Modeling and Analysis of MPPT Control for Grid-connected Solar PV System Using Artificial Neural Network Controller

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ABSTRACT

In our current generation, the electricity demand is growing day by day. Nowadays, the largest electricity is generated through conventional energy sources (thermal, nuclear, etc.), which are not sufficient to meet the demand as the availability of fossil fuels is being reduced, therefore due to the reduction in conventional energy sources, we are unable to meet demand. The alternative method of generating electricity is via non-conventional energy sources (wind energy, solar energy, hydro, biomass, etc.) which are environmentally friendly. As such, it is possible that one day the world could be entirely reliant on solar energy. With the help of technology, the cost of Solar Photo Voltaic (SPV) panels and associated equipment has reduced tremendously over recent decades. Low-voltage PV cells are aligned in a series to acquire high DC output voltage to interface solar energy to the grid.

To increase the system's efficiency, an integration of solar energy with conventional energy sources can be implemented. The solar system's low efficiency is caused by its reliance on sun radiation, which varies naturally. To improve efficiency and get around these problems, the Maximum electricity Point Tracking (MPPT) algorithm should be used to extract the majority of the system's electricity. The most popular methods for tracking the maximum power point are Incremental Conductance (INC) and Perturb and Observe (P & O). Because the IC algorithm is more precise when sun radiation changes quickly, the INC techniques outperform the P&O method in terms of efficiency. The voltage in the Perturb and Observe technique is extremely close to the maximum output power, but it cannot achieve the precise peak power. Multiple PV panels can improve the performance of a single panel, which is insufficient. In this work, the Artificial Neural Network (ANN) controller-based MPPT is compared with the analysis of the Incremental Conductance approach for MPPT. Using the MATLAB/Simulink environment, a model comprising several PV module panels with a conventional source and a DC/DC boost converter with various MPPT approaches was simulated. The simulation results demonstrate the superior efficiency of the Artificial Neural Networks (ANN) MPPT technology over alternative methods.
Keywords: Artificial Neural Network (ANN), Incremental Conductance (INC), Maximum Power Point Tracking (MPPT), Solar Photovoltaic (SPV).

I. INTRODUCTION

Because electricity is used in every sector in recently expanding places, the demand for it is growing quite quickly daily. Traditional production systems cannot meet the demand due to the high cost of input fuels and their limited availability. To generate enough electricity to meet the demand for electric loads, renewable energy resources are frequently exploited. The primary benefit of renewable energy resources is their boundless availability and costlessness. Excessive/continuous usage of traditional generating systems causes the extinction of the fuels which are limited.[1] Integrating these generating systems with renewable energy sources like solar will conserve the fuels. Solar energy is one of the renewable energies, which is widely used for power generation. Solar vitality is more reliable, environment friendly, and a daily available renewable energy resource. The solar system depends upon sun radiation which varies in nature due to this solar system suffers low efficiency and high costs. To increase efficiency and overcome drawbacks, most of the power should be extracted from these systems using an algorithm named Maximum Power Point Tracking algorithm. Another method is the physical tracking technique, in this process the Photovoltaic modules align orthogonal towards sun rays throughout the whole day. This tracking method can be done automatically or manually.

Various countries in the world are using solar systems widely to fulfill the load demand. Solar PV modules are employed for power generation from the sun which consists of solar cells. The solar cells are fabricated of doped Silicon and Germanium material. As the sun's rays tumble on the solar panels then the photon gets the energy from the rays and developed a photocurrent. Because of this, the solar panel works as a current source. But irradiation varies with time which shows the nonlinearity of solar systems. To achieve the extreme energy from the panel the Maximum Power Point Tracking procedures are employed [2]. By using these algorithms, we can improve the effectiveness of the PV technique. Presently the research is going on to find out the best algorithms to attain the peak power from solar panels. These techniques increase the efficiency of solar panels.

The production of solar power is essential for meeting demand loads. However, the temperature, amount of irradiation, material used in the construction of the panel, and the need for solar energy for future power generation all affect how much radiation is produced over time. For this reason, a lot of scholars have developed theories and techniques to achieve exceptional vitality. My motivation for writing this study is the difficulties in this sector and the emerging opportunities for research in it. The two most popular Maximum PowerPoint Tracking methods are Incremental conductance and Perturb and Observe (P & O). Because the IC algorithm is more precise in areas where solar radiation changes quickly, IC techniques are more efficient than P&O methods [3]. More sensors than just P&O are needed in the IC approach to track MPPT. The voltage in the Perturb and Observe technique is extremely close to the maximum output power, but it cannot achieve the precise peak power. An IC-IR algorithm [4,] phase inverters, PV arrays, and DC converters are all used in the proposed solar vitality system. The four 10 kW photovoltaic arrays, with a 40 kW maximum capacity, were created using Matlab software. PV modules are joined in both series and parallel to form the PV arrays. To increase the efficiency and dependability of the system, the boost converter's duty cycles are regulated using IC approaches, which are connected to the module. Radiation that changes over time is the module's input. The PV system needs a three-phase voltage source inverter to be connected to the grid.

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A. CONVENTIONAL SOURCE

Conventional energy sources are those that are often utilized and are typically non-renewable energy sources that have been in use for a considerable amount of time. Conventional energy sources include electricity, biomass, coal, oil, and natural gas. The majority of the energy used worldwide, including in India, comes from fossil fuels like coal, gas, and oil. About two-thirds of the nation's electricity comes from conventional resources and nearly all of transportation fuels. While the initial cost of conventional energy may be lower than that of unconventional energy sources like geothermal or solar power, the world's dependence on fossil fuels poses numerous problems, such as harm to the environment, resource security, and lack of sustainability. Finding and using their fresh deposits is likewise getting harder and harder. Another traditional power source that serves as a gauge of a country's economic health is electricity. An abundant electrical supply allows for unlimited growth in transportation, agriculture, and industry. The majority of the electrical energy consumed worldwide is produced by nuclear, hydroelectric, and thermal power facilities. Conventional energy sources are the three ways of generating power that are most frequently mentioned.
These are the more traditional or commonly used elec trical energy sources as a result.

B. PV ARRAY

A solar cell is one unit of a solar panel. A solar array is constructed after different solar cells are joined. In a photovoltaic system, solar cells are connected both in series and parallel. A block schematic of a Maximum Power Point Tracking (MPPT) system including a PV array, DC-DC converter, MPPT controller, and load is shown in Figure 1. A photovoltaic array is a collection of solar cells connected in series and parallel [7][8].

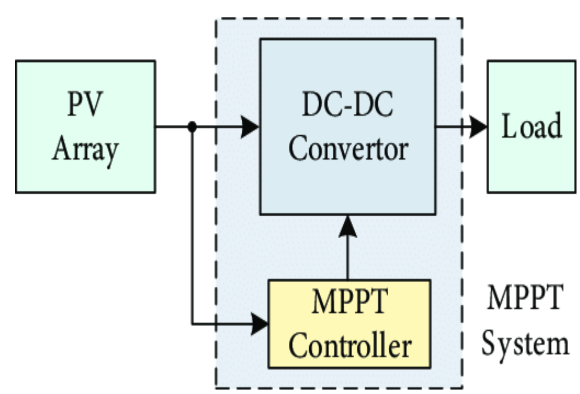

Fig.1. Block Diagram MPPT system

C. DC-DC CONVERTERS

Modern power management systems depend heavily on DC-DC converters, which are vital electronic circuits. Their main job is to change the voltage of a Direct Current (DC) source from one level to another, which guarantees a reliable and effective power supply to a range of electronic systems and devices. DC-DC converters maintain a consistent output voltage, giving the system's components dependable power, in applications where input voltage levels can fluctuate due to variables like battery discharge over time or variations in load circumstances.
With resistive equipment, such as transformers or linear regulators, which usually lose energy and produce heat, switching approaches can help reduce power losses. This leads to increased overall efficiency and longer battery life for portable electronics. Additionally, DC-DC converters enable flexible voltage level stepping, which facilitates effective power distribution management in electronic systems. To lower the possibility of ground loops and protect delicate components from noise and voltage spikes, they can also offer galvanic isolation, which involves separating the input and output grounds. Precise voltage regulation is another important characteristic of DC-DC converters. With an average variance of less than 1%, certain converters can maintain output voltage accuracy within a limited range. This degree of accuracy is essential for guaranteeing the appropriate functioning of electronic systems and equipment that need consistent power sources. They can be designed as standalone devices, integrated into larger power management systems, or embedded into individual components, such as microprocessors or microcontrollers.[9]

D. MPPT (Maximum Power Point) METHOD

MPPT Power and Voltage values are used for perturbation in the
Perturb and Observe (P&O) system.[10] The perturb and observe control method is made such that when there is a voltage shift, the maximum power is measured either in the rear direction for MPP in the forward direction if power drops.
Fig. 2 displays the MPPT PV curve.

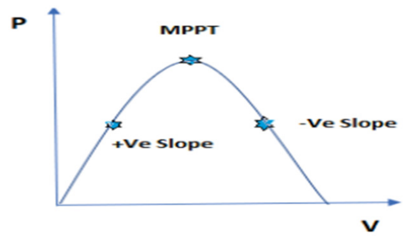

FIG.2. PV Curve for MPPT METHOD

If dp /dv > 0, the curve's left side, or +ve slope, is reached.
When dp/dv<0, the curve's right side, or -ve slope, is reached.
At the greatest powerpoint, dp/dv=0.
The Perturb & Observe method is mostly utilized for duty cycle adjustment and PV Maximum Power Tracking. P&O is an ongoing process that involves observation and perturbation to reach the maximum power point. In this procedure, an estimate of the approaching time is made by comparing the power and voltages at a time (t) with the sample collected at a time (t-1).
A minor variation in voltage modifies the solar panel' s power; if this power modification is positive, the vo ltage perturbation persists along the same path. However, if power is negative, it means that the distu rbance must be reduced and the maximum amount of time required to reach MPP is indicated. Thus, the entire PV system is examined. Figure 3 displays the P&O technique flow chart of MPPT.

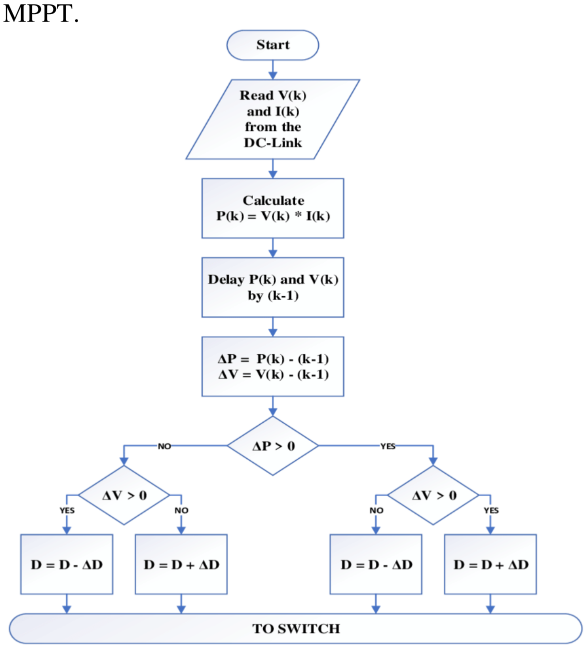

FIG.3. Flow chart of Perturb and Observe MPPT Technique

To fulfill the aforementioned donations, are acquired: Sections II and III explain the two methods, Incremen tal Conductance MPT and ANN MPPT, along with th e associated findings. Section IV contains the tariff calculations; Section VI provides the findings and future scope; and Section I V lists the key findings, comments, and methodology comparisons. the subsequent activities

II. ANALYSIS OF PV SYSTEMS WITH INCREMENTAL CONDUCTANCE METHOD FOR MPPT

The P&O algorithm has very minimal temporal comp lexity, but when it approaches the MPPT, it keeps dis turbing in both directions. This suggests that the algorithm is approaching the m aximum posterior probability (MPP) with great precis ion.

At this point, we have two options: we may use a wai t function to extend the method's execution time, we c an set an acceptable error limit complexity. However, the technique fails to account for the fast change in irradiation level, which causes a change in MPPT. Instead, it treats this as a perturbati on-induced change in MPP, which leads to the incorrect MPP being calculated.

We can use the incremental conductance method to get around this issue.

The Incremental Conductance (IC) method overcome s the drawbacks of the perturb and observe method fo r tracking peak power under rapidly changing air con ditions.

When the MPPT reaches the MPP, the IC can recogni ze it and cease influencing the operating point. If this requirement is not met, the relationship between dI/d V and I/V can be used to determine the direction in w hich the MPPT operating point needs to be perturbed. The fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP is the basis for this relationship. The ability to identify when the MPPT has reached th e MPPT where P&O oscillates about the MPP gives this algorithm an advantage over P&O. Additionally, incremental conductance has a higher accuracy than P and O in tracking conditions of quickly increasing and falling irradiance.[11]

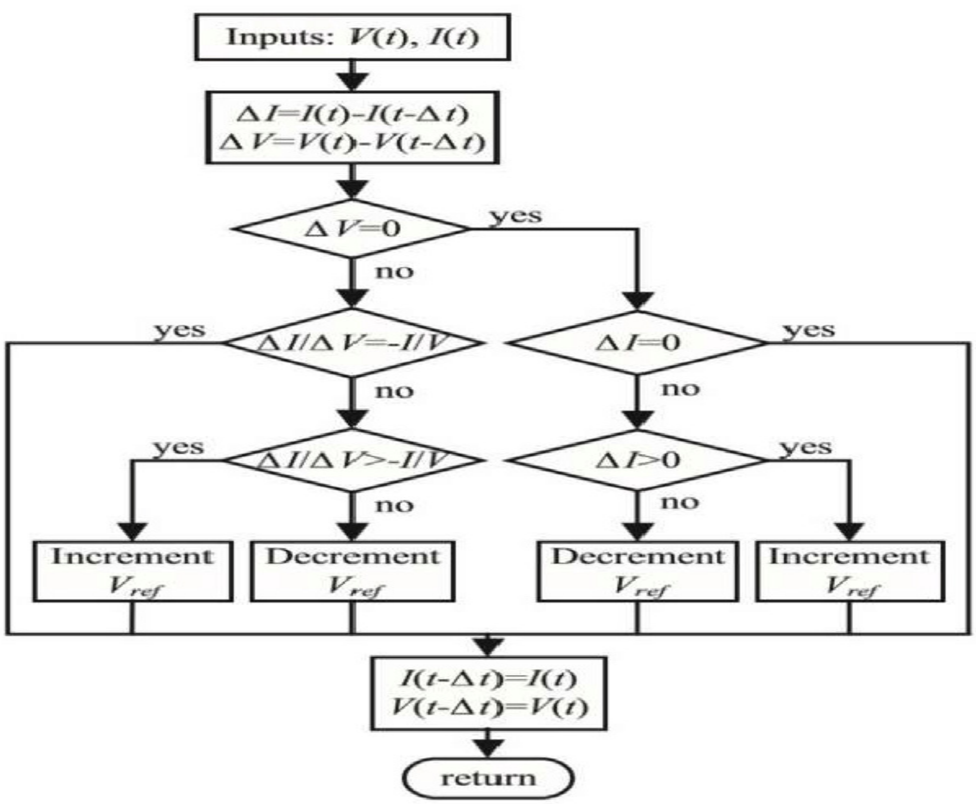

FIG.4.Algorithm for Incremental Conductance Method

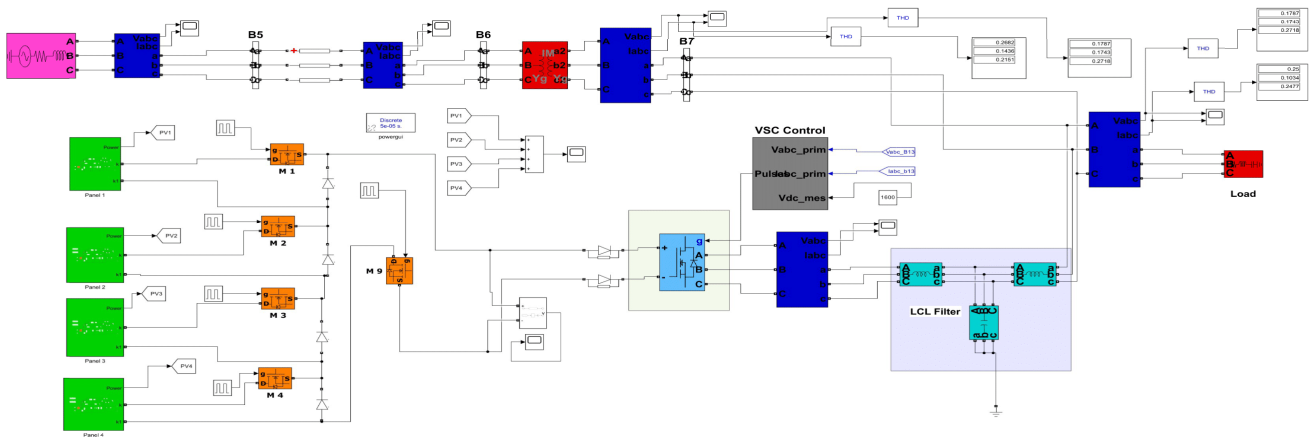

FIG.5. Simulink model of PV Systems with Incremental Conductance Method

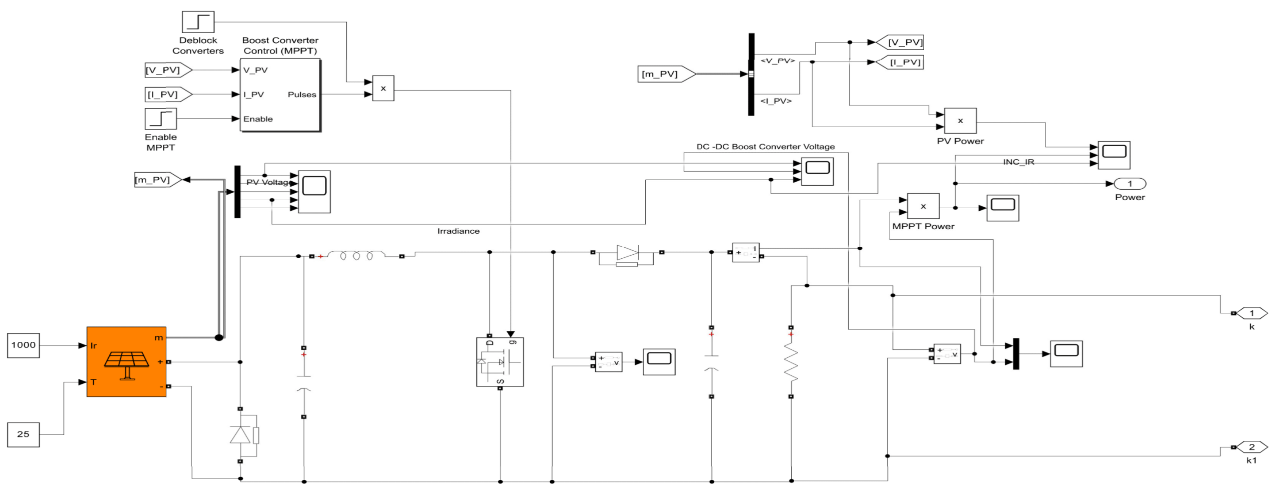

Fig.6. Subsystem of Incremental Conductance Method

RESULTS

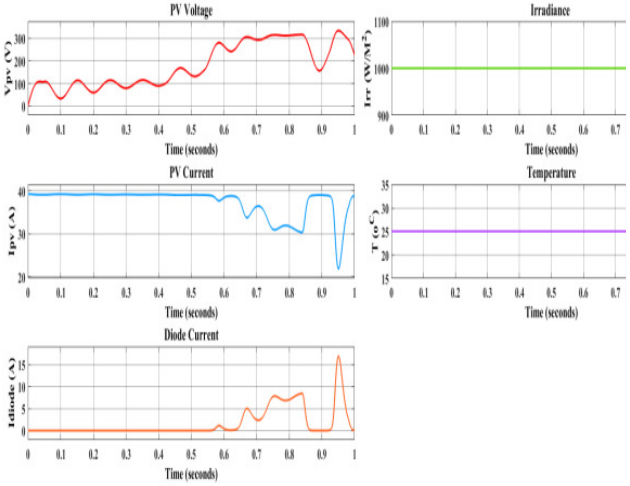

FIG.7. Solar PV output concerning Time

From the above figure, we can observe the photo voltaic cell output voltage, PV current, diode current, irradiance, and temperature. All are concerning time(T).

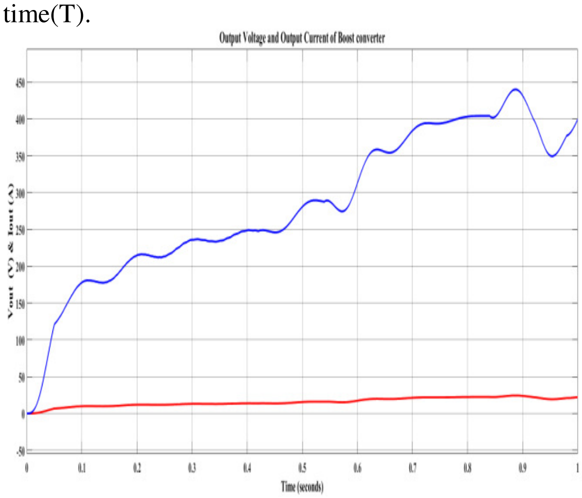

FIG.8. BOOST CONVERTER voltage and current Concerning Time

Output voltage and output currents of the boost converter are shown in Figure 8. concerning time.

Below figure 9, gives us the graphical representation of the output power of MPPT concerning the load power of the INC controller.

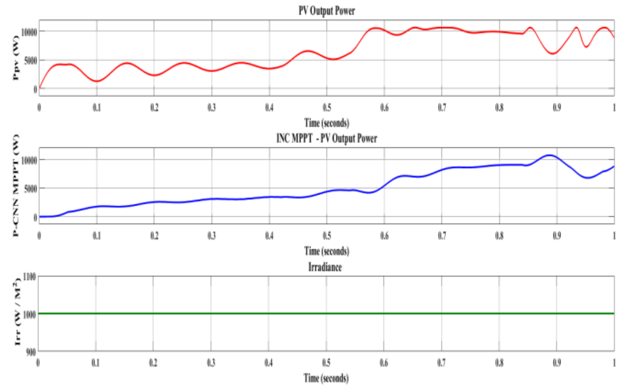

FIG.9. MPPT output power and load power using INC controller concerning Time

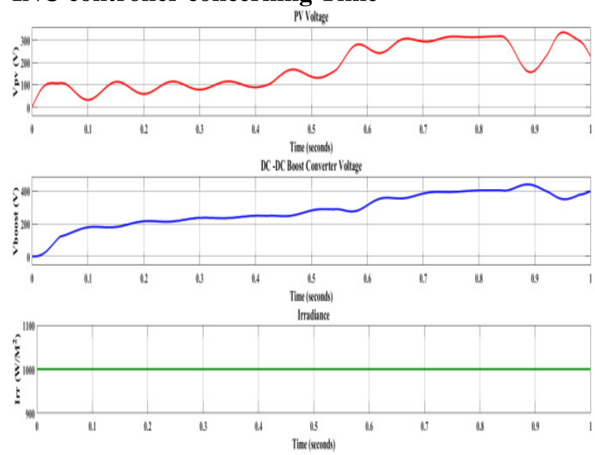

Fig.10. BOOST CONVERTER voltage and PV voltage concerning Time

figure 10, gives us the graphical representation of the voltage of the boost converter concerning pv voltage.

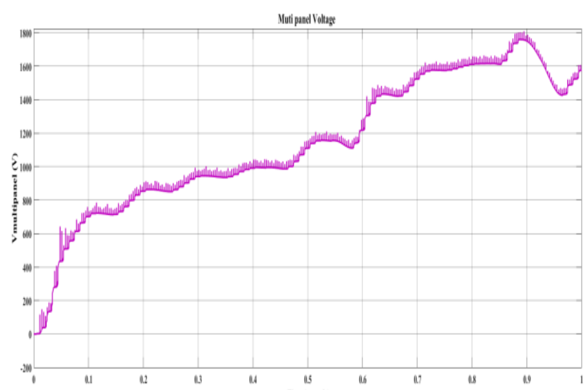

Fig.11. Total Multi Panel voltage

From the above figure, we can observe the total multi-panel output voltage concerning time(T).

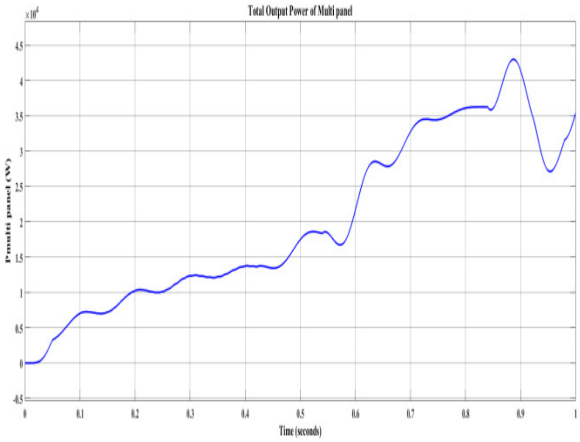

Fig.12. Total Multi-Panel Power Concerning Time

From the above figure, we can observe the total multi-panel output power concerning time(T).

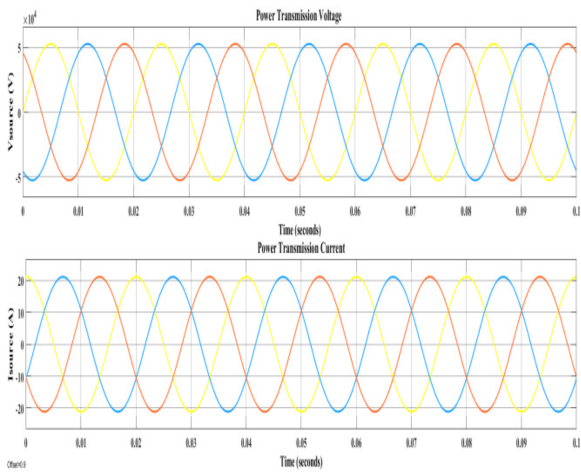

Fig.13. Conventional Source Voltage And Current

Here we are using a conventional source, then voltage and current parameters of the conventional source are shown in above figure 13.

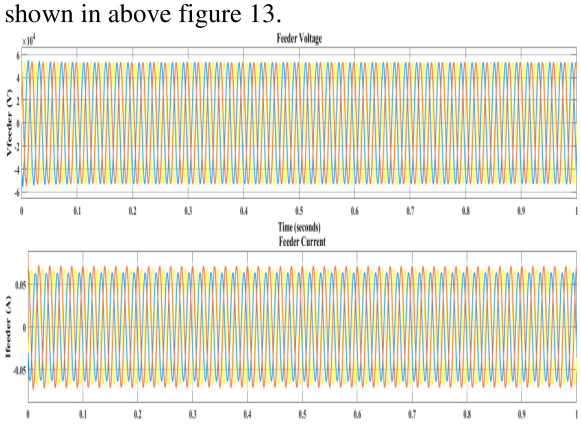

Fig.14. Feeder Voltage and Current Concerning Time

The voltage of the feeder and current of the feeder are shown in Figure 14.

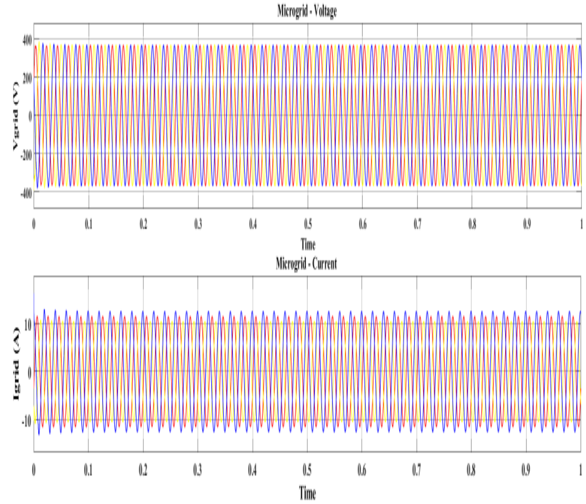

Fig.15 . Grid Voltage And Current

Grid Voltage and current concerning time are shown in above figure 15 and inverter voltage and inverter currents concerning time are shown in Figure 16 below.

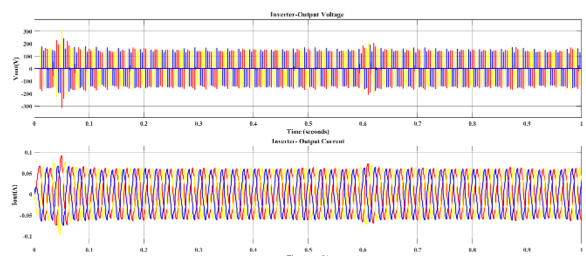

Fig.16. Inverter voltage and current

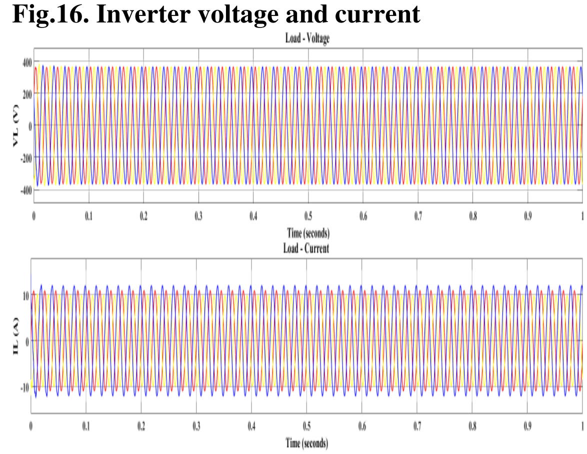

Fig.17. Load Voltage and Load Current

The load voltage and current of the INC controller are shown in the above figure.

III. ARTIFICIAL NEURAL NETWORK-BASED MPPT ALGORITHM FOR SOLAR PV SYSTEM

ANN BASED MPPT:

MPPT performance is based on how well harmonic components are removed from distorted current waveforms for accuracy and precision. The optimal performance for removing harmonic components from the voltage or current waveform has led to the development of the MPPT control algorithm. To control voltage, an INC controller is typically used. However, because of its limitations, such as the time-consuming and difficult process of detecting parameters, as well as other drawbacks like the inability to improve the system's transient response, an Artificial Neural Network (ANN) controller has been introduced in this research work. This is because of the controller's high speed of recognition, learning ability, and adaptability to any system. A mathematical model that draws inspiration from biological neural networks is called an Artificial Neural Network (ANN).

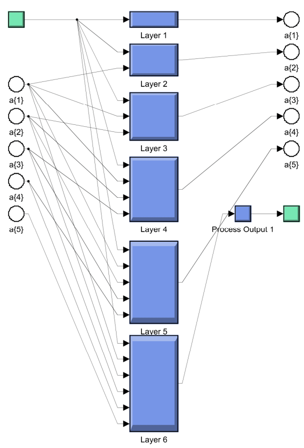

Fig.18.Structure of 7-layer ANN

An artificial neural network is made up of a network of connected artificial neurons that compute information using the connectionist technique. It is similar to the brain in two ways:

(i) The learning process is how the network gathers the data.

(ii) The data is stored using inter-neuron connection strengths.

Using the ANN model, a nonlinear relationship is bui
lt between the four flat plate configuration
inputs and the output temperature distribution matrix near the flat plate surface.
The input layer, five hidden layers, and one output la
yer make up a total of seven layers in the ANN model.
The four input parameters that have been explained a
bove are included in the first layer, and weighting, bi
asing, and activation are used to move the data to the subsequent layer.
By using the "Rectified Linear Unit" (ReLU) to incre
ase the nonlinear regression before the output layer, t
he first six layers are activated.
Using a sigmoid function, the output layer is activated type of artificial intelligence technique is the Artificial Neural Network (ANN). Compared to traditional methods, the artificial intelligence approach provides greater advantages.[12] The traditional approach has the drawbacks of responding slowly to abrupt variations in solar temperature and irradiance, as well as occasionally failing to follow Maximum PowerPoint. The overview of ANN in MPPT is shown in Fig. 18. Solar voltage and currents are the input. The duty ratio to the DC-DC converter is the neural network's target. A neural network will provide a specific duty ratio value in response to variations in solar temperature and irradiance, allowing for the determination of the Maximum Power Point and the conversion of v and I into duty cycles.
The network is produced by the Levenberg-Marquardt algorithm through training.
Duty ratio is computed and ANN is trained for variou
s combinations of temperature and sun irradiation.
Neural network training involves varying layer weigh
ts to get desired results.
Weights are changed during the training process to tr
ack the goal values with the least amount of error.
The Mean Squared Error (MSE) serves as the ANN's performance function.
an outline of the suggested system's blocks.
Solar energy is converted by the PV array into electri
cal energy, which is then fed into a boost converter.
The suggested solution makes use of ANN-based MPPT.
To obtain the most power points, the duty ratio will b
e altered using ANN control. the "n" and "n-1" intervals that were acquired using the conventional approach
following that, the obtained data is used to train the ANN Controller.

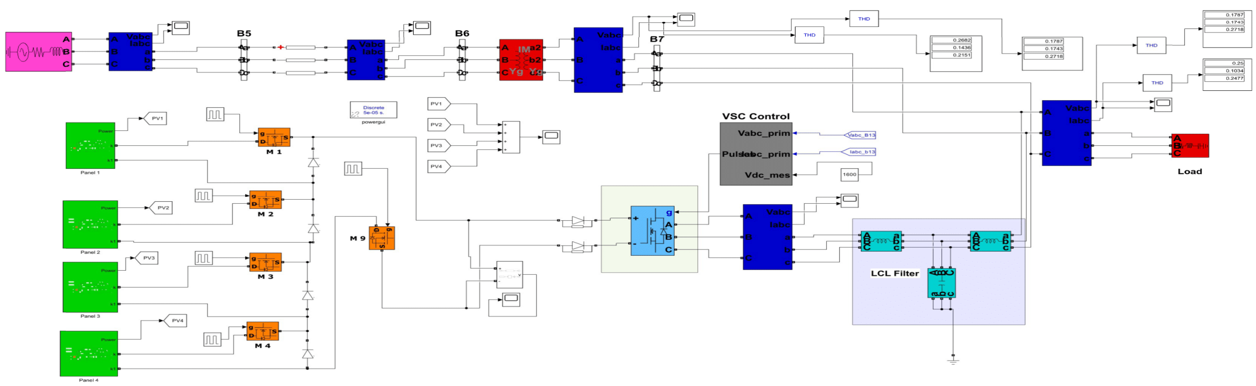

Fig.19. Grid-connected Photo Voltaic system using ANN Controller

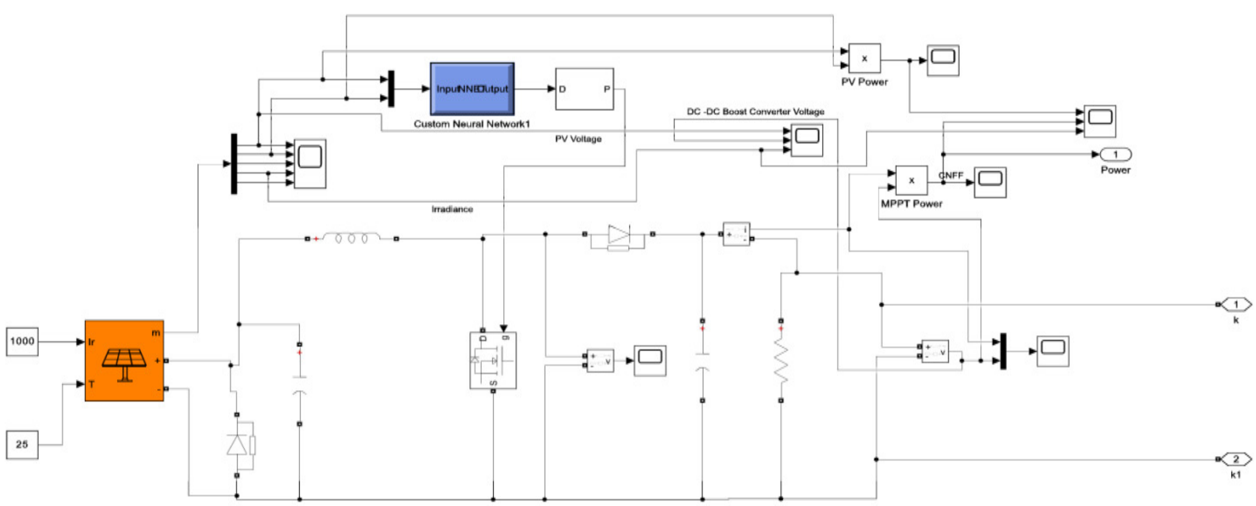

Fig.20. Sub System with ANN Circuit.

IV. RESULTS AND DISCUSSION

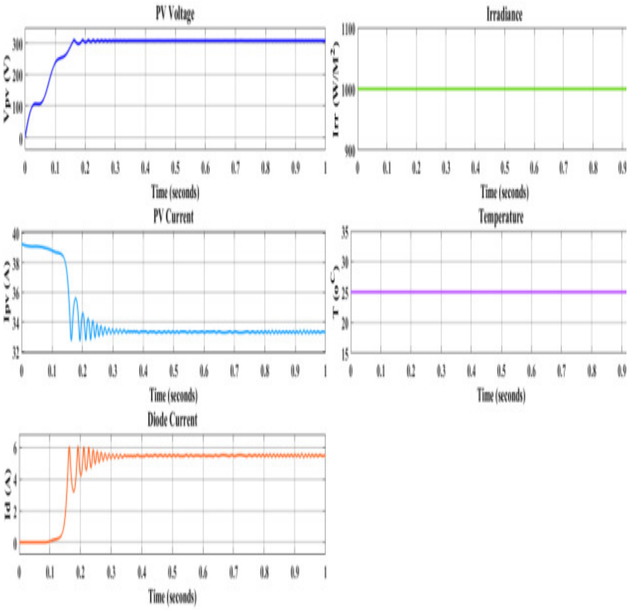

Fig.21. Solar PV output

From the above figure, we can observe that, photo voltaic cell output voltage, PV current, diode current, irradiance, and temperature. All are concerning time(T).

The output voltage and output currents of the boost converter are shown in below figure.23. concerning time.

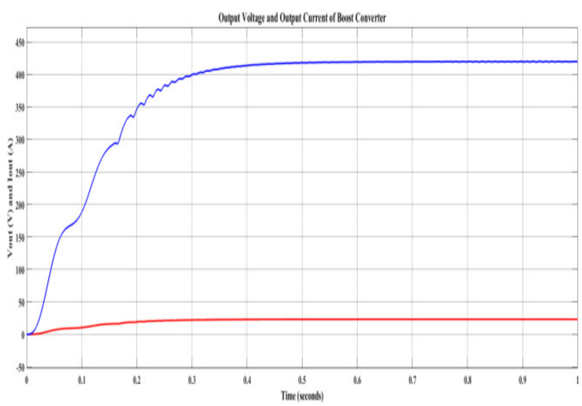

Fig.22. output voltage and output current of the boost converter

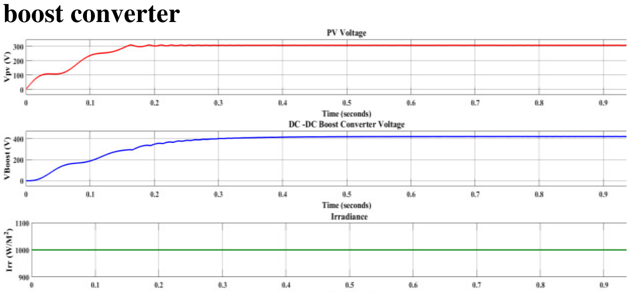

Fig.23. Boost Converter Voltage With Respect To Time

Below figure 24, gives us the graphical representation of the BOOST converter voltage with respect to time.

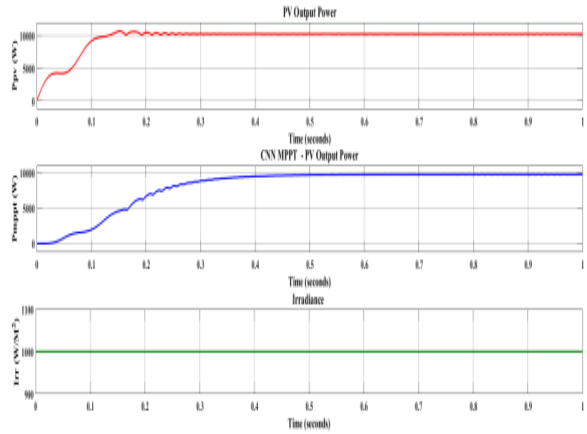

Fig.24. Comparison of PV output power and MPPT Power

Above figure 25 ,gives us the graphical representation of comparision of PV output power and MPPT power.

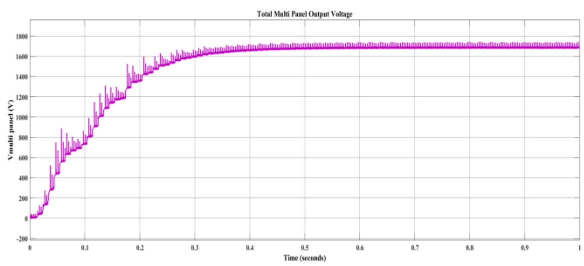

Fig.25. Multi panel output voltage

From the above figure we can observed Total Multi Panel output voltage with respect to time(T).

From the below figure we can observe total Multi Panel output power with respect to time(T).

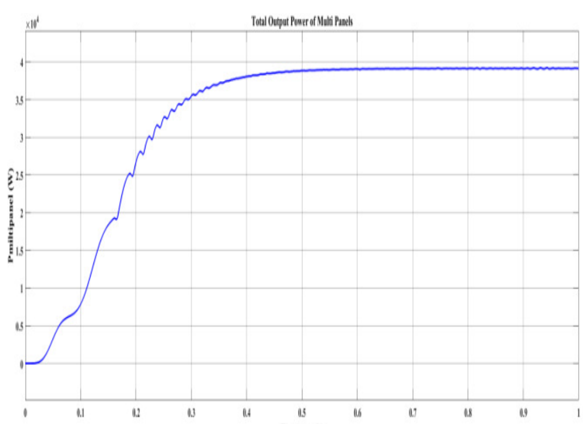

Fig.26. Multi-panel Output Power

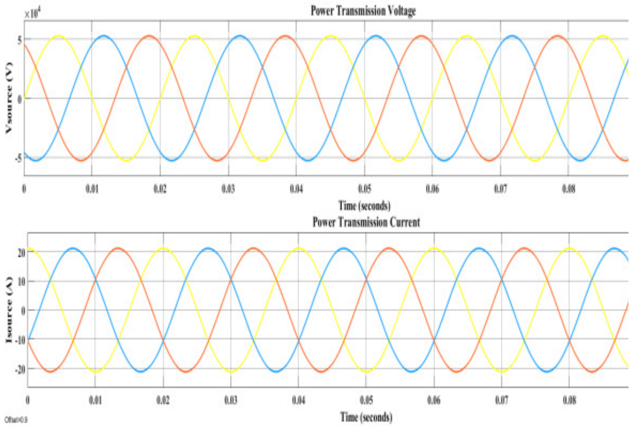

Fig.27. Conventional Voltage and Current

From the above figure, we can observe Conventional output voltage and current concerning time(T).

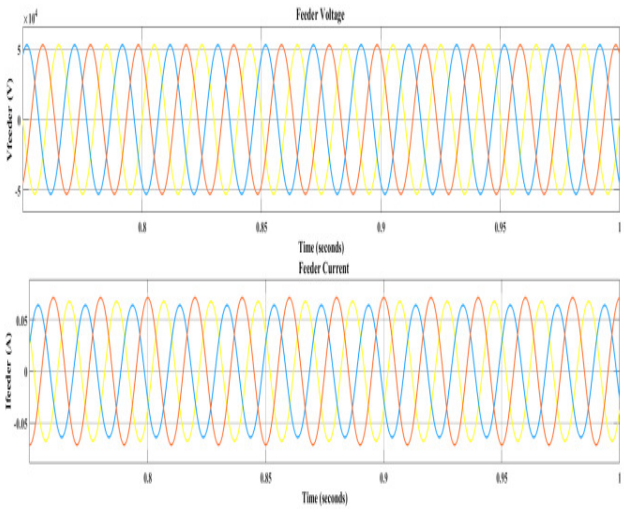

Fig.28. Feeder Voltage and Current

From the above figure, we can observe feeder output voltage and current with respect to time(T)

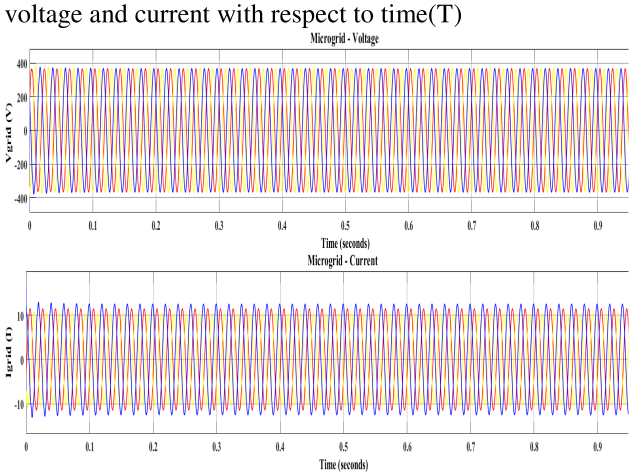

Fig.29. Grid Voltage And Current

From the figure.30, we can observe grid output voltage and current concerning time.

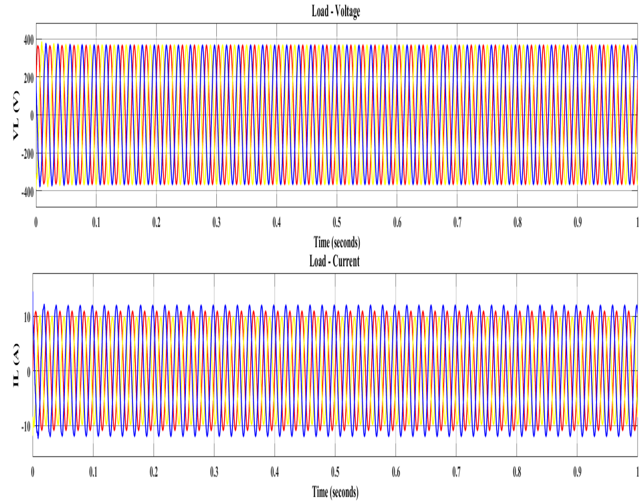

Fig.30. Load Voltage And Current

From the above figure, we can observe Load output voltage and current concerning time(T)

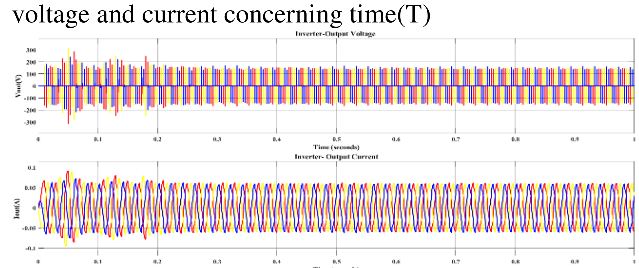

Fig.31. Inverter Output Voltage And Current

From the above figure, we can observe the Inverter output voltage and current concerning time(T)

V.TARIFF CALCULATIONS:

Tariff: The amount of money charged by electricity suppliers to various types of consumers is known as a tariff.

i.e. Electricity cost = Electricity consumption (KWH)× Tariff rate per unit (Rs/unit)

Estimation of Tariff for conventional and non-conventional sources connected to microgrids,

CASE I:

FOR 24 HOURS,

Solar panels (multi panels) generate a total power of 40w.

So, from the tariff equation,

Tariff=Electricity consumption (KWH)×Tariff rate per unit (Rs/unit)

Let us assume solar generating power for 8 hours. Then,

TARRIF = 40kw X 8 hours

= 320kw hr =320 units

1 unit charge for solar power = 2.44 rupees.[13] Then

$Tariff_{solar}$ for 8 hrs = 320 X 2.44 = 780.8 rupees

Similarly for conventional sources for the remaining 16 hours,

1 unit charge for conventional source is 1 rupee for 0-50kw and 2.6 rupees for (50-100) kw.[14]
Then'
$Tariff_{conventional / 16 hours}$ = 40 X 16 X 1.6 = 1024 rupees
Total Tariff per day = 780.8 + 1024 = 1804.8 rupees
If conventional provides 40 kw per day,
$TARRIF_{conventional}$ / day = 40 X24 X 1.6 = 1536 rupees

CASE II:

If the load demand is 80 kw, the Conventional source provides 40kw and the solar source provides 40 kw. Then,
TARIFF is given as,
Tariff=Electricity consumption (KWH)×Tariff rate per unit.
Tariffconventional/day = Tariffconventional(40kw)/8hours+ (80 kw)/16 hours.
Tariffconventional/day= (40 X 8 X 1.6) + (80 X 16 X 2.6) rupees
Tariffconventional/day + $Tariff_{solar/8 hours}$ = 3840 +780.8 =4620.8 rupees
If the load demand is 80 kw, the Conventional source provides 80kw alone
Tariffconventional/day= 24 X 80 X 2.6 = 4992 rupees
Tariff difference= 4992 - 4620.8 =371.2 rupees/day
From CASE I and CASE II, it is observed that the electricity cost is reduced as there is an increase in load demand. With technology improvement and market competition, solar parity is expected to reach grid parity. Parity means the cost of electricity generated from alternative energy becomes equal to or less than the cost of purchasing power from the grid.
By integrating solar energy with microgrids we can conserve conventional sources and the cost per unit can be minimized.

VI. CONCLUSION AND FUTURE SCOPE

This research introduces and compares an artificial neural network-based maximum energy harvesting methodology with an INC-based MPPT method to determine which algorithm performs better.
PV voltage and PV current are the inputs to the ANN, and the duty ratio for the boost converter is the output.
The "NN tool" in the MATLAB/SIMULINK model is used to train the ANN.
Based on comparison results, the ANN-based MPPT controller outperforms the other Maximum PowerPoint Tracking algorithms in terms of performance-like reaction to abrupt variations in PV voltage and current.
Based on the outcome, it can be said that the ANN-based MPPT approach performs better in terms of more output power when compared to the INC-based MPPT technique., less steady state oscillations, and the requirement of less settling time, along with this we estimated electricity cost per unit per day and observed that the cost per unit is reduced by integrating solar energy and conventional energy sources with microgrids.

We can maximize the benefit results by using ANFIS controller instead of ANN controller as future scope.

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