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Maximum Power Point Tracking with Artificial Neural Network

Divyansh Mathur

***Abstract*–Fossil fuels' rapid depletion andneed to protect the environmenthas left us to thinkupon alternatives and solutions to curb the excess use of conventional sources and shift focus on the renewable energy. As final year project, my inspiration was[1], and through it I'vetried my best to designa prototypemodel inclusive of techniques that support the need to harness the solar energy.**

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

I. INTRODUCTION

Maximum Power Point Tracking is a technique that Grid Tie Inverters, Solar Battery Chargers, and othersimilar devices use to get the maximum possible power from one or more solar panels. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear I-V curve. The MPPT System samples out the output of the cells and applies the proper load to obtain maximum power for any given environmental conditions, ranging from a clear sky to a heavily clouded one, from rainfall to misty, and even foggy. PV cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, FF, is a parameter that characterizes the non-linear electrical behavior of the cell. In tabulated data it is often used to estimate the maximum power that a cell can provide. With an optimal load under given conditions, power $P = FF*V_{OC}*I_{SC}$; V_{OC} being Open Circuit Voltage and I_{SC} being Short Circuit Current. For most purposes, FF, V_{OC}, and I_{SC} are enough pieces of information to give a useful conclusions on the electrical behavior of a cell operating under typical conditions[2, 3].For any given set of operating conditions, cells have a single operating point where the values of V &I of each cell result in a maximum power output. These values correspond to a particular load resistance which is equal to V/I as specified by the Ohm's Law. A PV cell has an approximately exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized at the point where the derivative, dI/dV, of the I-V curve is equal and opposite ofI/V ratio (the point where dP/dV=0). This is known as the Maximum Power Point and corresponds to the "Knee" of the curve.A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum Power Point Tracking technique is used to improve the efficiency of the panel. According to Maximum Power Transfer Theorem, the power output of a circuit is maximum when the Thevenin Impedance of the circuit (source impedance) matches with the load impedance. Hence the problem of tracking the maximum power point reduces to an impedance matching problem[4, 5, 6].

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Mr. Divyansh Mathur, 14/1 Civil Lines, Kanpur, Uttar Pradesh, India

II. BASIC IDEA

Since solar cells have a non-linear current-voltage characteristic, with the output power varying in correspondence with the voltage across the cell, it is therefore necessary to design a methodology that can be modeled in such a way that it obtains maximum power from the sun at all times. Thus, a variety of Maximum Power Point Tracking algorithms has been proposed which aim to extract and utilize the maximum portion of the incoming solar radiation.

The Photovoltaic Systems are one of the best direct solar to electrical energy conversion systems. A Photovoltaic System is an array of homogeneously series connected Solar Cells, each of them possessing the typical V-I characteristics. The main purpose of the PV Systems is to absorb radiation from the sun, transfer it to a transducer that converts it to electrical energy, and finally generate electricity. These systems are clean, reduce the Greenhouse Gases, and are non-polluting. However, a typical PV System consisting of PV Modules, a DC-AC Inverter, a Charge Controller, and Batteries, the PV modules generate DC Electricity which is used to charge the batteries through a charge controller. Meanwhile, the inverters convert the DC current to AC current. But, here the problems arise; the PV systems are high in the capital cost, largely dependon climate conditions such as solar radiation and ambient temperature, and these factors altogether make electricity generation a difficult process.

It is now that the MPPT system comes into effect, an algorithm which when included in charge controllers, can be used for extracting maximum available power from PV module under these uncertain conditions. MPPTfirst checks PV Array's output, then compares it to battery voltage, and finally fixes the best voltage that theArray can produce to charge the battery and convert it to get maximum current into it.

Maximum Power Point Tracking is most effective under the following conditions:

- Cold weather, cloudy or hazy days: Normally, PV Modules work better at hot temperatures and the Maximum Power Point Tracking System on each can thus be utilized to extract maximum power available from them.
- When battery is deeply discharged: The system can extract more current and charge the battery, if the state of charge in the battery is lower.

III. AIM

Theproblems encountered with basic algorithms for finding the Maximum Power Point Tracking are described here as under:

In the classical Perturb and Observe Algorithm that compares only two points, the Current Operation Point and the Subsequent Perturbation Point to observe their changes in power, the controller increases or decreases the PV array output voltage based on the difference in the output power.If these two points are positive weighted, the duty cycle of the converter should increase, while if they are negative weighted, the duty cycle should decrease[8]. Also in special cases with one positive and one negative weighting, the Maximum Power Point is not reached because the solar radiation changes rapidly and the duty cycle is therefore not able to change itself.

Though the Incremental Conductance Algorithm[7] can perform Maximum Power Point Tracking under rapidly varying irradiation and daylight conditions with an accuracy higher than the Perturb and Observe method, it however lacks behind too as it produces oscillations and can perform erratically under rapidly changing atmospheric conditions. The computational time is thereby increased as the sampling frequency is depressed owing to the higher complexity of the algorithm compared to the classical Perturb and Observe Algorithm.

While Incremental Conductance Algorithm addresses some of the shortcomings of the basic PO Algorithm, a particular situation in which it continues to offer reduced efficiency is in its tracking stage when the operating point fluctuates between two significantly different Maximum Power Points. For example, during cloud cover or when dark clouds hover in the sky, the MPPT system can change rapidly and by large magnitude values. Perturbation and Observation based techniques, including the Incremental Conductance, are limited in their tracking speed because they make fixed-size adjustments to the operating voltage in each of the iterations.

In the Constant Voltage Algorithm[7], the current from the PV Array must be set to zero momentarily to measure the Open Circuit Voltage, and afterwards set to 76 percent or 0.76 of the measured voltage. As a result of this transaction, a considerable amount of energy is pined away in the time duration when the current is set to zero. The approximation in setting the voltage to 76 percent of the measured voltage is therefore not accurate. Although simple and low in cost to implement, the interruptions in this algorithm reduce array efficiency and doesn't ensure a positive result in finding the actual Maximum Power Point.

Considering the obstructions faced while working with the above algorithms, a new design is proposed which works as a prototype for utilizing solar radiation in most of the weather conditions.The objectives of the Maximum Power Point Tracking System can be broadly given under two headings:-

A. Main Idea

Keeping in mind all the negative points of the basic algorithms and the techniques to overcome their drawbacks, the present design is so designed to take head on challenges with the existing algorithms.Some of the highlighting points that support the stated Improved Maximum Power Point using Artificial Neural Network Algorithm are as follows:

Algorithm of three-point weight comparison, an antidote to the two-point weight comparison, which runs periodically perturbing the solar array terminal points of the PV curve, has three distinct points, namely the Current Operation Point A, a point B perturbed from point A, and a point C doubly perturbed in the opposite direction from point B.

The algorithm aims to improve the tracking speed of the PO based techniques by storing current-voltage curves and their maximum power points, and using a classifier based system.

B. Operation with Batteries

In cases of non-availability of solar radiation for a prolonged time, the solar collectors won't be able to collect the required amount of radiation and that in period of time, will bring plant operations to a halt. The batteries play a vital role; storing a reasonable amount of energy to provide backup.

At night, an Off-Grid PV Power System uses batteries to supply power to its loads. Though the battery, when charged to its full capacity may have its operating voltage close enough to the PV Array's Peak Power Point, but this is unlikely to be true or happen at the time of sunrise when the battery is partially discharged. Charging may begin at a voltage considerably below the Array's Peak Power Point. MPP Tracking, hence, by its sophisticated techniques and well-designed protocols can resolve the mismatch.

When batteries in the Off-Grid system are fully charged and the production exceeds the local loads, the MPP Tracking can no longer operate the PV Array at its Peak Power Point, as the excess power has nowhere to go. The MPP Tracking must then shift the array's operating point away from the Peak Point until production exactly matches the demand. An alternative approach, commonly used in spacecraft is to divert the surplus PV power into a resistive load allowing the array to operate continuously at its Peak Point.

IV. PROJECT STUDY

The Improved Maximum Power Point Tracking System using Artificial Neural Network is a modification of the classical Perturb and Observe Technique which employs a PV module, a DC-DC Converter, a controller and a load. A feed-forward propagation Artificial Neural Network based controller is added here which takes Ambient Temperature (T) and Solar Radiation (G), as two out of its total four inputs, and converts them into information based on the predicted values of the Instantaneous Optimum Voltage ($V_{Optimum}$) of the Photo Voltaic System in order to ensure the maximum power operation[1].

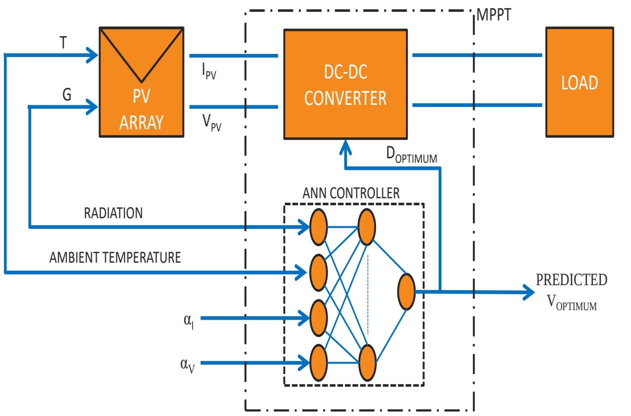

Fig 1: MPPT using ANN's Block Diagram

An artificial representation of the human body, the network tries to simulate its learning process through the various input fed to it during each cycle of data interpretation. It changes its structure based on the internal and external information that flows in and out of the network system[9].

However the major advantage of using the network here is to make sure the response of the Proposed Maximum Power Point Tracking System is faster than the classical Perturb and Observe Algorithm so as to increase the tracking efficiency.

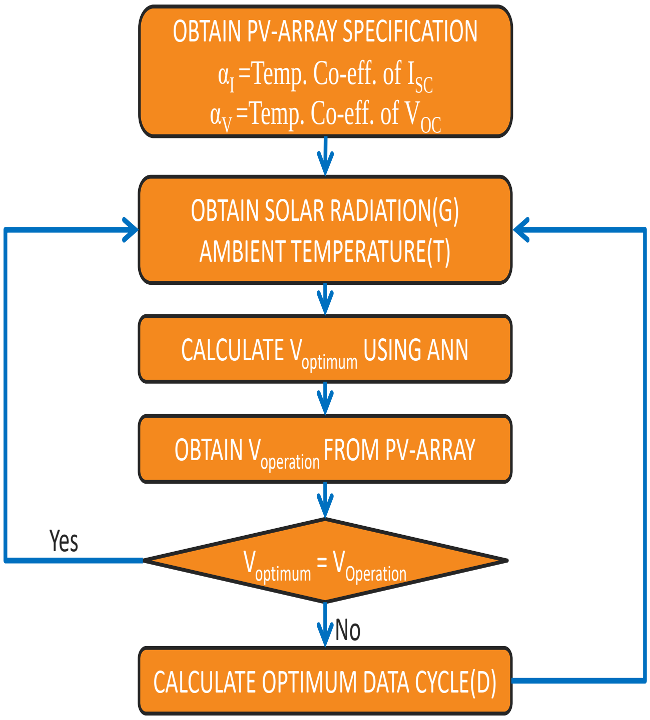

Fig 2:Flowchart of the Proposed Design Model

In the first step, the Photo Voltaic Array's specifications for Temperature Coefficient of Short Circuit Current $I_{SC}$and Temperature Coefficient of Open Circuit Voltage V_{OC}, are obtained and stored.The Artificial Neural Network now gets the values of Incident Solar Radiation G and Ambient Temperature T.The controller calculates $V_{Optimum}$.Now collect the magnitude of $V_{Operation}$ of the PV Array.If$V_{Operation}$ $\neq$ $V_{Optimum}$, then Duty Cycle is calculated and also controlled, else the flow switches on to get the next values of Solar Radiation and Ambient Temperature.

V. DESIGNING USING MATLAB® – SIMULINK®

Some of the most common circuits using conventional Logic and their corresponding proposed Reversible Logic are described here as under:

A. PV Array Design

The Photo Voltaic Array's model as designed in SIMULINK® is shown as temperature and insolation are considered as two inputs to the PV Array. While temperature has been taken as a saw-tooth waveform, insolation on the other hand is in the form of rising step input, ranging from 200 – 1000 W.m^{-2}. Insolation is fed to a gain, and temperature is set between levels via saturation. Diode equation function and summers determine the short circuit current I_{SC} which finally leads to the module's output current. This current when multiplied by the incident sinusoidal voltage leads to the generation of power. The entire system is masked and the value of modules arranged in series is one while those arranged in parallel are 50 which raises the current dramatically.The current and voltage are now multiplied, and the resulting outputs are then forwarded to the respective Graph Blocks.

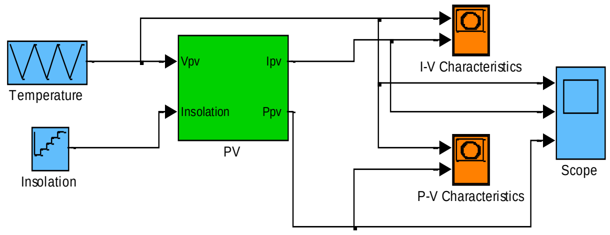

Fig 3:PV-Module SIMULINK® Model

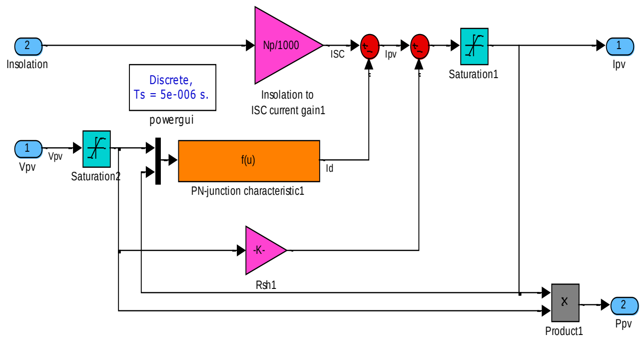

Fig 4: Unmasked PV Subsystem

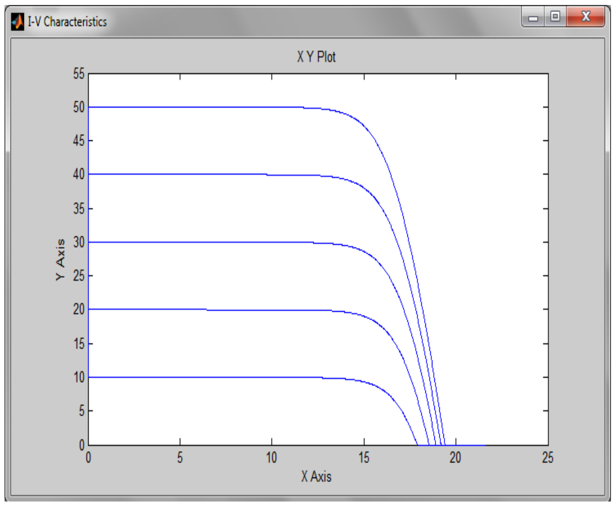

Fig 5: I-V Characteristic Curve

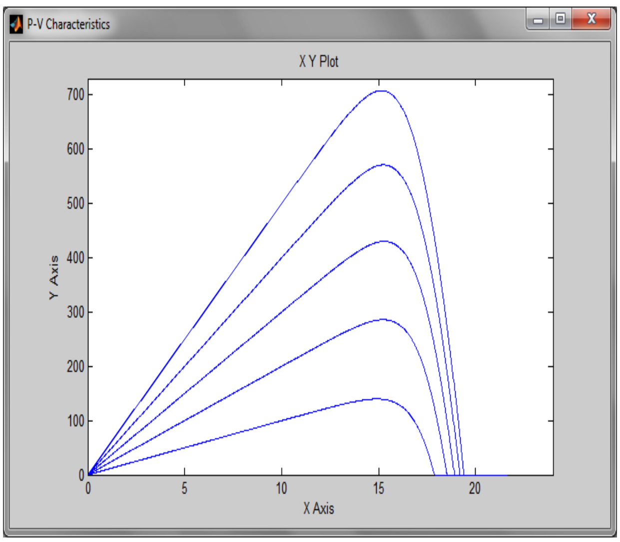

Fig6: P-V Characteristic Curve

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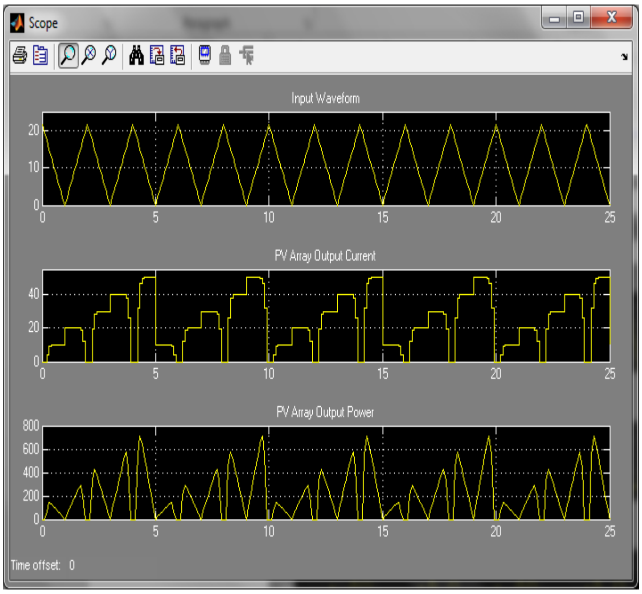

Fig 7: Output Waveforms for PV Module

B. Buck-Boost Converter Design

A buck-boost converter is a type of DC-DC converter that has an output voltage magnitude either greater than or less than the magnitude of the input voltage magnitude. It's described by a voltage source connected in parallel to an inductor, a reverse-biased free-wheeling diode, a capacitor, and a load of resistance R at the output terminal.

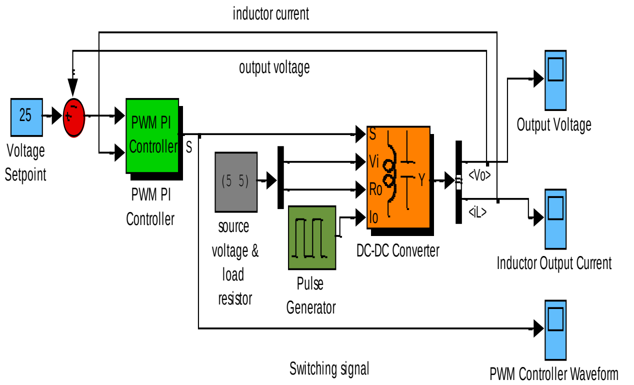

Fig 8: Buck-Boost Converter using PWM-PI Controller

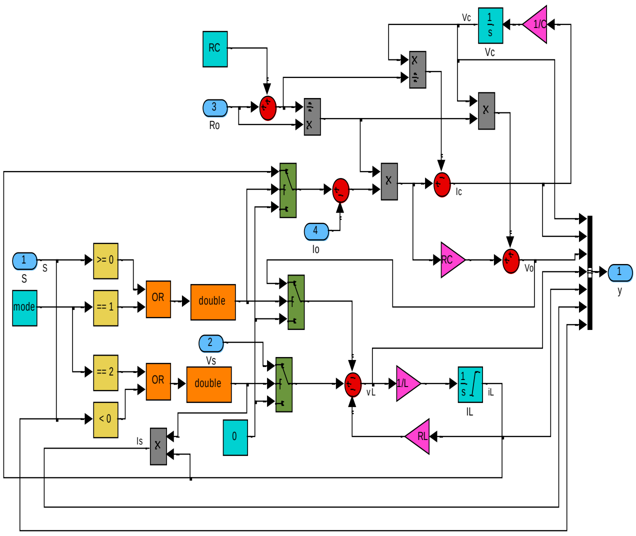

Fig 9: Unmasked Buck-Boost Converter

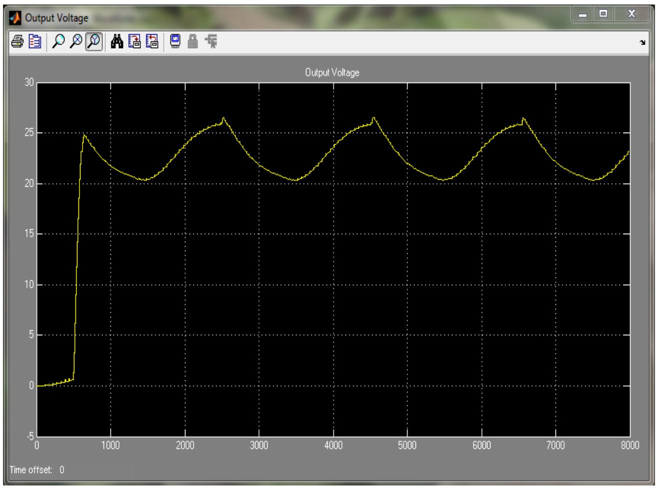

Fig 10: Converter's Output Voltage

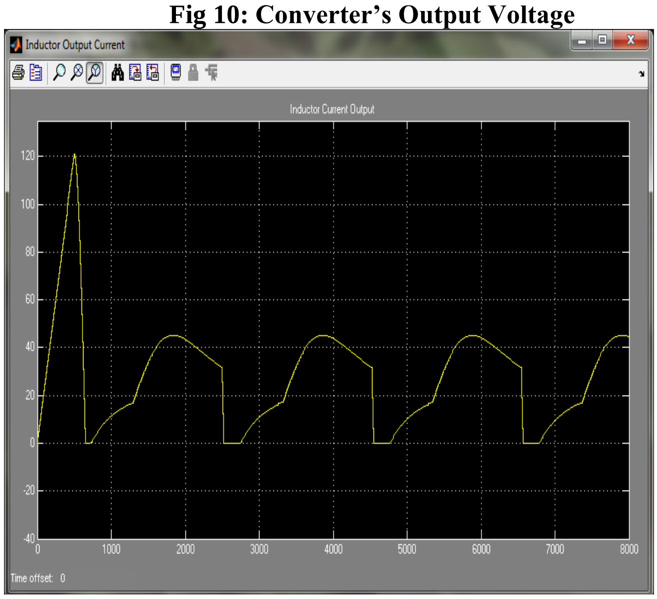

Fig 11: Converter's Output Current

C. *Artificial Neural Network Design*

The Artificial Neural Network has been designed using the simple short circuit current I_{SC} and open circuit voltage V_{OC} equations[1] which are described as:

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

where,

I_SC = Short Circuit Current
V_{OC} = Open Circuit Voltage
G^* = Reference Solar Radiation = 1000 W.m^{-2}
ISC* = PV I_{SC}at Ref. Solar Radiation = 50 A
α_i = Temperature Co-efficient of ISC = 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

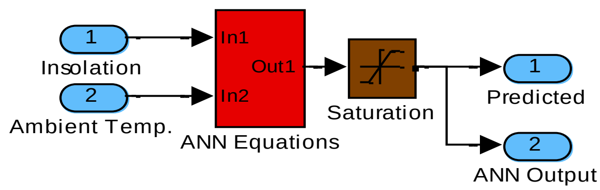

Fig 12: Artificial Neural Network Architecture

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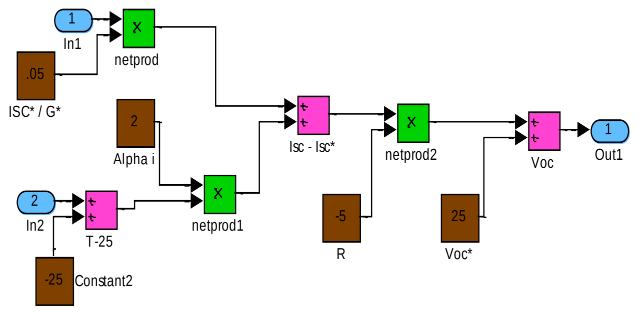

Fig 13: ANN Equations Design

D. Concluding Model

The concluding model is nothing but the combined designs of the PV Module, the Buck-Boost Converter, and the Artificial Neural Network Controller. The model is shown alongside, Fig 14.

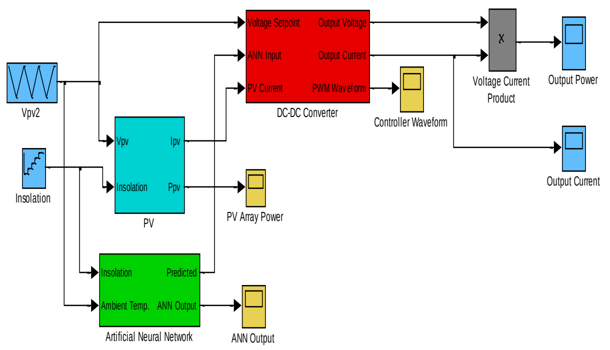

Fig14: Project's Overall SIMULINK® Model

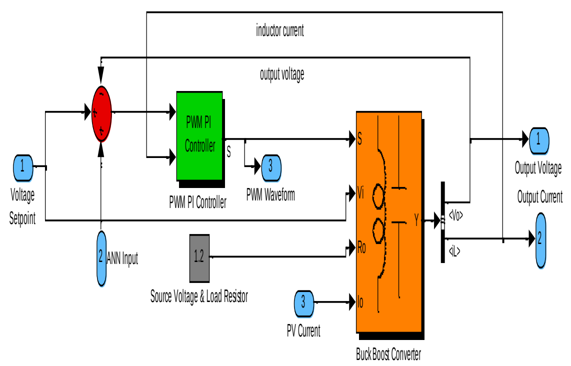

Fig 15: DC-DC Converter Subsystem

VI. RESULTS

The results are given as:

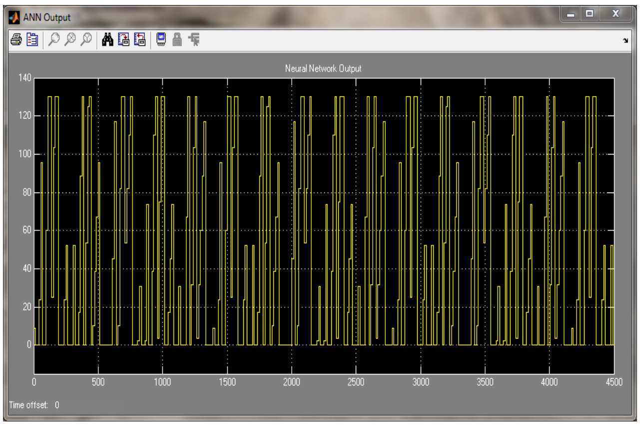

Fig 16: ANN's Predicted Output Waveform

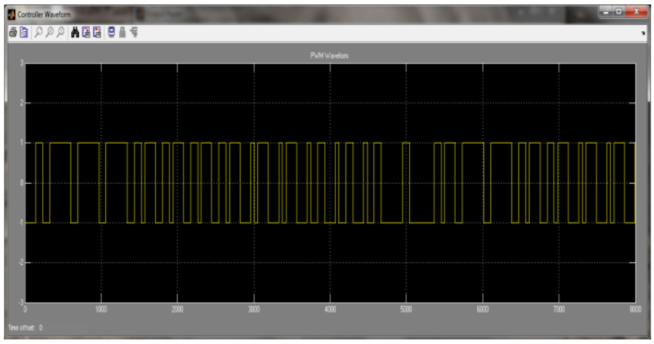

Fig 17:Controller's Waveform

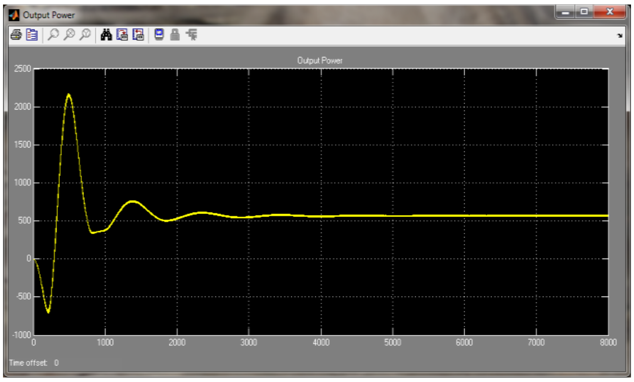

Fig 18:Final Output Power Waveform

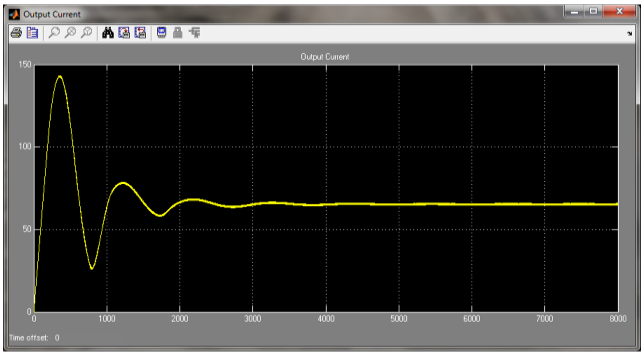

Fig 19: Final Output Current Waveform

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