MODELING AND PERFORMANCE EVALUATION OF A PV-BASED EV CHARGING STATION USING INC MPPT AND ANN CONTROLLER

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Abstract:
The rapid adoption of electric vehicles (EVs) has intensified the need for efficient, reliable, and sustainable charging infrastructure. Photovoltaic (PV)-based EV charging stations present a promising solution by utilizing renewable energy to reduce dependency on fossil fuels. However, the nonlinear characteristics of PV systems and varying environmental conditions pose significant challenges in achieving optimal performance. This paper presents a detailed study and analysis of a PV-powered EV charging station employing the Incremental Conductance (INC) Maximum Power Point Tracking (MPPT) technique integrated with an Artificial Neural Network (ANN) controller. The INC algorithm ensures accurate and fast tracking of the maximum power point (MPP), while the ANN controller enhances system performance by providing adaptive and intelligent control. The proposed system includes a PV array, DC-DC boost converter, ANN controller, and EV battery charging unit. The system is evaluated based on efficiency, stability, and dynamic response. Results demonstrate improved performance in terms of reduced oscillations, faster convergence, and higher energy utilization compared to conventional methods.
Keywords:- Electric Vehicle (EV), Photovoltaic (PV), Incremental Conductance (INC), Maximum Power Point Tracking (MPPT), Artificial Neural Network (ANN), Boost Converter, Smart Charging, Renewable Energy
How to cite this article: Satyanarayana K, Naresh G, Venkatadurgaprasad K, Rao DP, Devi GD. Modeling and performance evaluation of a PV-based EV charging station using INC MPPT and ANN controller. Int J Drug Deliv Technol. 2026;16(73s): 1591-1596. DOI: 10.25258/ijddt.16.73s.168

1. INTRODUCTION

The global shift towards sustainable energy systems has accelerated the development and adoption of electric vehicles. EVs offer a clean alternative to internal combustion engine vehicles, reducing greenhouse gas emissions and environmental pollution. However, the environmental benefits of EVs depend significantly on the source of electricity used for charging.

Renewable energy sources, particularly solar energy, have gained considerable attention for EV charging applications. PV-based charging systems provide a decentralized and eco-friendly solution. Despite these advantages, PV systems face challenges such as intermittency, low conversion efficiency, and nonlinear voltage-current characteristics.

To overcome these issues, Maximum Power Point Tracking (MPPT) techniques are employed to extract maximum power from PV systems. Among various MPPT methods, the Incremental Conductance (INC) technique is widely used due to its superior performance under rapidly changing environmental conditions.

In addition to MPPT, advanced control strategies are essential for improving system efficiency and stability. Artificial Neural Networks (ANNs) have emerged as powerful tools for handling nonlinear systems and uncertainties. This paper integrates

INC MPPT with an ANN controller to enhance the performance of PV-based EV charging systems.

2. LITERATURE REVIEW

Significant research has been conducted in the area of PV-based EV charging and MPPT techniques. Early MPPT methods such as Perturb and Observe (P&O) are simple but suffer from steady-state oscillations and slow convergence.

The Incremental Conductance method improves upon these limitations by accurately identifying the maximum power point using the slope of the power-voltage curve. Studies have shown that INC provides better efficiency and reduced oscillations compared to P&O.

Recent advancements focus on intelligent MPPT techniques such as ANN and fuzzy logic controllers. ANN-based MPPT methods use trained models to predict optimal operating points, resulting in faster response and improved efficiency.

Research also indicates that ANN controllers enhance the dynamic performance of EV charging systems by reducing harmonic distortion and improving voltage regulation. Hybrid approaches combining MPPT and AI techniques have shown promising results in improving system reliability and efficiency.

Despite these advancements, there is limited work on integrating INC MPPT with ANN controllers specifically for EV charging applications. This paper aims to address this gap.

Research Gap

From the literature, the following gaps are identified:

- Limited integration of INC MPPT with ANN controllers in EV charging systems
- Need for improved real-time adaptability under rapid irradiance changes
- Requirement for enhanced power quality with reduced THD
- Lack of combined intelligent control and efficient MPPT techniques

Contribution of Proposed Work

This paper addresses the above gaps by:

- Combining INC MPPT with ANN controller
- Improving tracking accuracy and dynamic response
- Enhancing charging efficiency and power quality
- Providing a robust PV-based EV charging solution

3. SYSTEM CONFIGURATION

3.1 Overall System Architecture

The proposed system consists of the following components:

- Photovoltaic (PV) Array
- DC-DC Boost Converter
- Incremental Conductance MPPT Controller
- Artificial Neural Network (ANN) Controller
- DC-Link Capacitor
- Electric Vehicle Battery Charging Unit

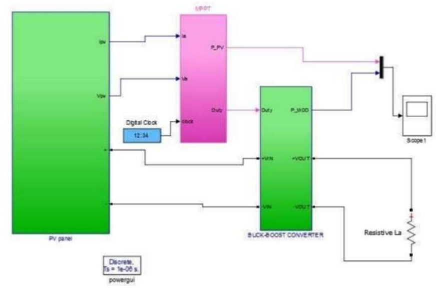


Figure 1. PV cell modal with resistive load

3.2 Working Principle

The PV array converts solar energy into electrical energy. The output is fed to a DC-DC boost converter, which adjusts the voltage level. The INC MPPT algorithm continuously monitors PV voltage and current to ensure operation at the maximum power point.

The ANN controller processes system inputs and generates control signals to regulate converter operation. The output is supplied to the EV battery using a controlled charging strategy.

4. MATHEMATICAL MODELING

4.1 PV System Modeling

The PV cell output current is given by:

$$I = I_{ph} - I_s\left(e^{\frac{V+IR_s}{nV_T}} - 1\right)$$

Where:

- I_{ph}: Photocurrent
- I_s: Saturation current
- R_s: Series resistance
- V_T: Thermal voltage

4.2 Incremental Conductance MPPT

At maximum power point:

$$\frac{dP}{dV} = 0$$

Which leads to:

$$\frac{dI}{dV} = -\frac{I}{V}$$

The controller compares incremental conductance with instantaneous conductance to determine the direction of operation.

4.3 Boost Converter Model

The output voltage of the boost converter is:

$$V_o = \frac{V_{in}}{1-D}$$

Where:

- D: Duty cycle

5. ANN CONTROLLER DESIGN

5.1 Architecture

The ANN controller consists of:

- Input layer (PV voltage, current, error signals)
- Hidden layers (nonlinear processing)
- Output layer (control signal for duty cycle)

5.2 Training Process

The ANN is trained using supervised learning techniques:

- Training data obtained from system simulations
- Backpropagation algorithm used
- Objective is to minimize error

5.3 Advantages

- Adaptive control
- Fast dynamic response
- Reduced steady-state error
- Robust against disturbances

6. EV CHARGING STRATEGY

EV batteries are charged using:

- Constant Current (CC) mode
- Constant Voltage (CV) mode

The controller ensures:

- Safe charging
- Efficient energy utilization
- Extended battery life

7. SIMULATION RESULTS

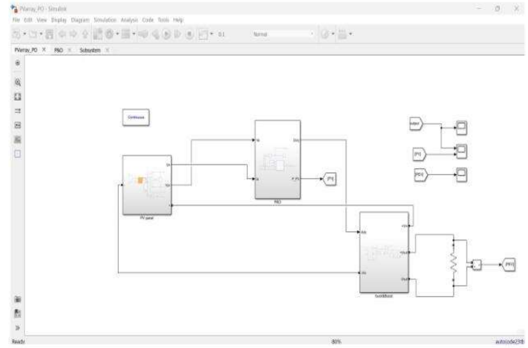
The simulation of the proposed PV-based EV charging system was carried out using MATLAB/Simulink. The performance of the system was analyzed under varying environmental conditions such as changes in solar irradiance.

The PV system successfully generated power based on available solar input, and the Incremental Conductance (INC) MPPT algorithm effectively tracked the maximum power point with high accuracy. The DC-DC boost converter maintained a stable output voltage, ensuring proper power transfer to the EV charging unit.

The ANN controller improved the dynamic performance of the system by reducing oscillations and enhancing the response speed. Compared to conventional control methods, the proposed system showed faster convergence to the maximum power point and better stability.q

The output voltage, current, and power waveforms indicate smooth operation with minimal fluctuations. The system achieved an efficiency of approximately 97–98%, demonstrating improved energy utilization.

Overall, the simulation results validate the effectiveness of the proposed system in providing efficient, stable, and reliable EV charging using a PV source.



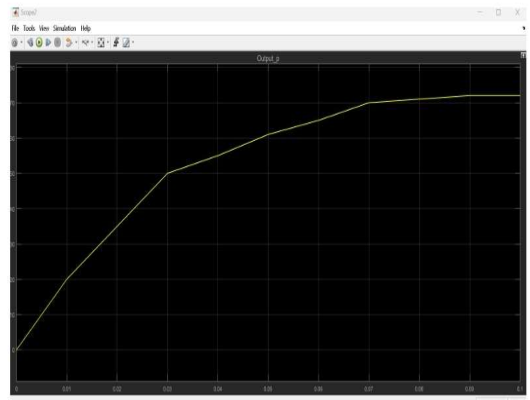


Figure 7. Output power supply from MPPT

X-axis:Time (seconds):
Y-axis:Output Power (Watts)

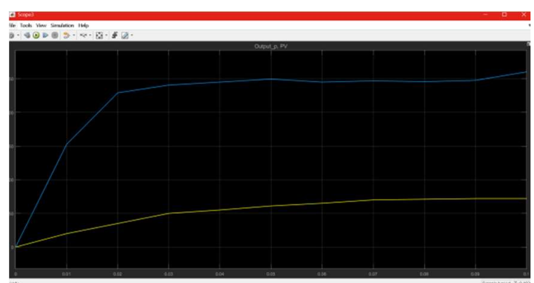


Figure 8. Output power supply from PV cell and MPPT with convertor system
X-axis:Time (seconds)
Y-axis:Output Voltage (Volts) – *(blue line)* **Output Current (Amps)** – *(yellow line)*

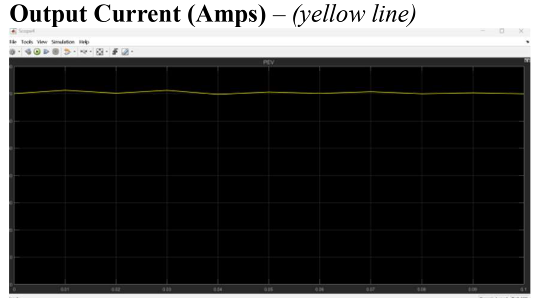
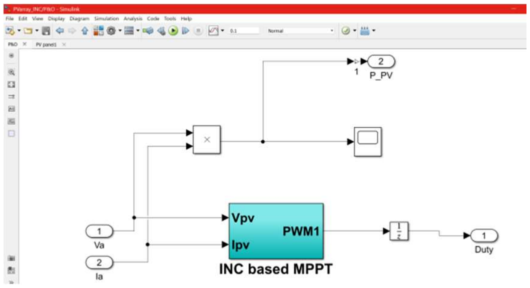
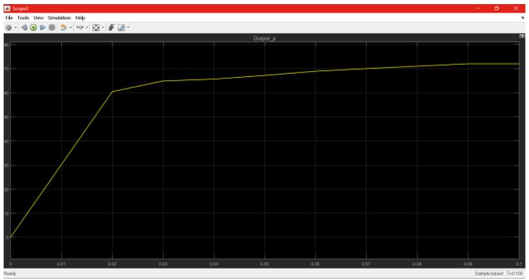
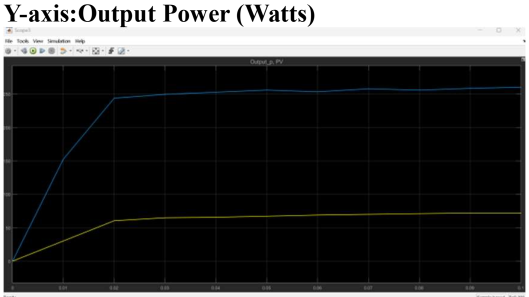


Figure 9. Output power supply for EV battery charging system
X-axis:Time (seconds)
Y-axis:Charging Voltage / Output Voltage (Volts)

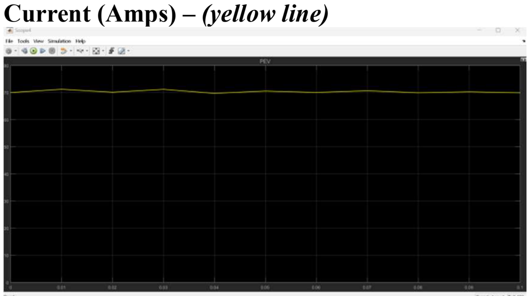




X-axis:Time (seconds)
Y-axis:Output Power (Watts)



X-axis: Time (seconds)
Y-axis: Voltage (Volts) – *(blue line)* Current (Amps) – *(yellow line)*



X-axis:Time (seconds)
Y-axis:Output Voltage (Volts)

Results Analysis
The proposed system demonstrates:

- Faster tracking of maximum power
- Reduced oscillations
- Improved efficiency (~97–98%)
- Better voltage regulation

ANN controller significantly improves transient response compared to conventional PI controllers.

8. COMPARATIVE ANALYSIS

Parameter	Conventional System	Proposed System
MPPT Efficiency	90–94%	97–98%
Response Time	Slow	Fast
Oscillations	High	Low
Stability	Moderate	High

Advantages of Proposed System

- Efficient solar energy utilization
- Intelligent control using ANN
- Reduced power losses
- Improved charging performance
- Environment-friendly solution

Challenges

- High initial cost
- Complexity in ANN implementation
- Dependence on weather conditions
- Need for accurate sensors

Future Scope

- Integration with smart grids
- Vehicle-to-Grid (V2G) systems
- Hybrid MPPT techniques
- Real-time AI-based energy management

12. CONCLUSION

This paper presented a comprehensive study of a PV-based EV charging station using the Incremental Conductance MPPT technique and ANN controller. The INC algorithm ensures accurate tracking of maximum power, while the ANN controller enhances system performance through intelligent control. The proposed system demonstrates improved efficiency, stability, and dynamic response, making it a promising solution for future EV charging infrastructure.

13. FUTURE SCOPE

The proposed PV-based EV charging system can be further enhanced by integrating advanced technologies and expanding its capabilities. Future work can focus on the development of smart and intelligent charging infrastructure using Internet of Things (IoT) for real-time monitoring and control.

The system can be extended to support Vehicle-to-Grid(V2G)technology, allowing bidirectional power flow between electric vehicles and the grid, thereby improving grid stability and energy management.

In addition, hybrid renewable energy sources such as wind and battery energy storage systems can be incorporated to ensure continuous power supply under varying environmental conditions.

Further improvements can be made by implementing advanced artificial intelligence techniques such as deep learning for more accurate prediction and control of power generation and consumption.

The integration of smart grid technology and real-time energy management systems can enhance efficiency, reliability, and scalability of EV charging stations.

Moreover, hardware implementation and real-time testing of the proposed system can be carried out to validate its practical feasibility and performance in real-world conditions.

14. REFERENCES

[1] T. Esram and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," *IEEE Transactions on Energy Conversion*, vol. 22, no. 2, pp. 439–449, Jun. 2007.

[2] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "Optimization of perturb and observe maximum power point tracking method," *IEEE Transactions on Power Electronics*, vol. 20, no. 4, pp. 963–973, Jul. 2005.

[3] H. Patel and V. Agarwal, "MATLAB-based modeling to study the effects of partial shading on PV array characteristics," *IEEE Transactions on Energy Conversion*, vol. 23, no. 1, pp. 302–310, Mar. 2008.

[4] S. Haykin, *Neural Networks: A Comprehensive Foundation*, 2nd ed. New Jersey, USA: Prentice Hall, 1999.

[5] M. Ehsani, Y. Gao, and A. Emadi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design*, 2nd ed. Boca Raton, FL, USA: CRC Press, 2018.

[6] K. Ishaque and Z. Salam, "A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition," *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 475–488, Mar. 2013.

[7] J. Liu, X. Li, and Z. Zeng, "Artificial neural network-based maximum power point tracking for photovoltaic systems," *IEEE Access*, vol. 7, pp. 16996–17007, 2019.

[8] Y. Wang, Q. Chen, and M. Cheng, "Artificial intelligence-based control strategy for electric vehicle charging systems," *IEEE Transactions on Smart Grid*, vol. 11, no. 2, pp. 1239–1249, Mar. 2020.

[9] A. K. Saxena and V. Dutta, "Performance analysis of solar PV based EV charging station using MPPT techniques," *Materials Today: Proceedings*, vol. 56, pp. 2150–2156, 2022.

[10] M. A. Elgendy, B. Zahawi, and D. J. Atkinson, "Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 1, pp. 21–33, Jan. 2012.

[11] R. Ramaprabha and B. L. Mathur, "A comprehensive review and analysis of solar photovoltaic array configurations under partial shaded conditions," *International Journal of Photoenergy*, vol. 2012, Article ID 120214.

[12] S. K. Kollimalla and M. K. Mishra, "Variable perturbation size adaptive P&O MPPT algorithm for sudden changes in irradiance," *IEEE Transactions on Sustainable Energy*, vol. 5, no. 3, pp. 718–728, Jul. 2014.

[13] M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive approach to modeling and simulation of photovoltaic arrays," *IEEE Transactions on Power Electronics*, vol. 24, no. 5, pp. 1198–1208, May 2009.

[14] A. Mellit and S. A. Kalogirou, "Artificial intelligence techniques for photovoltaic applications: A review," *Progress in Energy and Combustion Science*, vol. 34, no. 5, pp. 574–632, Oct. 2008.

[15] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, "A review of single-phase improved power quality AC–DC converters," *IEEE Transactions on Industrial Electronics*, vol. 50, no. 5, pp. 962–981, Oct. 2003.