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# ANN-based Maximum Power Point Tracking Technique for PV Power Management under Variable Conditions

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**Abstract**
Due to the increasing energy demand, traditional fossil fuels are gradually decaying day by day as analyzed by many researchers. Fossil fuels are not sufficient to fulfil the requirement of energy demand and it also produces greenhouse gas emissions. In this regard, worldwide research is going on related to renewable energy sources (RESs) like solar photovoltaic (SPV), wind turbines, fuel cells etc. The source of SPV is plentiful and environment friendly which converts solar radiation to non-linear electrical power. This power is not suitable for a stable system. Therefore, the maximum power point tracking (MPPT) controller is required to find the optimum maximum power point (MPP) to the load. The MPPT technology regulates the duty-cycle in favour of the DC-DC converter to continuously obtain maximum power from the SPV arrays. In the past few decades, the learning of MPPT techniques has made substantial progress in the RESs. This research article analyzes the performance of various MPPT techniques in the proposed SPV framework. The main investigation is to assess different MPPT techniques to optimize power from the SPV framework. The artificial neural network (ANN)-MPPT method has been observed to be more effective in output power production and transient response about the MPP than conventional perturb and observe (P&O)-MPPT and fuzzy logic controller (FLC)-MPPT technology.

**Keywords-** SPV array, DC-DC converters, MPPT technology, ANN, FLC, P&O.

## 1. Introduction

RESs play an important role in intersecting the rising demand for electric power with clean and green energy and reducing carbon emissions. The SPV frameworks connect sunlight and convert it directly to electrical energy using solar cells which comprise semiconductor materials like silicon. However, the power output of SPV frameworks is favourably dependent upon ecological circumstances such as irradiation and temperature, leading to varying energy yields. A hybrid configuration of an SPV power generating system with added RESs including wind (or tidal power) is possible. The energy from the sun is directly converted into usable electricity by an SPV panel (Eltawil and Zhao, 2013). The conversion efficiency of commercial SPV panels ranges from 7 to 19% only, which is a disadvantage of SPV systems (Dincer, 2011). It is not cost-effective to modify an SPV cell's structure to increase conversion efficiency. In other words, the MPPT technology is used to optimize the SPV power. The SPV system is developed to achieve maximum efficiency using the various MPPT technologies. It is used to maximize the output power of SPV panels through determinations of the conduction mode of the power boost converter (Noman et al., 2023). MPPT controller is developed to yield the MPP from an SPV panel using variable environmental conditions. Since MPP depends on abundant temperature and solar radiation of the SPV framework. Many researchers have investigated various MPPT technologies for achieving extreme power from SPV frameworks. In this regard, P&O, incremental conductance (IncCond), fractional open circuit voltage and fractional short circuit current are MPPT techniques to determine the MPP from RESs (Hassan et al., 2023). In favour of P&O with a variable step, this MPPT technique produces a better output response as compared to the other specified techniques (Mohammadinodoushan et al., 2021). MPPT controllers control the duty-cycle in favour of the power converter to obtain the maximum power from SPV frameworks. It follows the network theorem of maximum power transfer which matches the load impedances with the source impedances.

In general, MPPT technique performs a smooth output response of SPV array in terms of steady-state conditions and also improves the response in transient-state conditions during partial shading conditions (PSC) (Yadav et al., 2023). The traditional P&O technique is an easy and simple implementation in RES which can achieve maximum power with fluctuations about MPP from SPV frameworks. On the other hand, advanced MPPT techniques have offered better performance as compared to traditional P&O techniques using variable environmental conditions (Khan et al., 2022a). SPV framework is a primary source of renewable energy which is used in rural electrification using optimization techniques (Sangeetha et al., 2024). It makes a green energy solution for obtaining optimal power generation to the load and provides benefits to the global environment (Bhandakkar et al., 2023; Karad et al., 2024). There is produced no waste and also reduced greenhouse gas emission (Irfan et al., 2019). Presently, it is a market that had an annual growth rate of around 30% in the first half of the decade (Blaabjerg and Ionel, 2015). The main advantages of the SPV arrays are their long life and minimal maintenance cost. An SPV power generation system can also benefit the economics of agriculture, healthcare, education and housing (Javed and Ishaque, 2022).

SPV frameworks using different MPPT technologies can be used in grid-connected systems as well as for rural electrification (or remote areas) where a grid is not available. The SPV arrays convert the electrical energy from solar energy (Bensmail et al., 2015). In order to assert the process of SPV framework management, numerous MPPT technologies have been developed and established. MPPT technology can track the MPP with the fewest variances. The MPP is often determined using the P&O, IncCond, and hill climbing approaches (Mishra et al., 2021). Conventional algorithms are easily implementable with digital or analogue equipment. However, traditional algorithms have drawbacks such as poor dynamic performance, low efficiency, and steady state power oscillations. Therefore, investigators presented a novel MPPT technology based on linear tangents P&O (LT-P&O) which is constructed in MATLAB/ Simulink and validates their performance with hardware implementation. The simulation results demonstrate that the suggested algorithm performs superior as compared to traditional methods in favour of accuracy, efficiency and stability with low oscillation and dynamic performance. These control strategies give poor performance when the variation in the environmental conditions. In favour of the improvement in the research that new MPPT technologies are investigated such as FLC and artificial intelligence (AI) based MPPT technologies (Roy et al., 2021), Adaptive Neuro-Fuzzy Inference System (AN-FIS)-MPPT (Kumar et al., 2019; Moyo et al., 2021; Padmanaban et al., 2019). Similarly, scholars investigated the grey wolf optimization (GWO)-MPPT which is intended for assessing the optimal value in favour of unrevealed constraints of the SPV modules (Sharma et al., 2021). The Weibull - probability density function (PDF) is used to devise uncertainties which are associated with the wind although Beta - PDF is used to simulate the SPV ambiguity (Salkuti, 2021). The main goal of this investigation is to establish the ability of the SPV frameworks to maximize power extraction by altering irradiation conditions and a fixed temperature. A new circle-search algorithm has been proposed that uses super-twisting sliding-mode control in order to track MPP (100 kW) from SPV panels for commercial grid-connected framework management. This algorithm is integrated with a battery storage framework that smoothens output fluctuations. The scholars have found that their proposed method is more robust, tracks the MPP faster, converges to the minimum error value that is more efficient, and maximizes the extracted power from the SPV systems better than other specified methods (Ghazi et al., 2024). To develop the proposed horse herd optimization MPPT which produced better enhancement as compared to other various MPPT technologies for the SPV framework under fast alerting solar radiation and PSC (Ghazi et al., 2024). This MPPT technique achieved the MPPT efficiency of 98.1% and reduced the power fluctuations of 1.91% in stable and constant output power for the SPV framework at a tracking time of 2.2s. The adaptive terminal synergetic backstepping MPPT provides satisfactory results for the SPV framework than other specified adaptive integral backstepping MPPT using the same ecological situations (de Dieu Nguimfack-Ndongmo et al., 2024). Researchers proposed the modified heterogeneous-multiswarm particle swarm optimization to improve its robustness, high accuracy, and reduced functions for SPV systems as compared to other specified MPPT technologies (Ben Regaya et al., 2024). The model reference adaptive control MPPT yields the tracking efficiency of 99.77% and 99.69% in alteration of temperature and irradiations respectively with a simulation time is 3.6ms. This methodology is faster than 10 times from IncCond and 12 times from P&O MPPT (Manna et al., 2023). A novel GUI tool is designed to increase the understanding of various MPPT technologies for the SPV frameworks. It is executed and utilized in power electronics applications (Kayisli et al., 2024). Synchronous MPPT in the differential power processing method is applied to the dominant part of the system coupling using the decoupling method. This method provides the most targeted decoupling and also reduces the complexity of the decoupling. The synchronous MPPT technique is simulated and implemented in the SPV framework which is used to enhance the efficiency and decrease the tracking time of suggested MPPT (Xu et al., 2023). A reduced-order extended observer is developed to assess the output resistance of the DC-DC boost converter for the SPV panel. It is simulated and their experimental validation results demonstrate the output response using the passivity MPPT controller as compared to the IncCond under variations conditions such as irradiations, abundant temperature for the SPV panel (Linares-Flores et al., 2023). The sliding mode controller (SMC) consists of two control loop technologies (input-voltage control loop which computes the current of an inductor and current-control loop which computes the duty cycle of switching frequency). This method has been developed for an SPV framework that obtains the responses of reduction in settling time, overshoot and steady-state error which is compared to lead-lag and sliding mode proportional-integral methods (Inomoto et al., 2022).

Various MPPT techniques are investigated and compared with the following output power and voltage of proposed SPV frameworks. And choose the better MPPT system for achieving MPP of particular RES like SPV arrays by MATLAB simulation and analyzing the appropriate results under ecological conditions. In this research article, the novel SPV system comprises several components such as an SPV panel, a boost converter, various MPPT controllers, and load ($R_L$). The MPPT technologies such as P&O-MPPT, FLC and ANN are used to determine the optimum duty cycle for the boost converter. ANN-based MPPT techniques do not necessitate complete information on the interior architectures in favour of SPV frameworks. This means it provides less computation effort and more compact response. The comparative analysis of simulation results is explained using the P&O-MPPT and ANN-MPPT techniques for the proposed SPV frameworks and also compared by using FLC-based MPPT (Khan and Mathew, 2017). The proposed block diagram of the SPV using a boost converter and different MPPT technologies is shown in **Figure 1**. SPV panels, which use SPV panels convert solar renewable energy into electrical energy, have long been one of the best ways to obtain electrical power. SPV systems are used for a variety of purposes nowadays, including lighting, water pumping, battery charging, satellite power systems, and so on.

The residue of this research article is as follows: novelty of works is described in Section 2, the detailed explanation of P&O, FLC and ANN-MPPT technologies are discussed in Section 3, Section 4 represents the MATLAB/Simulation of SPV System using various MPPT Techniques, Section 5 provides the analysis of results and discussions, Section 6 demonstrations the conclusion.

## 2. Novelty of the Work

The primary goal of this research article is extreme the power production from an SPV panel under variable irradiations. An MPPT technique plays a vital role in obtaining power from SPV generators as they push the MPP available regardless of ongoing variations in irradiation conditions. The MPPT methods ensure the identification of the higher efficiency of the DC-DC power conversion to the Thus, in the global SPV system, MPPT controls the highest level of the system's efficiency. Using a DC-DC boost converter, the DC voltage generated from the SPV system is elevated. Different MPPT algorithms operate these trackers with the P&O technique which is receiving the most attention because it is so easy to implement within microelectronic programmable tracks. This examines and operates a proposed model that includes a variety of environmental variables to examine how an MPPT tracker controlled SPV panel output behaves. A simulation of a proposed framework in the MATLAB/Simulink program is performed after describing the components and functions of the proposed integrated system to verify its advantages.

The following is the block diagram of an ANN MPPT for an SPV array:

- ***SPV-Panel*:** The proposed framework's power source is the SPV modules. It turns solar energy into electrical energy.
- ***Sensors*:** Sensors are used to sense the values of voltage and current of the SPV modules. The ANN-MPPT uses this information to monitor the MPP.
- ***ANN MPPT Controller*:** The system's brain is the ANN controller. It is a neural network that has been taught to recognize the MPP in different operating circumstances. The ANN–MPPT uses the sensor's data to determine the duty cycle of the DC-DC power boost converter.
- ***DC-DC Converter*:** The duty cycle of the DC-DC power boost converter is regulated by the ANN-MPPT which adjusts the voltage from the SPV panel to the load voltage.
- ***Load*:** The proposed system produces the power response by the SPV array is known as a load. It could be a battery, a motor, or something else electrical framework.

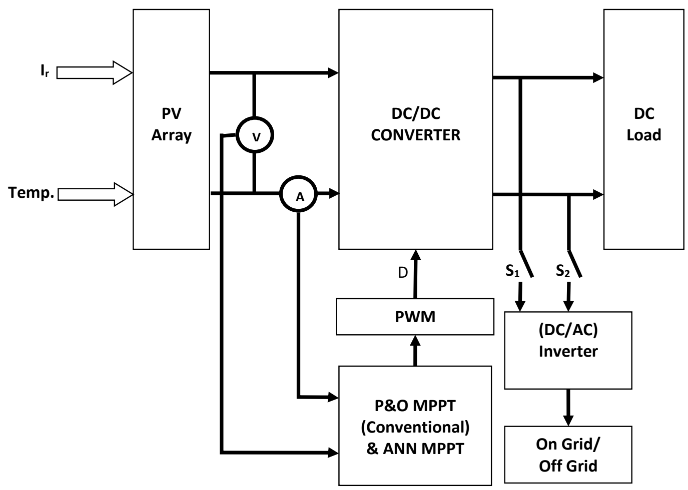


**Figure 1.** Proposed SPV model using various MPPT algorithms.

The manuscript provides the following contributions.
(i) To develop the proposed SPV model with the power converter using various MPPT systems.
(ii) Using the data acquisition arrangement to acquire data from the experimental setup.
(iii) To determine the optimum power using the SPV framework under different environmental situations.
(iv) Analyzing the proposed framework in comparison with different MPPT technologies.

## 3. Methodology

MPPT technologies are employed to determine the maximum output response by regulating the duty-cycle of the boost converter which matches the source impedance with the load impedance for the SPV framework.

### 3.1 Conventional P&O MPPT Technique

P&O schemes are typically chosen because it is inexpensive, easy to establish, require minimal maintenance, and require little supervision. Based on their reference perturbation parameter, P&O may be broadly divided into three types such as direct duty ratio perturbation, voltage perturbation, and current perturbation. Because P&O is not affected by temperature, exposed irradiance (or SPV characteristics), its operation only requires basic computational processes. MPPT frequency sometimes referred to as perturbation frequency is the number of perturbations per second (Elgendy et al., 2012). SPV system power output is frequently maximized using the P&O-MPPT. The parameters of the P&O-MPPT control technique are modest, dignified, and use a humble feedback arrangement. The SPV module's voltage is specified periodically as a perturbation in the P&O-MPPT, and the corresponding power response of the framework is matched by the previous perturbation cycle (Necaibia et al., 2019). This P&O - MPPT technology is commonly used for the SPV modules. The following steps of the P&O-MPPT technology are described below.

***Step* 1:** Measure and Calculate **-** The framework starts by sensing the value of voltage and current of the SPV panel. Sensed values are multiplied to estimate the output response power.
***Step* 2:** Perturbation **-** The operating voltage of an SPV array is intentionally changed through a small increment of the perturbation. It is often completed by regulating the duty cycle for a boost converter.
***Step* 3:** Observation **-** The framework senses the output response power again after the perturbation.
***Step* 4:** Compare and Decide **–** This technique compares the power attained after a perturbation with the power before.
***Step* 5:** Power Increases **-** If power is increased after the perturbation, it indicates the power of the system is touching about the MPP. If perturbation is in the same direction, then it is repeated to further approach the MPP.
***Step 6*:** Power Decreases **-** If power is decreased after the perturbation, it indicates the power of the system has moved away from the MPP. If the perturbation is in a reversed direction, then it gets back on track towards the MPP.
***Step* 7;** Repeat **–** The process of perturbing, observing, comparing and deciding is continuously repeated. The size of the perturbation can be adjusted to achieve a balance between fast-tracking and minimizing fluctuations in the MPP. The P&O-MPPT is a good starting point for MPPT due to its simplicity. However, advanced techniques can offer better performance under certain conditions.

### 3.2 FLC - MPPT Technique

The FLC-MPPT is a method used for standalone photovoltaic arrays. This method simplifies the computation of the duty-cycle to boost converter by using changing voltage and current due to variations in the environmental conditions. In simulations, the FLC - MPPT technique performed well as traditional P&O-MPPT in terms of the dynamic and steady-state performance of the SPV framework. Regulations were established to ensure the stability of the framework. An analysis of the stability performed by Mamdani FLC –MPPT is described based on Lyapunov's theory. The gathered data indicates FLC can trajectory the MPP and perform better than the P&O – MPPT (Khan and Mathew, 2017). In FLC-MPPT, the initial step involves fuzzification of the inputs which typically consist of errors and their variations (Khan et al., 2022b). The user can choose how to identify these errors and changes in them, providing several degrees of freedom. Next, the fuzzy logic stage computes and translates the error and its variations into linguistic variables which are then looked up in the table of the rule base. The response of this stage is often a variation in the duty ratio of the dc-dc power converter. In case of an error, the output of the FLC from the earlier stage needs to be rehabilitated from the linguistic variable into numerical value in the final step of defuzzification (Baramadeh et al., 2021; Kassahun et al., 2023). The FLC method is applied in SPV arrays to achieve MPPT. The following steps are used for FLC systems.

***Step* 1:** Definition of System - identify the boost converter used with the SPV array for adapting the MPPT technique.
***Step* 2:** Design of the FLC.
***Sub-step* 1:** Inputs - Define measurable parameters as FLC inputs. Common choices are variation in power ($\Delta$P) and variation in voltage ($\Delta$V).

***Sub-step* 2:** Membership Functions - Assign membership functions to each input and the output i.e. change of duty cycle (ΔD) of the FLC. These functions map crisp values such as actual measured ΔP and ΔV to fuzzy levels e.g., Low, Medium, and High. Triangular or bell-shaped membership functions are common.
***Sub-step* 3:** Rule Base: Create a set of rules based on expert knowledge or historical data. The rules relate the fuzzy inputs to the desired fuzzy output for controlling the converter and changing the operating point towards the MPP.
***Step* 3:** Operation of the FLC.
***Sub-step* 1:** Fuzzification - Convert crisp ΔP and ΔV measurements into fuzzy values using the membership functions.
***Sub-step* 2:** Inference Engine - The fuzzy rules are employed for the fuzzified inputs to establish the fuzzy output level for ΔD.
***Sub-step* 3:** Defuzzification – It converts the fuzzy output level for ΔD into a crisp value that can be used to regulate the duty-cycle of the boost converter.
***Step* 4:** Implementation - The FLC output adjusts the duty-cycle of the DC-DC converter, affecting the operating voltage of the SPV panel. By continuously monitoring ΔP and ΔV and adjusting the duty cycle, the FLC follows the MPP, maximizing power output from the SPV array.

### 3.3 ANN-Based MPPT Technique

An ANN replicates a biological neural network (NN) which essentially links with numerous parameters in order to data points. Without the need for complex mathematical equations, this approach is able to mix several parameters (Pandey and Jena, 2017). Relating several parameters to vast amounts of unknown data points requires less theoretical work with ANN than with standard approaches (Kiran et al., 2022). ANNs are trained using imported data through supervised learning, also known as training. Similar to the human brain, ANN is made up of a variety of neurons. A fractional quantity known as weight links these neurons together. In the training phase, outcomes are altered in order to improve accuracy. Weights are held constant until errors exceed the permissible level. **Figure 2** represents the two-layer ANN model. The right side of the NN indicates different times at which the inputs could be incorporated. The data set for all input/output parameters is fragmented into two classes, and the class by the greater proportion of data sets is used as a training set for ANN. This is trained and then verified using the data set for validation, which is the subsequent group and includes the remaining data sets. Along with their training data points, the input-output parameters for NNs are imported. Before making an acceptable error, this network needs to be trained. Once an error has been identified the qualified network is validated by introducing the input parameters of the data set for validation and envisaging the values of the corresponding output parameter.

A basic ANN architecture has been created in order to propose a model and estimate the output profile of power of a polycrystalline solar module. It has been confirmed that the ANN can estimate the volume of PV electricity produced with some degree of accuracy. Analytical, polynomial, multiple linear, and one-diode models have all been shown to perform less well than ANN MPPT systems. The ANN model is developed which is capable of forecasting the SPV power generated based on the predicted values of solar irradiance and air temperature. These predicted values can be obtained from forecasters or numerical weather prediction models. If these models are specific to the SPV panel being used, then they can be used to predict the generated power output of SPV arrays in standalone (or grid-connected) SPV systems in the specified area.

ANN methods are becoming increasingly popular for SPV array applications, particularly in partial shading conditions (fault detection) and power output prediction. The following steps are used for ANN systems (Husain et al., 2024; Malik et al., 2023; Tomar et al., 2022).

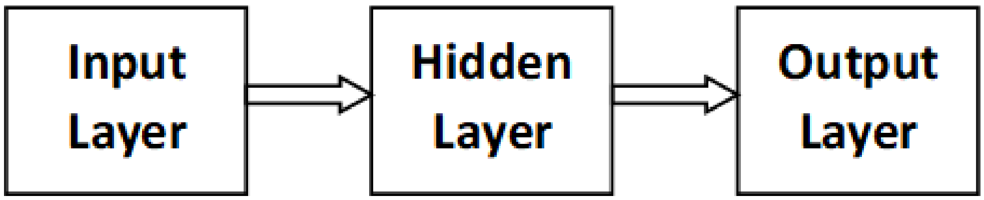


**Figure 2.** Fundamental structure of the two-layer ANN model.

***Step* 1:** Data Collection **-** The first step involves gathering data relevant to the task.
***Sub-step* 1:** Environmental data **-** SR, ambient temperature, and wind speed for power output prediction.
***Sub-step* 2:** Electrical data **-** SPV voltage, SPV current for fault detection, power output prediction.
***Step* 2:** Data Preprocessing -The collected data might need cleaning and formatting to ensure the NN can process it effectively.

- Handling missing values.
- Standardizing the data to a common scale.

***Step* 3:** Network Design and Training **-** The architecture of the NN is designed based on the specific application.
***Sub-step* 1:** Network type **-** Multilayer Perceptron (MLP), Recurrent Neural Network (RNN), etc.
***Sub-step* 2:** A number of layers – It consists of an input layer, an output layer and hidden layers. Hidden layers can be used more than one.
***Sub-step* 3:** Decide- It decides the number of neurons in each layer.
***Sub-step* 4:** NN is trained using specified data with the following process.

- Feeding the input data to the network.
- The network calculates an output based on the initial weights assigned to connections between neurons.
- The calculated output is compared to the desired output based on actual measurements.
- The errors between the calculated and desired outputs are used to adjust the weights in the network through an algorithm like backpropagation.
- This process is repeated iteratively until the network achieves an acceptable level of accuracy.

***Step* 4:** Validation and Testing

- Once trained, the performance of the neural network is calculated using data it hasn't been trained on. This helps assess its generalizability to unseen data.
- Metrics, like mean squared error for power output prediction or classification accuracy for fault detection are used for evaluation.

***Step* 5:** Deployment and Monitoring

- If the network performs well, it can be deployed for real-time applications.
- In fault detection, the network would continuously analyze incoming data and raise alarms if anomalies are detected.
- For power prediction, the network would provide forecasts based on current and past environmental data.
- The network's performance should be monitored over time, and retraining might be necessary if its accuracy degrades.

## 4. MATLAB/Simulation of SPV System Using Various MPPT Techniques

The SPV arrays, boost converters, P&O and ANN MPPT controllers, and resistive loads make up the simulation model for the proposed system. The parameters and their values for SPV arrays are given in **Table 1** while the parameters and their values for boost converters are given in **Table 2**.

A power boost converter is also called a step-up converter which is a type of electrical circuit. It can increase (or step up) the voltage in favour of a DC power source. This device can be used for desirable voltage response from the SPV arrays. The operations of the boost converter are discussed in the following manner (Shaikh et al., 2023).

### a) Basic Principles of the Power Boost Converter

***Switching converter -*** A power boost converter is a mode of switching converter that means it uses rapid switching to achieve its voltage conversion. It contains at least two semiconductors (a transistor and a diode) and an energy storage element that is an inductor.

***Energy storage –*** It is a key element (inductor) of the boost converter's operation which stores the energy in the form of the magnetic field. In this regard, the switch is turned on and current flows through the inductor which builds up its magnetic field and stores energy.

***Voltage boost –*** If the switch of the power converter is turned off, and the inductor tries to resist the change in current it releases the energy that has been stored in its magnetic field. The output capacitor receives this energy and charges to a voltage greater than the source voltage.

**Table 1.** Module parameter “Znshine PV-Tech XM6-72-330-M”.

| S. No. | Specifications | Value |
|---|---|---|
| 1. | Maximum Power (W) | 329.9975 |
| 2. | Cell per module | 72 |
| 3. | Open circuit Voltage $V_{OC}$ (Voltage) | 46.720 |
| 4. | Short-circuit current $I_{SC}$ (Amp) | 8.650 |
| 5. | Voltage at MPP $V_{MP}$ (Voltage) | 38.150 |
| 6. | Current at MPP Imp (Amp) | 8.650 |
| 7. | Light-generated current $I_L$ (Amp) | 9.2073 |
| 8. | Saturation current of $I_o$ (Amp) | $7.0896*10^{-11}$ |
| 9. | Diode Ideality factor | 0.98754 |
| 10. | Shunt resistance $R_{SH}$ (ohm) | 342.5146 |
| 11. | Series resistance $R_S$ (ohms) | 0.35408 |
| 12. | Parallel Strings | 1 |
| 13. | Series-connected modules per string | 2 |

**Table 2.** Specification of boost converter for SPV framework.

| S. No. | Parameter | Value |
|---|---|---|
| 1. | Inductor (H) | 0.01 |
| 2. | Capacitor $C_{out}$ (F) | $2*10^{-3}$ |
| 3. | Capacitor $C_{in}$ (F) | $2*10^{-3}$ |
| 4. | Load resistance $R_L$ (ohm) | 100 |
| 5. | Input resistance Rin (ohms) | 1 |
| 6. | IGBT | 1 |
| 7. | Diode | 1 |
| 8. | Duty cycle | variable |

### b) Components for Construction of Boost Converter

***Inductor (L) –*** This electrical element stores energy in its magnetic field during the on mode and releases it to the output during the off mode.

***Switch (IGBT)* –** The IGBT switch controls the current flow in the inductor.
***Diode* –** This device acts like a one-way valve which allows current to flow to the capacitor but blocks it from flowing back to the input source.
***Output capacitor ($C_o$)* –** This storing element smooths out the output voltage and stores energy for the load.

**c) Applications of the Power Boost Converter**

Power converters are widely used in different applications that require a higher voltage than the source.
***SPV Power devices (or Battery-powered devices)* –** This framework boosts the voltage from a low input voltage to power higher voltage circuits.
***Light emitting diode (LED) drivers* –** Boost converter can help to boost the voltage to drive LEDs which naturally require a higher voltage than the input power source.
***Solar panels* –** This converter boosts the voltage from solar panels to supply power to a framework.
***Power supplies* –** As part of a larger power converter circuit to supply the various voltage levels within a device.

**d) Limitations of the Boost Converter**

***Increased voltage and decreased current* –** Remember that power is conserved (P = V x I). Therefore, the boost converter increases the voltage that does so at the expense of the output current. It receives more voltage but has less current available.
***Switching complexity* –** Boost converters involve switching devices which amend the complexity of the design compared to simpler linear regulators.

The proposed SPV model using a boost power converter and different MPPT methods is revealed in **Figure 3**, and the test pattern of solar irradiation used as the input for SPV arrays is revealed in **Figure 4**.

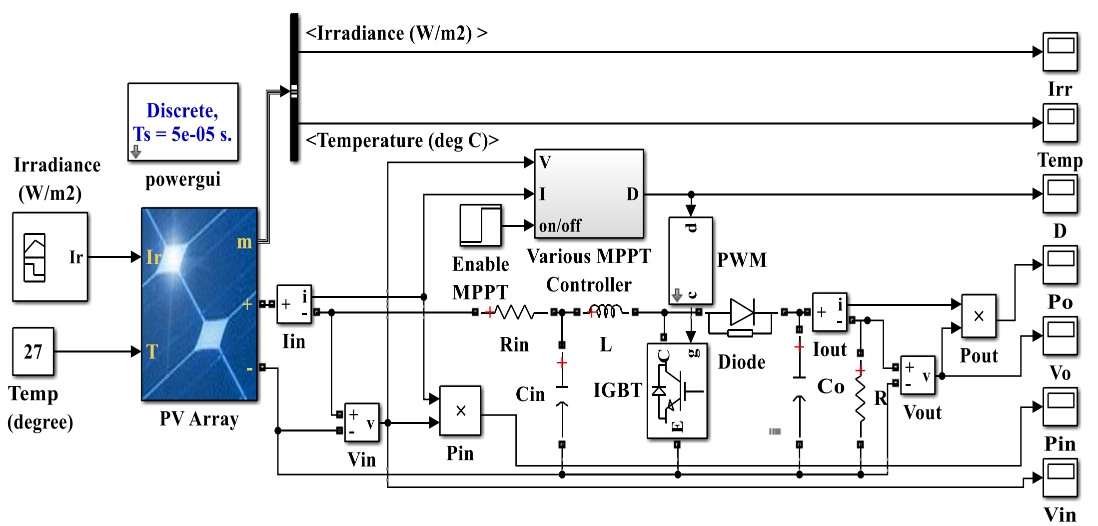


**Figure 3.** Proposed Simulink model of SPV frameworks using various MPPT controllers.

The results show the voltage response and power response in favour of an SPV array, in addition to the input voltage and power of the boost power converter. It is seen that the response in favour of the SPV array's voltage and power is non-linear. Therefore, these responses are not usable for any sustainable frameworks. **Figure 7** and **Figure 8** demonstrate the comparative graph of output voltage and output power of the boost converter using the SPV framework and various MPPT Controllers. One two-series SPV module (Znshine PV-Tech XM6-72-330-M) and the MPP unit are associated in order to load resistance (100-ohm) to make up the system. The sensors in this experiment are used to measure the system voltage and current values. **Table 1** provides additional specifications and their values. Typically, an off-grid SPV system consists of load and SPV modules that are connected via charge controllers. According to the block design in **Figure 1**, an MPPT charge controller has been included to increase system effectiveness. In order to maximize the power output of the SPV module and transmit it to the load, an MPPT charge controller is connected between the SPV module and the load. DC-DC power converter is used to transform the voltage level of the DC response. The project utilizes a boost converter which increases the voltage while decreasing the current. In a power semiconductor switch like Insulated Gate Bipolar Transistor (IGBT), an inductor (L), input resistance ($R_{in}$), the input capacitor ($C_{in}$), a diode (D), and the output capacitor ($C_o$) are the fundamental parts of the converter which are as illustrated in **Figure 3**.

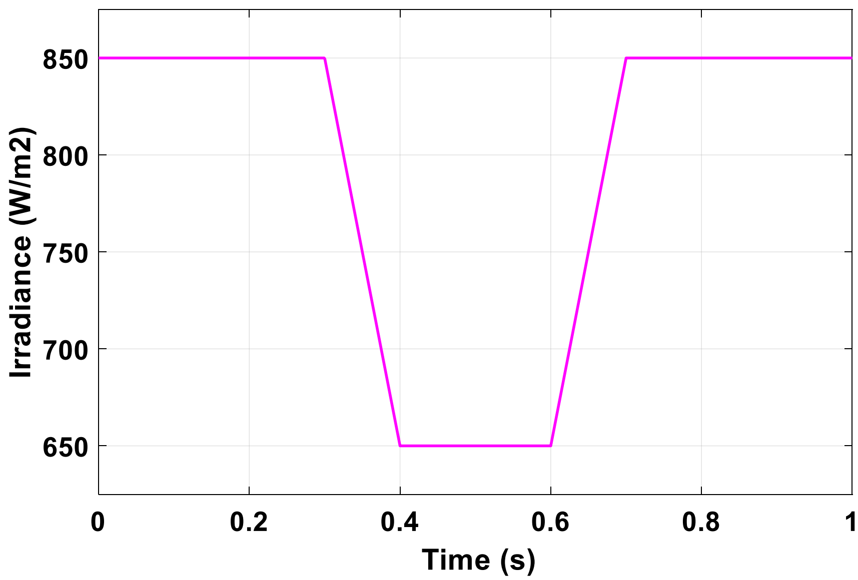


**Figure 4.** Test pattern of solar irradiance for proposed model.

Under dynamic irradiance changes, the effectiveness of the suggested algorithm was verified. Two scenarios were used to evaluate the SPV system such as one in which the irradiance value was reduced from 850W/m$^2$ to 650W/m$^2$ and the other in which it was raised from 650W/m$^2$ to 850W/m$^2$.

Analyses the waveform of module output voltage and power for a solar panel and illustrates how the P&O MPPT works. After periodically varying the array terminal voltage/current, P&O MPPT is compared to the power output of the SPV to that of the perturbation cycle before it. The system first experiences a small disturbance, which affects the module's power. If a disturbance causes the power to increase.

The MPPT of SPV power-generating systems changes because of changing atmospheric conditions, hence keeping accurate track of the MPP is crucial for designing effective SPV systems. The characteristics of SPV arrays are demonstrated in **Figure 7** and **Figure 8**, the MPPT and the power produced by them are dependent on environmental conditions. Additionally, the MPPT alters with shifting radiation which suggests the array terminal voltage must be continuously adjusted if maximum power is to be delivered.

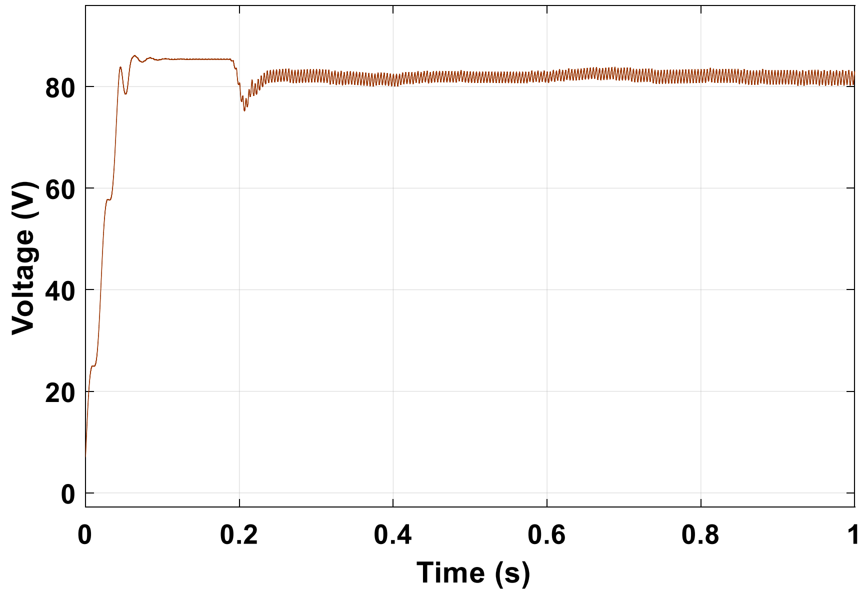


**Figure 5.** Output voltage of SPV model.

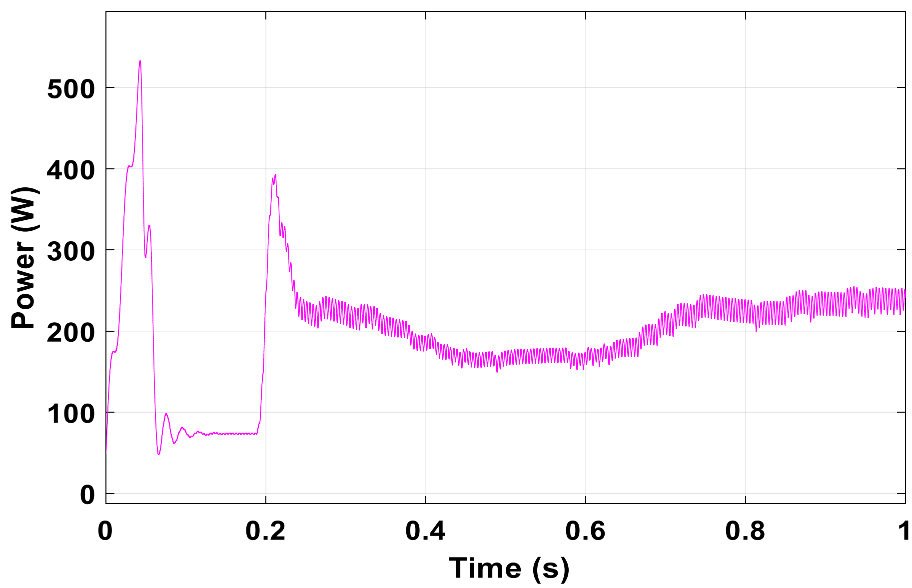


**Figure 6.** Output power of SPV model.

However, The P&O – MPPT can cause fluctuations in the MPP even under steady-state conditions, particularly in a retort in order to rapid deviations in solar irradiance. It can lead in order to a decrease overall efficiency of the frameworks and unnecessary stress on components. Thus, the P&O–MPPT is easy and commonly used, more advanced algorithms like the IncCond, and P&O-VS have been advanced in order to affect the constraints and enhance the complete performance in favour of the MPPT process.

This work aims at providing a P&O algorithm that is simple, less complicated, effective, and enhanced. The augmented approach is considered to be a significant improvement over the traditional P&O method. It minimizes fluctuations in the steady-state while tracking the greatest power point at a high speed. The motivation for this approach comes from the association between the voltage (open-circuit) and voltage (MPP). Simulations were used to evaluate the effectiveness and efficiency in favour of the novel MPPT under variable solar irradiance and ambient temperature. In order to demonstrate the effectiveness of the P&O – MPPT and FLC, their performance was compared to that of the ANN MPPT method.

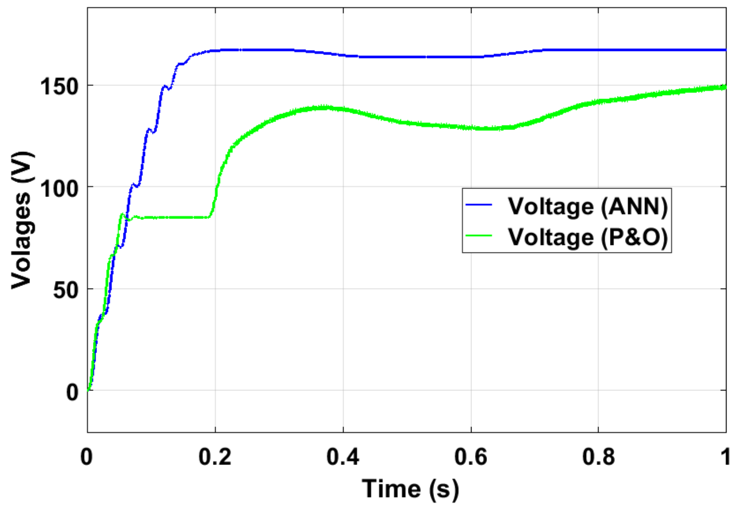


**Figure 7.** Comparative analysis of output voltages of boost converter using SPV framework and various MPPT controllers.

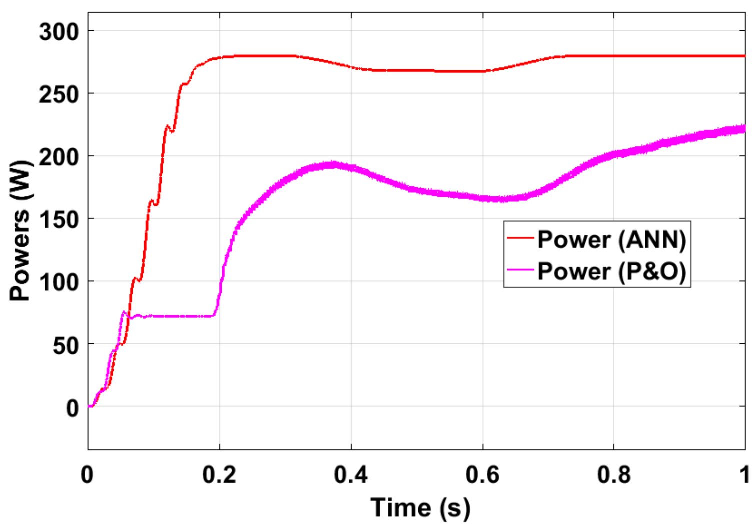


**Figure 8.** Comparative analysis of output powers of boost converter using SPV framework and various MPPT controllers.

In spirit, various MPPT techniques are used for achieving the maximum power from SPV arrays with varying levels of complexity, accuracy, and ease of implementation. P&O is the simplest although least accurate, FLC offers a balance, and ANN is the most accurate although most complex.

## 5. Results and Discussions

To determine the maximum power from the SPV Panel using various MPPT technologies, the analysis of simulation results is carried out by MATLAB/ SIMULINK. The simulation of the proposed model is done in one second. The proposed model with a boost converter and various MPPTs like P&O and ANN controllers has output voltages of 140V and 160V respectively which are revealed in **Figure 7**. The output power values of a boost converter using P&O and ANN-MPPT controllers are 200W and 280W respectively which is revealed in **Figure 8**. The voltage response and power response of a boost power converter gradually increase within 0 to 0.3 seconds. The P&O - MPPT controller is used for 0.3–0.4 seconds (**Figure 4**) during which there is a decrease in solar irradiation. It can be clearly realized in **Figure 7** and **Figure 8**. ANN-MPPT prevents the boost converter's output voltage and power values from dropping during the boost converter's 0.4–0.6 second drop. The output values therefore rise to 160 V and 270 W.

Numerical simulations with a sample time of 50 microseconds have been used to test the P&O's performance in the MATLAB/Simulink platform. For simulated irradiance fluctuations and abundant temperature, a simulation time of 1 s was considered. The MATLAB/ Simulink configuration is shown in **Figure 5 and Figure 6**. The MPP variable for each simulation is displayed in **Figure 7** and **Figure 8**. In comparison to P&O - MPPT and ANN-MPPT yield more precise and consistent results. **Table 3** presents a comparative analysis of output voltages and output powers of the boost converter using the SPV framework and various MPPT techniques. It is clearly seen that the ANN-based MPPT technique produces maximum power which is shown in **Figure 9**.

**Table 3.** Comparative analysis of output voltages and output powers of boost converter using SPV framework and various MPPT techniques.

| Parameters | Output Response using P&O MPPT | Output Response using ANN MPPT |
|---|---|---|
| Voltage | 160V | 270V |
| Power | 200W | 280W |

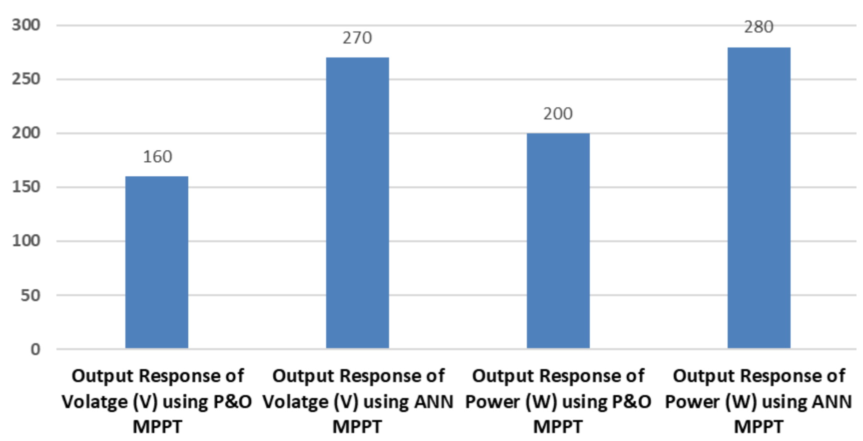


**Figure 9.** Comparative analysis of output responses of voltages and powers using SPV framework and various MPPT techniques.

The viability of the suggested strategy was demonstrated by simulation results produced in MATLAB/Simulink under variable environmental conditions. Additionally, the proposed approach eliminates the problem that the traditional P&O had in terms of choosing between steady-state oscillations and dynamic response. The ANN approach is then contrasted with other traditional MPPT methods. On the whole, the SPV system's efficiency was greatly improved by the proposed MPPT approach. In light of comparisons with other algorithms, the proposed algorithm has the advantage of not only having the highest tracking efficiency but also being simpler to implement than more recent algorithms because it does not require thresholds that must be determined from the parameters of the SPV module. The suggested algorithm offers a large $\Delta D$, and can track the MPP more quickly than conventional P&O MPPT algorithms.

It adjusts the operating point of the framework by small increments, observes the power output and keeps moving in the direction that increases power. It can oscillate around the true MPP. The FLC approach uses fuzzy rules to represent the relationship between input parameters like voltage and current and the desired output. It can handle imprecise data and is more robust than P&O under varying conditions, but it requires setting and tuning fuzzy rules. ANN method involves training an NN on data that represents the relationship between system inputs and the MPP. Once trained, the network can very accurately predict the optimal operating point. NNs are more complex to implement and require more computational resources compared to P&O and FLC.

## 6. Conclusions

SPV systems using various MPPT technologies have appeared as a promising solution for sustainable energy generation. Advanced MPPT technologies play a crucial role in accelerating the global changeover to greener energy by optimizing the performance of SPV systems. To compute MPP and increase the effectiveness of the SPV panel using ANN, FLC and P&O MPPT technologies have been analyzed and compared. ANN - MPPT technique yields more precise and consistent results for the SPV system and also minimizes fluctuations in the MPP. ANN models have the advantage of not requiring supplementary constraints which are not continually offered. Contrary to implicit models which require more difficult computations and parameters that are not always available. For instance, the inherent model requires beyond intricate results as well as certain characteristics such as $R_s$ and $R_{sh}$ that are not provided by the manufacturers. These parameters could be calculated numerically and empirically which is challenging. ANN models offer simplicity, accuracy and practicability when estimating SPV power from experimental data. Although currently used for polycrystalline silicon, this technique has the potential to be applied to other solar technologies. The efficiency of renewable energy systems can be increased from AI-based MPPT and AI-based hybrid MPPT technologies.

#### Conflict of Interest

The authors confirm that they have no conflicts of interest to declare for this publication.

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