Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

ANFIS control of four-quadrant DC/DC chopper for wireless EV charging

Hawraa Q. Hameed[a*], **Hosham S. Anead**[a], **Khalid F. Sultan**[b]

[a] Electric Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
[b] Electromechanical Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: hawraa.q.alfaisal@uotechnology.edu.iq

HIGHLIGHTS

- Wireless charging for electric vehicles presents notable advantages and associated challenges
- The technology minimizes reliance on cables, enhancing convenience for users
- By improving the overall experience, it may encourage wider adoption of electric vehicles
- Electric vehicles have varying charging rates, impacting recharge durations and capacities
- Techniques like fuzzy logic and genetic algorithms are used to refine the charging process

ARTICLE INFO

Handling editor: Ivan A. Hashim

Keywords:
Wireless Charging; Electric Vehicle (EV); ANFIS; Battery Charging; Intelligent Control

ABSTRACT

Wireless charging of electric vehicles (EVs) poses issues like power ripples that reduce battery lifetime. This study proposes a four-quadrant DC/DC chopper controlled by an adaptive neuro-fuzzy controller (ANFIS) for wireless EV charging. The system is modeled and simulated in Matlab/Simulink. Compared to a PI-PSO controller, the proposed ANFIS control reduced the ripple factor in power over half to about 0.7% and optimized stability and efficiency. Though settling time increased, the difference in rise time was negligible. Future work will improve dynamic response. The ANFIS-controlled DC/DC chopper enhances wireless charging performance with minimal power ripples for safe, efficient EV power transfer.

1. Introduction

The demand for electricity generation has grown as a result of rising consumer demand around the world. Simultaneously, the price of generating energy via fossil fuels has increased due to an increase in the cost of natural gas and the government's focus on minimizing greenhouse gas emissions [1]. Electric vehicles (EVs) assist in lowering reliance on fossil fuels, carbon dioxide emissions, and pollution emissions [2]. More specifically, The Paris Agreement's global climate agenda motivates the demand for EVs to reduce carbon dioxide emissions worldwide to handle the rising global warming challenge. Using EVs instead of combustion-engine vehicles would reduce emissions and significantly less local air pollution, reduce oil demand, and promote a local EV manufacturing sector for job creation.EVs can be divided into a variety of categories, including hybrid electric vehicles that plugin (PHEVs) [3], hybrid electric vehicles (HEVs), and pure electric cars (PEVs) [4]. While each type of EV has unique technical advantages, there are still significant technical obstacles to overcome, particularly concerning energization. In particular, modern technology uses a cable to link EVs and power supplies. The equivalent drawbacks in this scenario include human handling, loss of cable, and flexibility. More essential, manually plugging and unplugging cords run the risk of sparking electricity. Excessive humidity conditions may result in short circuits, creating a safety risk. Wireless charging, which can energize EVs cordlessly in contrast to traditional cable-based charging technology, demonstrates great convenience and safety. There are still some unanswered concerns, particularly about how long it takes for an EV battery to

http://doi.org/10.30684/etj.2024.146136.1673
Received 16 January 2024; Received in revised form 18 February 2024 ; Accepted 01 March 2024; Available online 27 March 2024
2412-0758/University of Technology-Iraq, Baghdad, Iraq

recharge and how to handle high-voltage connections safely while it's raining or snowing. A wireless charging system is a viable option since it offers high levels of convenience and safety, which are crucial for electric vehicles [5]. The aim is to transmit energy wirelessly from the ground (source of the power) for the load (internal battery) [6]. Hence, the fundamental issues of inadequate battery life in electric vehicles Because of an absence of battery storage or a high initial cost from installing many batteries can be resolved by Wireless Power Transfer (WPT) technology. The stationary wireless charging system can be used for charging EVs in a garage or a public place [7]. Several researchers who study wireless charging systems emphasize the system's transmission effectiveness and power. The wireless charging process's parameter states will vary as the charge is increased due to the highly nonlinear rechargeable lithium battery system. A technique for immediately charging the battery after rectifying the output from the receiver side is suggested [8], simplifying the system's receiver side for wireless charging. This technology allows the receiver rectifier's current and voltage to directly satisfy the lithium battery's charging needs by adjusting the transmitter's DC input voltage in the inverter. A fuzzy logic (FL) control strategy to enhance transferring power was given by an author in [9]. The primary side of the inductive link's input current was changed in amplitude and phase using the (FL) controller to vary capacitance and excitation frequency. Charging an electric vehicle necessitates a significant amount of power. The proposed fuzzy logic controller [10] helps to keep the output voltage constant on the load side. The FL approach can consistently sustain 400V output even when the comparable resistance of the battery increases between 210 and 230 Ω [11] presented a new approach to controlling using fuzzy logic that combines GA with optimization and the adaptability and resilience of fuzzy controls. This approach offers quick transient responsiveness with reduced oscillation and a smaller overshoot. The PID control method has existed for about 70 years since its introduction. Because its benefits include a straightforward principle, robust regulation, excellent operating reliability, and continuous stability, it has emerged as one of the most effective control techniques for dynamic systems. Generally, PI that excludes derivative action can control an electronic system. However, it is difficult to identify the PI parameters when there aren't pertinent real values and situations. A novel approach is proposed for controlling electric vehicle charging systems that are connected to the grid, using an Adaptive Neuro-Fuzzy Inference System ANFIS controller [12], (ANFIS) can accurately maintain a constant current level during charging, extending battery life and improving charging efficiency. Building and testing a prototype in a lab has shown that this system can be implemented in the real world. Although input voltage, temperature, and other factors affect the charging process, the ANFIS controller maintained a constant current. Thus, this essay employs the four-quadrant DC-DC chopper with a neuro-fuzzy logic control approach for controlling the output power regarding the system for wireless charging. This study presents the fundamental idea of the wireless charging system, the charging of electric vehicles, and a mathematical model. The equation and equivalent circuit model are developed. Section III presents the system methodology is presented. In section IV, a design of an Adaptive Neuro-Fuzzy (ANFIS) controller and the wireless charging system is developed in the Simulink model. Results from the simulation are evaluated and discussed at the end.

2. Wireless charging

2.1 Wireless charging system for electric vehicle charging

Shape, coil dimensions, and material selection are the three most crucial factors to consider in wireless charging systems when reducing resistance and the impact on the effectiveness of the transferring power for large air gaps. Figure 1 shows the charging process for wireless electric vehicles. Here, the inverter transforms the grid's AC power into the DC the converter needs before rectifying it into AC fit for the coil for transmission positioned on the ground. This AC power was wirelessly transmitted using the magnetic resonance method to the receiving coil installed underneath the car's chassis, where it was transformed back into DC power for the battery charge [13].

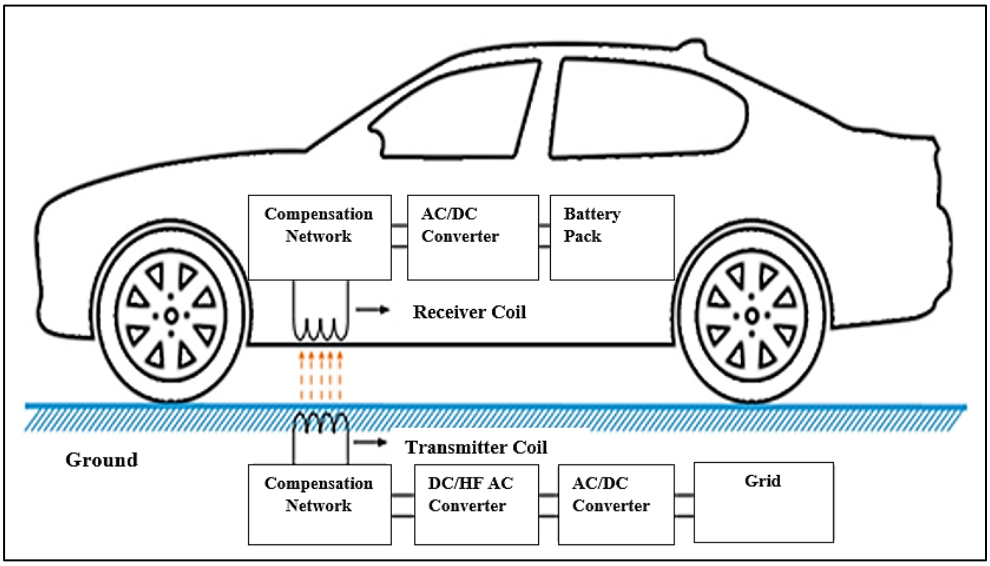


Figure 1: Charging process for wireless electric vehicles

2.2 Mathematical model of wireless power transfer

A WPT system using inductive coupling uses the coefficient of coupling and mutual inductance between coils to supply power to the load. Magnetic resonance tuning and matching techniques increase load power and efficiency. In the WPT system, the four topologies (SS, SP, PS, and PP) involve series or parallel resonance on the secondary side and series or parallel compensation on the primary side. Compensatory capacitors for the coil are the most prevalent compensation types used in the sending and receiving circuits of the wireless power transmission system [14,15]. Four basic topologies of the compensation circuit are illustrated in Figure 2.

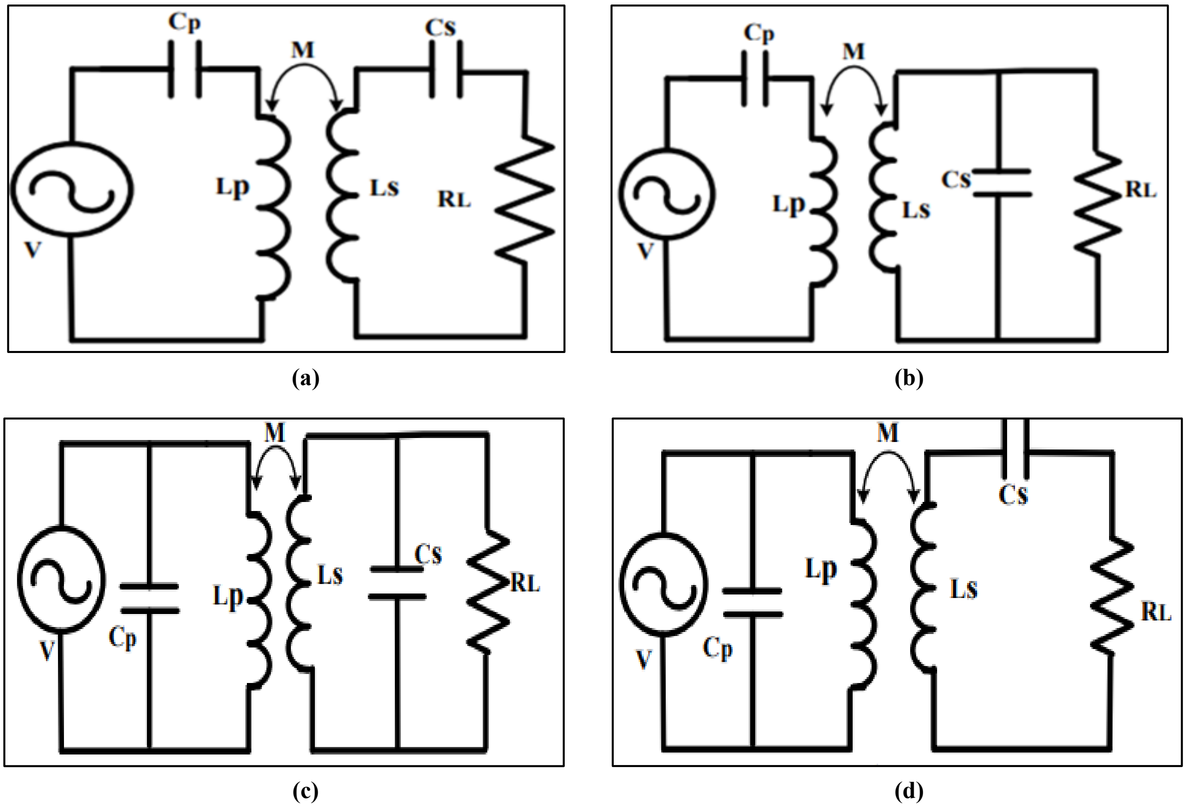


Figure 2: The compensation circuits Type: (a) Series capacitor-Series capacitor (SS), (b) Series capacitor -Parallel capacitor (SP), (c) Parallel capacitor –Parallel capacitor (PP) and (d) Parallel capacitor –Series capacitor (PS)

Kirchhoff's voltage law produces a mathematical representation of the specified circuit. The Equation 1, is show the voltage that is transmitted is expressed through the transmitting coil:

$$V_s = \left(R_1 + j\omega_0 L_1 + \frac{1}{j\omega_0 c_1}\right) I_1 + j\omega_0 M I_2 \quad (1)$$

Where the DC voltage supply, receiving, sending currents, mutual inductance, capacitance-inductance of the primary side, angular frequency, and resistance is represented by the variables V_S, I_1, I_2, M, C_1, L_1, ω_0, and R_1, respectively. Kirchhoff's law is employed to analyze the circuit's receiver side results as in the equation 2:

$$0 = \left(R_2 + j\omega_0 L_2 + \frac{1}{j\omega_0 c_2}\right) I_2 + j\omega_0 M I_1 \quad (2)$$

The secondary inductance, capacitance, and resistance are L_2, C_2, and R_2. A matrix can be used to express Equations 1 and 2:

$$\begin{bmatrix} Z_1 & Z_m \\ Z_m & Z_2 + Z_L \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} V_s \\ 0 \end{bmatrix} \quad (3)$$

The primary coil impedance Z_1, secondary coil Z_2, mutual impedance Z_m, and load impedance Z_L are represented according to 4, 5, 6, and 7.

$$Z_1 = \left(R_1 + j\omega_0 L_1 + \frac{1}{j\omega_0 c_1}\right) \quad (4)$$

$$Z_2 = \left(R_2 + j\omega_0 L_2 + \frac{1}{j\omega_0 c_2}\right) \quad (5)$$

$$Z_m = (j\omega_0 M) \quad (6)$$

$$Z_L = (R_L) \quad (7)$$

By resolving 3 as follows, the primary and secondary currents can be determined:

$$I_1 = \frac{V_S(Z_2+Z_L)}{Z_1(Z_2+Z_L)-Z_m^2} \quad (8)$$

$$I_2 = \frac{V_S Z_m}{Z_1(Z_2+Z_L)-Z_m^2} \quad (9)$$

The secondary and primary currents express the receiving coil's induced voltage that transmits to the sending coil. V_{12} can be expressed according to 10:

$$V_{12} = Z_m I_2 \quad (10)$$

The reflected impedance is the calculated division of the voltage produced by the transmitter current that depends on the emitter, and Zr is obtained. The reflected impedance represents the receiver's capacitance, impedance, and load impedance.

$$Z_r = V_{12}/I_1 = Z_m^2/(Z_2+Z_L) \quad (11)$$

The input impedance, Z_{in}, is connected to the primary impedance, and the reflected impedance, Z_{in}, is found by Equation 12:

$$Z_{in} = Z_1/Z_m^2/(Z_2+Z_L) \quad (12)$$

The output power P_L and transmitted power P_t can be stated as follows, respectively, in 13 and 14 [16]:

$$P_L = Re(Z_L^*)|I_2|^2/2 \quad (13)$$

$$P_1 = Re(Z_m^*)|I_1|^2/2 \quad (14)$$

3. System methodology

3.1 Coil parameter

This study examines an electric vehicle's charging capabilities using a converter, a controller, and a wireless charging system. With the WPT system under discussion, there is just one receiver coil and 19 transmitter coils. Each circular coil is exactly one size, with only one of them. These are described in Table 1 [16].

Table 1: Coil parameters

Parameter	Measurement
Number of turns	20 turns
Inner radius	72 mm
wire radius	4 mm
Air gap between turns	3 mm
Outer radius	172 mm

3.2 The controller

3.2.1 PI-PSO controller

Based on the type of error, the controller for proportional-integral (PI) employs a practical strategy to control. It can be used with many different types of systems. Most PI controller applications are found in power systems, power electronics systems, charging systems, etc. Preferably, monitor and regulate the system's output voltage, current, and power with the reference needed in our applications or by inserting a regulating controller into the wireless charging system to regulate and boost the output. Proportional gain (kp) and integral gain (ki) are the two parameters that must be chosen (and occasionally optimized) to the specified procedure for the desired responses output from the four quadrants DC-DC chopper Particle swarm optimization can be used to adapt this controller (PSO) quickly. Hence, the advantage of the best position in its memory and knowledge of the better location is that each bird "particle" uses this strategy to update its location inside the swarm to find the ideal place [17,18]. Figure 3 illustrates the Algorithm flowchart for PSO. Several fitness criteria, like integral absolute, integral absolute square, and integral time square errors (ITSE), are frequently used in optimization strategies to assess system performance. The steady-state error, rising time, increasing time, and overshoot are all contained in these efficiency standards. Also, the optimization procedure and the drive system's tightness have been detailed [19]. The ITSE fitness function, shown in 15, is employed in this study as the performance standard for the system's output response:

$$ITSE = \int_0^{\infty} t\, e^2\,(t)dt \qquad (15)$$

The tendency of particles moving within the searching field toward the global optimal solution, which tracks the corresponding particles of the optimum solution (the shown particles are part of the total particles), as shown in Figure 4. The solid red line depicts the path followed by the particles toward the global optima. The hybrid controller of PI-PSO is proposed.

The final position of the particles after 100 iterations illustrates the optimum values of the current controllers (Kp and Ki). Also, Figure 5 shows the trajectory of the objectives FF during the optimization process.

A MATLAB program is created to determine the ideal controller parameter values Kp and Ki. 100 iterations are required to reach the Kp and Ki of PI controller optimum values, as illustrated in Figure 6. The block diagram of the PI-PSO system optimization controller is illustrated in Figure 7.

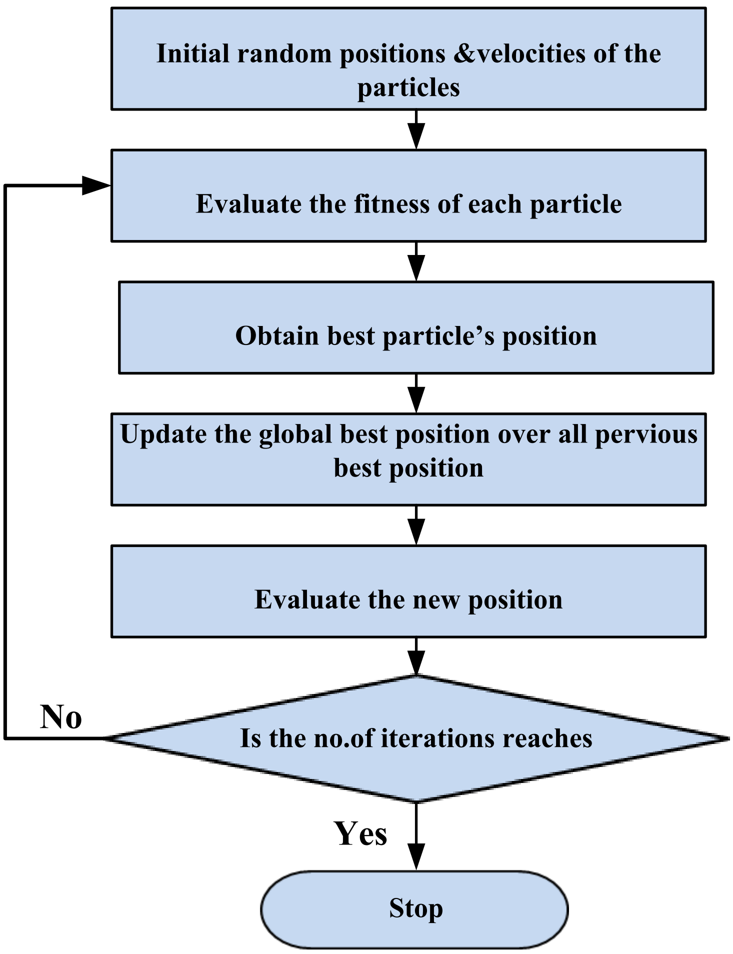


Figure 3: PSO algorithm's flowchart

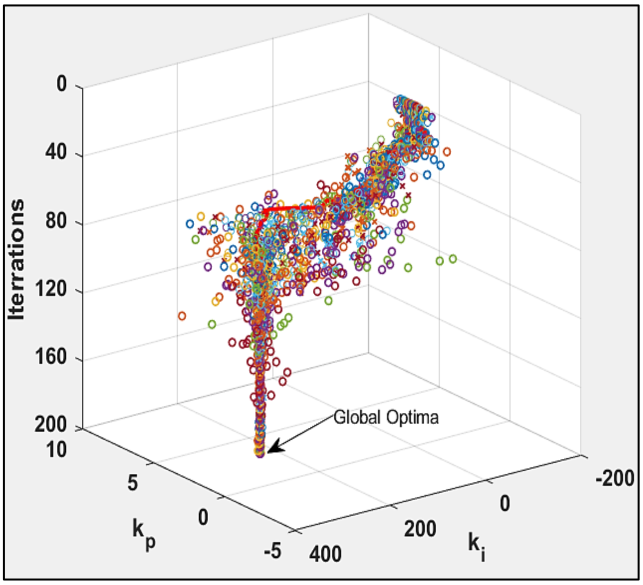


Figure 4: Praticles convergence towards the global optima

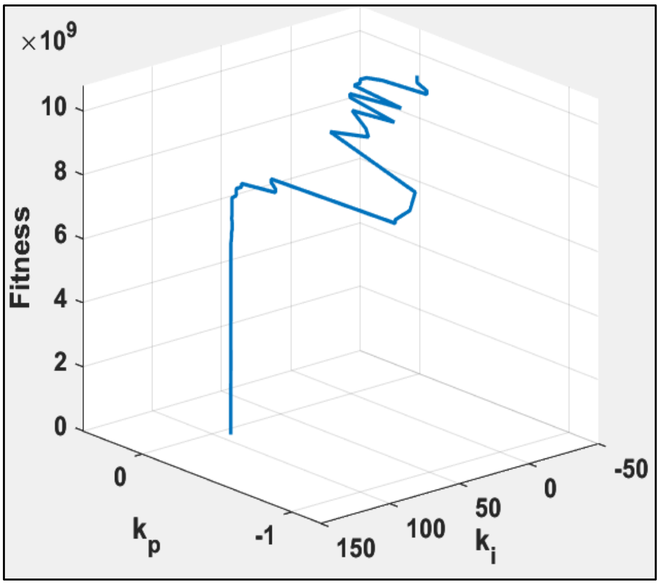


Figure 5: Fitness function minimization trajectory

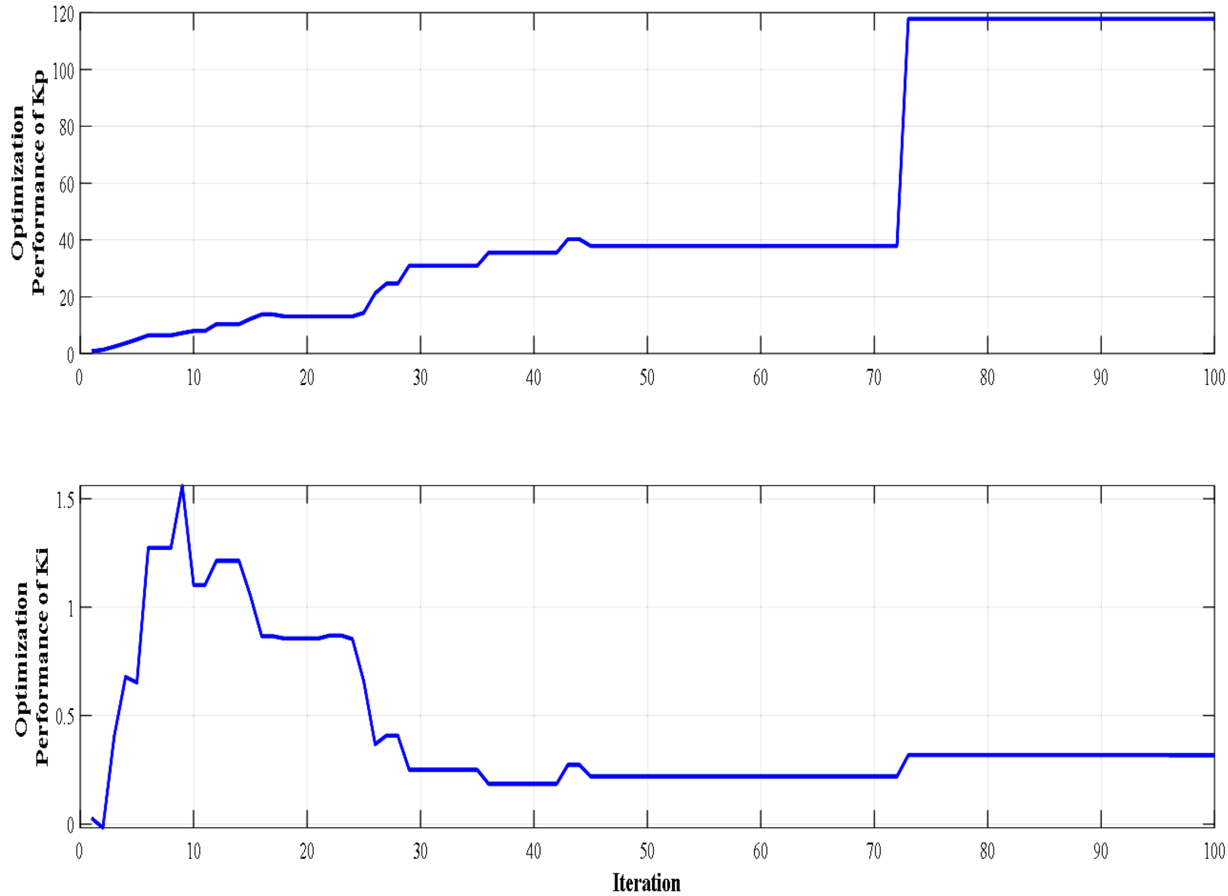


Figure 6: The controller settings for the optimization process

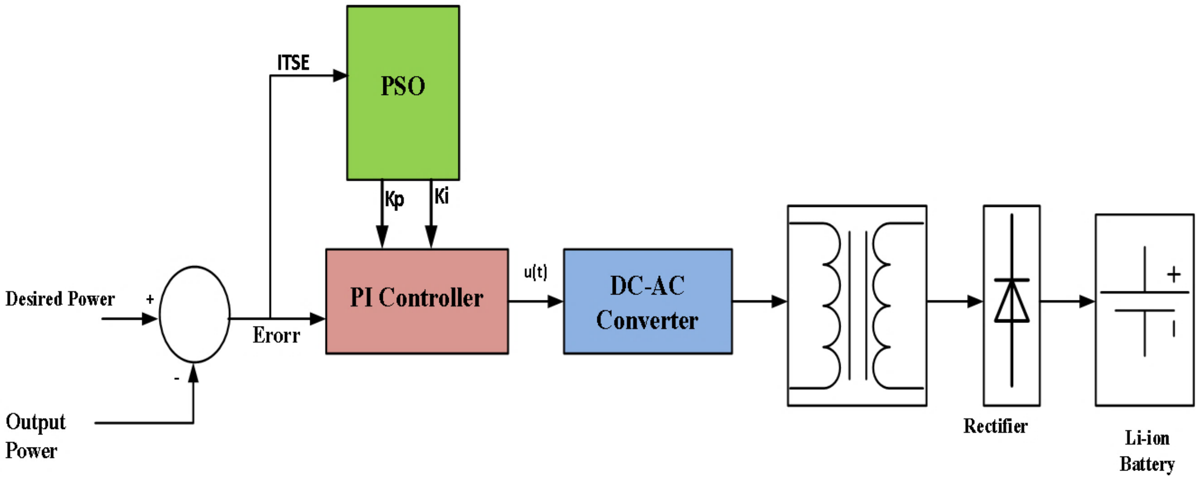


Figure 7: Block diagram of the PI-PSO system controller

3.2.2 The four-quadrant DC/DC converters (choppers)

A chopper with four operating quadrants is referred to as a four-quadrant chopper. With this chopper, the electricity can flow from load to source and from source to load. Power electronics uses the full-bridge structure with programmable power switches to build four-quadrant DC/DC converters as well as PWM single-phase inverters, rectifiers, power active filters, and load voltage, current, and power management in the four-quadrant region. Using four semiconductor switches, a four-quadrant chopper was built (IGBT). Each of the circuit's two legs contains two switches. The controls for the identical leg of the circuit are switched on and off, respectively. Figure 8 illustrates a Four-quadrant DC chopper power circuit. Further to the polarity, the average voltage and current output values can be set by correctly switching the IGBTs. Its structure gave advantages such as quick reaction and flexible control. Complementary PWM signals regulate the IGBTs from each leg [20].

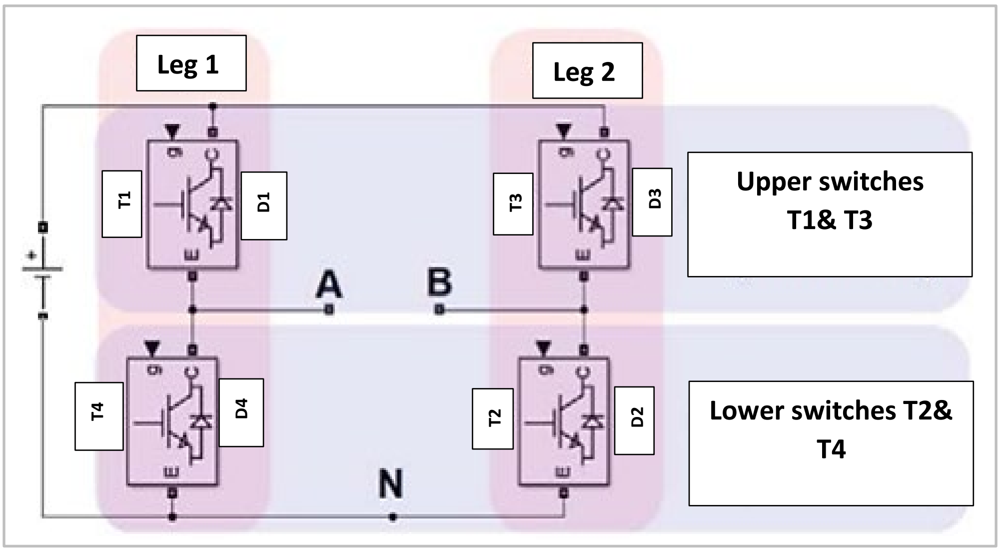


Figure 8: Four-quadrant DC chopper power circuit

3.2.3 Adaptive neuro-fuzzy system

A system's-based fuzzy inference rules table and MFs design were based on the operator's or designer's prior expertise. This suggests that there isn't a systematic method for developing a fuzzy system. In contrast, the input/output data from simulations or experiments can be utilized to train neural networks. The model that satisfies those data is subsequently represented by the network. The Adaptive Neuro-Fuzzy Inference System, also known as ANFIS, can be created by combining these methodologies with an integrated Neuro-Fuzzy system to create a more effective intelligent system capable of enhanced performance and design [21]. As suggested by the name, a system-based fuzzy inference is methodically created utilizing the design of the neural network approach. This indicates that the neural network training approach can be used to construct the MFs and rules table if appropriate for a fuzzy system. There are rules for the input and output data. Sugeno's approach is frequently applied in adaptive neuro-fuzzy systems. As an illustration, if the fuzzy system's inputs are X and Y and its output is "F":

If $X = A1, Y = B1, then\ Z = f1$
If $X = A2, Y = B2, then\ Z = f2$

The output "F" can be constructed as:

$$F = \frac{W_1}{W_1+W_2} f_1 + \frac{W_2}{W_1+W_2} f_2 \quad (16)$$

where: A_1, A2, B1, and B2 are the MFs input, f_1, f_2 are singleton MFs and the output, and W_1 and W_2 are those degrees of fulfillment (DOF) of rules 1 and 2, which may be adjusted utilizing any training procedure for satisfying the input-output data [21-23].

4. Design of an adaptive neuro-fuzzy controller

While wireless charging electric vehicles, output current ripple can be controlled using a discrete adaptive neuro-fuzzy controller. An electric vehicle's output current can be modified by this type of controller to fulfill the input reference command signal by altering the nonlinear feedback signal. Two input controllers are: the first is the signal of error, and the second is the time integral error signal, which gives a criterion of the cumulative error between the current output and the previous reference of the system. These two signals serve as the fuzzy system's inputs, as seen in Figure 9.

It should identify the system's status and predict an appropriate signal for linear feedback (k). The adaptive controller in this study, which has the structure depicted in Figure 10, performs the fuzzy controller's function with the help of two inputs and three MFs from each input's triangle. Figure 11 shows its rules.

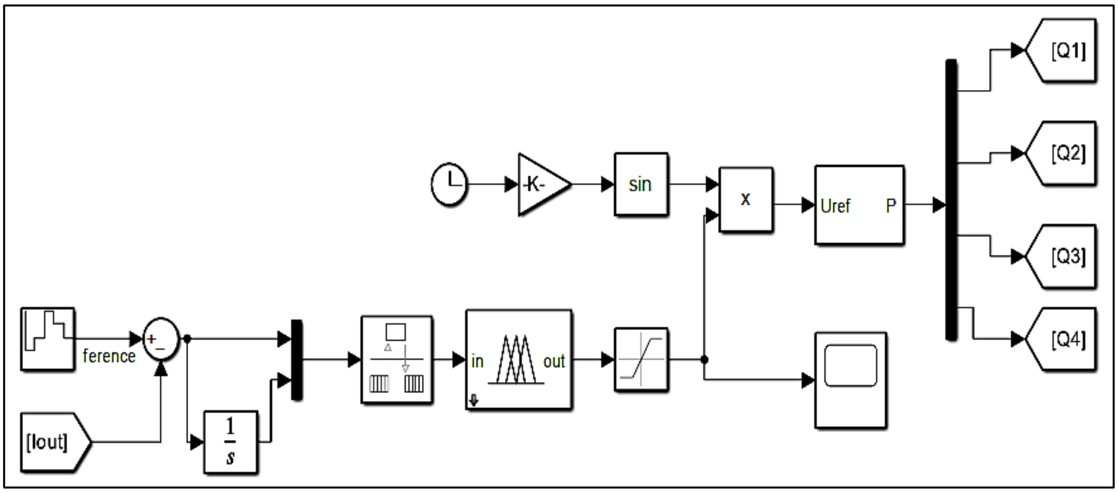


Figure 9: Neuro-Fuzzy Controller Simulation

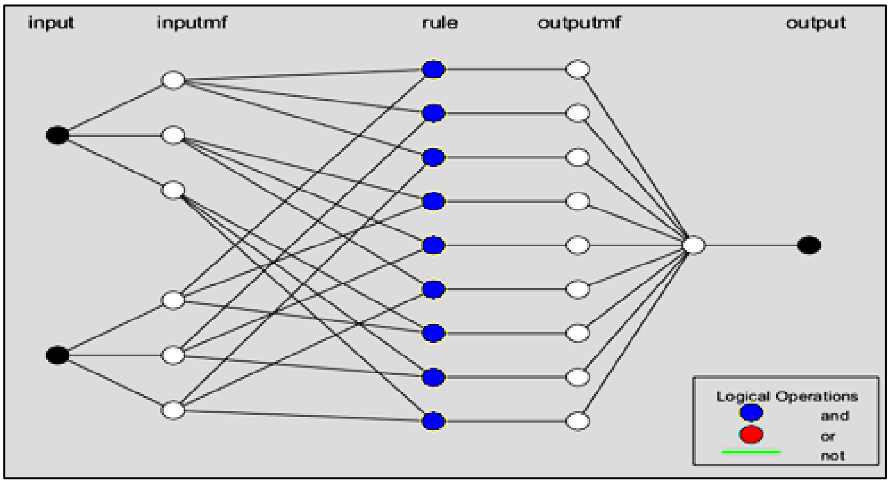


Figure 10: Neuro-Fuzzy Network Structure

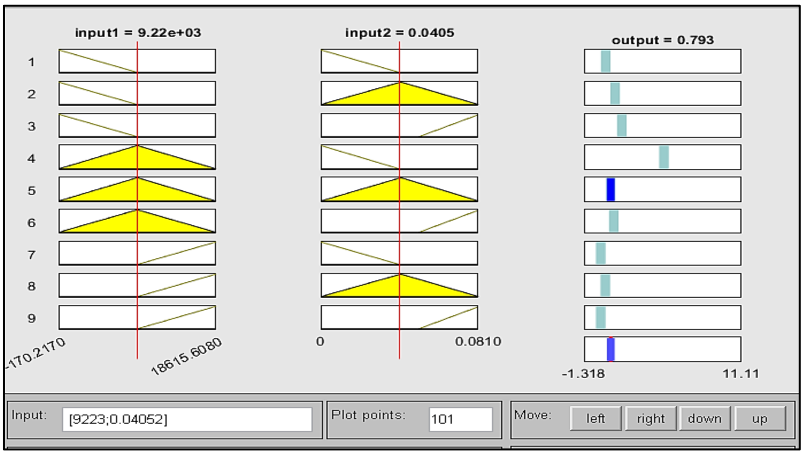
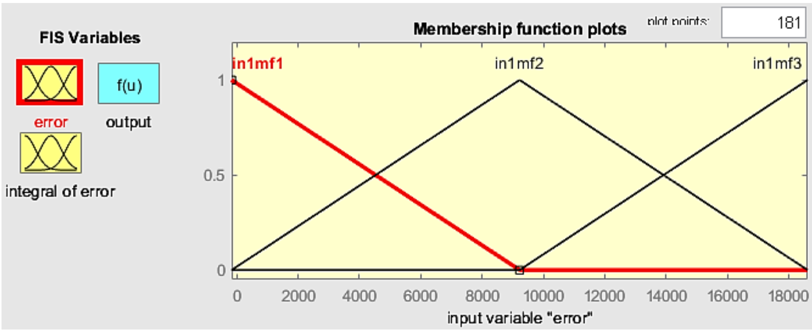


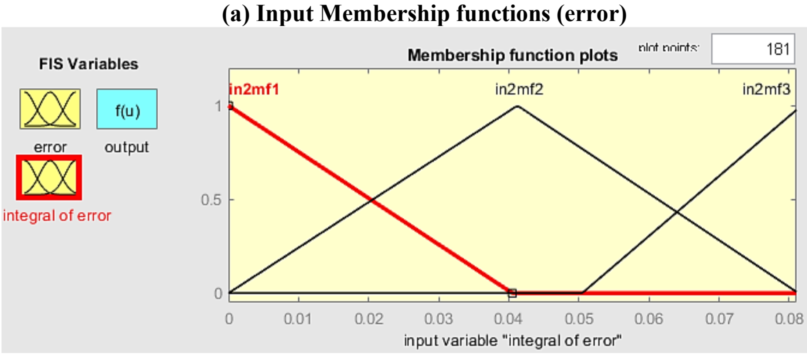
Figure 11: Neuro-Fuzzy rules

Using a neural training system with many inputs and outputs data sets, the output MFs and rules are modified. Figures 12 (a) and (b) respectively illustrate MFs, the ANFIS input/output surface performance is illustrated in Figure 13.

The overall system is implemented in MATLAB/Simulink. The comparable charging model is constructed, and Figure 14 illustrates how the whole wireless charging system model was designed. A DC supply, a Four Quadrant DC/DC Chopper with an ANFIS controller, a comparable circuit for the wireless charging system, a rectifier, and a lithium battery comprise the entire system. Table 2 displays the system's specifications.



(a) Input Membership functions (error)



(b) Output Membership functions (integral error)

Figure 12: Input/output membership functions

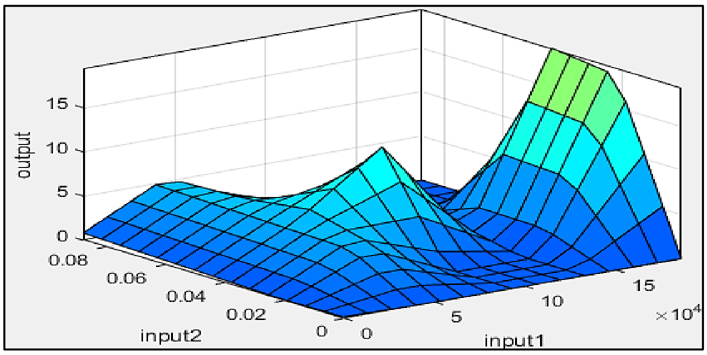


Figure 13: ANFIS Input/output Surface Performance

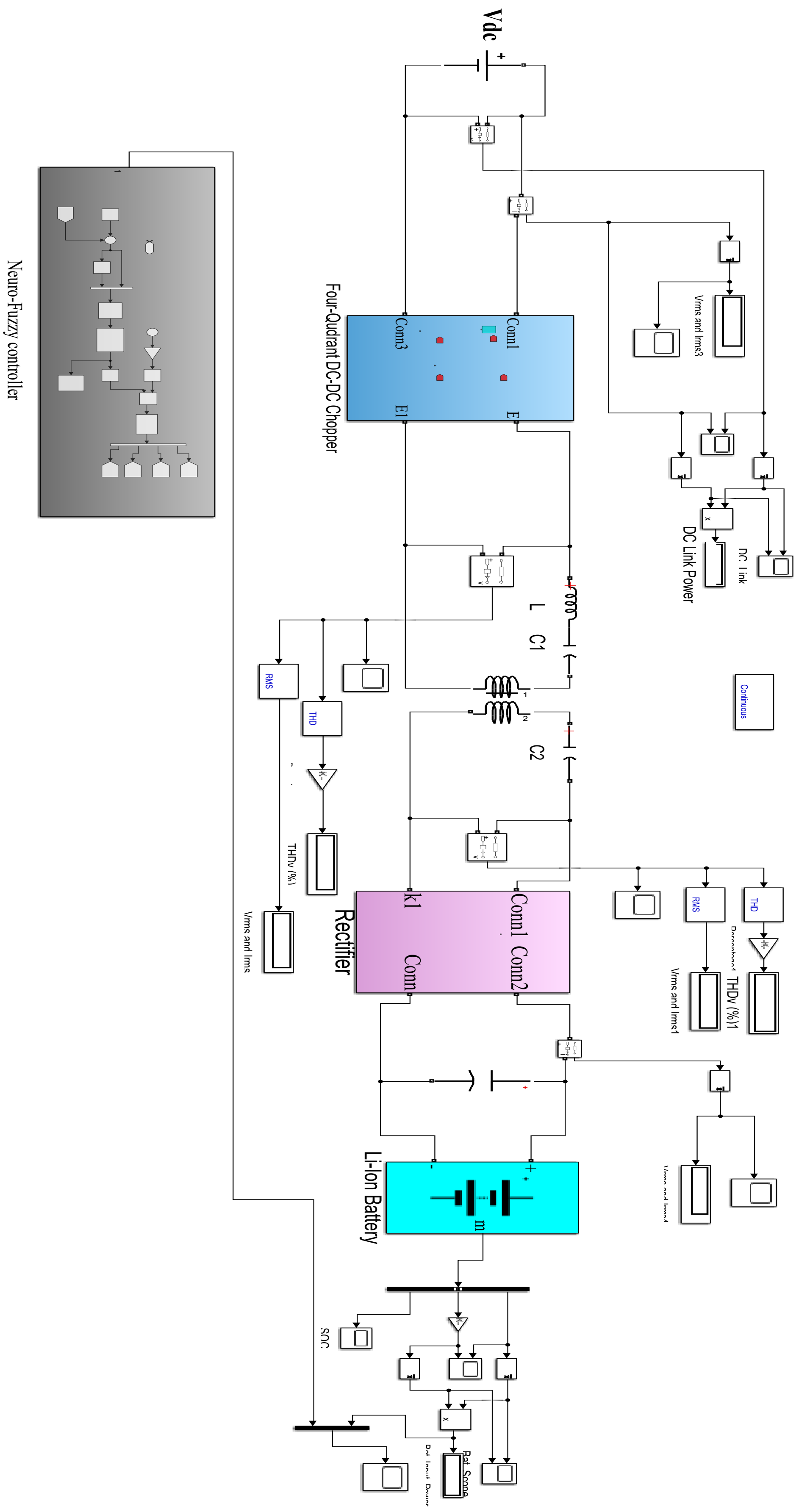


Figure 14: The overall system simulation

Table 2: The system's specifications

Specification	Value
Dc voltage	120 V
Switching frequency	30 KHz
LC filter	
L	9 µH
C	105.74 pF
WPT circuit	
Lp	266.16 µH
Rp	1 mΩ
Ls	256.79 µH
Rs	1 mΩ
C2	109.69pF
PI parameter	
Kp	100
Ki	0.35
Mutual impedance	
Rm	0
Lm	85.46 µH
Battery parameter	
Battery type	Lithium-Ion
Nominal voltage	48 V
Initial state-of-charge (%)	20%

The current, voltage, and power of the EV battery without the controller are shown in Figure 15 and 16. The power is not continuous and has a significant ripple, as can be seen, which could cause battery degradation and performance fluctuations in EVs.

A PI-PSO controller is offered to reduce ripples. The controller's results showed that the dynamic response was computed as a rise time of 0.5 ms and a settling time of 1.8 ms with a ripple factor of around 0.52, the battery voltage, current, and output power waveforms illustrated in Figures 17,18 and 19 respectively, the output power waveform is compared with the reference to show the performance of the PI-PSO controller.

As a consequence, a four-quadrant DC/DC chopper with an Adaptive Neuro-Fuzzy controller is suggested to reduce power fluctuations in the charging system running smoothly and with high stability, which leads to raising the efficiency of the battery charging process and preserving the battery life for a longer period. While still ensuring the system's high performance and efficiency. The dynamic response was computed as a rise time of 0.5 ms and a settling time of 3.5 ms with a ripple factor of around 0.25. The battery voltage and current waveforms are illustrated in Figures 20 and 21, respectively, and Figure 22 exhibits the output power with reference power.

The performance for both proposed controllers of output power with the reference power is shown in Figure 23. Table 3 shows all the results obtained from PI-PSO and the four quadrant DC/DC chopper with a Neuro-Fuzzy controller.

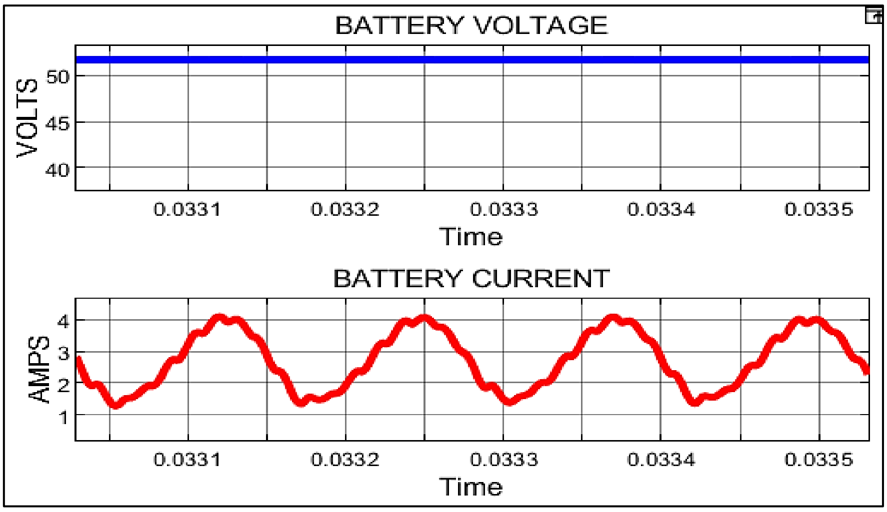


Figure 15: The output voltage & current without a controller

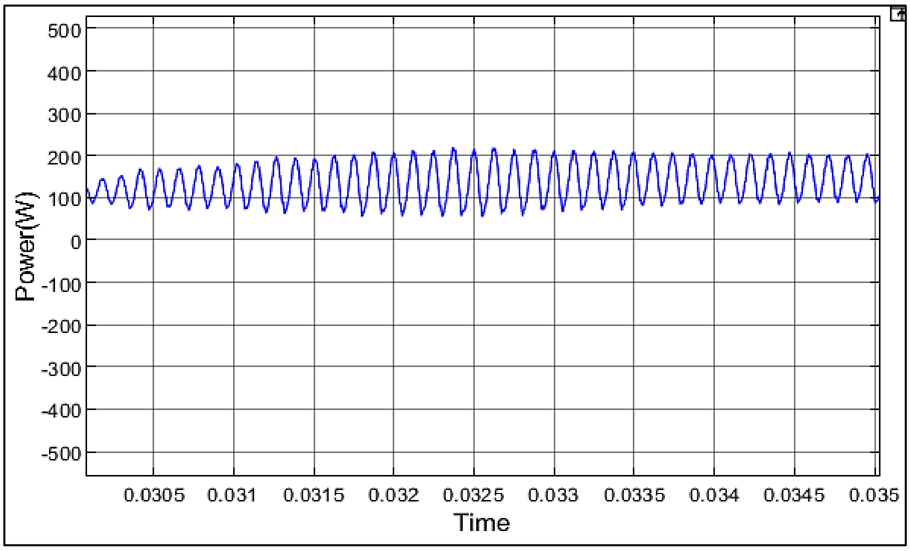


Figure 16: The output power system without a controller

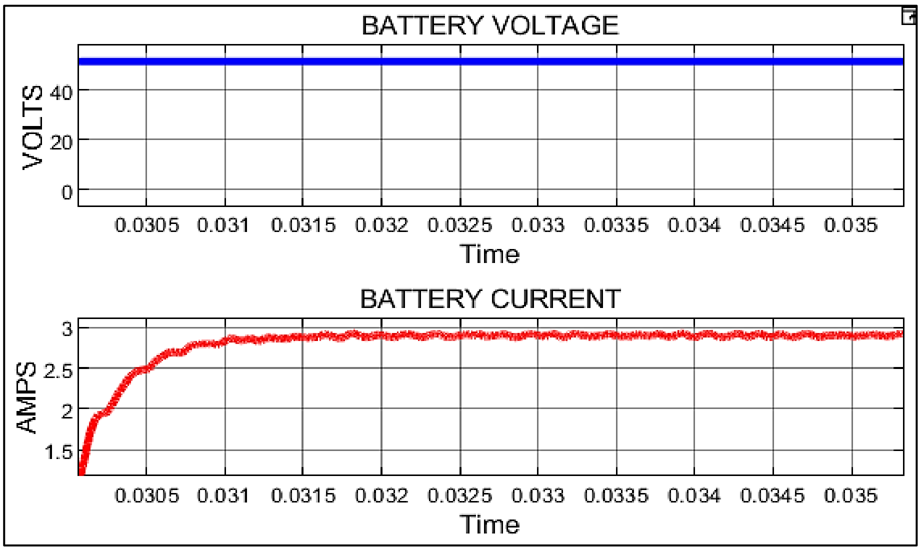


Figure 17: The output voltage & current with the PI-PSO controller

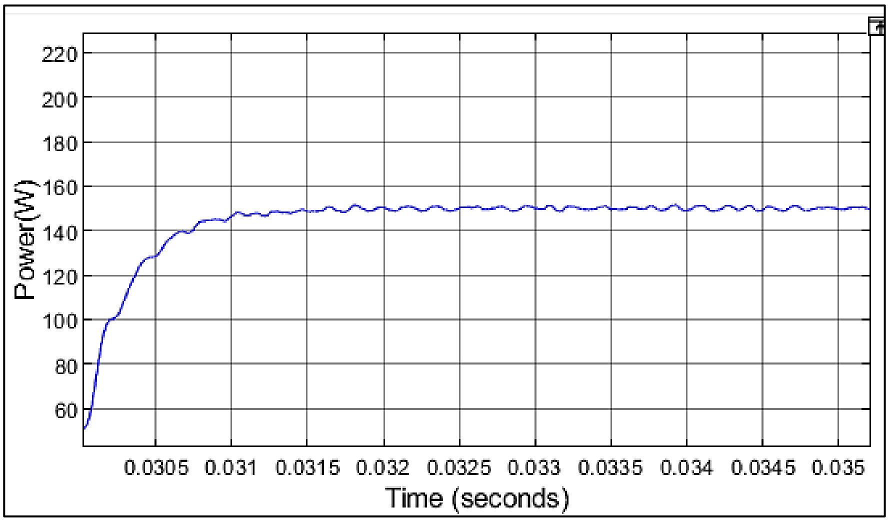


Figure 18: The output power with the PI-PSO controller

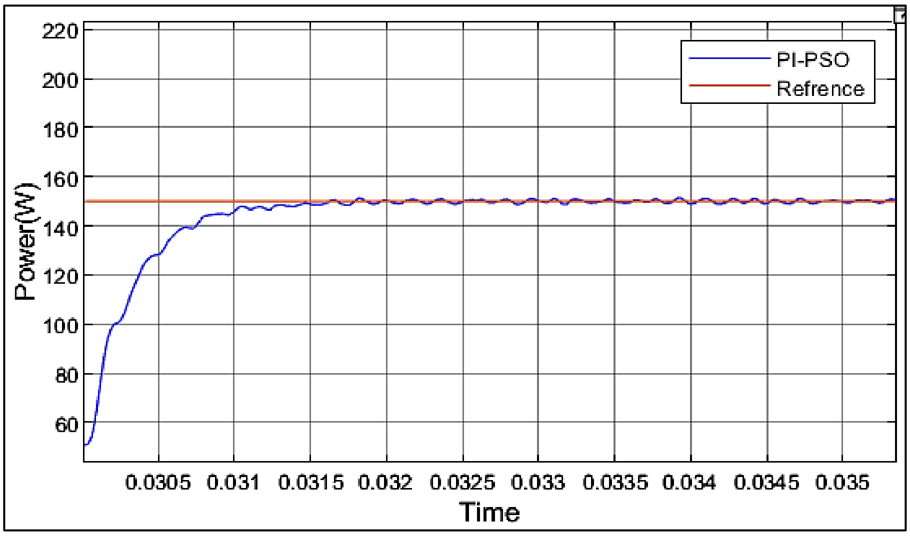


Figure 19: The output and reference power with the PI-PSO controller

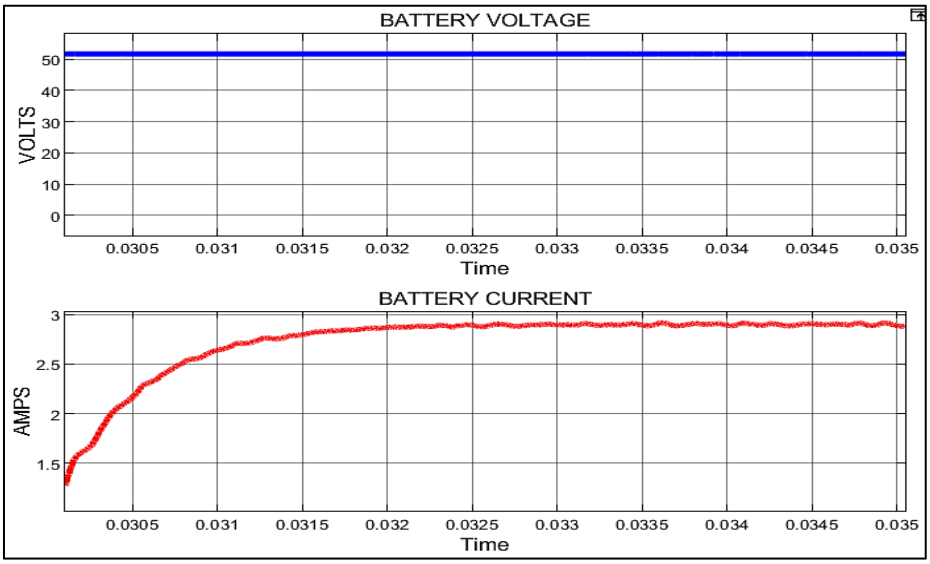


Figure 20: The output voltage & current with the proposed controller

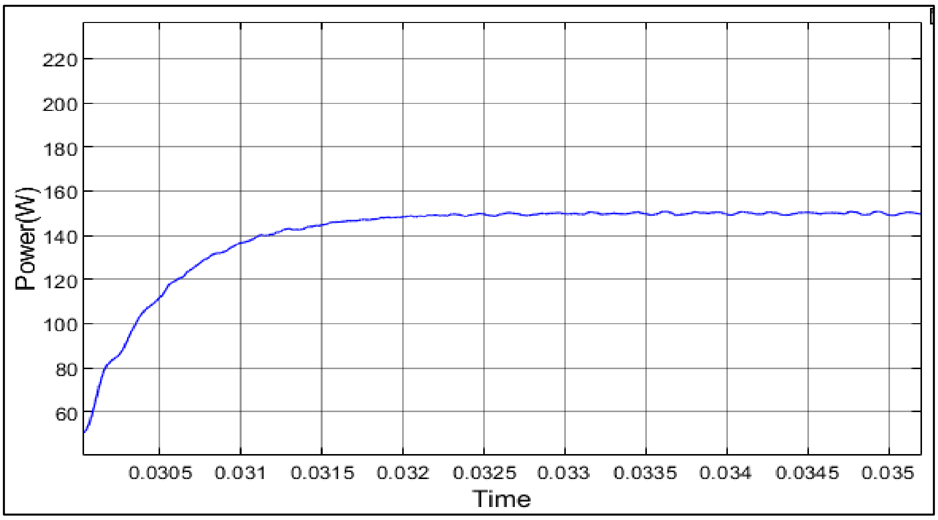


Figure 21: The output power with the proposed controller

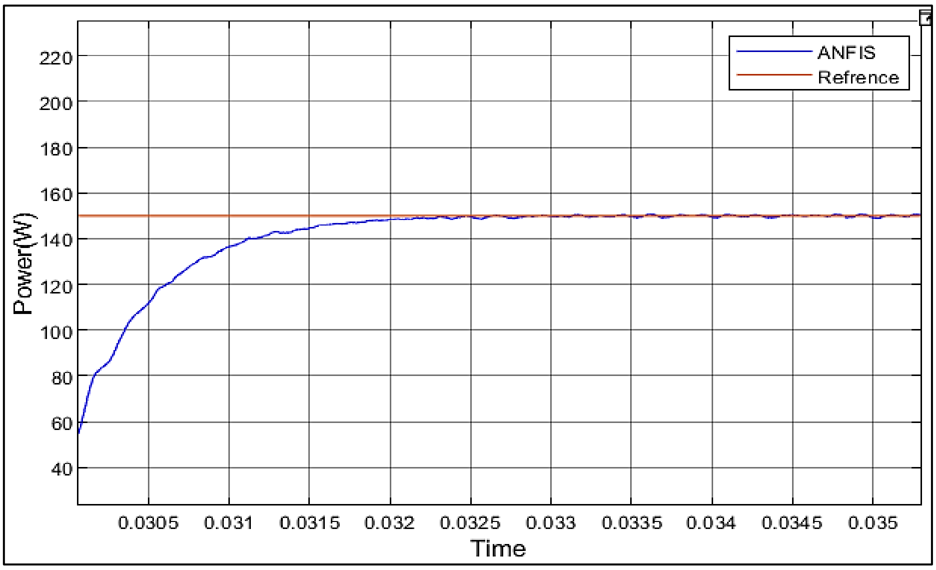


Figure 22: The output and reference power with the proposed controller

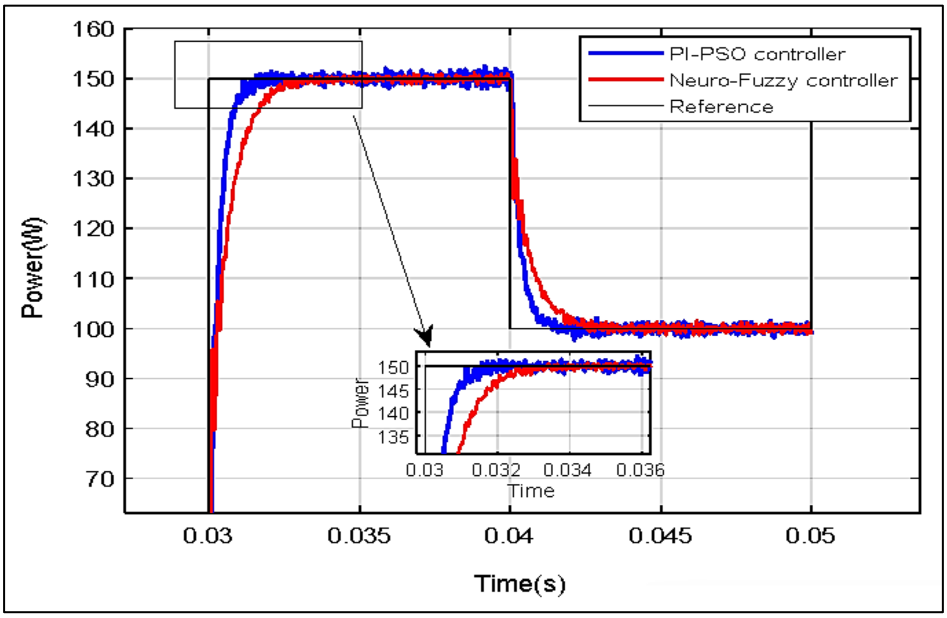


Figure 23: A comparison performance of PI-PSO&ANFIS proposed controllers

Table 3: A comparison Results from PI-PSO&ANFIS controllers

Results	PI-PSO controller	Proposed controller
Rise time (ms)	0.6	1.05
Settling time (ms)	1.85	3.3
Ripple factor%	1.33	0.7

5. Conclusion

The output power has ripples in the charging process, which has a bad impact on the performance of the wireless power transfer, then the EV behavior will be unreliable. A four-quadrant DC-DC Chopper with an Adaptive Neuro-Fuzzy Controller is proposed to mitigate the rate of ripples. This paper study applied MATLAB/Simulink to implement wireless power transmission for electric vehicle charging. The effectiveness of the PI and ANFIS controllers of the wireless charging system of EVs was analyzed. The ANFIS strategy can achieve high control performance from the modeling and simulation. The ripple factor was about 0.7%. This means these ripples decreased by almost half as low as they were in the PI-PSO controller.

On the other hand, it was observed through the system's dynamic responsiveness that the rise time difference between the two controllers is so slight that it cannot be considered. In contrast, the settling time is longer than on the PI-PSO controller, which should be focused on in future research to improve the dynamic response of the wireless charging system. Develop systems that autonomously adjust charging parameters based on the real-time power system and vehicle conditions and integrate energy storage systems to stabilize power fluctuations. Overall, this paper has contributed to developing more efficient and reliable electric vehicle wireless charging systems by minimizing power fluctuation to ensure optimum power transfer and charging.

Author contributions

Conceptualization, H. Hameed, H. Anead, K. Sultan; writing—review and editing, H. Hameed, H. Anead, K. Sultan. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

[1] S. A. Kashani, A. Soleimani, A. Khosravi, M. Mirsalim, State-of-the-Art Research on Wireless Charging of Electric Vehicles Using Solar Energy, Energies, 16 (2023) 282. https://doi.org/10.3390/en16010282

[2] M . Budhia, G. Covic, J. Boys, Magnetic design of a three-phase Inductive Power Transfer system for roadway powered Electric Vehicles, IEEE Vehicle Power and Propulsion Conference, Lille, France, 2010, 1-6. https://doi.org/10.1109/VPPC.2010.5728981

[3] F. L. Mapelli, D. Tarsitano and M. Mauri, Plugin hybrid electric vehicle: Modeling, prototype, realization, and inverter losses reduction analysis. IEEE Trans. Ind. Electronics, 57 (2010) 598-607. https://doi.org/10.1109/TIE.2009.2029520

[4] J. Dixon, I. Nakashima, E. F. Arcos, M. Ortuzar, Electric vehicle using a combination of ultra-capacitors and ZEBRA battery, IEEE Trans. Ind. Electronics, 57 (2010) 943-949. https://doi.org/10.1109/TIE.2009.2027920

[5] D. H. Tran, V. B. Vu, W. Choi, High-efficiency wireless power transfer system with intermediate coils for the on-board chargers of electric vehicles, IEEE Trans. Power Electronics, 33 (2018) 175-187. https://doi.org/10.1109/TPEL.2017.2662067

[6] M. Ibrahim, L. Pichon, L. Bernard, A. Razek, J. Houivet, O. Cayol, Advanced modeling of a 2 kW series-series resonating inductive charger for real electric vehicle, IEEE Trans. Vehicular Technol., 64 (2015) 421–430. https://doi.org/10.1109/TVT.2014.2325614

[7] M. Elwalaty, M. Jemli, H. Ben Azza, Modeling Analysis, and Implementation of Series-Series Compensated Inductive Coupled Power Transfer (ICPT) System for an Electric Vehicle, J. Electr. Comput. Eng., 2020, 1-10. https://doi.org/10.1155/2020/9561523

[8] W. Lee, J. Kim, S. Cho, Il-Oun Lee, Direct Wireless Battery Charging System, Int. Power Electronics Conf., 2018. https://doi.org/10.23919/IPEC.2018.8507851

[9] R. W. Porto, L. Murliky, G. Oliveira, V. J. Brusamarello, IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Milan, Italy, 2017,1-6. https://doi.org/10.1109/EEEIC.2017.7977659

[10] P. R. Shabarish, R. P. Krishna, B. Prasanth, K. Deepa, P. V. Manitha, V. Sailaja, Fuzzy based Approach to Enhance the Wireless Charging System in Electric Vehicles, 4th International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, 2020, 176-181. https://doi.org/10.1109/ICECA49313.2020.9297505

[11] Y. Lu, P. Cao, L. Xiong, B. Xu, A Novel Fuzzy Logic Control on the FVVT Lift of Internal Combustion Engine, Tenth International Conference on Intelligent Control and Information Processing (ICICIP), Marrakesh, Morocco, 2019,126-132. https://doi.org/10.1109/ICICIP47338.2019.9012187

[12] P. Rames, A. Yamini, M. S. Ram, V. Bhargavi, P. B. Sujith, N. Jyothis, A Novel ANFIS controller-based Grid connected EV charging system with constant current control topology, Int. J. Sci. Res. Comput. Sci. Eng. Inf. Technol., 9 (2023) 342–350. https://doi.org/10.32628/IJSRCSEIT

[13] A. Erhuvwu, Modeling of Magnetic Resonance Wireless Electric Vehicle Charging, Electronic Theses and Dissertations, Georgia Southern University, 2019.

[14] P. Cao,Yong, Y. Lu, C. Lu, X. Wang, W. Xu, H. Zhang, A study on modeling of wireless charging system based on fuzzy logic control, Journal of Physics: Conference Series, 2021. https://doi.org/10.1088/1742-6596/1983/1/012053

[15] Y. H. Sohn, B. H. Choi, E. S. Lee, G. C. Lim, G.-H. Cho, C. T. Rim, General Unified Analyses of Two-Capacitor Inductive Power Transfer Systems: Equivalence of Current-Source SS and SP Compensations, IEEE Trans. Power Electron., 30 (2015) 6030-6045. https://doi.org/10.1109/TPEL.2015.2409734

[16] A. Smagulova, M. Lu, A. Darabi, M. Bagheri, Simulation Analysis of PI and Fuzzy Controller for Dynamic Wireless Charging of Electric Vehicle, IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Madrid, Spain, 2020, 1-6. https://doi.org/10.1109/EEEIC/ICPSEurope49358.2020.9160851

[17] S. S. Salman, A. T. Humod, F. A. Hasan, Optimum control for dynamic voltage restorer based on particle swarm optimization algorithm, Indones. J. Electr. Eng. Comput. Sci., 26 (2022) 1351-1359. https://doi.org/10.11591/ijeecs.v26.i3.pp1351-1359

[18] F. A. Hasan, A. T. Humod, L. J. Rashad, Robust decoupled controller of induction motor by combining PSO and Kharitonov's theorem, Eng. Sci. Technol. Int. J., 23 (2020) 1415-1424. https://doi.org/10.1016/j.jestch.2020.04.004

[19] A. M. Salih, A. T. Humod, F. A. Hasan, Optimum Design for PID-ANN Controller for Automatic Voltage Regulator of Synchronous Generator, 4th Scientific International Conference Najaf (SICN), Al-Najef, Iraq, 2019, 74-79. https://doi.org/10.1109/SICN47020.2019.9019367

[20] K. Tutuncu, R. Ozcan, Design and Analysis of PI Controller-Based Four-Quadrant DC Motor Drive with Bipolar and Unipolar Switching Methods, Int. Conf. Eng. Technol., (2019) 298-303.

[21] B. K. Bose, Handbook of power electronic: Modern Power Electronic and AC Drives, The University of Tennessee, Knoxville, Prentice Hall PTR, 2002.

[22] A. AL-Annie, Structural Design Methodology of Genetic Fuzzy Controller for Nonlinear Control Systems, Ph.D. dissertation, Al-Rasheed College of Engineering and Science at the University of Technology, 2005.

[23] K. S. Tang, F. M. Kim, C. Guanrong, S. Kwong, An optimal fuzzy PID controller, IEEE Trans. Ind. Electron., 48 (2001) 757-765. https://doi.org/10.1109/41.937407