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A novel machine learning based maximum power point tracking in interleaved buck-boost converter for portable solar-powered electric vehicle charging in rural areas

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ABSTRACT

Need for off-grid electric vehicle (EV) charging solutions, using intelligent control systems, such as machine learning (ML)-based maximum power point tracking (MPPT), to harness solar energy, offers a means of optimizing efficiency even in the face of fluctuations. This innovative strategy combines clean energy, cutting-edge power electronics, and practical application, which makes it perfect for fostering innovation in areas with inadequate infrastructure. For rural areas without grid infrastructure, this paper presents a novel design and performance assessment of a portable solar-powered EV charging system. To maximize solar energy harvesting and charging efficiency, the system combines an interleaved buck-boost converter with an ML-driven MPPT algorithm. It is appropriate for small electric vehicles (EVs) like auto rickshaws because it uses a 48 V lithium iron phosphate ($LiFePO_4$) battery. A supervised regression model trained on real-time electrical (voltage, current, and power) and environmental (temperature, irradiance) parameters is used to implement the MPPT algorithm. The system was created using MATLAB/Simulink, and the key performance parameters were evaluated using real-time information. Analyses of the key performance metrics like charging efficiency, converter stability, and tracking accuracy show a superior energy harvesting efficiency of 97%.

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1. INTRODUCTION

The popularity of electric vehicles (EVs) has increased all over the globe, where the usage of conventional vehicles is slowly becoming out of choice. Governments have started investing in subsidies for EVs as part of sustainable development. The adoption of EVs has a serious impact on the minimization of greenhouse gases and carbon footprints. The novel approach involving the integration of renewable energy sources (RES) [1] with EVs has started to gain more attention and acceptance all over the world. The EV performance mainly depends on its battery, and research and development are going on to improve battery efficiency and life span. By the end of 2030 [2], EVs will become more stable with advanced features. Also, the entire transportation sector has become a more sustainable approach.

As far as the Indian scenario is concerned, there are new policies and amendments in the EV framework from the government end. The government has already initiated schemes such as faster adoption and manufacturing electric vehicle (FAMEV) [3] and production-linked incentive scheme (PLI), which foster the increased popularity of EVs. The FAMEV and PLI schemes encouraged the manufacturers and vendors of EVs, which increases the adoption of EVs in the transportation sector. This results in an increase in electric autorickshaws, electric scooters, electric cars, and buses in the transportation sector of India. In India, the establishment of EV charging stations has drastically increased as the grid facility is available directly. While rural and remote areas are considered, the availability of grid facilities is limited. In such cases, the establishment of an EV charging system is difficult in rural areas. More research and development (R&D) are required for the establishment of charging stations in remote areas. Also, the concept of portable charging stations is a new research area in India.

A solar photovoltaic (SPV)-based portable remote charging system is a new concept to overcome the issues of grid unavailability in rural areas. The portable mobile EV charging system involves an SPV panel (SPV), a power electronic converter (PEC) [4], a controlling unit, and a battery. The portable EV charging system supports emergency charging at any point in time. It minimizes the anxiety of using EV, and increases the confidence of using EV among the public. There are many technical challenges with respect to EVs that limit the overall performance of the EV system. When it comes to solar power, it has an intermittent nature and merely depends on irradiance and temperature. The above-mentioned problems affect the performance of the solar panel, which acts as a source for a portable EV system. In order to operate the solar panel at its maximum power, shift the operating point in the optimum manner. In order to shift the operating point of a solar panel to the optimum point, it is known as the maximum power point (MPP). The method of shifting the operating point in the optimum way is referred to as maximum power point tracking (MPPT) [5]. There are traditional algorithms, such as the incremental conductance algorithm (ICA) and the perturb and observe algorithm (POA), that are widely used. Nowadays, artificial intelligence (AI)- based MPPT [6] is emerging in portable EV systems. The AI-based MPPT is superior to traditional algorithms in terms of tracking speed, accuracy of tracking, speed of convergence, and problems associated with multiple local maxima. Also, the AI MPPT [7] shows stability during rapidly changing atmospheric conditions and is completely free from oscillations around the MPP. In addition to that, a traditional DC-DC converter is not able to operate in the portable EV charging system due to its failure to maintain high voltage with high gain, and is unable to ensure quick charging operations. Also, the traditional DC-DC converter [8] is unable to maintain high voltage regulation and has poor efficiency, which is undesirable.

In order to mitigate the issues of traditional MPPT algorithms, an intelligence-based machine learning (ML) algorithm [9] is implemented in this research. In spite of using a traditional DC-DC converter, an interleaved DC-DC converter is implemented. The DC-DC converter acts as an interfacing device between the solar panel and the battery unit, basically acting as an efficient voltage controller. The interleaved buck-boost converter minimizes current ripple, balances the switching stress uniformly, and improves the dynamic response and overall efficiency. The regression-based machine learning algorithm (RB-MLA) is used in the proposed portable EV charging system, which generates the optimum duty cycle in accordance with panel current, solar irradiance, and panel temperature. The regression model learns the non-linear characteristics between panel input parameters and panel output parameters and generates the optimum MPP, which is desirable for maximum power transfer. The RB-MLA used in the system shows superior performance over conventional MPPT algorithms such as ICA and POA [10]. The RB-MLA outperforms traditional MPPT in terms of tracking speed, accuracy, and stability in the MPP region.

The proposed portable EV charging system is used in a standalone mode, which is appropriate in rural areas where the grid facility is unavailable. The proposed portable EV charging is the integration of a solar panel as the power supply system, an intelligent MPPT control, and a high-efficiency interleaved buck-boost converter. The entire portable EV charging system is modelled using the MATLAB/Simulink environment. Also, the scope of real-time implementation of the proposed system is discussed in this research. The major contributions of the proposed research are as follows: implementation of a portable EV charging system for rural areas, design and simulation of an interleaved buck-boost converter for efficient charging of the battery with minimization of ripple, addition of RB-MLA for operating the converter with optimum duty ratio irrespective of a rapidly changing environment, and performance evaluation based on simulation. The complete research article is divided as follows: i) Section 2 presents the methods; ii) Section 3 discusses the results; and iii) Section 4 concludes the paper.

2. METHOD

This section presents the design and specifications of the proposed portable solar-powered EV charging system, which integrates a regression-based machine learning algorithm (RB-MLA**)** with an interleaved buck-boost converter [11]. The portable EV charging system is typically dedicated to rural areas in the standalone mode. The SPV is supplied to the EV load through the RB-MLA controller and the power electronic interface. A lithium iron phosphate (LiFePO4) is used for storing energy from a solar panel. The interleaved buck-boost converter ensures regulated output power and, using RB-MLA, the operating point of the solar panel is shifted to the MPP, ensuring maximum power flow from the source to the load. The proposed system shown in Figure 1 is suitable for rural areas where the availability of the grid facility is limited. The RB-MLA ensures the maximum power flow from the source to the load with all the real-time constraints. The major focus on the system is implementation of RB-MLA for maximum power transfer from SPV panel to the EV load [12] at real time environment. The method of implementation of the proposed portable EV charging system is described in the coming sub sections.

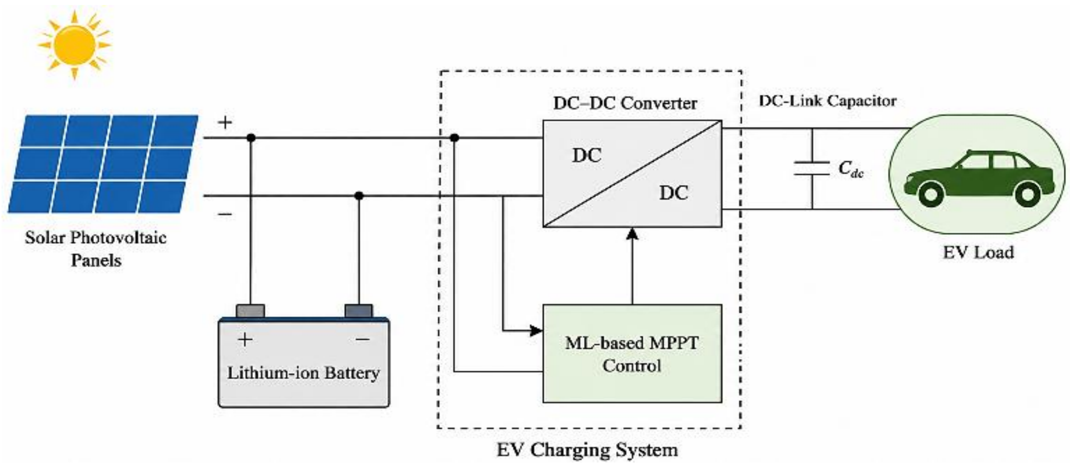


Figure 1. Block diagram of EVs using an SPV source

2.1. System design

The system includes the design of the SPV panel, battery sizing, the design of the interleaved buck-boost converter, and the development of RB-MLA. The solar array is the main power source of the portable EV charging system. A solar array of 900 W is constructed by connecting three solar panels, each of 300 W, connected in a series-parallel combination. A monocrystalline panel is used to ensure high efficiency for the proposed system. The operating voltage of the solar photovoltaic array is 38 V. The voltage (V_{mp}) corresponding to maximum power is 32 V, and the current (I_{mp}) corresponding to maximum power is 9.4 A. An interleaved DC-DC boost converter is a power electronic circuit designed to step up a lower input voltage to a higher output voltage while improving current handling, reducing ripple, and enhancing thermal distribution. The topology consists of two or more boost converter phases connected in parallel and operated with a fixed phase shift, typically 180° in a two-phase system, as shown in Figure 2. This arrangement enables smoother input/output waveforms and better performance compared to a single-phase boost converter.

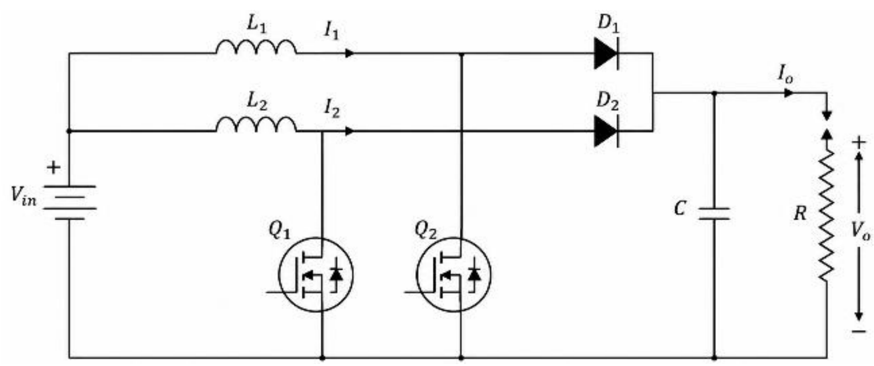


Figure 2. Two-phase interleaved boost DC-DC converter with coupled inductors

As illustrated in Figure 2, L_1 and L_2 are the inductors for the two interleaved phases, Q_1 and Q_2 are the active switching devices (typically metal oxide semiconductor field effect transistor (MOSFET)), D_1 and D_2 are the freewheeling diodes, and C is the output filter capacitor. The R represents the load connected to the converter. The input supply voltage is denoted as V_{in}, and the regulated output voltage is V_0. Each switch operates with a fixed duty cycle but at a phase shift of 180° relative to the other. This means that when one switch is conducting, the other is in its off-state for a complementary portion of the switching cycle. The interleaved boost converter operates in two interleaved switching sequences: During the on state, either Q_1 or Q_2 conducts at a time, permitting either L_1 or inductor L_2 to store energy from the input supply. In parallel, another indicator starts releasing the energy to the load, either D_1 or D_2. During the off state, the stored energy from the inductor gets discharged to the load through either D_1 or D_2. The interleaved operation occurs in the converter to enhance the voltage stability, minimize the current ripple, and improve the efficiency of high current applications such as EVs. The interleaved buck-boost converter performs in such a way that it suppresses ripple content, minimizes thermal-related problems in the semiconductor devices and improves the reliability of the overall system. The reason for opting for the interleaved buck-boost converter is high ripple content elimination and better thermal performance. To determine the required duty cycle D, rearrange the equation as shown in (1).

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

The inductors L_1 and L_2 are needed for the interleaved operation. In the portable EV system, the converter is selected in the continuous conduction mode (CCM) [13]. The inductors are estimated using (2).

$$L = \frac{V_{in} \times D}{\Delta I_L \times f_s} \tag{2}$$

The following assumptions are made for the effective inductor design. The total current ripple, ΔI_L = 20% of average input current, the switching frequency f_s = 50 kHz, and maximum input and output voltages are maximum V_{in} = 80 V, maximum I_{in} = 20 A respectively. In order to assure reliable operation, the inductor value is selected as L=54 mH. The output capacitor design is performed using (3).

$$C = \frac{I_{out} \times D}{f_s \times \Delta V_{out}} \tag{3}$$

Assume that the output current, I_{out} = 20 A, duty cycle D = 0.5, and ripple voltage $\Delta V_{out} = 1\ V$. A larger value of capacitance 4700 µF is selected which ensuring low ripple and improved load step response. In this system, to maintain larger value of capacitance a combination of electrolytic and ceramic capacitors is connected in parallel. The overall design parameters are summarized in Table 1.

This section provides clear-cut information on how the RB-MLA is integrated with the interleaved buck-boost converter in the portable EV charging system. Overall development of portable EV charging system consists of system configuration and design, development of supervised regression ML model, simulation and strategy of evaluation.

Table 1. Design parameters of portable EV charging system

Parameter	Value/range	Remarks
PV input voltage V_{in}	30–80 V	Variable irradiance range
Output voltage V_{out}	48 V	Battery regulated
Output current I_{out}	Up to 20 A	Depending on solar conditions and SOC
Switching frequency f_s	50 kHz	Interleaved, per phase
Inductor value L	54 µH (each phase)	Ensures CCM, low ripple
Output capacitor C	4.7 mF	Electrolytic + ceramic hybrid
Real time controller	ESP32 / STM32F4	ML inference + PWM generation
ML model	Linear Regression	Predicts duty cycle from solar parameters
Model input features	V_{pv},I_{pv},T_{pv}, , I_{pv}, T_{pv}, G	For real-time inference
Model output	Duty cycle	Used to modulate PWM signal
Efficiency η	~92–94% (target)	Based on simulations and estimated losses

2.2. System configuration

The portable solar EV charging system consists of three 300 W mono-crystalline photovoltaic panels configured to provide a net capacity of 900 W. The panels are connected to a 48 V, 100 Ah $LiFePO_4$ battery [14] through an interleaved buck-boost converter. The reason for selecting the interleaved buck-boost converter is that it powers efficiently under varying solar irradiance, while maintaining stable voltage and reducing ripple content through interleaving action. The design of the interleaved buck-boost converter includes the design of passive components such as inductors and capacitors, switching devices such as MOSFETs, and protective devices according to the standard requirements. As per the design calculation mentioned in (2) and (3), the selected values of both inductors are 54 µH and the capacitance value of 4.7 mF, ensuring continuous conduction mode (CCM). The input voltage varies from 30 V to 80 V from the SPV panel, and the selected switching frequencies of the MOSFET switches are 50 kHz to keep the electromagnetic interference (EMI) within a safe limit.

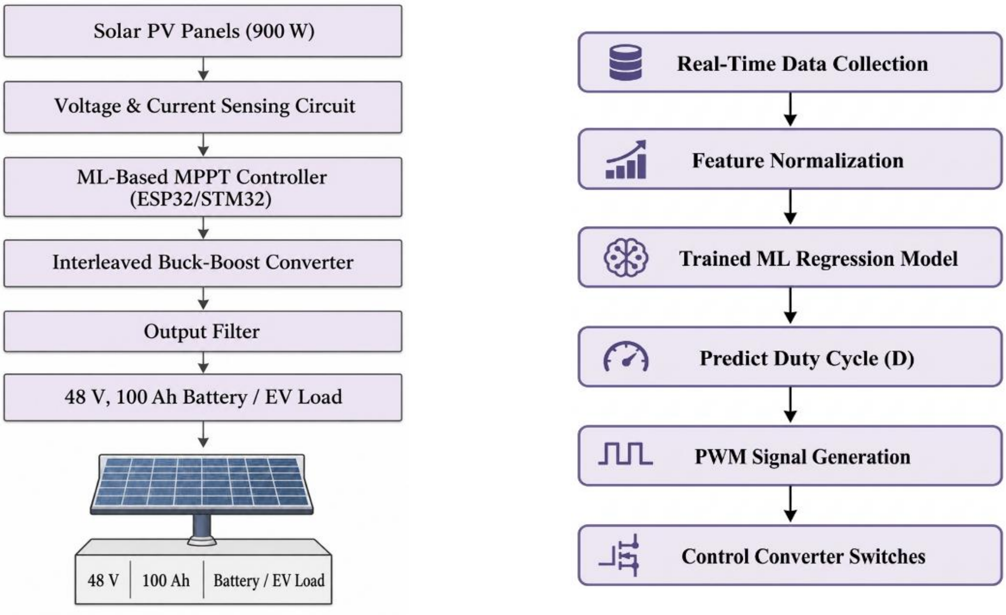
2.3. Development of MPPT control in the portable EV charging system

In order to ensure the operating point at its maximum power point (MPP), RB-MLA based MPPT control is used. The RB-MLA is a practically feasible and computationally efficient algorithm capable of implementing in the real time system. The output of the model is the predicted duty cycle (D) required to drive the interleaved buck-boost converter toward maximum power extraction. The implementation of MPPT control is illustrated in Figures 3(a) and 3(b). To build the training dataset, a MATLAB/Simulink model of the SPV-converter system was developed under varying environmental conditions. These simulations were used to generate thousands of labelled data points representing optimal operating points. The overall dataset was split into 80% training and 20% testing sets to confirm generalization. Once the training is done, the regression model is exported to an embedded C environment using TensorFlow Lite Micro [15].

The real-time implementation runs on a low-power controller (ESP32 or STM32), interfacing with voltage and current sensors to process real-time data and continuously update the duty cycle of the interleaved buck-boost converter. The steps involved in the implementation of RB-MLA are given below:

- Step 1: Load ML model parameters (β_0, β_1, ..., β_n)
- Step 2: Acquire V_{pv}, I_{pv}, T, G from sensors
- Step 3: Normalize features
- Step 4: Compute duty cycle: $D = \beta_0 + \beta 1 x V_{pv} + \beta 2 x I_{pv} + \beta 3 x T + \beta 4 x G$
- Step 5: Output duty cycle to pulse width modulation (PWM) controller
- Step 6: Update every 100 ms
- Step 7: Loop back to Step 2

Those seven steps are inculcated for the implementation of portable EV charging system.



(a) (b)

Figure 3. Portable solar EV charging system: (a) system configuration and (b) ML MPPT control

2.4. Steps for the simulation

The overall portable EV charging system, including SPV array, interleaved buck-boost converter, RB-MLA, and EV load, is simulated in MATLAB/Simulink environment. The simulation environment included variable irradiance conditions ranging from 200 W/m² to 1000 W/m² and ambient temperatures varied between

25 °C and 45 °C. These external environmental conditions were chosen to reflect real-time solar availability in rural environments. System performance was evaluated using three key metrics:
- MPPT efficiency (%): Ratio of tracked power to theoretical maximum power.
- Response time (s): Time taken to reach MPP under changing input conditions.
- Charging time (h): Time required to charge the battery to full state-of-charge.

Results were compared against traditional POA and ICA algorithms to showcase the relative improvement in proposed dynamic tracking and energy harvesting. The overall steps involved in the development of RB-MLA for a portable EV system are shown in Figure 4. The step-by-step flowchart illustrated in Figure 4 represents the systematic methodology followed for developing the proposed RB-MLA integrated with an interleaved buck-boost converter for portable solar-based EV charging. The overall process begins with checking the system requirements, load rating, battery size and assuming the need for practical implementation. The SPV panel sizing is estimated once the EV load is fixed and based upon the availability of source and load specifications, the power electronic interface, such as an interleaved buck-boost converter, is designed with practical values. This dataset serves as the base for training a supervised machine learning regression model. The platform for the model development is using the scikit-learn framework [16] and optimized to minimized prediction error. As soon as the training of the dataset is completed, the model can be exported to an embedded-compatible format suitable for low-power microcontrollers like the ESP32 or STM32 versions. In order to evaluate the effectiveness of the proposed system, a comprehensive simulation model is developed in MATLAB/Simulink. This model includes the SPV array, battery, interleaved buck-boost converter, and RB-MLA. The system is evaluated under various environmental and load conditions. The performance matrix, such as tracking efficiency, charging time, and dynamic response, is measured and compared with conventional MPPT control, like POA and ICA [17]. The final step includes analyzing the results to validate the performance parameters, such as accuracy, responsiveness, and efficiency improvements, offered by the proposed solution. The proposed method helps to implement the entire portable EV charging system with practical aspects.

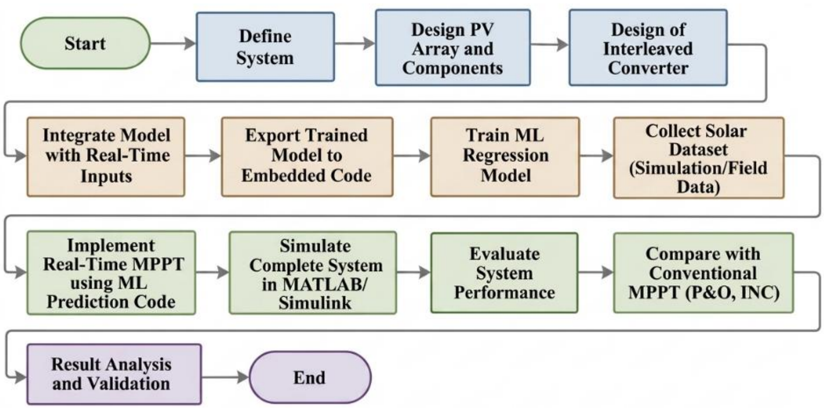


Figure 4. Steps involved for the development of RB-MLA for portable EV

3. RESULTS AND DISCUSSION

The Simulink model of a portable EV charging system is developed using the MATLAB/Simulink environment. The Simulink model consists of a SPV panel model, an interleaved buck-boost converter model, an EV load, a battery, and an RB-MLA-based MPPT block presented in Figure 5. The key performance parameters [18] include tracking efficiency, tracking time, power ripple, charging time, and the amount of energy saved. The performance of RB-MLA-based MPPT is evaluated and compared with the traditional MPPT algorithms, such as perturb and observe (POA) and incremental conductance algorithm (ICA). Also, the performance of the battery used in the portable EV charging system is analyzed with real-time parameters. The overall Simulink model is shown in Figure 5.

The Simulink model of a portable EV charging system consists of a SPV panel, a converter, an MPPT control block, a battery, and an EV load. The model is designed such that the proposed system must have better efficiency, flexibility, and reliability for the standalone operation. The converter segment regulates the output as the SPV panel output fluctuates with respect to the environmental conditions. The MPPT control block [19] is designed to ensure the solar panel output is operated in the optimum way. The battery storage unit is modelled in such a way that it ensures an uninterruptible power supply to the portable EV system. The modelling of each segment mentioned in the Simulink model is briefly presented in the sub-section below.

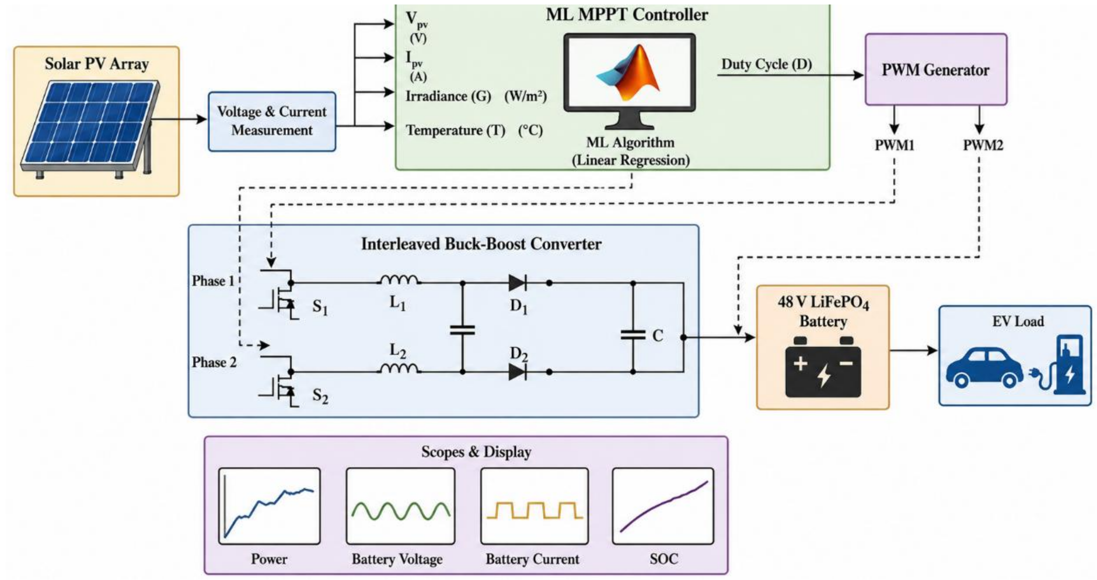


Figure 5. Simulink model of portable EV charging system

3.3. Performance comparison of MPPT control for EV charging system

To validate the effectiveness of the RB-MLA strategy, a series of performance comparisons was conducted against conventional algorithms such as POA and ICA [20]. The performance matrix, such as tracking efficiency, response time, ripple content, and battery charging profile, is evaluated. Also, the behavior of RB-MLA and how it effectively tracks the MPP. The performance of MPPT is summarized in Table 2.

It is observed that compared to the conventional MPPT algorithms, such as POA and ICA, RB-MLA shows 97.2% of tracking efficiency, which is a superior performance. As compared to the conventional MPPT algorithms such as POA and ICA, RB-MLA converges at 0.9 s, where POA and ICA converge at 1.8 s and 1.4 s, respectively. In the case of power stability, RB-MLA shows better performance compared to traditional MPPT algorithms such as POA and ICA. The RB-MLA takes only 4.3 hours to complete the full charging of the lithium iron phosphate ($LiFePO_4$) battery [21], whereas ICA takes 5.2 hours and POA takes 5.6 hours, respectively, as the RB-MLA shows faster charging, which improves the utilization of energy reduction in the charging time. The performance comparison is presented in the bar diagram shown in Figure 6.

Table 2. Performance analysis of MPPT algorithm

Sl. No	MPPT algorithm	Average tracking efficiency (%)	Tracking time (s)	Power ripple (%)	Charging time (0–100%) (h)
1	POA	91.4	1.8	6.3	5.6
2	INC	92.7	1.4	5.1	5.2
3	RB-MLA	97.2	0.9	2.8	4.3

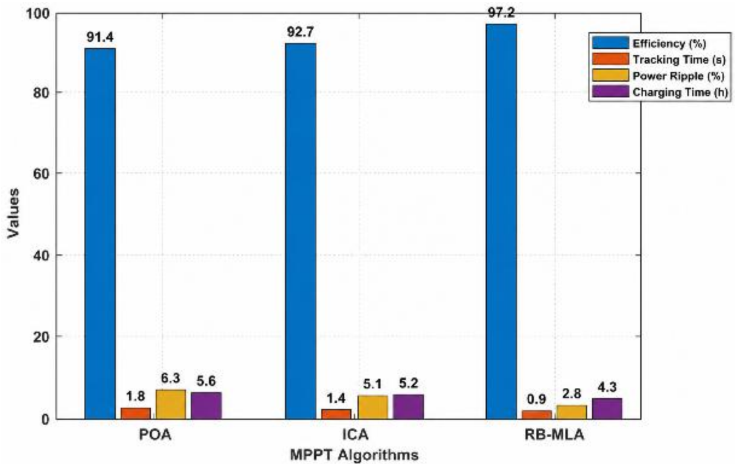


Figure 6. Comparison of the performance of the traditional and the RB-MLA algorithm

Table 3 shows that the proposed portable EV charging system is tested under different irradiance conditions ranging from 200 W/m^2 to 1000 W/m^2, RB-MLA outperforms the power output under each solar irradiance condition. The average improvement of RB-MLA over POA is 10.93% in power output, whereas 5.22% was improved over ICA MPPT control [22]. When irradiance reached 800 W/m², RB-MLA peaked at 635 W, keeping its superiority over ICA (610 W) and POA (580 W). The comparative charging profile for different MPPT control algorithms is presented in Table 4.

A comparative analysis was carried out to check the charging behavior of the battery under three MPPT control methods: P&O, INC, and the proposed RB-MLA method. Once the charging is done for 1 hour, the RB-MLA achieved a state of charge (SOC) [23] of 23%, comparatively ahead of ICA (18%) and POA (14%). This early-stage pro continued consistently through the cycle. At hour three, the RB-MLA controller reached 61% SOC, whereas ICA and POA only managed 52% and 46%, respectively. By the fourth hour, the RB-MLA charged the battery to 83%, whereas ICA was at 71%, and POA trailed with 64%. The RB-MLA-based controller reached full charge (100% SOC) within 5.5 hours, compared to 96% (ICA) and 90% (POA) in the same duration, which is presented in Figure 7. The battery charging profile [24] of a portable solar EV charging system for traditional algorithms and ML-based MPPT algorithms is shown using area and bar diagrams in Figures 7(a) and 7(b).

Table 3. Power output vs. irradiance for different MPPT algorithm

Sl. No	Irradiance (W/m²)	POA power output (W)	INC power output (W)	RB-MLA power output (W)
1	200	148	156	165
2	400	290	310	330
3	600	430	456	485
4	800	580	610	635
5	1000	705	730	755

Table 4. Charging profile comparison of MPPT control algorithm

S.No	Charging time (h)	POA SOC (%)	ICA SOC (%)	RB-MLA SOC (%)
1	1	14%	18%	23%
2	2	29%	34%	42%
3	3	46%	52%	61%
4	4	64%	71%	83%
5	5	82%	88%	98%
6	5.5	90%	96%	100%

(a)

(b)

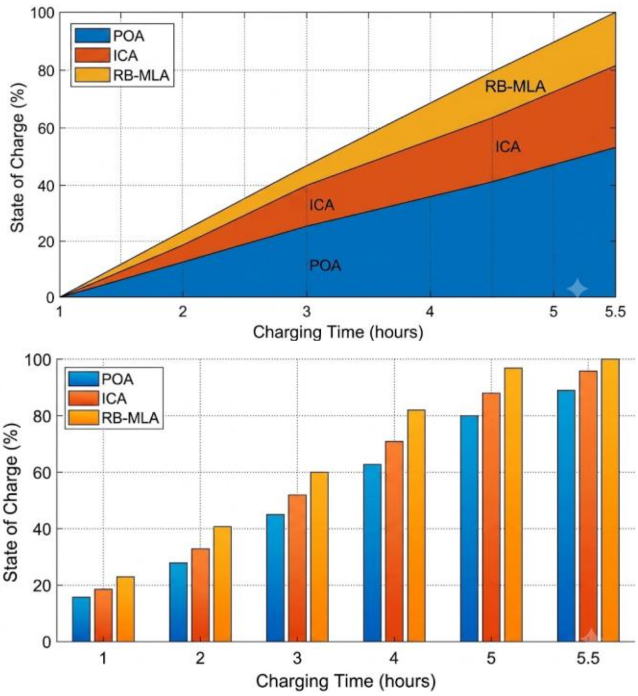


Figure 7. Battery charging profile comparison: (a) area plot and (b) bar diagram

This steady and faster charging behavior highlights the efficiency of the RB-MLA in rapidly changing irradiance and load demands. The improved tracking precision confirms that more useful energy is harvested, minimizing overall charging time and improving system performance, which is very crucial for portable EV charging applications in off-grid and rural placements [25]. The comparison of the energy harvesting potential and efficiency of MPPT algorithms is presented in Table 5.

Table 5 presents the comparative analysis of the MPPT algorithm on harvested energy. The results show that the RB-MLA MPPT algorithm outperforms traditional MPPT algorithms such as POA and ICA in terms of harvested energy, average energy efficiency, and the effective utilization of time. The RB-MLA could harvest 3952 Wh of energy over 6 hours compared to the POA and ICA MPPT algorithms. In terms of the average efficiency, RB-MLA shows 96.5% of efficiency compared to POA and ICA MPPT algorithms. The complete charging of the portable EV charging system is completed by the RB-MLA-based MPPT algorithm in 4.9 hours, whereas POA and ICA consume 5.6 hours and 5.3 hours, respectively.

The dynamic response comparison of POA, ICA, and RB-MLA-based MPPT algorithm is presented in Figure 8. It is observed that the RB-MLA approach indicates a quick response with 0.9 s, 0,8 s, and 0.1 s during the respective irradiance transitions of 400 to 800 W/m2, 800 to 600 W/m^2, and 600 to 1000 W/m^2, respectively. The suitability of the RB-MLA MPPT algorithm in the rapidly changing environment is presented in Figures 8(a) and 8(b).

Table 5. Energy harvested over a 6-hour operation (rural condition)

Sl. No	MPPT algorithm	Energy harvested (Wh)	Average efficiency (%)	Effective utilization time (hrs)
1	POA	3560	91.1	5.6
2	ICA	3715	92.5	5.3
3	RB-MLA	3952	96.5	4.9

(a)

(b)

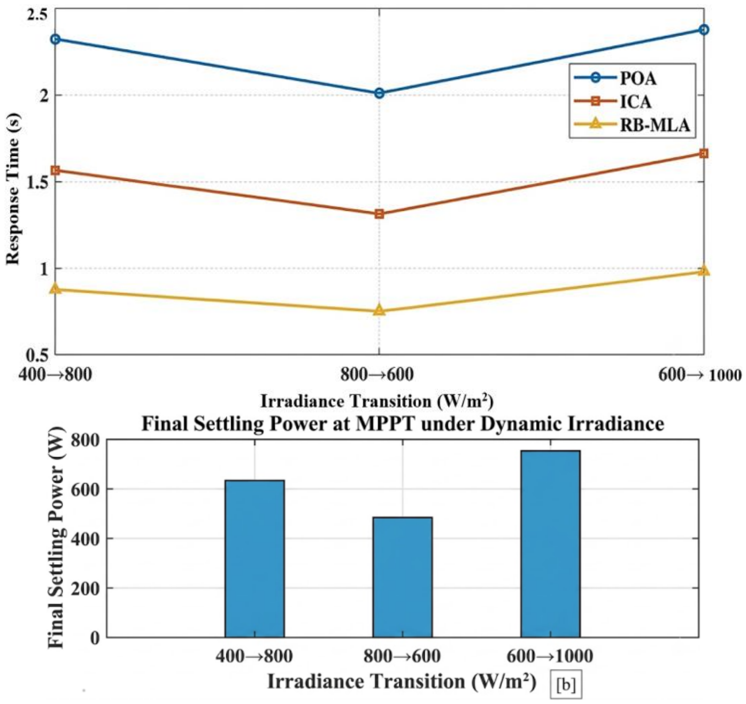


Figure 8. MPPT dynamic responses: (a) rapid irradiance change and (b) final settling power

4. CONCLUSION

The research work presented a comprehensive design, development, and performance validation of a new regression-based machine learning algorithm (RB-MLA) strategy embedded with an interleaved buck-boost converter for portable EV charging applications. The proposed system was typically fine-tuned to suit rural and standalone applications by utilizing solar energy efficiently and optimally. The integration of a supervised regression model into the MPPT controller enabled dynamic adaptation to rapidly varying atmospheric conditions, thereby drastically enhancing energy harvesting and power conversion efficiency. Simulation and performance analysis under rapidly changing irradiance and temperature conditions clearly demonstrated the superiority of the RB-MLA approach over the conventional perturb and observe algorithm (POA) and incremental conductance algorithm (ICA). The RB-MLA achieved a peak tracking efficiency of 97.2%, compared to 92.7% and 91.4% for ICA and POA, respectively. Furthermore, it showcased the quicker convergence time of 0.9 seconds, the lowest power ripple content of 2.8%, and decreased the total battery charging time to 4.3 hours—a drastic improvement over conventional approaches. Comparative analyses also ensured higher energy harvesting (3952 Wh) and shorter effective charging durations (4.9 hours) using the RB-MLA under simulated real-world solar conditions. Battery modelling results further validated system robustness, showing smooth charging and discharging profiles aligned with lithium iron phosphate ($LiFePO_4$) chemistry. The RB-MLA presented optimal adjustment of charging currents and voltages, ensuring safe, quick, and efficient energy storage. Altogether, the proposed RB-MLA integrated system enhances the efficiency and responsiveness of solar-based portable EV charging. Also, it makes a technically viable and practically convenient solution for energy utilization for rural areas. The combination of power electronics and smart control ensures the potential of artificial intelligence (AI)-assisted renewable energy systems (RES) in enhancing the sustainable transportation infrastructure in developing countries.

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J. J. Jijesh	✓		✓	✓			✓			✓	✓		✓	✓
G. B. Arjun Kumar	✓			✓	✓		✓			✓	✓		✓	✓
Dileep Reddy Bolla				✓	✓		✓			✓	✓		✓	✓
K. N. Sunil Kumar	✓		✓					✓	✓	✓	✓	✓	✓	✓

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

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

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

REFERENCES

[1] G. Singh, S. C. Misra, Y. Daultani, and S. Singh, “Electric vehicle adoption and sustainability: insights from the bibliometric analysis, cluster analysis, and morphology analysis,” *Operations Management Research*, vol. 17, no. 2, pp. 635–659, Jun. 2024, doi: 10.1007/s12063-024-00442-y.

[2] A. Hassan, M. A. Mahmoud, M. A. Al-Sharafi, M. Ibrahim, N. A. Iahad, and S. S. Gunasekaran, “Bibliometric analysis of electric vehicle adoption and environmental sustainability research (2014–2024): trends and implications,” *Studies in Computational Intelligence*, vol. 1161, pp. 43–58, 2024, doi: 10.1007/978-3-031-61463-7_3.

[3] N. B. Adhia, S. R. Takke, and P. D. Sonawwanay, “Indian scenario of electric vehicles—a review,” *Techno-Societal 2022*, pp. 261–269, 2024, doi: 10.1007/978-3-031-34648-4_27.

[4] V. K. P. Kariyat and J. J. Janardhanan, "Design and development of modified high efficient high gain DC-DC converter for spv standalone systems," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 3, p. 1562, Sep. 2023, doi: 10.11591/ijpeds.v14.i3.pp1562-1576.

[5] S. Nasri, N. Mansouri, A. Mnassri, A. Lashab, J. Vasquez, and H. Rezk, "Global analysis of electric vehicle charging infrastructure and sustainable energy sources solutions," *World Electric Vehicle Journal*, vol. 16, no. 4, p. 194, Mar. 2025, doi: 10.3390/wevj16040194.

[6] S. Pareek, A. Sujil, S. Ratra, and R. Kumar, "Electric vehicle charging station challenges and opportunities: a future perspective," in *2020 International Conference on Emerging Trends in Communication, Control and Computing (ICONC3)*, IEEE, Feb. 2020, pp. 1–6. doi: 10.1109/ICONC345789.2020.9117473.

[7] F. J. Lozano, R. Lozano, D. F. Lozano-García, and A. Flores-Tlacuahuac, "Reducing energy poverty in small rural communities through in situ electricity generation," *Discover Sustainability*, vol. 4, no. 1, p. 13, Feb. 2023, doi: 10.1007/s43621-023-00128-8.

[8] I. Hoeck, E. Steurer, Ö. Dolunay, and H. Ileka, "Challenges for off-grid electrification in rural areas. assessment of the situation in namibia using the examples of gam and tsumkwe," *Energy, Ecology and Environment*, vol. 7, no. 5, pp. 508–522, Oct. 2022, doi: 10.1007/s40974-021-00214-5.

[9] S. A. Alenabi, A. O. Farshbafian, A. Mansouri, H. Karimi, and A. Siadatan, "Hybrid solar-biogas system for efficient energy management in electric vehicle charging station," in *2025 29th International Electrical Power Distribution Conference (EPDC)*, IEEE, Oct. 2025, pp. 1–6. doi: 10.1109/EPDC67173.2025.11278294.

[10] S. Afshar, P. Macedo, F. Mohamed, and V. Disfani, "A literature review on mobile charging station technology for electric vehicles," in *2020 IEEE Transportation Electrification Conference & Expo (ITEC)*, IEEE, Jun. 2020, pp. 1184–1190. doi: 10.1109/ITEC48692.2020.9161499.

[11] H. Rashid *et al.*, "A comprehensive review on economic, environmental impacts and future challenges for photovoltaic-based electric vehicle charging infrastructures," *Frontiers in Energy Research*, vol. 12, Aug. 2024, doi: 10.3389/fenrg.2024.1411440.

[12] Y. Gulzar, M. Dutta, D. Gupta, S. Juneja, A. B. Soomro, and M. S. Mir, "Revolutionizing mobility: a comprehensive review of electric vehicles charging stations in India," *Frontiers in Sustainable Cities*, vol. 6, Feb. 2024, doi: 10.3389/frsc.2024.1346731.

[13] P. Bastida-Molina, Y. Rivera, C. Berna-Escriche, D. Blanco, and L. Álvarez-Piñeiro, "Challenges and opportunities in electric vehicle charging: harnessing solar photovoltaic surpluses for demand-side management," *Machines*, vol. 12, no. 2, p. 144, Feb. 2024, doi: 10.3390/machines12020144.

[14] S. S, N. S. Manjarekar, S. Barik, and S. Swain, "A delayed charging enabled station for electric vehicles," *Computers and Electrical Engineering*, vol. 123, p. 110166, Apr. 2025, doi: 10.1016/j.compeleceng.2025.110166.

[15] K. H. Tajaldin and H. J. Motlak, "Design and implementation DC/DC luo converter controlled by adaptive fractional pi and p&o mppt," *Journal Européen des Systèmes Automatisés*, vol. 57, no. 1, pp. 201–210, Feb. 2024, doi: 10.18280/jesa.570120.

[16] A. Rachid *et al.*, "Electric vehicle charging systems: comprehensive review," *Energies*, vol. 16, no. 1, p. 255, Dec. 2023, doi: 10.3390/en16010255.

[17] H. M. Abdullah, A. Gastli, and L. Ben-Brahim, "Reinforcement learning based EV charging management systems–a review," *IEEE Access*, vol. 9, pp. 41506–41531, 2021, doi: 10.1109/ACCESS.2021.3064354.

[18] M. F. Akhtar, S. R. S. Raihan, N. A. Rahim, M. N. Akhtar, and E. Abu Bakar, "Recent developments in dc-dc converter topologies for light electric vehicle charging: a critical review," *Applied Sciences*, vol. 13, no. 3, p. 1676, Jan. 2023, doi: 10.3390/app13031676.

[19] M. S. H. Lipu *et al.*, "Review of electric vehicle converter configurations, control schemes and optimizations: challenges and suggestions," *Electronics*, vol. 10, no. 4, p. 477, Feb. 2021, doi: 10.3390/electronics10040477.

[20] M. S. Endiz, G. Gökkuş, A. E. Coşgun, and H. Demir, "A review of traditional and advanced MPPT approaches for PV systems under uniformly insolation and partially shaded conditions," *Applied Sciences*, vol. 15, no. 3, p. 1031, Jan. 2025, doi: 10.3390/app15031031.

[21] R. H. Malele, B. Mendu, and B. B. Monchusi, "Microcontroller-driven battery management in hybrid energy systems: a systematic review of applications, control strategies, and emerging trends," *IEEE Access*, vol. 13, pp. 29341–29360, 2025, doi: 10.1109/ACCESS.2025.3539929.

[22] N. Debdouche, A. Chebabhi, H. Benbouhenni, F.-Z. Hadjaidji, Z. M. S. Elbarbary, and S. F. Al-Gahtani, "Synergetic simplified super-twisting algorithm control for stability enhancement of PV/bess-based dc microgrid," *Scientific Reports*, vol. 15, no. 1, p. 7392, Mar. 2025, doi: 10.1038/s41598-025-92042-4.

[23] H. Ahessab, A. Gaga, and B. EL Hadadi, "Revolutionizing photovoltaic power: an enhanced grey wolf optimizer for ultra-efficient mppt under partial shading conditions," *Scientific African*, vol. 27, p. e02586, Mar. 2025, doi: 10.1016/j.sciaf.2025.e02586.

[24] R. P. Narasipuram, M. M. Pasha, S. Tabassum, and A. S. Tandon, "The electric vehicle surge: effective solutions for charging challenges with advanced converter technologies," *Energy Engineering*, vol. 122, no. 2, pp. 431–469, 2025, doi: 10.32604/ee.2025.055134.

[25] J. Ingilala and I. Vairavasundaram, "Investigation of high gain dc/dc converter for solar PV applications," *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 5, p. 100264, Sep. 2023, doi: 10.1016/j.prime.2023.100264.

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