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Maximum Power Point Tracking with Artificial Neural Network

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***Abstract*—The urgent depletion of fossil fuel resources and the pressing need for environmental preservation have spurred a critical examination of alternative energy solutions. In response, this study focuses on the development of innovative approaches to mitigate the overreliance on conventional energy sources and transition towards sustainable alternatives. As part of a final year project, the research draws inspiration from this imperative and endeavors to design a prototype model that integrates advanced techniques for harnessing solar energy.**

Index Terms–Maximum Power Point, Buck-Boost Converter, Neural Network Architecture

I. INTRODUCTION

Maximum Power Point Tracking (MPPT) is a technique utilized by Grid Tie Inverters, Solar Battery Chargers, and similar devices to extract the maximum possible power from one or more solar panels. Solar cells exhibit a complex relationship between solar irradiation, temperature, and total resistance, resulting in a non-linear I-V curve. The MPPT System samples the output of the cells and adjusts the load to obtain maximum power under varying environmental conditions, ranging from clear skies to heavy clouds, rain, mist, and fog. PV cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor (FF), Open Circuit Voltage (V_{OC}), and Short Circuit Current (I_{SC}) are key parameters used to estimate the maximum power a cell can provide. Under specific operating conditions[2, 3] ,cells have a single operating point where voltage and current result in maximum power output. This point corresponds to a particular load resistance determined by Ohm's Law (V/I). A PV cell exhibits an approximately exponential relationship between current and voltage. According to basic circuit theory, power delivery is optimized where the derivative of the I-V curve equals the inverse of the I/V ratio (where dP/dV=0), known as the Maximum Power Point. A typical solar panel converts only 30 to 40 percent of incident solar irradiation into electrical energy. MPPT is employed to enhance panel efficiency. According to the Maximum Power Transfer Theorem, power output is maximum when the Thevenin Impedance of the circuit matches the load impedance, thus reducing the maximum power point tracking problem to an impedance matching problem [4, 5, 6].

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II. BASIC IDEA

It is therefore vital to develop a methodology that can be modelled in such a way that it always extracts the maximum amount of power from the sun, given that solar cells have a non-linear current-voltage characteristic and that the output power varies in correspondence with the voltage across the cell. As a result, several Maximum Power Point Tracking algorithms have been put out, all of which seek to collect and make use of as much of the sun's energy as possible.

Among the best techniques for converting solar energy directly into electrical power are photovoltaic systems. An array of solar cells with uniform series connections that each have the standard V-I properties makes up a photovoltaic system. The primary goal of photovoltaic systems (PV) is to collect solar radiation, transmit it to a transducer for energy conversion, and ultimately produce electricity. These solutions don't pollute the environment, are clean, and lower greenhouse gas emissions. Nonetheless, in a standard photovoltaic system made up of batteries, a charge controller, a DC-AC inverter, and PV modules, the PV modules provide DC electricity that powers the charge controller and charges the batteries. Concurrently, the inverters change the DC current into AC current. However, this is where the issues lie: PV systems have a high initial cost and are heavily dependent on environmental elements like solar radiation and ambient temperature, which combined make the process of generating electricity challenging.

This is the moment when the MPPT system kicks in. With the help of charge controllers, this algorithm allows PV modules to extract their maximum power output in these unpredictable circumstances. In order to charge the battery and convert it to receive the highest current possible, MPPT first

verifies the PV array's output, compares it to the battery voltage, and then settles on the optimal voltage the array can generate.
Maximum Power Point Tracking (MPPT) is most effective in the following situations:

- Cold weather, cloudy, or hazy days: While Photovoltaic (PV) Modules usually operate better in hot temperatures, MPPT Systems can optimize power extraction even in adverse weather conditions.
- Deeply discharged batteries: When batteries have low charge levels, the MPPT system can extract more current and efficiently recharge them, enhancing overall energy utilization.

III. AIM

The following describes the issues with fundamental algorithms for determining the Maximum Power Point Tracking: The controller adjusts the PV array output voltage in accordance with the variation in output power in the traditional Perturb and Observe Algorithm, which compares only two points—the Current Operation Point and the Subsequent Perturbation Point—to see how their powers change. The duty cycle of the converter should rise if these two points are positively weighted and fall if they are negatively weighted[8]. The Maximum Power Point is not achieved in certain instances with one positive and one negative weighting as well since the duty cycle cannot adjust on its own due to the quick variations in solar radiation.
While the Incremental Conductance Algorithm [7] boasts superior accuracy in Maximum Power Point Tracking (MPPT) under rapidly fluctuating irradiation and daylight conditions compared to the Perturb and Observe method, it also suffers from drawbacks. Specifically, it tends to generate oscillations and may exhibit erratic behavior in rapidly changing atmospheric conditions. Moreover, due to its higher complexity relative to the classical Perturb and Observe Algorithm, the Incremental Conductance Algorithm increases computational time, especially when sampling frequency is reduced.
When the operating point oscillates between two noticeably different Maximum Power Points, the tracking stage of the algorithm continues to provide reduced efficiency, even though the Incremental Conductance Algorithm addresses some of the basic PO Algorithm's shortcomings. When there are clouds or when there are dark clouds in the sky, for instance, the MPPT system can alter quickly and with significant magnitude changes. Because they alter the operating voltage in steps of a defined magnitude each time, perturbation and observation-based techniques—such as incremental conductance—have a restricted tracking speed.
In the Constant Voltage Algorithm, the PV Array's current must be momentarily brought to zero in order to measure the Open Circuit Voltage [7]. 76 percent, or 0.76, of the recorded voltage is then where it needs to be placed. When the current is set to zero, this process causes a sizable quantity of energy to be discharged. Consequently, the voltage setting of 76% of the observed voltage is not precise; rather, it is an estimate. This method contains interruptions that reduce array efficiency and do not ensure that the true Maximum Power Point will be located, while being cheap and simple to create.

A novel design is put out that functions as a prototype for harnessing solar radiation in the majority of weather situations, taking into account the challenges encountered when using the aforementioned algorithms. Two headings can be used to broadly summarise the goals of the Maximum Power Point Tracking System:-

A. Main Idea

The current design addresses the limitations of basic algorithms by introducing the Enhanced Maximum Power Point Tracking through Artificial Neural Network Algorithm. This innovative approach employs a three-point weight comparison method, enhancing tracking speed compared to traditional techniques. By periodically adjusting the solar array's terminal points along the PV curve, it optimizes performance. The algorithm stores current-voltage curves and their maximum power points, utilizing a classifier-based system to improve efficiency. Overall, this comprehensive strategy aims to overcome existing algorithm limitations and enhance maximum power point tracking in solar power systems.

B. Operation with Batteries

Plant operations will eventually come to an end if solar radiation is not available for an extended period of time since the solar collectors will not be able to gather the necessary amount of radiation. A significant portion of energy is stored by the batteries, which serve as a backup source.
During nighttime operation, an Off-Grid PV Power System relies on batteries to provide power to its loads. While the battery may reach its full capacity and have an operating voltage close to that of the PV Array's Peak Power Point, this alignment is improbable at sunrise, especially when the battery is partially discharged. In such cases, charging may commence at a voltage significantly below the Array's Peak Power Point. However, Maximum Power Point (MPP) Tracking, through its advanced techniques and meticulously designed protocols, can effectively address this mismatch, ensuring optimal performance and energy efficiency despite varying conditions.
The MPP Tracking is unable to run the PV Array at its Peak Power Point when the batteries in the Off-Grid system are completely charged and production surpasses the local demands since the extra power has nowhere to go. Once production precisely meets demand, the MPP Tracking must then move the array's operating point away from the Peak Point. A different strategy that is frequently employed in spacecraft is to convert extra PV power into a resistive load, which enables the array to run constantly at its Peak Point.

IV. PROJECT STUDY

The Enhanced Maximum Power Point Tracking System utilizing Artificial Neural Network represents an advancement upon the classical Perturb and Observe Technique. This modified system comprises a PV module, a DC-DC Converter, a controller, and a load. Notably, it incorporates a feed-forward propagation Artificial Neural Network-based controller, which is integrated to enhance its functionality. This controller utilizes Ambient Temperature (T) and Solar Radiation (G) as two of its four inputs, leveraging predicted values to derive the Instantaneous Optimum Voltage (VOptimum) of the Photo Voltaic System. By doing so, the system ensures optimal operation at maximum power, thereby enhancing efficiency and performance [1].

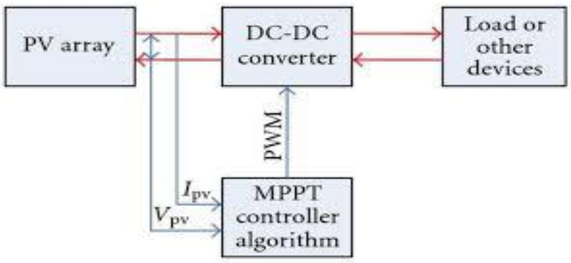
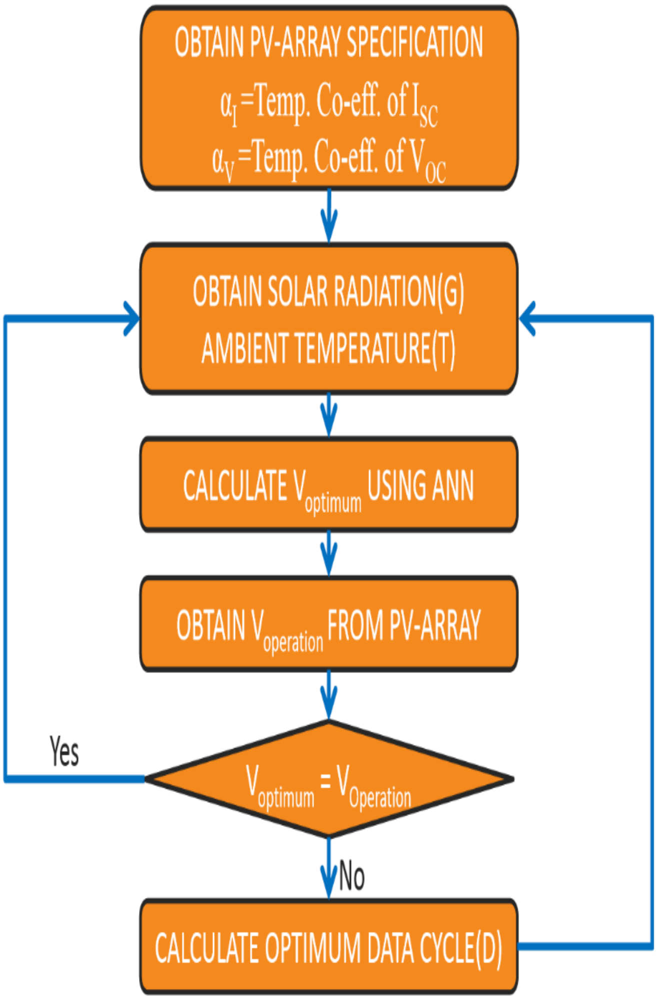


Fig 1: MPPT using ANN's Block Diagram

With the different inputs it receives throughout each cycle of data interpretation, the network, an artificial depiction of the human body, attempts to mimic its learning process. It modifies its structure in response to information that enters and exits the network system, both internally and externally[9]. The main benefit of utilising the network in this case, though, is ensuring that the Proposed Maximum Power Point Tracking System responds more quickly than the traditional Perturb and Observe Algorithm in order to improve tracking efficiency.

Fig 2: Flowchart of the Proposed Design Model



Initially, the specifications for the Temperature Coefficient of Short Circuit Current (ISC) and the Temperature Coefficient of Open Circuit Voltage (VOC) of the Photo Voltaic Array are acquired and stored. Subsequently, the Artificial Neural Network receives the Incident Solar Radiation (G) and Ambient Temperature (T) values. Using these inputs, the controller computes the Optimum Voltage (VOptimum). Next, the controller gathers the operational voltage magnitude of the PV Array. If the operational voltage (VOperation) does not match the Optimum Voltage (VOptimum), the Duty Cycle is determined and regulated accordingly. Otherwise, the process progresses to acquire the subsequent values of Solar Radiation and Ambient Temperature.

V. DESIGNING USING MATLAB® – SIMULINK®

The following is a description of some of the most popular circuits that use conventional logic along with the suggested reversible logic that matches them:

A. PV Array Design

The SIMULINK® model illustrates the Photo Voltaic Array's functionality with temperature and insolation as inputs. Temperature, presented as a saw-tooth waveform, and insolation, a rising step input ranging from 200 to 1000 W.m-2, are processed. Insolation is amplified while temperature is

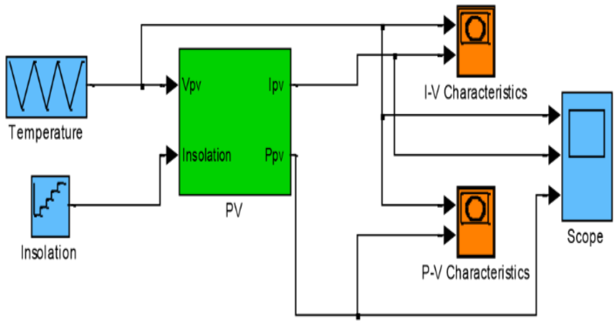
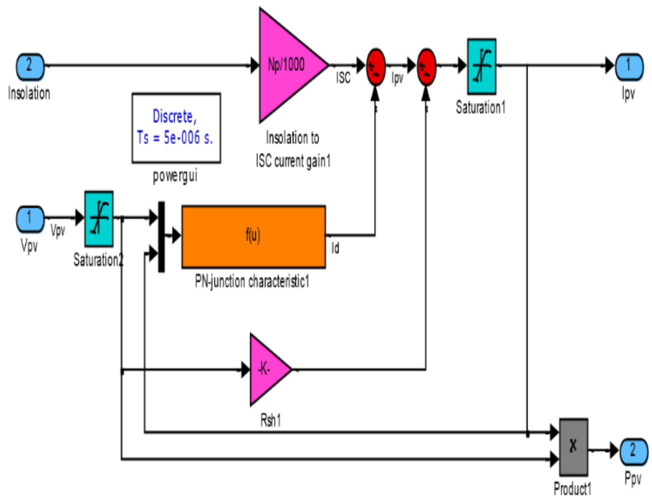


Fig 3:PV-Module SIMULINK® Model



regulated within limits. Short circuit current (ISC) is derived using the Diode equation function and summers, contributing to the module's output current. This current, when multiplied by the incident sinusoidal voltage, generates power. The system configuration includes one module in series and 50 in parallel, significantly boosting the current. Finally, the multiplied current and voltage are analyzed through Graph Blocks.

Fig 4: Unmasked PV Subsystem

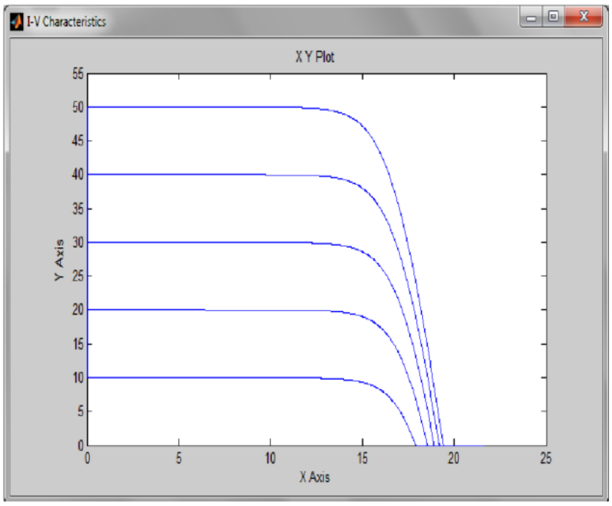


Fig 5: I-V Characteristic Curve

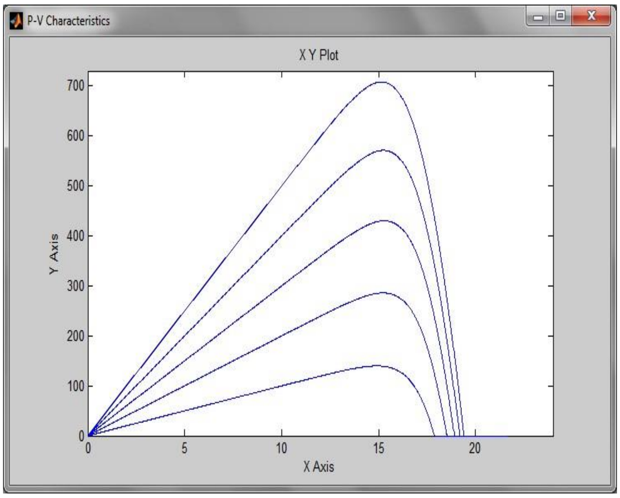


Fig 6: P-V Characteristic Curve

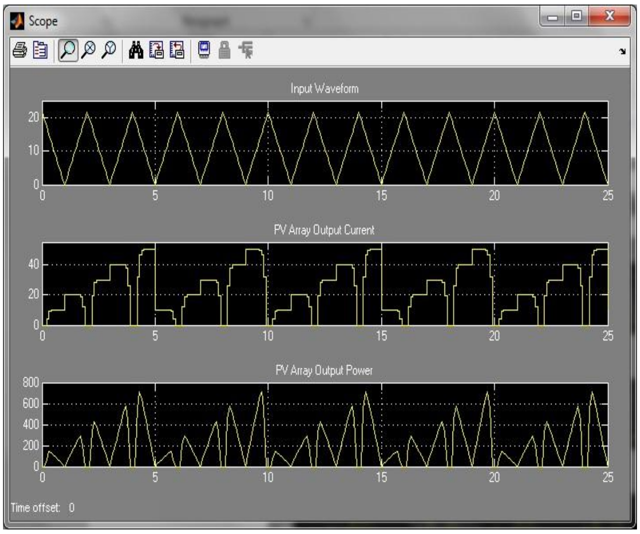


Fig 7: Output Waveforms for PV Module

B. Buck-Boost Converter Design

One kind of DC-DC converter that has an output voltage magnitude that is either more or less than the input voltage magnitude is called a buck-boost converter. It is characterised by an inductor, a reverse-biased free-wheeling diode, a capacitor, and a load of resistance R at the output terminal, all of which are connected in parallel.

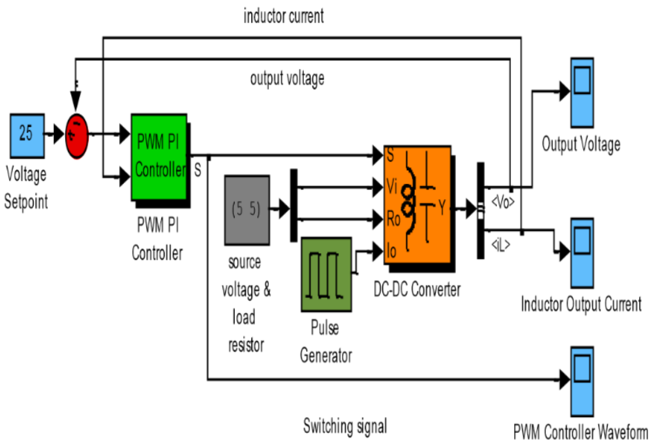


Fig 8: Buck-Boost Converter using PWM-PI Controller

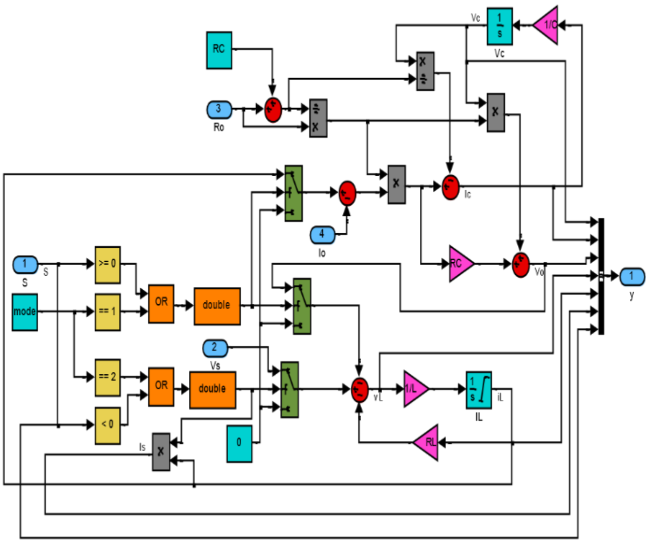


Fig 9: Unmasked Buck-Boost Converter

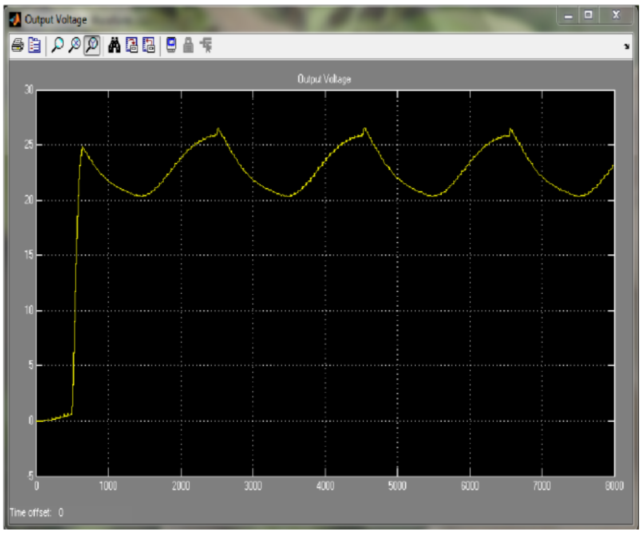


Fig 10: Converter's Output Voltage

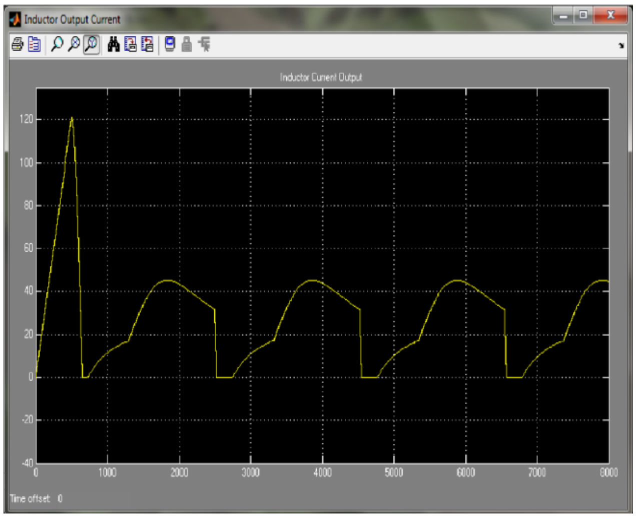


Fig 11: Converter's Output Current

C. Artificial Neural Network Design

Utilising the open circuit voltage (VOC) and basic short circuit current (ISC) equations [1], which are defined as follows, the Artificial Neural Network was created.

$I_{SC} = I_{SC}{}^{*}(G/G^{*}) + \alpha_i(T-T^{*})$

$V_{OC} = V_{OC}{}^{*} + \alpha_v(T-T^{*}) - R(I_{SC} - I_{SC}{}^{*})$

where,

I_{SC} = Short Circuit Current

V_{OC} = Open Circuit Voltage

G^{*} = Reference Solar Radiation = 1000 W.m^{-2}

$I_{SC}{}^{*}$ = PV I_{SC} at Ref. Solar Radiation = 50 A

α_i = Temperature Co-efficient of I_{SC} = 2

T^{*} = Reference Temperature = 25^{0}C

$V_{OC}{}^{*}$ = V_{OC} at Ref. Temperature = 25 V

α_v = Temperature Co-efficient of V_{OC} = 0

R = Resistance = 5 Ω

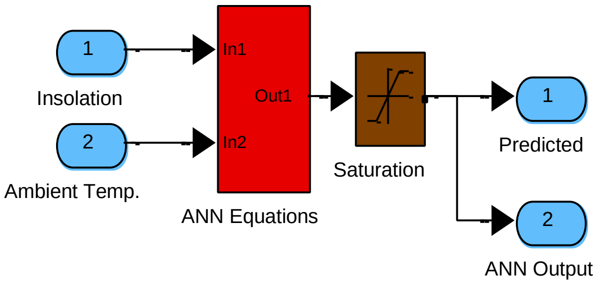


Fig 12: Artificial Neural Network Architecture

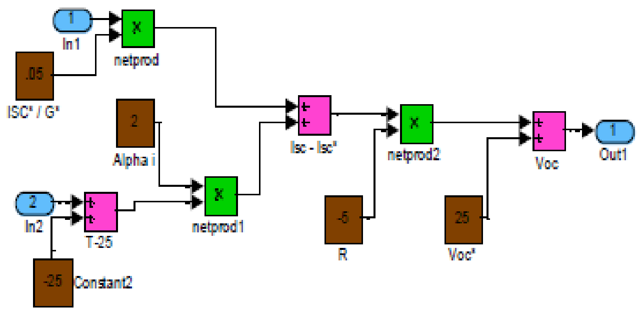


Fig 13: ANN Equations Design

D. Concluding Model

All that remains of the final model is the amalgamation of the designs of the Artificial Neural Network Controller, the Buck-Boost Converter, and the PV Module. The model is displayed next to Fig. 14.

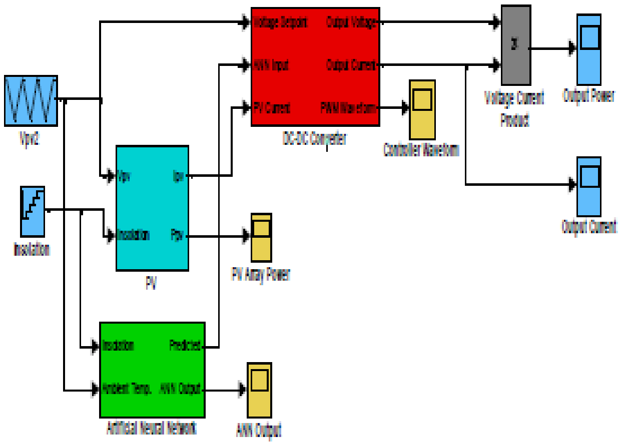


Fig14: Project's Overall SIMULINK® Model

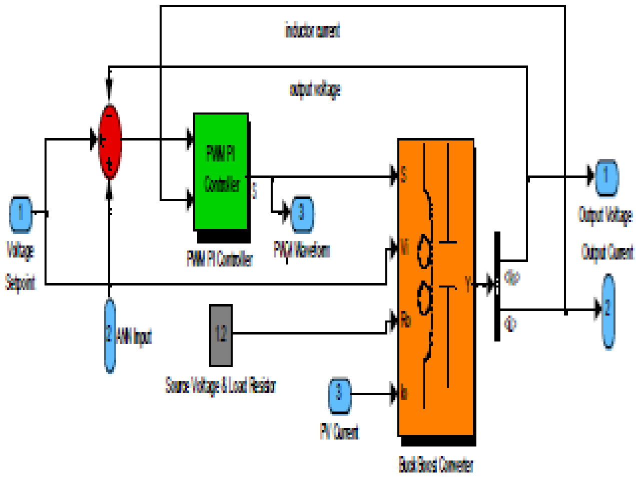


Fig 15: DC-DC Converter Subsystem

VI. RESULTS

The results are given as:

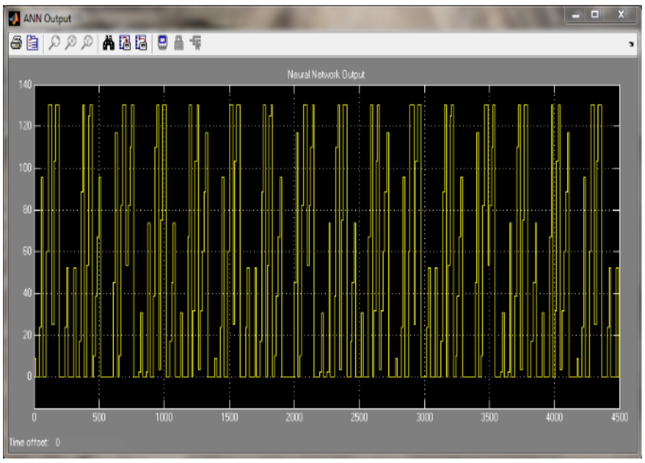


Fig 16: ANN's Predicted Output Waveform

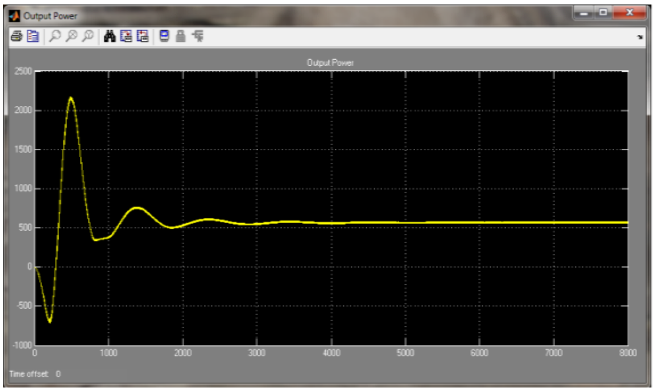


Fig 17: Final Output Power Waveform

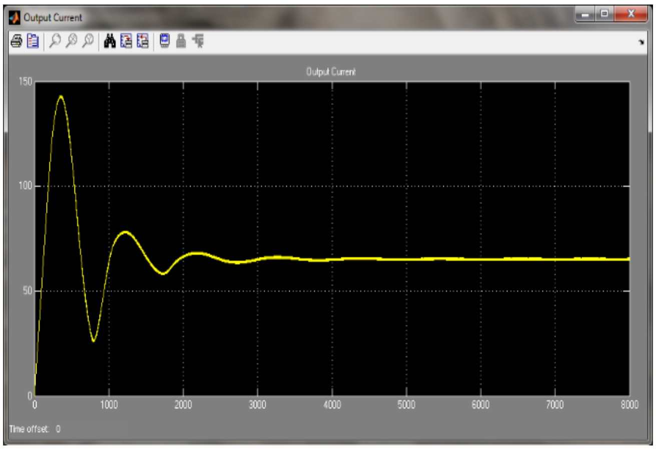


Fig 18: Final Output Current Waveform

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