



MACHINE LEARNING ALGORITHMS FOR ENHANCING MPPT IN CLEAN ENERGY SYSTEMS

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ABSTRACT

Artificial Intelligence (AI) and Machine Learning (ML) play a crucial role in improving clean energy systems, particularly solar energy. This study proposes a data-driven MPPT approach using a regression tree algorithm in photovoltaic (PV) systems. A novel dataset, built from high-resolution experimental data under various environmental conditions, served for training and validation. The ML model achieved 96% accuracy in predicting optimal operating parameters. This AI-based framework enables dynamic and precise estimation of the Maximum Power Point (MPP). The system enhances overall efficiency and supports the clean energy transition. Realtime model deployment confirms its practical feasibility. The method shows potential for integration into smart solar regulators. The approach offers adaptive control and improved sustainability. This research highlights the synergy between ML and clean energy technologies.

Keywords: Maximum Power Point Tracking MPPT, Machine Learning, Artificial Intelligence, Clean Energy Optimization, Intelligent Control Strategies.

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1. INTRODUCTION

The creation of systems that can mimic human intelligence is the focus of the specialized field of computer science known as artificial intelligence (AI). Its main goal is to enable computers to solve complex problems consistently and reproducibly. Computer scientists help machine learning processes that allow for autonomous improvement based on processed data by

creating customized algorithms [1]. AI has a widespread impact on many aspects of our lives and communities, most notably in the automation of a wide range of industries like renewable energy. Furthermore, AI's various subfields and algorithms help to improve analytical abilities. As an example, AI applications include solar system fault detection and solar energy production prediction [2,3,4]. Among the emerging technologies, machine learning stands out.

To predict Maximum Power Point Tracking (MPPT), we use a machine learning model in this study—more precisely, the regression tree model. The data used comes from experimental measurements made under various sun and temperature conditions. The effectiveness of the developed model is demonstrated by its remarkable 96% accuracy score. Additionally, a specialized platform for visualizing I(V) and P(V) graphs in various environmental settings has been developed, along with MPPT predictions based on these visual representations.

2. MACHINE LEARNING FOR MPPT TRAKING

An Only 30 to 40 percent of incident solar radiation is converted into electrical energy by a typical solar panel. The Maximum Power Point Tracking (MPPT) technique is used to increase this efficiency [14] [15]. [16]. The first step in the machine learning process is gathering data, which is then sorted and prepared for use as training data. This data serves as the informational foundation for the development of machine learning models. The quantity of training data frequently has a positive correlation with these models' effectiveness [1]. There are several different learning paradigms in machine learning, but supervised learning is the most common. By using labeled datasets to train algorithms, supervised learning makes it easier to classify data or make precise predictions about results. By using a training set of input-output pairs, it is possible to (see Fig. 1).

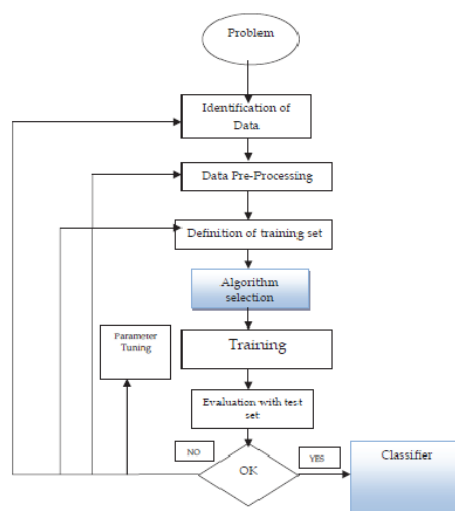


Fig. 1. Supervised learning process.

2.1. Methodology

The workflow depicted in Fig. 2 comprises several key stages. Initially, we focus on dataset preparation, a critical aspect of the machine learning process. Subsequently, we proceed to construct our machine learning model, followed by subjecting the dataset to rigorous training procedures to extract predictive values. Lastly, we deploy the trained model onto a designated platform to optimize the extraction of the maximum power point.

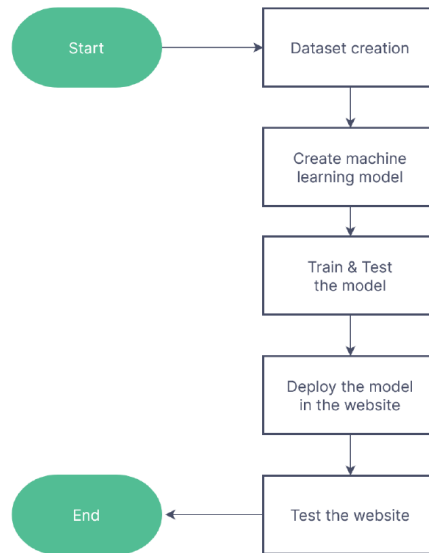


Fig. 2. Workflow Diagram

2.2 Dataset Collection

Engineering scientists place a high value on data, especially when it comes to machine learning and its many uses. The quality and applicability of the data used determine how accurately a model is trained. As shown in Table 1, real-time experimental electrical measurements of voltage (V) and current (I) are used in this investigation.

Table 1. Experimental electrical measurements of current and voltage

I₁(A)	V₁(V)	I₁(A)	V₁(V)	I₁(A)	V₁(V)
0	98.0	1.30	89.0	2.40	79.0
0.32	96.0	1.40	88.0	2.50	77.0
0.40	95.0	1.50	87.5	2.60	75.0
0.50	95.5	1.60	87.0	2.70	72.5
0.60	94.0	1.70	86.0	2.75	70.0
0.70	93.5	1.80	85.0	2.80	66.5
0.80	93.0	1.90	84.0	2.85	63.0
0.90	92.0	2.00	83.0	2.9	62.0
1.00	98.0	2.10	82.0	2.95	56.0
1.10	90.5	2.20	81.0	3.00	47.0
1.20	90.0	2.30	80.5		

I'₁(A)	V'₁(V)	I'₁(A)	V'₁(V)	I'₁(A)	V'₁(V)
0.00	96.0	1.30	86.0	2.40	74.0
0.32	94.0	1.40	85.0	2.45	73.0
0.40	93.5	1.50	84.0	2.50	71.0
0.50	93.0	1.60	83.0	2.55	70.0
0.60	92.0	1.70	82.0	2.60	66.5
0.70	91.0	1.80	81.0	2.65	61.5
0.79	90.5	1.90	80.5	2.70	55.0
0.90	89.0	2.00	79.0	2.75	120.5
1.00	88.0	2.10	78.5	2.80	0.0
1.10	87.5	2.20	77.5		
1.20	87.0	2.30	76.0		

I''₁(A)	V''₁(V)	I''₁(A)	V''₁(V)	I''₁(A)	V''₁(V)
0.00	99.0	1.09	85.0	1.67	68.0
0.30	95.0	1.16	84.0	1.68	66.0
0.37	94.0	1.20	83.0	1.69	64.0
0.46	93.0	1.30	81.5	1.70	57.0
0.58	92.0	1.40	79.0	1.72	43.0
0.62	91.0	1.49	77.0	1.74	32.0
0.70	90.0	1.55	75.0	1.75	10.0
0.75	89.0	1.60	73.0	1.77	0.0
0.85	88.0	1.62	70.0		
0.90	87.0	1.62	70.5		
1.00	86.0	1.66	69.0		

Measured current and voltage values of a solar panel are shown in the table as (I1, V1), (I'1, V'1), and (I''1, V''1), respectively, under different irradiation conditions of 83, 70, and 83 W/m² [2].

The construction of our dataset, which is necessary for training the machine learning model, is guided by the first two tables. Through the use of specified equations, they enable the extraction of additional inputs from the dataset.

The third table, meanwhile, is used to assess the effectiveness of the model. Three important parameters are included in our dataset: temperature (T), maximum power point (Pm), and irradiance (Ei). A range of temperature and irradiance values is necessary to create this dataset.

Five modules, specifically the LA361K51 SI-polycrystalline type with an open circuit, make up the photovoltaic panel (PVP).

$$I_2 = I_1 + I_{cc} * (E_2/E_1 - 1) + \alpha * (T_2 - T_1) \quad (1)$$

$$V_2 = V_1 + \beta * (T_2 - T_1) - R_s * (I_2 - I_1) - K * I_2 * (T_2 - T_1) \quad (2)$$

Where:

$\alpha = 1.6e-3$ A/°C (coefficient of the influence of the temperature on the current)

$\beta = -7.8e-2$ V/°C (coefficient of the influence of the temperature on the voltage)

$R_s = 0.4 * 5$ Ω (serial resistor)

$K = 5.5e-3$ Ω /°C (correction factor of the curve)

(I1, V1): a characteristic of reference at E1=83% and T1=30°C.

With this assumption, we get a dataset of 19393 records.

3. IMPLEMENTATION AND RESULTS

3.1. Methodology

As mentioned in the previous section, we employed a supervised machine learning algorithm—more precisely, a regression tree—to carry out our analysis. The open-source scikit-learn (sklearn) library, version 1.3.0, was used for the modeling process. The actions taken are described in the code snippet that follows.

```
import pandas as pd
from sklearn.tree import DecisionTreeRegressor
from sklearn.model_selection import train_test_split
```

We fixed the size of test records to be 20% of the whole data. After that, we fit our model with training records [1]. Upon executing the model, we obtained a commendable accuracy score of 96% when comparing the actual target values from the dataset with the values predicted by the model [1].

```
model1.score(Xtest,ytest)
✓ 0.0s
0.9651539443867421
```

Furthermore, leveraging this trained model, we proceeded to predict optimal power point values corresponding to varying levels of irradiance and temperature conditions [1].

3.2. PV SMART Platform Implementing

Our goal with this PV SMART platform was to illustrate the power-voltage (P-V) and current-voltage (I-V) properties of photovoltaic panels (PVP) while clarifying the impact of temperature and irradiance. We also aimed to define the difference between the P(V) and I(V) curves, the following figure (Fig 3) represents the process behind the Original Graph button.

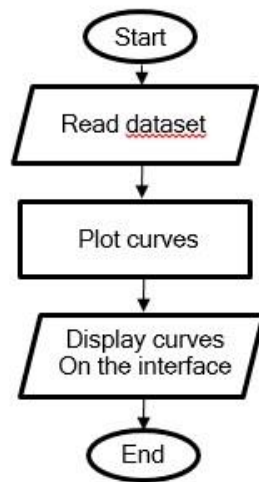


Fig. 3. Flowchart of Original Graph button process. [1]

The regression model, which is intended for maximum power point tracking (MPPT) prediction, was also incorporated into our platform, which consists of both front-end and back-end elements.

The interface of the platform has a sidebar with buttons that allow the creation of relevant data, such as the I(V) and P(V) graphs for varying temperatures and irradiation levels, as well as the predicted MPPT value obtained from the regression tree model.

In addition to visual representations of the I(V) and P(V) curves, the main section of the interface shows the temperature and irradiation values associated with each generated graph. This interface's development made use of HTML, CSS, and JavaScript. Flask version 2.3.2 and Python version 3.11.4 were used on the back-end [1]. The used data was processed appropriately and saved in an Excel sheet. The platform dynamically displays the I(V) and P(V) graphs on the interface along with the corresponding irradiance and temperature values when the "original data" button is clicked (Fig. 4).

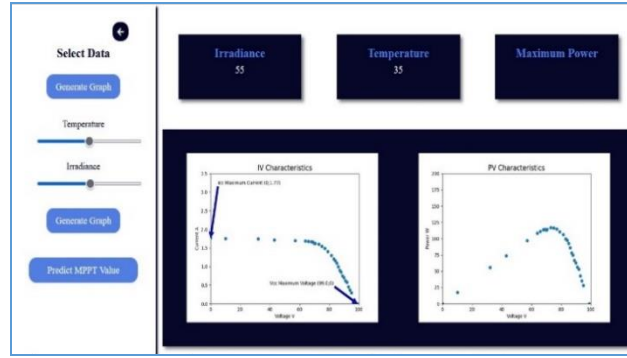


Fig. 4. I(V) and P(V) characteristics for $E_1=55\%$, $T_1=35^\circ\text{C}$

The platform then creates different graphs by altering the temperature and irradiance values and selecting the "generate graph" button, providing more information about the behavior of the system (Fig. 5).

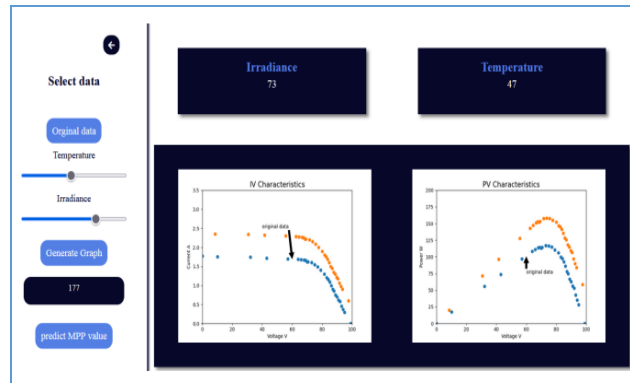


Fig. 5. I(V) and P(V) characteristics for $E_2=73\%$, $T_2=47^\circ$

Lastly, by selecting the "predict MPPT value" button, the platform allows users to predict the maximum power point for the generated graph, as shown in Fig 6.

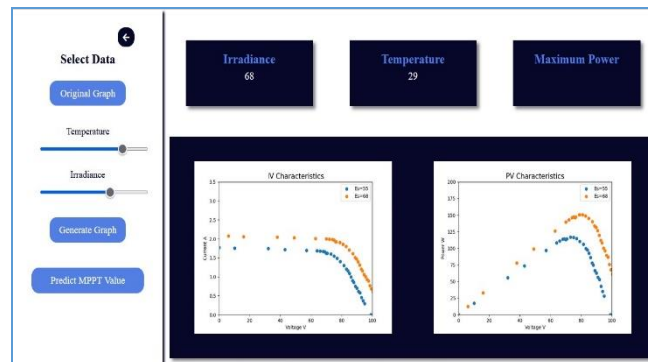


Fig. 6. The predicted value of maximum power point (P_m).

4. CONCLUSION

We forecasted the maximum power point in our study using a regression tree model. Even though measurement discrepancies cause a discernible difference between the model's predicted values and actual measurements, the model nevertheless received a respectable accuracy score of 96%.

In addition, we created a platform that can display PV (power-voltage) and IV (current-voltage) graphs at different temperatures and radiation levels. Based on the information obtained from these graphs, this platform makes it easier to predict the maximum power point.

Furthermore, our study demonstrates how artificial intelligence can identify solar system flaws. To maximize the effectiveness of these eco-friendly systems, we stress the significance of maximum power tracking. Furthermore, we emphasize how intelligent systems can be used to predict future solar

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