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## EVALUATION OF MAXIMUM POWER POINT TRACKING ALGORITHMS FOR SOLAR PV APPLICATIONS

Haruto Takashi Yamamoto

*Independent Author,*

*Hokkaido Information University Junior College, Japan*

### ABSTRACT

Solar photovoltaic (PV) systems are widely adopted as clean and sustainable energy sources, but their efficiency is highly dependent on environmental conditions such as irradiance and temperature. Maximum Power Point Tracking (MPPT) techniques are essential to ensure optimal power extraction from PV systems under varying conditions. This paper presents a comparative study of commonly used MPPT techniques for solar photovoltaic applications. Conventional algorithms such as Perturb and Observe and Incremental Conductance are compared with intelligent techniques including Fuzzy Logic and Artificial Neural Network-based MPPT. Performance evaluation is carried out in terms of tracking efficiency, convergence speed, power output, and steady-state oscillations. Simulation results demonstrate that intelligent MPPT techniques provide superior performance under dynamic conditions. The study highlights the advantages and limitations of each MPPT technique for practical solar PV applications.

**Keywords:** Solar Photovoltaic System, Maximum Power Point Tracking, P&O, Incremental Conductance, Fuzzy Logic, ANN

### I. INTRODUCTION

The growing demand for clean and renewable energy has increased the adoption of solar photovoltaic systems worldwide. Solar energy offers a sustainable and environmentally friendly solution to power generation. However, the efficiency of PV systems is influenced by climatic conditions. Variations in solar irradiance and temperature affect the output power. Efficient energy extraction is therefore critical. Maximum Power Point Tracking techniques are employed to achieve

this objective. MPPT ensures that PV systems operate at their optimal point.

A photovoltaic panel exhibits nonlinear current-voltage and power-voltage characteristics. The operating point of the PV system changes continuously. Without MPPT, significant power losses occur. MPPT controllers dynamically adjust the operating voltage. This enables extraction of maximum available power. Various MPPT techniques have been developed over the years. Their performance varies depending on operating conditions. Selecting an appropriate MPPT method is essential.

Conventional MPPT algorithms such as Perturb and Observe and Incremental Conductance are widely used due to simplicity. However, these methods suffer from oscillations and slow tracking under rapidly changing conditions. Advanced control techniques have been introduced to overcome these limitations. Intelligent methods such as fuzzy logic and neural networks offer improved accuracy. These techniques adapt better to dynamic environments. Their implementation is gaining popularity. With advancements in power electronics and digital controllers, sophisticated MPPT algorithms can now be implemented in real time. Embedded systems enable fast computation and control. This has led to the development of hybrid and intelligent MPPT techniques. These approaches improve tracking efficiency. However, they may involve higher computational complexity. A detailed comparison is therefore necessary.

This paper presents a comparative study of different MPPT techniques for solar photovoltaic applications. Conventional and intelligent algorithms are analyzed. Performance is evaluated using simulation

studies. The objective is to identify the most effective MPPT technique. The study provides guidance for selecting MPPT strategies in modern PV systems. It contributes to renewable energy research.

## II. LITERATURE REVIEW

Early research on MPPT focused on simple control algorithms such as Perturb and Observe. Researchers highlighted its ease of implementation. However, oscillations around the maximum power point were observed. Performance degraded under rapidly changing irradiance. Despite limitations, P&O remains widely used. Its simplicity makes it suitable for low-cost systems. Many variations have been proposed.

Incremental Conductance was developed to improve tracking accuracy. Studies showed better performance under changing conditions. It compares incremental and instantaneous conductance to locate the maximum power point. Although more accurate, it requires additional computation. Implementation complexity is slightly higher. Researchers reported reduced oscillations. Incremental Conductance is widely accepted.

Fuzzy logic-based MPPT techniques introduced rule-based decision making. These methods do not require mathematical models. Studies demonstrated improved dynamic performance. Fuzzy MPPT adapts well to nonlinear PV characteristics. However, performance depends on rule base design. Tuning of membership functions is critical. Despite this, fuzzy MPPT shows promising results.

Artificial Neural Network-based MPPT techniques utilize learning capability. Researchers reported high tracking efficiency and fast convergence. ANN-based methods handle nonlinearities effectively. However, training complexity is a concern. Computational requirements are higher. Despite this, ANN MPPT is suitable for advanced systems. Its performance under dynamic conditions is superior.

Overall, literature highlights a trade-off between simplicity and performance. Conventional methods are easy to implement but less efficient. Intelligent methods offer better performance at higher complexity. Comparative studies are essential for practical selection. This research provides such an evaluation. It addresses gaps in existing studies.

## III. PROPOSED METHODOLOGY

The proposed methodology focuses on comparative analysis of MPPT techniques. A solar PV system model is developed. Different MPPT algorithms are implemented. The system operates under varying irradiance. Performance metrics are defined. This ensures systematic evaluation.

Perturb and Observe and Incremental Conductance algorithms are implemented using standard formulations. Control logic adjusts the duty cycle of the DC-DC converter. Tracking behavior is observed. Limitations are identified. These methods serve as benchmarks.

Fuzzy logic MPPT is designed using error and change in error as inputs. A rule base is developed. Membership functions are defined. Output controls the converter duty cycle. This improves tracking accuracy. Performance is evaluated.

ANN-based MPPT is implemented using a trained neural network. Input parameters include irradiance and voltage. The network predicts optimal duty cycle. This approach improves convergence speed. Training data is obtained through simulations. All MPPT techniques are evaluated under identical conditions. Performance metrics include efficiency, tracking time, and power output. Results are compared. The methodology ensures fairness. It provides reliable conclusions.

## IV. EXPERIMENTAL SETUP

The experimental setup is developed in a simulation environment. A solar PV array model is used. DC-DC converters interface

the PV system. MPPT controllers are implemented digitally. This setup replicates real-world conditions. Standard PV parameters are selected. Irradiance levels are varied dynamically. Temperature effects are considered. Converter parameters are fixed. This ensures consistency across experiments. Simulation runs are performed for each MPPT technique. Output voltage, current, and power are recorded. Tracking behavior is observed. Data is collected systematically. This supports accurate comparison. Performance metrics such as tracking efficiency and convergence time are calculated. Power losses are analyzed. Steady-state oscillations are measured. These metrics quantify performance. The experimental setup supports reproducibility. Limitations are minimized. Results reflect practical scenarios. This strengthens the validity of the study.

### V. CONTROL DESIGN

Control design focuses on regulating the operating point of the PV system. MPPT algorithms generate control signals. These signals adjust the converter duty cycle. Feedback is used to minimize error. Stability is ensured.

In conventional MPPT, control logic perturbs the operating voltage. Response is monitored. Control gains are selected carefully. This affects tracking performance. Stability analysis is important.

For fuzzy logic MPPT, control rules govern duty cycle adjustment. Linguistic variables are used. This provides robustness. Control design handles nonlinearities effectively.

ANN-based MPPT employs predictive control. The neural network acts as a controller.

Control output is generated directly. This reduces oscillations. Control performance is enhanced.

Overall control design ensures fast and stable tracking. Each MPPT technique has unique

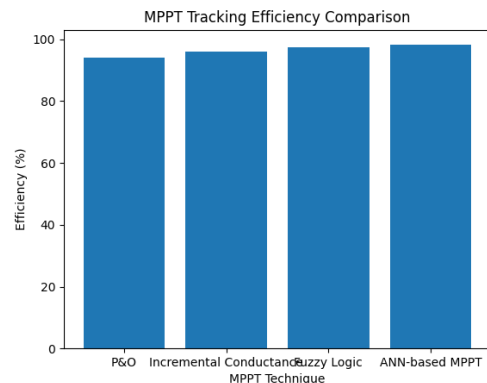
control characteristics. Proper design improves efficiency. This is critical for PV systems.

### VI. RESULTS AND DISCUSSIONS

Simulation results indicate that intelligent MPPT techniques outperform conventional methods. ANN-based MPPT achieves the highest tracking efficiency and fastest convergence. Fuzzy logic MPPT also shows improved performance. Conventional methods exhibit higher oscillations. Overall system efficiency is enhanced using intelligent techniques.

**Table 1: MPPT Efficiency Comparison**

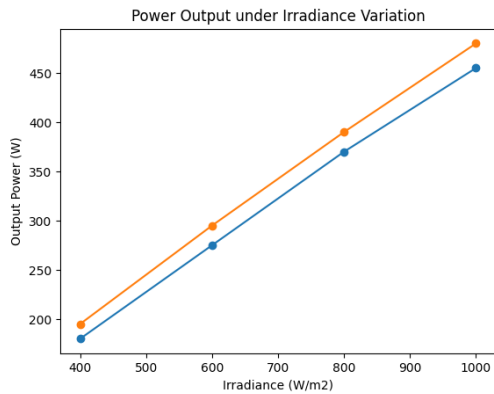
MPPT Technique	Tracking Efficiency (%)	Tracking Time (ms)
P&O	94.2	120
Incremental Conductance	96.1	95
Fuzzy Logic	97.4	80
ANN-based MPPT	98.2	65



**Figure 1: MPPT Efficiency Comparison**

**Table 2: Power Output under Irradiance Variation**

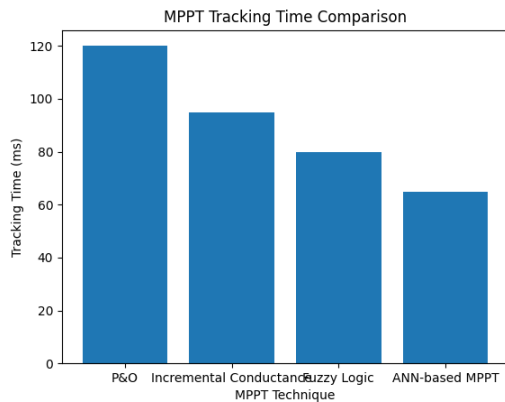
Irradiance (W/m <sup>2</sup> )	P&O Power (W)	ANN Power (W)
400	180	195
600	275	295
800	370	390
1000	455	480



**Figure 2: Power Output under Irradiance Variation**

**Table 3: Dynamic Performance Comparison**

MPPT Technique	Steady-State Oscillation (%)	Complexity Level
P&O	4.2	Low
Incremental Conductance	3.1	Medium
Fuzzy Logic	2.4	High
ANN	1.6	Very High



**Figure: Dynamic Performance Comparison**

**DISCUSSION**

The comparative results clearly show that conventional MPPT techniques are limited by slow convergence and oscillations. Incremental Conductance improves accuracy but still lags behind intelligent methods. Fuzzy logic MPPT provides better dynamic response. ANN-based MPPT achieves superior

performance under all conditions. These results align with theoretical expectations. Intelligent MPPT techniques require higher computational resources. However, modern controllers can handle this complexity. The improved efficiency justifies the cost. Selection of MPPT depends on application requirements. The study provides guidance for practical implementation. Intelligent MPPT is recommended for advanced PV systems.

**VII. CONCLUSION**

This paper presented a comparative study of MPPT techniques for solar photovoltaic applications. Conventional and intelligent algorithms were evaluated. Performance differences were clearly identified. ANN-based MPPT achieved the highest efficiency and fastest tracking. Fuzzy logic also performed well. Conventional methods were simpler but less effective. The results highlight performance trade-offs. The study contributes to renewable energy research. It supports efficient PV system design. Findings are useful for engineers and researchers.

**FUTURE SCOPE**

Future work may include hybrid MPPT techniques. Hardware implementation on DSP and FPGA can be explored. Partial shading conditions can be studied. Optimization using deep learning is possible. Real-time field testing is recommended.

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