improving charging efficiency and ensuring reliable EV power transfer. This approach offers a sustainable, high-efficiency solution, contributing to the green transportation ecosystem by integrating clean energy with modern EV charging expertise

The main contribution of this paper is to

1. Design a PV powered EV system for efficient and sustainable energy generation.
2. Implement an ANFIS based MPPT control to optimize power output from the PV system.
3. Integrate a WPT mechanism in the proposed system to enable seamless and automated charging of the EV.

2. SYSTEM DESCRIPTION

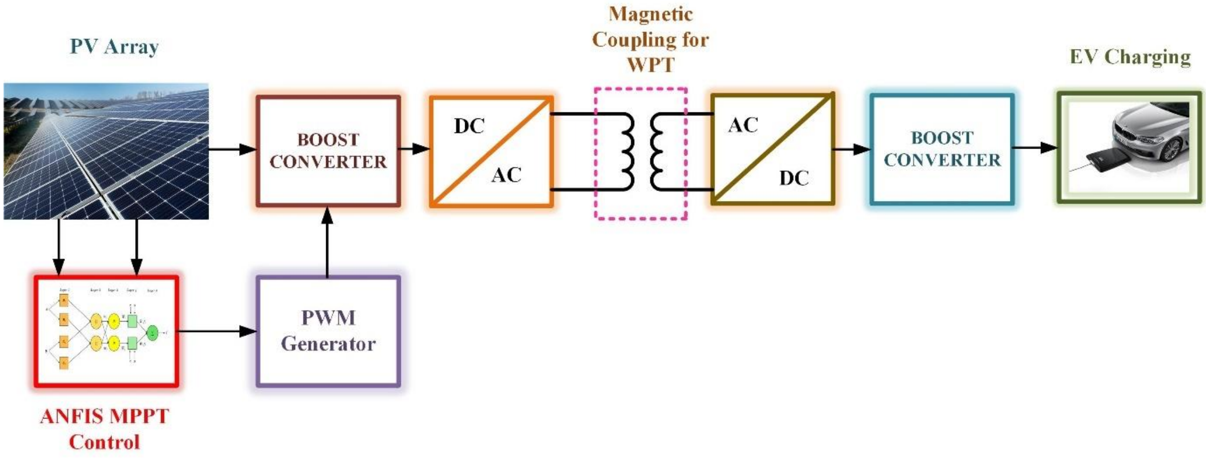

Figure.1 Overall Representation of WPT

The block diagram presented in Figure.1 represents a WPT system for EV charging, powered by a PV module. The PV array generates DC power, which is regulated by an ANFIS based MPPT controller to increase energy output under varying sunlight conditions. This MPPT controller sends control signals to a PWM generator, which regulates the duty cycle of the Boost Converter to maintain optimal power flow. The Boost regulator raises the DC voltage from the PV array to a suitable level for wireless transmission. Next, the DC power is converted to AC by an inverter, allowing it to pass through a magnetic coupling section, which transfers power wirelessly. On the EV side, the obtained AC power is transferred back to DC by a rectifier and regulated through another Boost Converter, which ensures a steady voltage for efficient EV battery charging. This setup provides a clean, efficient charging solution by utilizing solar energy and WPT technology, managed by advanced ANFIS-based MPPT control.

2.1 PV Model & Boost Regulator

A PV cell is the simple component of a PV scheme. It transforms the irradiance into electric power. The resistances are connected to the PV diode in a feasible scenario, as seen in Figure 2. In a conventional PV cell, the resistances are not incorporated.

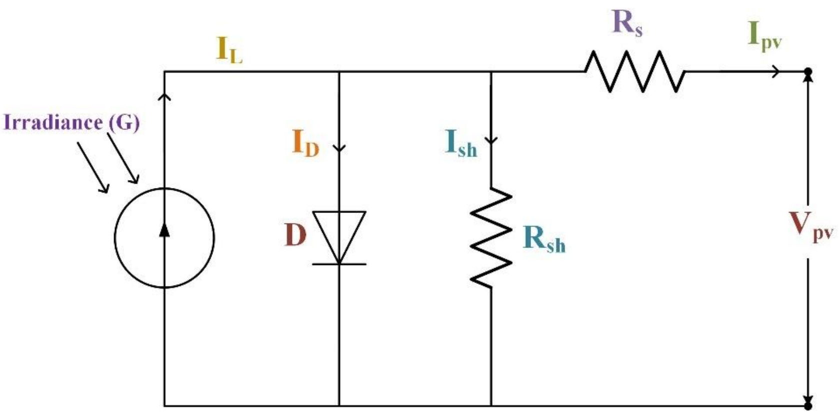

Figure.2 Equivalent circuit of PV

Here, the PV diode's semiconductor and p–n junction are resistive and not optimal, which leads to the insertion of a series and shunt resistances. Kirchhoff's law, which is found in Equ(1), may determine the solar cell's current generator:

$$I_{pv} = I_L - I_d - I_{sh} \qquad (1)$$

where I_L is the current obtained from PV module , which is presented in Equ(2):

$$I_L = G(I_{sc}[1 + k_t(T - T_{stc}) \qquad (2)$$

where G is the irradiance, T is the temperature, kt is the temperature coefficient, T_{STC} is the Temperature at STCmm,I_{SC} is the short circuit current and I_d is the diode current which presented as in Equ (3):

$$I_d = I_o\left\{e^{\left(\frac{qV_d}{nkT}\right)} - 1\right\} \qquad (3)$$

where $I\ o$ is the current of PV ; $V\ d$ is the outcome voltage ; q is charge of electron, k is Boltzmann's constant and n is the diode factor. Combining all the above constraints the following Equ (4) represents the model of PV

$$I_{pv} = I_L - I_o\left[e^{\left(\frac{q(V_{pv}+IR_s)}{nkT}\right)} - 1\right] - \left[\frac{V_{pv}+IR_s}{R_{sh}}\right] \qquad (4)$$

The PV cells are linked in series and parallel in different topologies to create an optimum PV module, and then in different combinations to create the ideal PV array, in order to get the desired voltage and current.

A DC-DC boost converter's readily adjustable MPPT controller has made it a popular choice for solar conversion systems. The output side of the boost regulator is often used to control and supply a higher voltage than the input side. Equation (5) illustrates a boost regulator voltage gain:

$$V_G = \frac{V_{out}}{V_{in}} = \frac{1}{1-D} \quad (5)$$

where Vout & Vin is the output & input voltage, and D is the MPPT controller's duty cycle, which the PWM transforms into a signal.

2.2 ANFIS MPPT

The ANFIS methodology, which blends ANN architecture and FLC inference, is considered a hybrid approach. The ANFIS method has numerous nonlinear uses in a range of domains, specifically in the domains of electrical engineering, there are wind turbines and PV modules. The ANFIS structure is composed of 5 layers, which are fuzzification, rules, normalization, subsequent, and addition, as illustrated in Figure 3. Every adaptive node in the training data's first layer operates by utilizing Equ (6) and (7).

$$L_{1,i} = \mu x_i(x) \quad for\ i = 1,2 \quad (6)$$

$$L_{1,i} = \mu y_{i-2}(x) \quad for\ i = 3,4 \quad (7)$$

where the defined membership value for the inputs x and y is $L_{1,i}$ and the defined membership function is μ. The layer and node numbers of the training data are denoted by the subscripted 1 and i, respectively. Lowest training error is attained using optimal membership functions.

According to a single fuzzy rule, each node in Layer 2 is fixed. Equ (8) provides the result value:

$$L_{2,i} = \omega_i = \mu X_i(x)\mu Y_i(y) \quad i = 1,2 \quad (8)$$

Using Equation (9) to normalize the firing strength, each node in Layer 3 is fixed.

$$L_{3,1} = \omega_i = \frac{\omega_i}{\omega_1+\omega_2} \quad (9)$$

Each node in Layer 4 is modified and computed using the consequent rule, as shown in Equ (10):

$$L_{4,1} = \omega_i f_i = \omega_i(p_i x + q_i y + r_i) \quad (10)$$

where during the course of training, the following parameters pi, qi, and ri must be adjusted. Adding together all of the input nodes in Layer 5 yields the final output signal, which is given by Equ (11):

$$L_{5,1} = \sum_i \omega_i f_i = \frac{\sum_i \omega_i f_i}{\sum_i \omega_i} \quad (11)$$

The reference power is the result of the ANFIS algorithm, which typically uses the operational temperature and irradiance level as inputs to the training data. The measured voltage and current of the PV operation are used to determine the real PV power under the same weather circumstances. After comparing these two power measurements, a PI controller uses the error to modify the PV module's operational MPP by generating a signal for a DC–DC converter via a PWM generator.

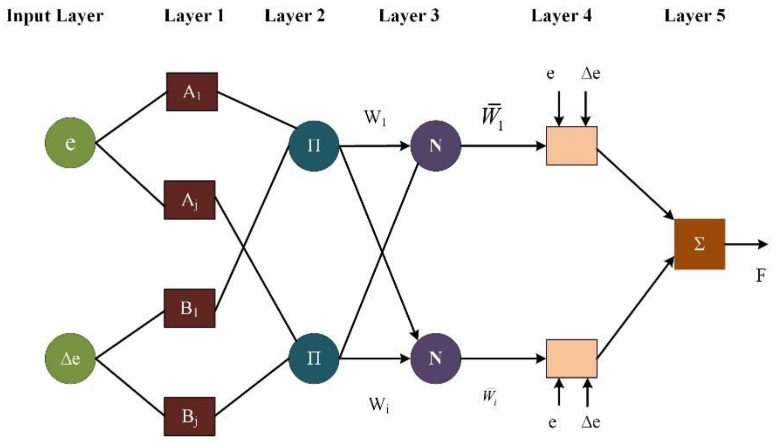

Figure.3 ANFIS Layers

The relationship between input & output function is represented in Figure.4. Figure.5 exhibits the rule base for the input & output functions.

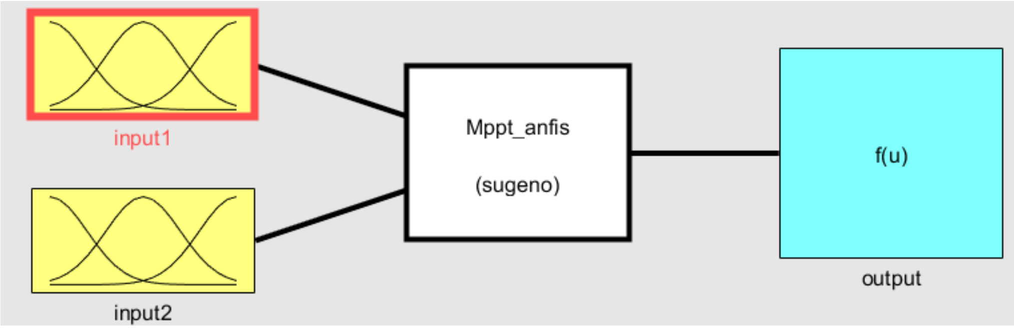

Figure.4 Input & output Functions of ANFIS MPPT

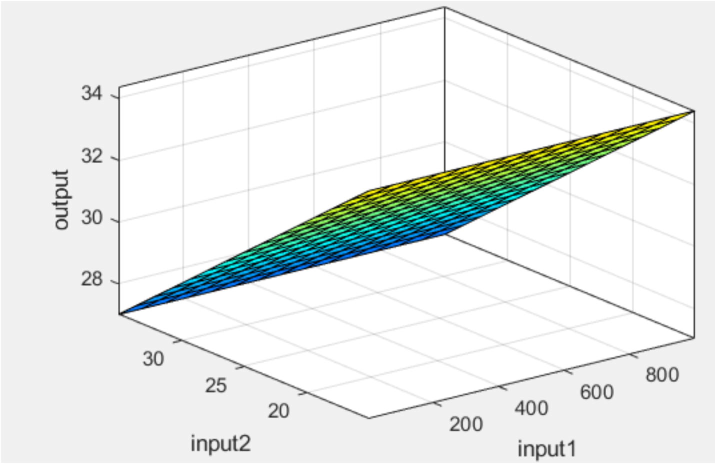

Figure.5 Representation of Rule base of ANFIS MPPT

2.3 Wireless Power Transfer For EV

Wireless charging for EVs is increasingly essential due to its convenience, safety, and potential to enhance charging infrastructure. Traditional plug-in charging requires drivers to manually connect cables, which can be cumbersome, especially in adverse weather conditions or for people with limited mobility. Wireless charging, on the other hand, allows drivers to simply park their EV over a charging pad, making the process fully automated and hands-free. This technology reduces wear and tear on physical connectors, which can degrade over time, especially with frequent use. Additionally, wireless charging minimizes electrical hazards by eliminating exposed wires, which enhances safety, particularly in public charging stations. Wireless charging also enables the development of dynamic charging systems, where EVs can recharge while in motion on specially equipped roads, potentially extending driving range and reducing downtime. Overall, wireless charging addresses many of the limitations associated with conventional charging, making EVs more accessible and promoting widespread adoption.

3. SIMULATION RESULTS

The operation of the proposed method is analysed in MATLAB. Table 1 provides detailed specifications for various components used in the simulation of the PV-powered EV charging system with WPT. The PV module parameters include a voltage of 29 V and a current of 7.35 A at the MPP, yielding a maximum power of 213.15 W. To achieve the desired power output, 23 modules are connected in series, with five parallel strings. The PV-side boost converter is designed with an inductor of 3mH and a capacitor of 100 µF to stabilize the output from the PV modules before it is fed into the WPT system. For the WPT coils, winding 1 on the PV side has an inductance of 8.793e-5 H, while winding 2 on the load side has an inductance of 1.241e-4 H, with a mutual inductance of 2.106e-5 H, which facilitates efficient energy transfer between the coils. On the load side, a boost converter with a 1 mH inductor and a 33 µF capacitor is used to regulate the power received wirelessly before it charges the electric vehicle. These parameters are chosen to optimize the efficiency and stability of power transfer within the system.

Table 1. Parameters used in the Simulation.

Sl.NO	Specifications	Value
PV Details		
1	Voltage at MPP (V)	29
2	Current at MPP (A)	7.35
3	Maximum Power (W)	213.15

4	No of Series- modules	23
5	No of Parallel strings	5
PV side Boost Converter Details		
6	Inductor L(mH)	3
7	Capacitor C (µF)	100
WPT Coil Details		
11	Winding 1(PV Side) (H)	8.793e-5
12	Winding 2(Load Side) (H)	1.241e-4
13	Mutual Inductance	2.106e-5
Load side Boost Converter Details		
15	Inductance (mH)	1
16	Capacitance (µF)	33

The results obtained when the PV system runs under a constant irradiance of 1000 W/m² are summarized below, demonstrating the system's competence and power output. At this irradiance level, the PV system generates a power output of 248 W, yielding a high efficiency of 99.1%. This indicates that the PV system effectively converts almost all available solar energy into usable electrical power with minimal losses.

The specific parameters of the PV system at this operational condition are detailed in Figure 6. These parameters may include key values such as voltage, current, and power at MPP, which together highlight the system's optimal performance under ideal irradiance conditions. Figure 7 further illustrates the voltage and current characteristics of the rectifier, which plays a fundamental part in converting the AC power obtained from wireless power transfer into DC power suitable for battery charging. At this stage, the output voltage of the system reaches 149.1 V, as shown in Figure 8. This stable output voltage is essential for ensuring a consistent power supply to the electric vehicle (EV) battery, allowing it to charge effectively and safely.

In summary, under a steady irradiance of 1000 W/m², the PV system demonstrates efficient energy conversion, stable voltage output, and suitable power characteristics, which contribute to effective EV battery charging. This setup showcases the capability of the PV-powered wireless charging system in delivering reliable, clean energy to support EVs.

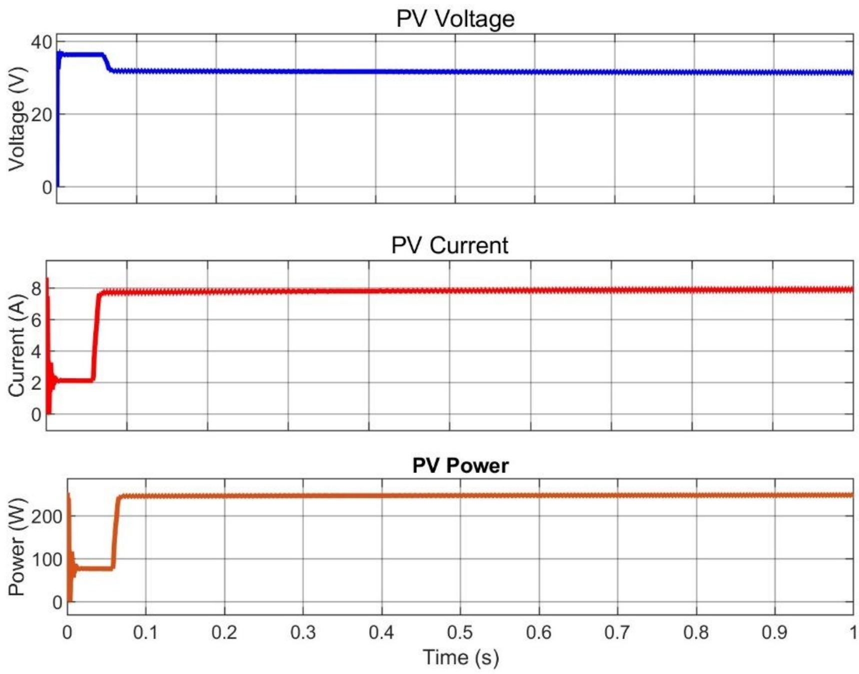

Figure.6 PV Parameters at Constant irradiance

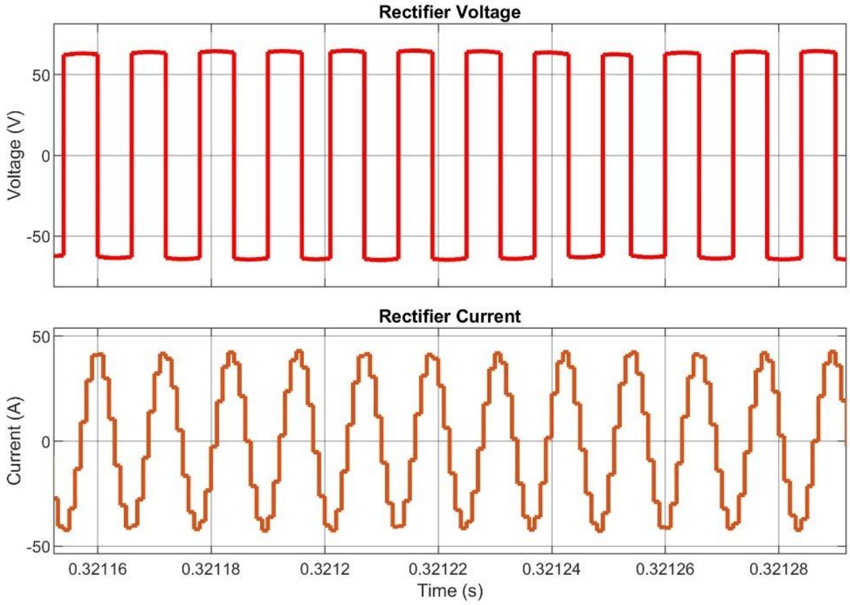

Figure.7 Rectifier Voltage & Current at Constant irradiance

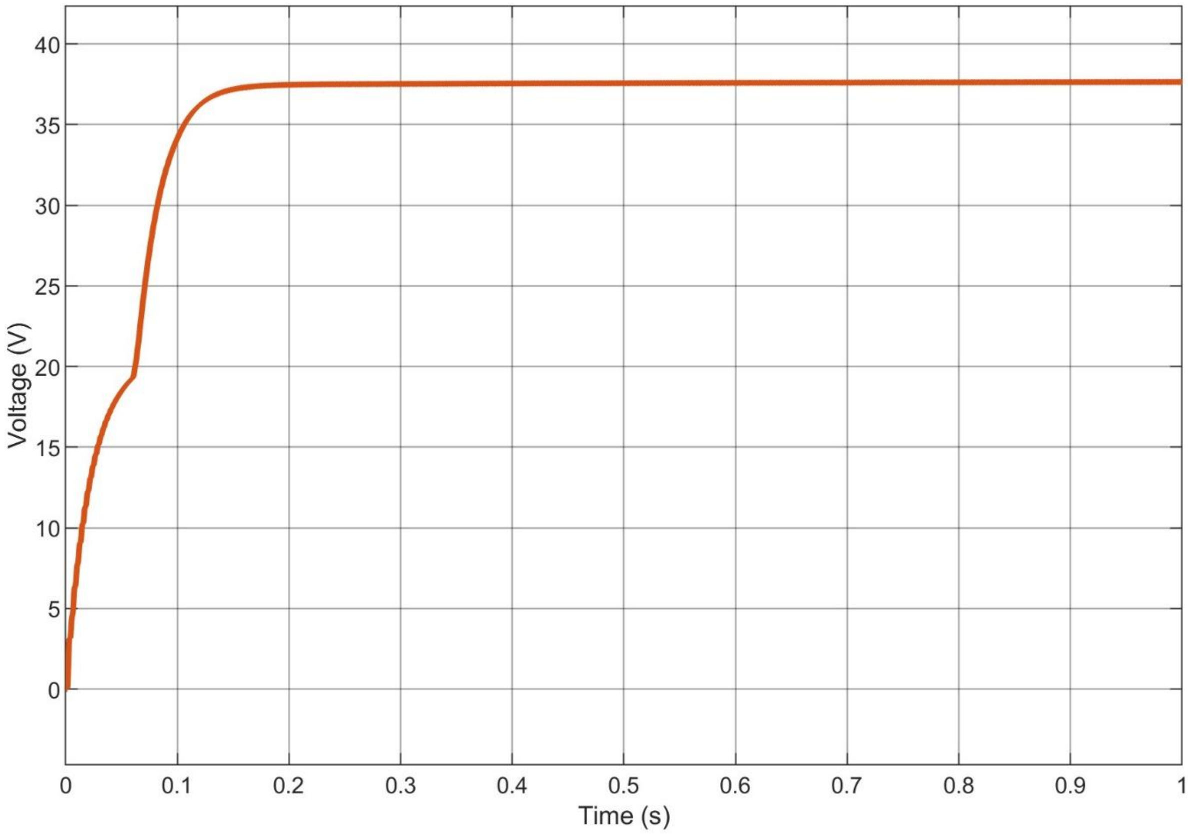

Figure. 8 Output Voltage of Load side Converter at Constant Irradiance

In the following scenario, the PV is operated at varying irradiance conditions, The Power obtained by PV is given in Figure.9. It shows the variation of the power during different irradiance conditions. Rectifier Voltage & Current at Varying irradiance are provided in Figure.10. Output Voltage of Load side Converter is represented in the Figure.11.

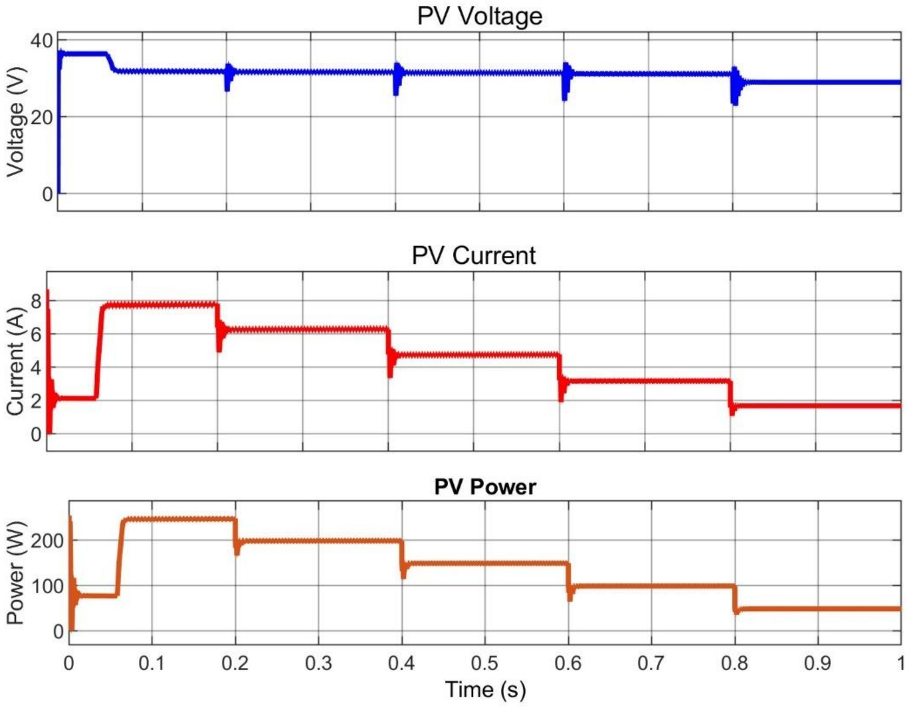

Figure.9 PV Parameters at Varying irradiance

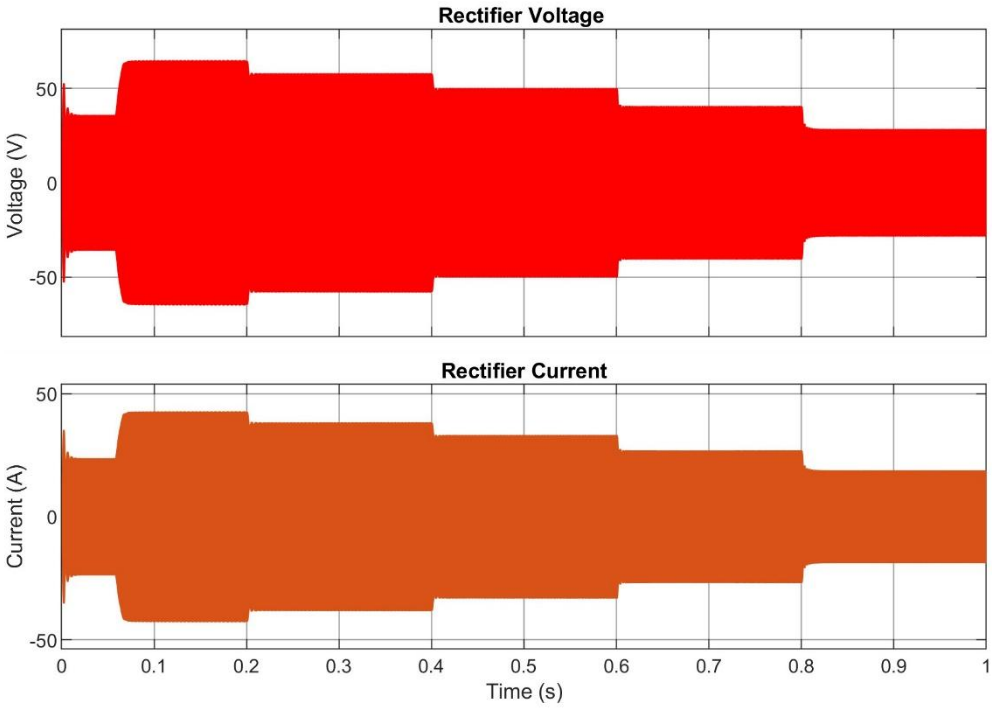

Figure.10 Rectifier Voltage & Current at Varying irradiance

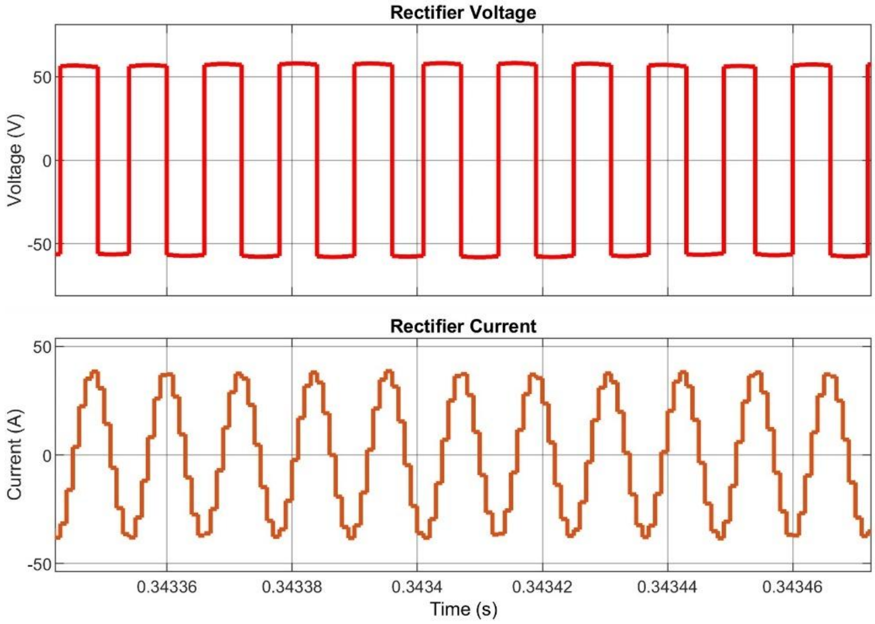

Figure.11 Zoomed in view of Rectifier Voltage & Current at Varying irradiance

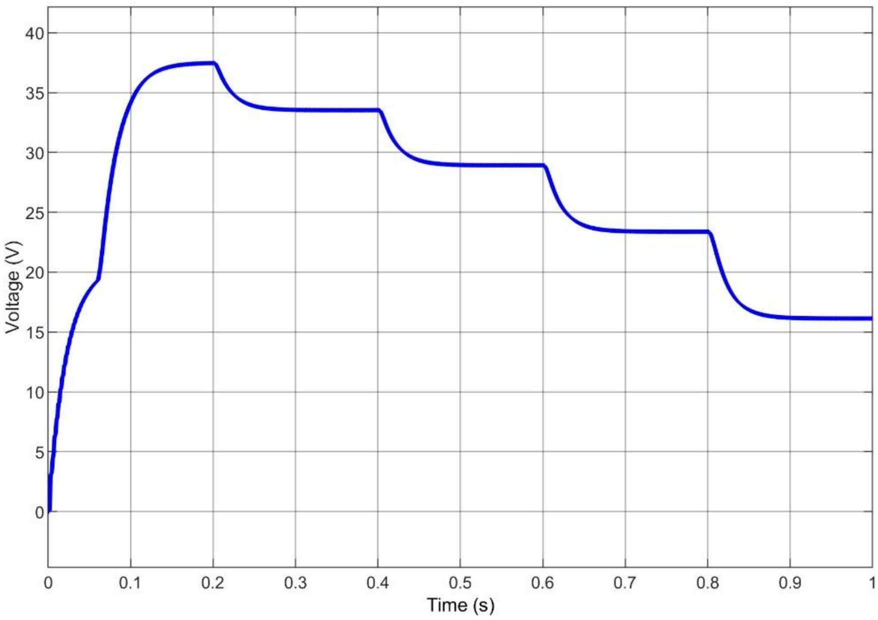

Figure. 11 Output Voltage of Load side Converter at Constant irradiance

Table.2 Efficiency of PV during Varying irradiance Condition

Irradiance (W/m2)	Theoretical Power (W)	Power Obtained (W)	Efficiency (%)
1000	250.20	247.40	98.88
800	200	197.1	98.55
600	149.71	149.4	99.79
400	99.02	98.61	99.59
200	48.39	48.14	99.48

Table 2 shows the efficiency of the PV system under different irradiance conditions, comparing theoretical power with the actual power obtained. At the highest irradiance level of 1000 W/m², the theoretical power output is 250.20 W, while the system achieves 247.40 W, resulting in an efficiency of 98.88%. As irradiance decreases, efficiency remains high, with slight variations. For instance, at 800 W/m², the efficiency is 98.55%, and at 600 W/m², it reaches 99.79%. At lower irradiances, such as 400 W/m² and 200 W/m², the system maintains efficiencies of 99.59% and 99.48%, respectively. These results indicate that the PV system performs efficiently across varying sunlight levels, consistently converting solar energy into electrical power with minimal losses. After the WPT stage, a stable DC voltage of 116 V is achieved, which is then directed to the electric vehicle (EV) battery for charging. The ANFIS MPPT algorithm shows a important part in this system by optimizing the power extraction from the PV array. Through continuous adjustments, the ANFIS MPPT maintains maximum efficiency, ensuring that the PV system consistently delivers the maximum possible power under varying environmental conditions.

This optimized power from the PV array is supplied to the rectifier, where it is converted from AC to DC, making it suitable for the WPT system. The rectified power is then directed to a magnetic coupling inductor, which allows for power transfer without physical connections linking the transmitter and receiver coils. This wireless energy transference technique enables safe, efficient, and convenient power delivery to the EV without the need for traditional plug-in connections. After passing through the magnetic coupling, the transferred power is again converted into DC, which is essential for compatibility with the EV's battery. To further stabilize the output, a boost converter is used, ensuring that the voltage remains at a constant level suitable for EV charging applications. This regulated output provides a reliable and steady charging voltage, facilitating effective and safe energy transfer to the EV's battery system, thereby enhancing the practicality and efficiency of the wireless charging solution.

4. CONCLUSION

In conclusion, the integration of Wireless Power Transfer (WPT) with solar-based charging systems using an ANFIS for MPPT presents a highly efficient and sustainable solution for Electric Vehicles (EVs). This approach optimizes energy harvested from PV panels by dynamically adjusting to changing irradiance conditions, maximizing energy transfer efficiency and ensuring reliable wireless charging output even in varying environmental conditions. The simulation outcomes proves the effectiveness of the ANFIS-based MPPT in outperforming traditional methods, achieving an impressive efficiency of 99.1% under constant irradiance conditions and maintaining high efficiencies ranging from 98.55% to 99.79% under varying irradiance levels. The ANFIS methodology, a hybrid approach blending neural network architecture and fuzzy logic inference, proves to be a versatile and effective control strategy for optimizing power output from the PV system. By leveraging clean, inexhaustible solar energy for EV charging and eliminating the need for physical connectors, this smart charging technology not only enhances sustainability but also improves user convenience and minimizes maintenance. The seamless and automated nature of wireless charging, coupled with the adaptability of ANFIS-based MPPT, positions this system as a promising solution for both off-grid and urban environments, contributing to the advancement of green transportation technology

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