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Comparison of Artificial Intelligence Based Maximum Power Point Techniques for Photovoltaic systems

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Abstract: *Modern photovoltaic (PV) system charge controllers commonly use Maximum Power Point Tracking (MPPT) technologies to advance specialist alteration effectiveness. The role of an MPPT regulator is to ensure that power drawn from the PV panels remains at its peak, even under changing weather conditions. This ensures optimal power transfer amid the planetary board and the connected consignment. Since temperature and solar irradiation levels fluctuate throughout the day, incorporating MPPT technology is essential for PV systems. As solar energy constitutes a significant portion of the global renewable energy market, advancements in MPPT methods can lead to increased system efficiency and reduced costs.*

However, traditional MPPT techniques often struggle to maintain efficiency under rapidly changing climatic conditions and may become trapped at local maxima rather than reaching the global maximum power point. Challenges such as stability, tracking speed, and accuracy can be addressed by adopting intelligent MPPT methods that leverage soft computing tools. This study focuses on comparing two AI-based MPPT techniques: Artificial Neural Networks (ANN) & Adaptive Neuro-Fuzzy Inference Systems (ANFIS). MATLAB simulations are used to evaluate the performance of these methods. Experimental results demonstrate that both ANN and ANFIS outperform conventional MPPT techniques by effectively avoiding local maxima and handling partially shaded conditions, thereby improving overall efficiency.

Keywords: *Fuzzy Logic, Maximum power point tracking, PhotoVoltaic, Artificial Intelligence,*

I. INTRODUCTION

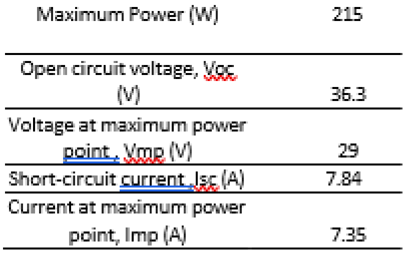
Renewable energy plays a central part in delivering supportable power to address the increasing demand for energy. Though, the routine of photovoltaic (PV) systems is significantly influenced by environmental factors, which can result in reduced efficiency and higher costs. To ensure extreme power transfer from PV boards below varying weather conditions, these systems need to operate at their Maximum Power Point (MPP). This is achieved through the use of a DC/DC convertor equipped by an brainy charge regulator, which adjusts the burden cycle of the PWM wave to reach the optimal operating point. The Maximum Power Point Tracking (MPPT) regulator continuously identifies the MPP using specialized algorithms, known as MPPT algorithms.

The MPPT process becomes particularly challenging under Partially Cool Conditions (PSC), where parts of PV array receive uneven solar irradiance due to obstacles like clouds. In such scenarios, traditional algorithms like Hill Climbing (HC), Incremental Conductance (InCnd), Perturb and Observe (P&O), Current Sweep, & Fractional Short Circuit Current (ISC) often get stuck at a Local Maximum Power Point (LMPP) instead of identifying the Global Maximum Power Point (GMPP). Limitation arises because these algorithms cannot effectively distinguish between LMPP and GMPP. To address these issues, advanced techniques have been developed. Artificial Intelligence (AI)-based MPPT methods have shown promising results, and researchers have also explored hybrid AI approaches to enhance tracking performance under complex conditions.

II. METHODOLOGY

A separate photovoltaic (PV) scheme will be developed, comprising a PV plate to capture lunar energy, a DC-DC convertor for energy regulation, an intelligent MPPT controller for efficient charge management, a PWM modulator, and a DC load. The MPPT regulator will implement two(2) artificial intelligence (AI)-based procedures: Artificial Neural Networks (ANN) & the Adaptive Neuro-Fuzzy Inference System (ANFIS). The entire impartial PV arrangement, depicted in Figure-1, willpower be planned & its functionality virtual using MATLAB software and the Simulink Toolbox. The performance of both AI-based methods will be evaluated and compared.

Table 1. PV Panel specification



Maximum Power (W)	215
Open circuit voltage, Voc (V)	36.3
Voltage at maximum power point, Vmp (V)	29
Short-circuit current, Isc (A)	7.84
Current at maximum power point, Imp (A)	7.35

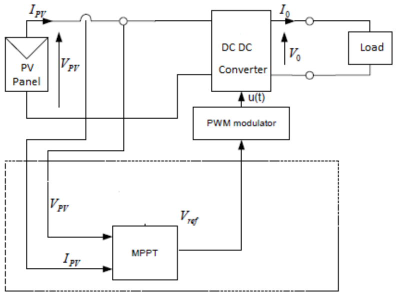


Figure 1. PV system

III. DISCUSSION

The modeling and recreation of a photovoltaic (PV) system in MATLAB below both slow and rapidly shifting climatic situations are illustrated in Figure 2.1. The setup uses a Soltech 1STH-215-P PV panel with a power capacity of 215 Watts, connected to a 48V DC increase converter. The tolerant DC yield from the PV panel is stabilized using the boost converter, which employs an IGBT as the switching device. The boost converter is designed with the succeeding specifications: input capacitor (C1) of 100 µF, output capacitor (C2) of 550 µF, and an inductor (L) of 300 µH. A 48V lead-acid battery serves as the load in the system.

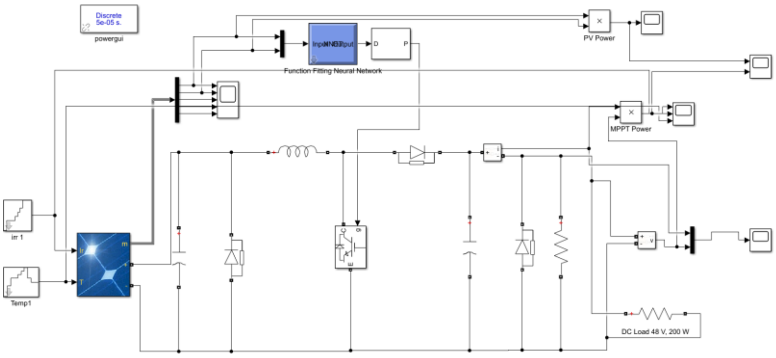
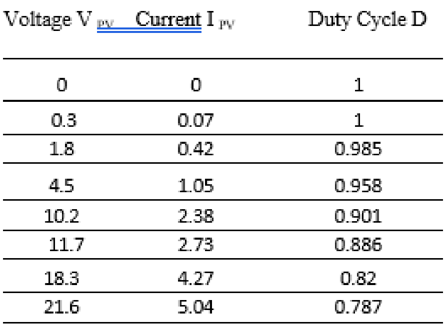


Figure 2. ANN MPPT PV System

Technical conditions of the SunPower SPR-305 PV board are provided popular Table-1, while the IV and PV performance curves of sheet are illustrated in Figure 3.

Table 2. Training data



Voltage V_{PV}	Current I_{PV}	Duty Cycle D
0	0	1
0.3	0.07	1
1.8	0.42	0.985
4.5	1.05	0.958
10.2	2.38	0.901
11.7	2.73	0.886
18.3	4.27	0.82
21.6	5.04	0.787

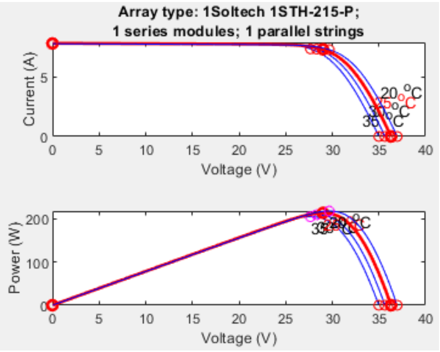


Figure 3. PV system panel characteristics

Table 2 presents a dataset of 132 samples that will be utilized for training Artificial Neural Network (ANN). The burden cycle is determined using method D=VoutVinD = \frac{V_{\text{out}}}{V_{\text{in}}}D=Vin Vout, with values ranging between 1 and 0.5. Symbol 4 exemplifies the relapse results of the role calculation performed by the ANN during testing.

IV. PERFORMANCE EVALUATION OF ANN MPPT BASED PV SYSTEM

Artificial Neural Network (ANN) is qualified by means of two input parameters: PV power and PV existing. A taster the drill statistics is provided in Table_1. The sheet voltage and current serve as the exercise inputs for the ANN, while the target yield is the obligation series (D). The Levenberg-Marquardt (LM) algorithm employed_as the exercise function. To evaluate how accurately the ANN can approximate the MPPT function, metrics such as mean square error (MSE) & the deterioration factor studied. Figure 4 illustrates an MSE value of 1.0779×10−51.0779 \times 10^{-5}1.0779×10−5, with the best act achieved at epoch 13. The forecast outputs demonstrate a strong fit to the training data, as indicated by the high relapse coefficient value of 0.99972, shown in Figure 5. These results suggest that implementing ANN in the MPPT controller enhances tracking competence.

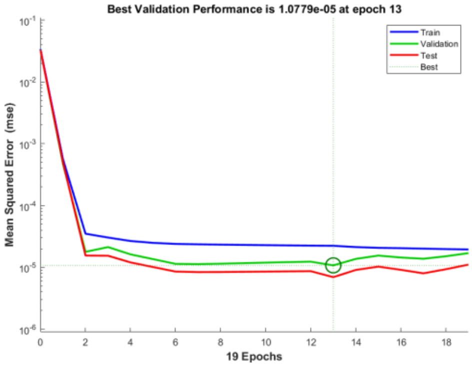


Figure 4.Mean Square Error

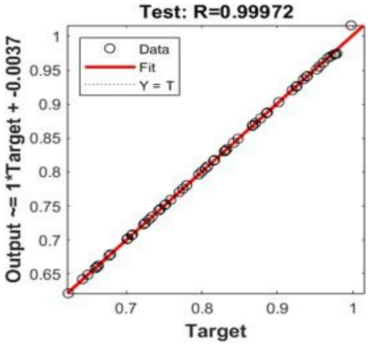


Figure 5. Regression of testing

The maximum power productivity from the board is recorded by way of 219W, while the power captured by the MPPT is 193.4W within a time frame of 0.804 seconds. The efficacy of the MPPT is determined by means of a specific formula and calculated to be 89.1%.

$$\text{Efficiencv}=\frac{Maximum\ popper\ tracked}{Maximum\ pnale\ popper}\text{X } 100\%$$

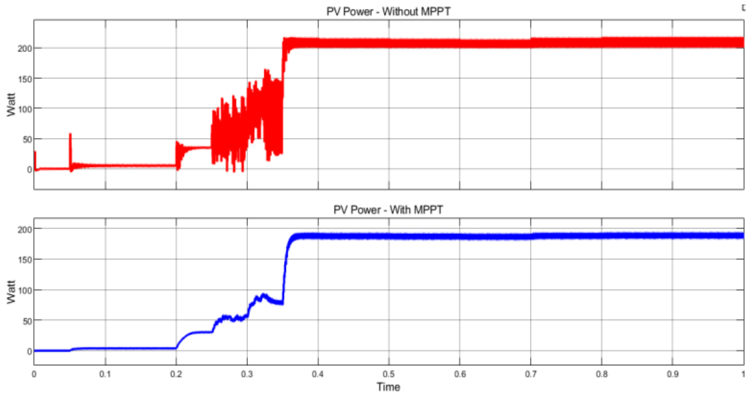


Figure 6.ANN MPPT performance

V. PERFORMANCE ANALYSIS OF ANFIS BASED MPPT

The Adaptive Neuro-Fuzzy Inference System (ANFIS) is a fuzzy logic-based extrapolation mechanism erected upon adaptive systems. It employs a amalgam methodology combining Artificial Neural Networks (ANN) and fuzzy logic, establishing a relationship between inputs and outputs based on predefined IN-O/P data sets. ANFIS leverages the advantages of both ANN and fuzzy logic, making it an effective general estimator for solving nonlinear dynamic hitches. The de_fuzzification process utilizes the centroid method to determine the duty cycle. ANFIS training was completed in two epochs with a Root Mean Square Error (RMSE) of 0.7×10^{-6}. The maximum power produced by PV panel was 217 W, while the MPPT tracked 203 W within 0.398 seconds. The MPPT productivity, planned using the given formula, was found to be 93.162%.

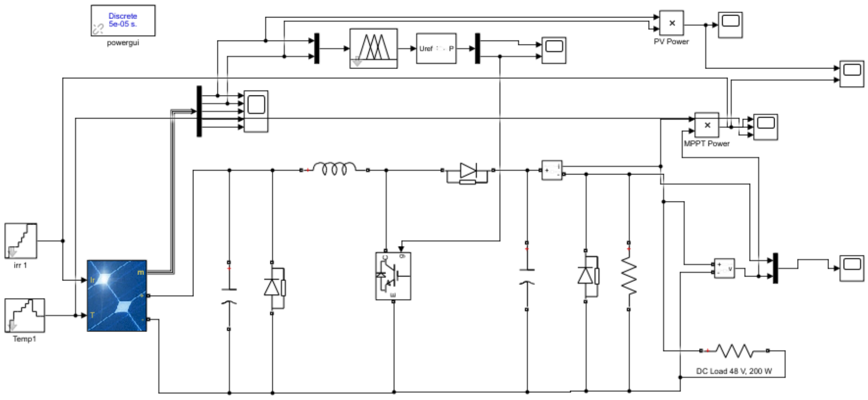


Figure 7. ANFIS MPPT based PV system

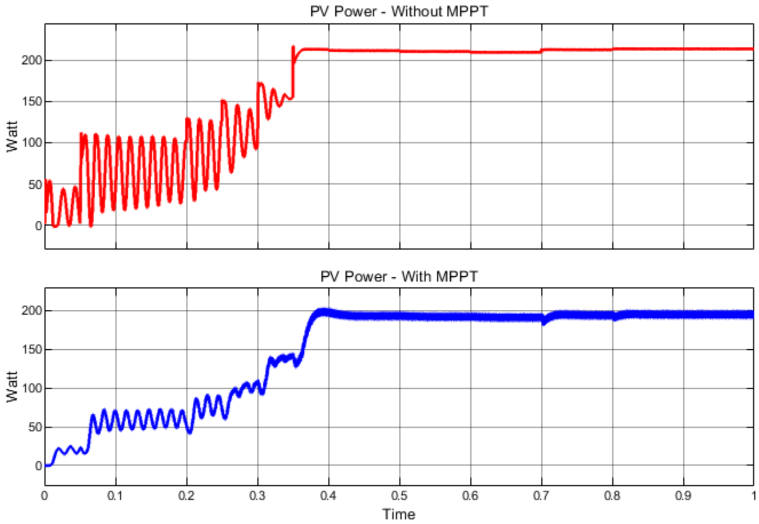


Figure 8. ANFIS MPPT performance

VI. Assessment of ANN & ANFIS

The results are potted in Table 1.

Table 1. Comparison of ANN & ANFIS Performance

Algorithm	Max Panel power Tracked	Maximum Power (W)	Tracking time(sec)	Efficiency (%)
ANN	219	193.4	0.802	89.124
ANFIS	217.9	203	0.392	93.162

Founded on the data accessible in Table_1, ANFIS_based MPPT controller demonstrates higher efficiency in tracking the maximum power point (MPP) linked to the ANN-based controller. The ANFIS controller also exhibits a faster tracking speed. When comparing the power outputs of the two methods, the ANN controller shows a smaller overshoot, while the ANFIS controller experiences greater oscillations but achieves a shorter settling time.

VII. CONCLUSION

Two Artificial Intelligence-based MPPT techniques, ANN and ANFIS, are compared. The findings show that AI-driven MPPT methods effectively path the maximum power point (MPP) level underneath moving weather environments and partial covering scenarios. ANN and ANFIS achieved efficiencies of 89.124% & 93.162%, respectively, thru following speeds of 0.802 Sec and 0.392 Sec. The ANFIS-based PV system demonstrated superior performance in terms of MPP tracking efficiency and hurry, being nearly twice as fast as ANN. ANFIS also eliminates issues like the intensive training requirements and overfitting problems often associated with ANN. Both methods can avoid being surrounded in resident MPPs through partial covering and minimize vacillations around MPP through rapidly changing climatical situations. However, under such conditions, a robust training phase is necessary. Integrating hybrid search techniques could further enhance the efficiency of MPPT controllers.

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