MAXIMUM POWER POINT TRACKING (MPPT) FOR THE SOLAR PV SYSTEM

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by

SHIVRAJ VISHWAKARMA
(Roll No. 1673720051)

Under the Supervision of
DR. M. ASLAM HUSAIN
(Assistant Professor)

DEPARTMENT OF ELECTRICAL ENGINEERING
RAJKIYA ENGINEERING COLLEGE
AMBEDKAR NAGAR- 224122 (U.P.)

Affiliated to
DR. A. P. J. ABDUL KALAM TECHNICAL UNIVERSITY, LUCKNOW (U. P.), INDIA
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Dedicated to my parents....

for.

Giving me a dream.

And,

to my teachers....

for

Helping me to realize that

dream.

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UNDERTAKING

I declare that the work presented in this report titled **"Maximum Power Point Tracking (MPPT) for Solar PV Systems"**, submitted to the **Department of Electrical Engineering, Rajkiya Engineering College, Ambedkar Nagar**, for the award of the **Bachelor of Technology degree**, is my original work & have not **plagiarized or submitted** the same work for the award of any other degree. In case this undertaking is found **incorrect**, I **accept** that our degree may be **unconditionally withdrawn.**

Shivraj

(Shivraj Vishwakarma)

Date: 08/09/2020.

Place: **Ambedkar Nagar (U. P.)**

Department of Electrical Engineering
Rajkiya Engineering College,
Ambedkar Nagar- 224122 (U.P.)

CERTIFICATE

This is to certify that **Mr. Shivraj Vishwakarma** has carried out the project work presented in this report entitled **"Maximum Power Point Tracking(MPPT) for the Solar PV System"** for the award of **Bachelor of Technology** in **Electrical Engineering** from **Dr. A. P. J. Abdul Kalam Technical University, Lucknow** under our/my supervision during the academic session 2019-20.

SUPERVISOR

(Dr. M. Aslam Husain)
Assistant Professor

APPROVAL FOR SUBMISSION

(Prof. S. P. Singh)
Associate Professor & Head

Date:

Place: Ambedkar Nagar (U. P.)

Department of Electrical Engineering
Rajkiya Engineering College,
Ambedkar Nagar (U. P.)

HEAD
Electrical Engineering Department
Rajkiya Engineering College
Ambedkar Nagar (U.P.) 2241

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Shivraj

(Shivraj Vishwakarma)

Date: 08/09/2020.
Place: **Ambedkar Nagar (U. P.)**

ABSTRACT

The need for renewable energy sources is on the rise because of the acute energy crisis in the world today. India plans to produce 20 Gigawatts Solar power by the year 2020, whereas we have only realized less than half a Gigawatt of our potential as of March 2010. Renewable energy sources (RES) such as solar, wind, and tidal are considered the solution to overcome the global energy crisis. Among these RES, solar energy is considered one of the potential sources to solve the crisis as it is available in abundance and free of cost. And thus, it becomes essential to extract maximum power from solar PV cells under variable atmospheric conditions. Maximum power point tracking (MPPT) scheme is used to extract maximum power from solar PV cells. Solar energy is a vital untapped resource in a tropical country like ours. The main hindrance for the penetration and reach of solar PV systems is their low efficiency and high capital cost. In this thesis, we examine a schematic to extract maximum obtainable solar power from a PV module and use the energy for a DC application. This project investigates in detail the concept of Maximum Power Point Tracking (MPPT) which significantly increases the efficiency of the solar photovoltaic system.

The Maximum Power Point Tracker (MPPT) is the optimum operating point of a photovoltaic module. It plays a very important role to obtain the maximum power of a solar panel as it allows an optimal use of a photovoltaic system, regardless of irradiation and temperature variations. In this research, we present a novel technique to improve the control's performances optimization of the system consisting of a photovoltaic panel, a boost converter and a load. Simulations of different parts of the system are developed under MATLAB/Simulink.

The MPPT Technique that we have used during the simulation and on which we have tested our Solar PV system is Particle Swarm Optimization (PSO) technique. The simulation is done for two cases, one is without the implementation of the MPPT technique and other one is with the implementation of the MPPT technique. The Results of the cases are compared and discussed.

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LIST OF SYMBOLS

=	Equal
-	Subtraction
/	Division
+	Addition
$\sqrt{}$	Square Root
$\approx$	Approximate
>	Greater Than
$\geq$	Greater than or equal to
$\times$	Multiplication
$\lvert . \rvert$	Absolute Value
Δ	Delta (for difference)
( )	Small bracket
[ ]	Big bracket
$\frac{d}{dt}$	Differentiation with respect to t.
$\int(.)dt$	Integration with respect to t.
∂	Del
$\circ$	Degree
Ω	Omega.

LIST OF ABBREVIATION

AC	Alternating Current.
DC	Direct Current.
PWM	Pulse-Width Modulation.
MPP	Maximum Power Point.
MPPT	Maximum Power Point Tracking.
PSO	Particle Swarm Optimization.
GW	Gigawatt.
KW	Kilowatt.
P&O	Perturb and Observation.
PV	Photovoltaic.
mH	Milli Henry.
μF	Micro Farad.
KHz	Kilo Hertz.

CHAPTER 1

<u>INTRODUCTION</u>

1.1 THE NEED FOR RENEWABLE ENERGY

Sustainable power source is the vitality which originates from regular assets, for example, daylight, wind, downpour, tides and geothermal warmth. These assets are inexhaustible and can be normally recharged. Thusly, for every down to earth reason, these assets can be viewed as limitless, dissimilar to lessening traditional petroleum products [1]. The worldwide vitality crunch has given a recharged driving force to the development and improvement of Clean and Renewable Energy sources. Clean Development Mechanisms (CDMs) [2] are being embraced by associations all over the globe.

Aside from the quickly diminishing stores of petroleum derivatives on the planet, another central point neutralizing non-renewable energy sources is the contamination related with their ignition. Contrastingly, sustainable power sources are known to be a lot of cleaner and produce vitality without the hurtful impacts of contamination not at all like their customary partners.

1.2 DIFFERENT SOURCES OF RENEWABLE ENERGY

1.2.1 WIND POWER

Wind turbines can be utilized to bridle the vitality [3] accessible in wind currents. Current day turbines go from around 600 kW to 5 MW [4] of appraised power. Since the force yield is an element of the block of the breeze speed, it increments quickly with an expansion in accessible breeze speed. Ongoing progressions have prompted air foil wind turbines, which are more proficient because of a superior streamlined structure.

1.2.2 SOLAR POWER

The tapping of sunlight-based vitality owes its starting points to the British stargazer John Herschel [5] who broadly utilized a sun powered warm authority box to prepare food during a campaign to Africa. Sunlight based vitality can be used in two significant manners. Right off the bat, the caught warmth can be utilized as sunlight based warm vitality, with applications in space warming. Another option is the transformation of episode sunlight-based radiation to electrical vitality, which is the most usable type of vitality. This can be accomplished with the assistance of sun based photovoltaic cells [6] or with concentrating sunlight-based force plants.

1.2.3 SMALL HYDROPOWER

Hydropower establishments up to 10MW are considered as little hydropower and considered sustainable power sources [7]. These include changing over the expected vitality of water put away in dams into usable electrical vitality using water turbines. Run-of-the-stream hydroelectricity expects to use the motor vitality of water without the need of building repositories or dams.

1.2.4 BIOMASS

Plants catch the vitality of the sun through the procedure called photosynthesis. On burning, these plants discharge the caught vitality. Along these lines, biomass functions as a characteristic battery to store the sun's vitality [8] and yield it on prerequisite.

1.2.5 GEOTHERMAL

Geothermal vitality is the warm vitality which is created and put away [9] inside the layers of the Earth. The slope in this way evolved offers ascend to a consistent conduction of warmth from the center to the outside of the earth. This angle can be used to warm water to deliver superheated steam and use it to run steam turbines to create power. The principle inconvenience of geothermal vitality is that it is normally restricted to locales close to structural plate limits, however late headways have prompted the spread of this innovation [10].

1.3 RENEWABLE ENERGY TRENDS ACROSS THE GLOBE

The current pattern across created economies steers the result for Renewable Energy. Throughout the previous three years, the landmasses of North America and Europe have grasped more sustainable force limit when contrasted with traditional force limit. Renewables represented 60% of the recently introduced power limit in Europe in 2009 and about 20% of the yearly force creation [7].

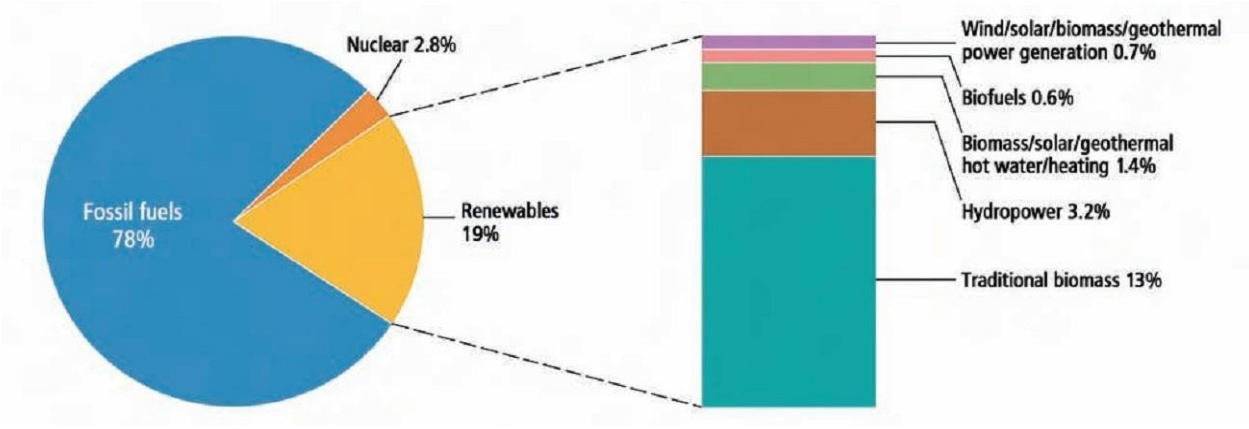

Figure 1.1: Global energy consumption [7]

As can be seen from the figure 1.1, wind and biomass involve a significant portion of the current sustainable power source utilization. Late progressions in sun oriented photovoltaic innovation and consistent hatching of undertakings in nations like Germany and Spain have brought around huge development in the sun based PV showcase too, which is anticipated to outperform other sustainable power sources in the coming years.

By 2009, in excess of 85 nations had some approach focus to accomplish a foreordained portion of their capacity limit through renewables. This was an expansion from around 45 nations in 2005. The majority of the objectives are likewise exceptionally aspiring, arriving in the scope of 30-90% portion of national creation through renewables [7]. Essential strategies are the European Union's objective of accomplishing 20% of all out vitality through renewables by 2020 and India's Jawaharlal Nehru Solar Mission, through which India intends to create 20GW sun-based vitality continuously 2022.

CHAPTER 2

LITERATURE REVIEW

Studies show that a sun-based board changes over 30-40% of vitality episode on it to electrical vitality. A Maximum Power Point Tracking calculation is important to expand the effectiveness of the sun-oriented board.

There are various procedures for MPPT, for example, Perturb and Observe (slope climbing strategy), Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control and so on. Among all the strategies Perturb and watch (P&O) and Incremental conductance are most generally utilized on account of their straightforward usage, lesser opportunity to follow the MPP and a few other monetary reasons.

Under suddenly changing climate conditions (irradiance level) as MPP changes constantly, P&O accepts it as a change in MPP because of bother instead of that of irradiance and once in a while winds up in ascertaining incorrectly MPP [11]. Notwithstanding, this issue gets maintained a strategic distance from in Incremental Conductance strategy as the calculation takes two examples of voltage and current to figure MPP. Notwithstanding, rather than higher proficiency the unpredictability of the calculation is high contrasted with the past one and subsequently the expense of execution increments. So, we need to alleviate with a tradeoff among multifaceted nature and proficiency.

It is seen that the proficiency of the framework additionally relies on the converter. Regularly, it is greatest for a buck geography, at that point for buck-support geography and least for a lift geography. At the point when numerous sun-oriented modules are associated in equal, another simple method TEODI is likewise powerful which works on the rule of evening out of yield working focuses in correspondence to constrain relocation of info working purposes of the indistinguishable working framework. It is easy to execute and has high effectiveness both under writing material and time differing climatic conditions [12].

CHAPTER 3

STANDALONE PHOTOVOLTAIC SYSTEM COMPONENTS

3.1 PHOTOVOLTAIC CELL

A photovoltaic cell or photoelectric cell is a semiconductor gadget that changes over light to electrical vitality by photovoltaic impact. On the off chance that the vitality of photon of light is more prominent than the band hole then the electron is radiated and the progression of electrons makes current.

In any case, a photovoltaic cell is not quite the same as a photodiode. In a photodiode light fall on n-channel of the semiconductor intersection and gets changed over into current or voltage signal yet a photovoltaic cell is consistently forward one-sided.

3.2 PV MODULE

Usually, a number of PV modules are arranged in series and parallel to meet the energy requirements. PV modules of different sizes are commercially available (generally sized from 60W to 170W). For example, a typical small-scale desalination plant requires a few thousand watts of power.

3.3 PV MODELING

A PV cluster comprises of a few photovoltaic cells in arrangement and equal associations. Arrangement associations are answerable for expanding the voltage of the module while the equal association is liable for expanding the current in the cluster. Commonly, a sun powered cell can be displayed by a current source and a transformed diode associated in corresponding to it. It has its own arrangement and equal obstruction. Arrangement opposition is because of obstruction in the way of stream of electrons from n top intersection and equal obstruction is because of the spillage current.

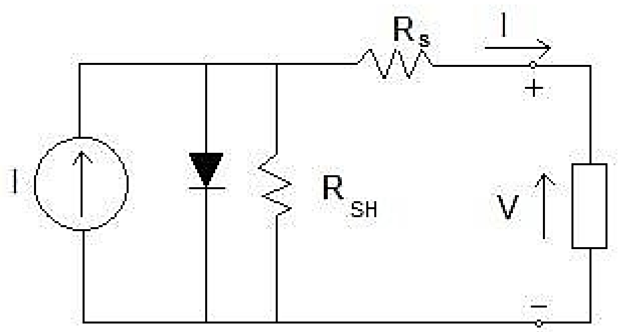

Figure 3.1: Single diode model of a PV cell

In this model we think about a current source (I) alongside a diode and arrangement opposition (Rs). The shunt obstruction (RSH) in equal is exceptionally high, has an insignificant impact and can be ignored.

The yield current from the photovoltaic exhibit is

$$\boldsymbol{I = I_{sc} - I_d} \qquad \textbf{(3.1)}$$

$$\boldsymbol{I_d = I_o\,(e^{\frac{qV_d}{kT}} - 1)} \qquad \textbf{(3.2)}$$

Where, Io is the opposite immersion current of the diode, $\boldsymbol{q}$ is the electron charge, V_d is the voltage over the diode, $\boldsymbol{k}$ is Boltzmann consistent (1.38 * 10-19 J/K) and **T** is the intersection temperature in Kelvin (K)

From eq. 3.1 and 3.2,

$$\boldsymbol{I = I_{sc}} - I_o\left(e^{\frac{qV_d}{kT}} - 1\right) \qquad \textbf{(3.3)}$$

Using suitable approximations,

$$\boldsymbol{I = I_{sc} - I_o\,(e^{\frac{q(V+IRs)}{\eta kT}} - 1)} \qquad \textbf{(3.4)}$$

Where, I is the photovoltaic cell current, V is the PV cell voltage, T is the temperature (in Kelvin) and η is the diode ideality factor.

So as to show the sun-based board precisely we can utilize two diode model yet in our task our extent of study is constrained to the single diode model. Additionally, the shunt opposition is high and can be disregarded over the span of our investigation.

The I-V attributes of a normal sun-based cell are as appeared in the Figure 3.2.

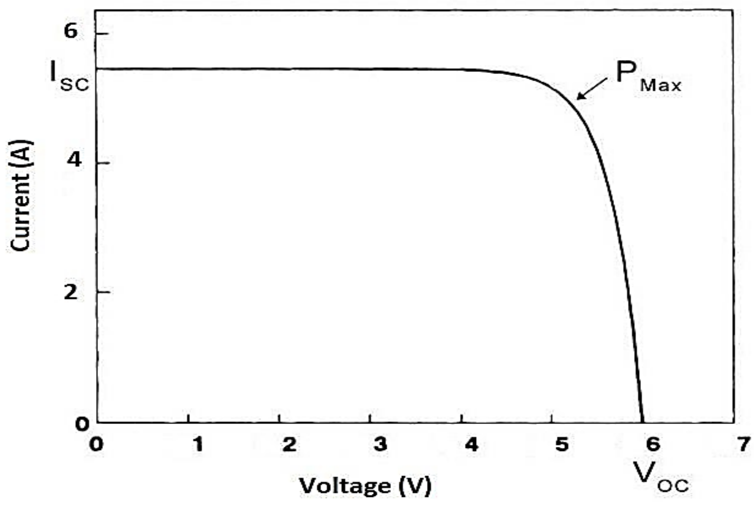

Figure 3.2: I-V characteristics of a solar panel [13]

At the point when the voltage and the current qualities are duplicated, we get the P-V attributes as appeared in Figure 3.3. The point showed as MPP is where the board power yield is most extreme.

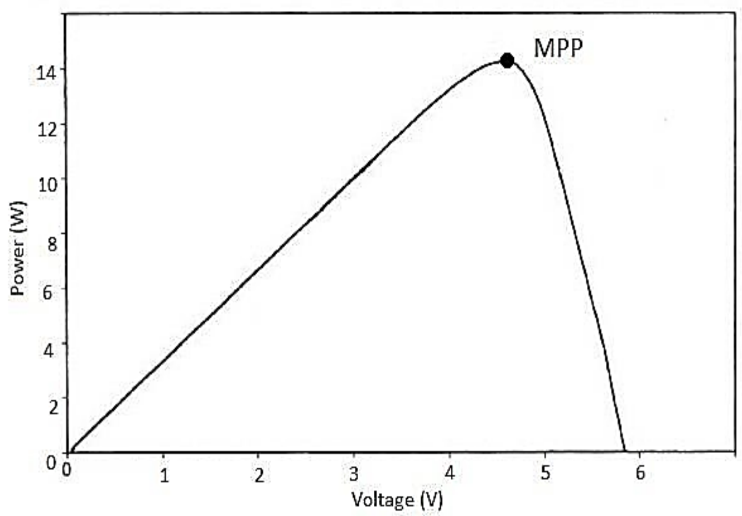

Figure 3.3: P-V characteristics curve of photovoltaic cell [13]

3.4 BOOST CONVERTER

As expressed in the presentation, the most extreme force point following is fundamentally a heap coordinating issue. So as to change the information opposition of the board to coordinate the heap obstruction (by fluctuating the obligation cycle), a DC-to-DC converter is required. It has been contemplated that the proficiency of the DC-to-DC converter is most extreme for a buck converter, at that point for a buck-help converter and least for a lift converter however as we mean to utilize our framework either for binds to a network or for a water siphoning framework which requires 230 V at the yield end, so we utilize a lift converter.

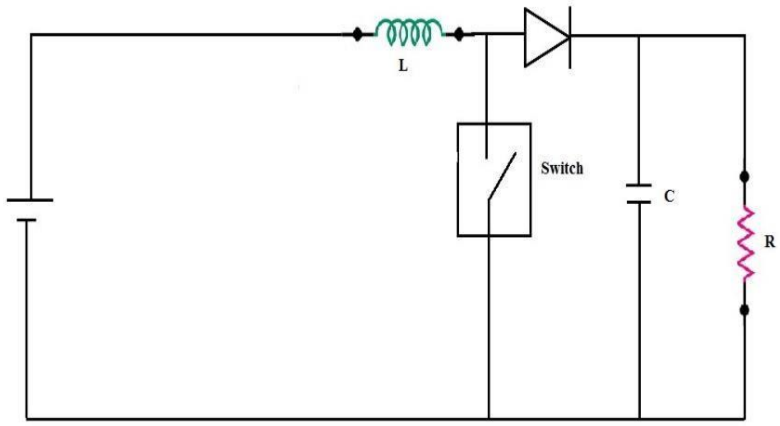

Figure 3.4: Circuit diagram of a Boost Converter

3.4.1 Mode 1 operation of the Boost Converter

At the point when the switch is shut the inductor gets charged through the battery and stores the vitality. In this mode inductor current ascents (exponentially) however for effortlessness we accept that the charging and the releasing of the inductor are straight. The diode hinders the current teaming thus the heap current stays consistent which is being provided because of the releasing of the capacitor.

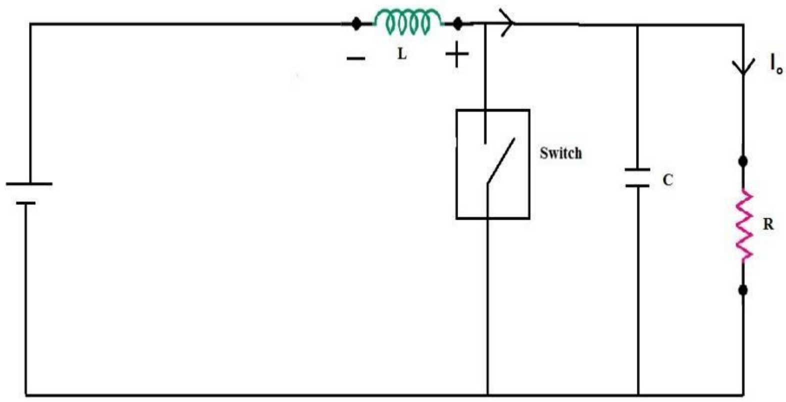

Figure 3.5: Mode 1 operation of Boost Converter

3.4.2 Mode 2 operation of the Boost Converter

In mode 2 the switch is open thus the diode turns out to be short-circuited. The vitality put away in the inductor gets released through inverse polarities which charge the capacitor. The heap current stays consistent all through the activity. The waveforms for a lift converter are appeared in Figure 3.7.

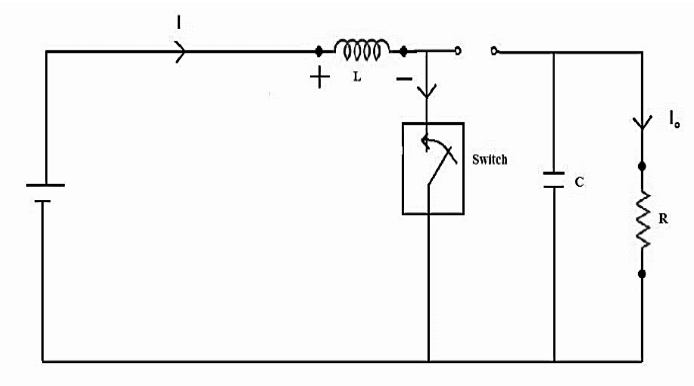

Figure 3.6: Mode 2 operation of Boost Converter

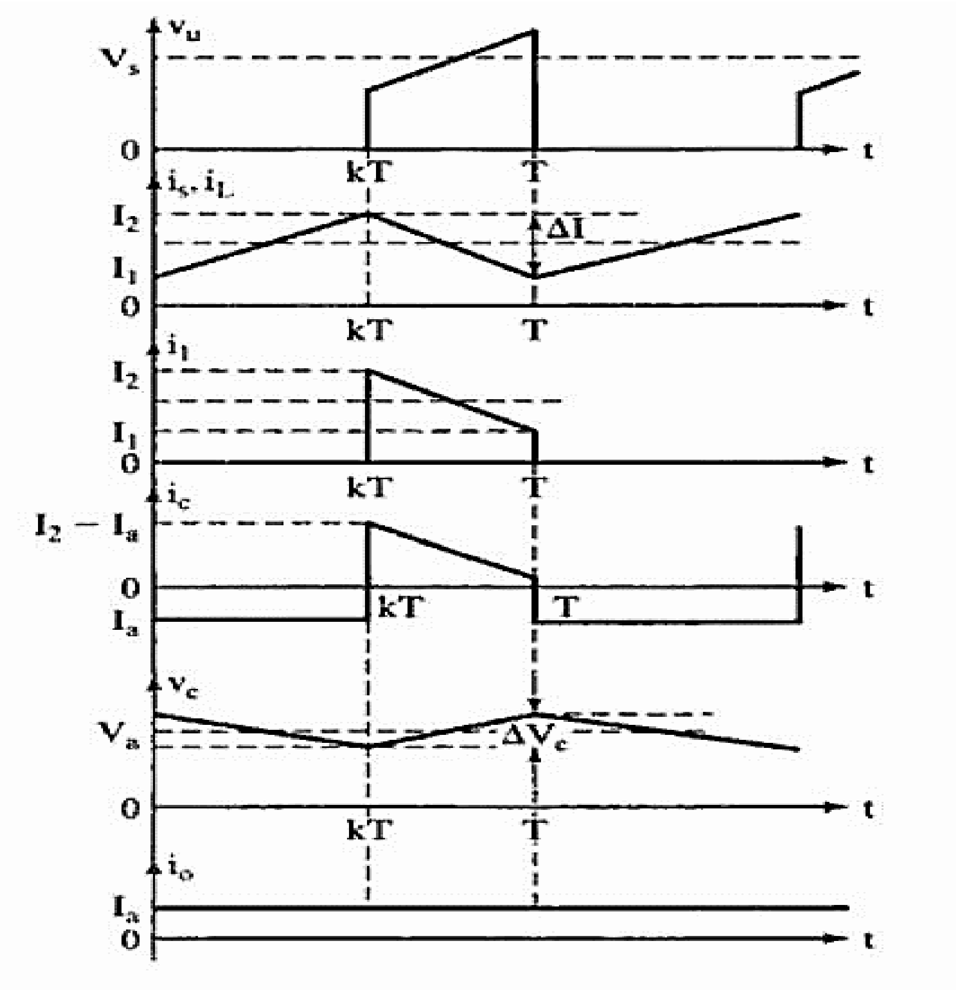

Figure 3.7: Waveforms for a Boost Converter [14]

CHAPTER 4

MAXIMUM POWER POINT TRACKING ALGORITHMS

4.1 AN OVERVIEW OF MAXIMUM POWER POINT TRACKING

An ordinary sun powered board changes over just 30 to 40 percent of the occurrence sun-based light into electrical vitality. Most extreme force point following method is utilized to improve the effectiveness of the sun powered board.

As per Maximum Power Transfer hypothesis, the force yield of a circuit is greatest when the Thevenin impedance of the circuit (source impedance) matches with the heap impedance. Consequently, our concern of following the most extreme force point diminishes to an impedance coordinating issue.

In the source side we are utilizing a lift convertor associated with a sunlight-based board so as to improve the yield voltage so it very well may be utilized for various applications like engine load. By changing the obligation pattern of the lift converter fittingly we can coordinate the source impedance with that of the heap impedance.

4.2 SOME DIFFERENT MPPT TECHNIQUES

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

1) Curve-Fitting Technique
2) Fractional short circuit current
3) Fractional open circuit voltage
4) One-Cycle Control (OCC) Technique
5) Differentiation Technique
6) Load Current/Load Voltage Maximization Technique
7) Feedback voltage or Current Technique
8) Feedback of Power Variation with Volatge Technique
9) Feedback of Power Variation with Current Technique
10) Gauss-Newton Technique
11) Perturb and Observe (hill climbing method)

12) Particle Swarm Optimization (PSO) Method
13) Artificial Neural Network (ANN)-Based MPPT
14) Fuzzy Logic (FL)-Based MPPT
15) Hybrid MPPT

The choice of the algorithm depends on the time complexity the algorithm takes to track the MPP, implementation cost and the ease of implementation.

4.2.1 Curve-Fitting Technique

Using this method of MPPT technique we can find the estimated value of related power (P) and voltage (V). The relation can be in the form of following equation (1). In the P-V characteristics of a P-V panel, the extreme value is MPP. Hence first of all we need to predict P-V characteristics in this technique. With the help of mathematical equation or numerical approximation we have to construct a model of P-V panel [16], [17]. For accurate P-V curve fitting, a third-order polynomial function as

$$P = aV^3 + bV^2 + cV + d \tag{4.1}$$

Here coefficient a, b, c and d are calculated by sampling of P-V power and voltage in interval. By differentiating of equation (1),

We get,

$$\frac{dP}{dV} = 3aV^2 + 2bV + c \tag{4.2}$$

At MPP

$$\frac{dP}{dV} = 0 \tag{4.3}$$

So, voltage of MPP can be calculated as

$$V_{MPP} = \frac{-b \pm \frac{1}{2}\sqrt{b^2 - 3ac}}{3a} \tag{4.4}$$

In a few milliseconds by repeatedly sampled in a span by using mathematical equation that is defined in [17], we can calculate a, b, c and d. And then finally V_{MPP} is calculated.

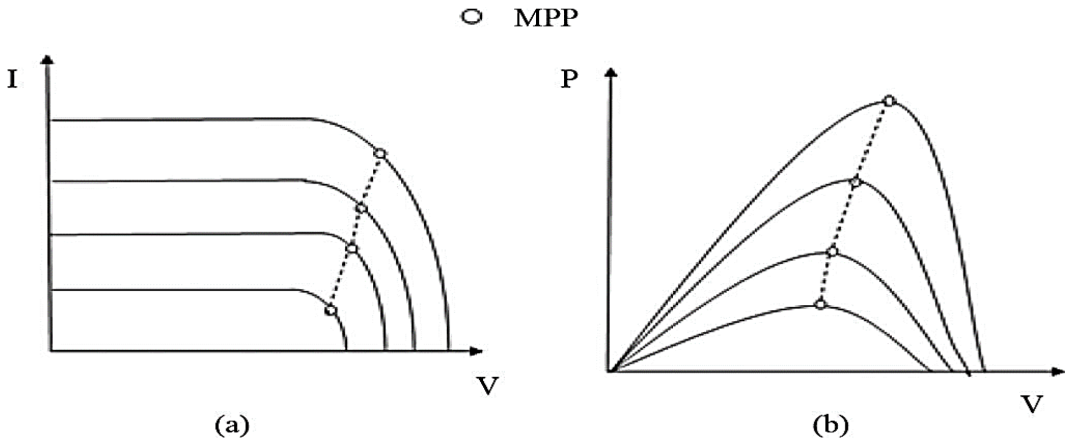

Figure 4.1. (a) and (b) are the characteristics of P-V panel at various environmental Conditions for Curve Fitting

4.2.2 Fractional Short-Circuit Current (FSCI) Technique

In this technique there is an extra control system is used to find out the short circuit current. Here the target is to reduce losses in the power that comes during the result of intermittent. The proposed technique suits good for minor cost P-V application.

There is available only a single operating point $P(V_{MPP}, I_{MPP})$ that is called MPP where the maximum power is available of the panel (P_{MPP}) at a pre-defined condition *(fig. 1).*if I_{MPP} or V_{MPP} are tracked one of them, we can also tracked the corresponding P_{MPP}.

With the help of mathematical numerical or equation approximation, we find in this technique the V-I characteristics of panel. The wide range of environmental condition and variation level of panel should be countable. On account of the V-I characteristics we found a relationship between I_{MPP} and I_{SC} is constructed for I_{MPP} is linearly depended on I_{SC} that is shown into below.

$$I_{MPP} \approx K_{SC} I_{SC} \tag{4.5}$$

The variation value of K_{OC} between 0.64 and 0.85 [18], [19], [20]. The value of K_{SC} can be calculated by reading the P-V system at specified range of solar radiation and temperatures.

4.2.3 Fractional Open-Circuit Voltage (FOCV) Technique

In this type of technique, the value of V_{MPP} can be calculated from the following empirical relationship:

$$VMPP \approx K_{OC}V_{OC}. \tag{4.6}$$

Here we found that the value of K_{OC} lies between 0.78 and 0.92 [18], [19]. The value of K_{OC} can be calculated by reading the P-V system at specified range of solar radiation and temperatures. In this *FOCV* method the system is as open-circuited at the load side for a portion of second and then we can calculate the value of $V_{OC.}$ After that we can calculate the value of V_{MPP} using equation (6). By repeating this, each few second the value of V_{OC} is sampled repeatedly and then the value of V_{MPP} is varied. The main issue with this type of MPPT technique the P-V array is disturbed after the load variation between two successive sampling of the array voltage. The duration of the successive arrays is too long, due to this there is a countable loss.

4.2.4 One-Cycle Control (OCC) Technique

OCC technique is applied to a single stage inverter as these inverters are cost effective, compact, simple in construction and reliable [20]. It is basically a nonlinear control technique as the PV array voltage(V) decides the value of output current (I_{out}). To have the higher efficiency, there is the requirement of perfect tuning of the L, C parameters of the system [21].

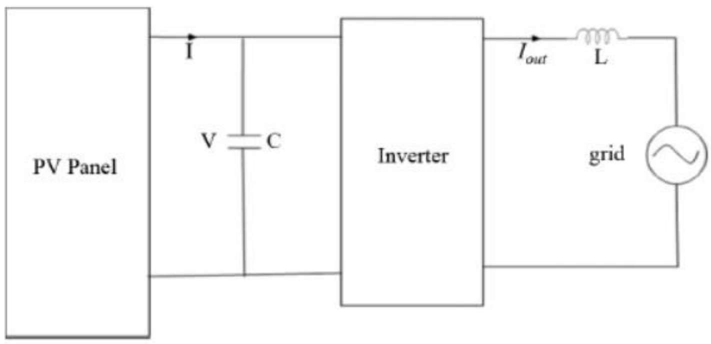

Figure 4.2. Block Diagram of OCC technique

4.2.5 Differentiation Technique

This technique requires to solve the number of differentiations to get the condition of MPP which a quite time consuming and of a demand's huge efforts.

$$\frac{dP}{dt} = \frac{d(VI)}{dt} = I\frac{dV}{dt} + V\frac{dI}{dt} = 0 \tag{4.7}$$

We need to separately find out all the parameters involved in the above equation which increases the complexity of the process. To solve the equations in less time, a very fast processor will be required [14].

4.2.6 Load Current/Load Voltage Maximization Technique

Power stages and the controller are its main component. Here our aim is to maximize the load current or load voltage at the end. When we are trying to maximize the output current or voltage the output power will also increases. Here we are assuming that the converter is lossless. it means the PV array has maximum power at the load end. Generally, the loads are two type either voltage source type or current source type. If the load is voltage source type then we have to put constant value of the load voltage, for the maximum load power we have to take maximum load current. As of the above if the load is current source type then we have to take constant value of the load current. To maximized the output power, we have to take the maximum value of the load voltage. This is applicable for non-linear load. This technique has a problem, the system used in this never track the exact MPP the reason is that lossless converter is not possible. At the power stages that is realized by of switch mode power converter, the duty cycle is described by the control input [22].

4.2.7 Feedback voltage or Current Technique

The system that does not contain the battery to have the constant bus voltage then we need a device to fix this problem and this function is performed by a controller. Thus, a controller takes an input from the output side and gives that into the bus like feedback which helps in keeping the constant voltage. The feedback of panel current or voltage is collated with a precalculated reference current or voltage. To have this controller working correctly so that it operates near to the MPP, we need to change the duty ratio of converter continuously [23].

4.2.8 Feedback of Power Variation with Volatge Technique

This technique has a similar approach like feedback voltage technique with one difference which is that in this technique the power is varied with respect to the variation in the voltage (dP/dV) fig 3. The output power is measured and we keep changing the duty cycle till the derivative (dP/dV) is equal to zero to have the condition of maximum power.

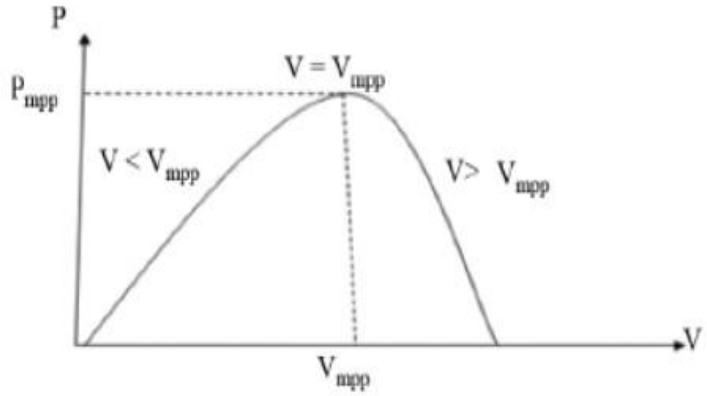

Figure 4.3. P-V curve explaining feedback variation of power with voltage

4.2.9 Feedback of Power Variation with Current Technique

The only disparity in this approach and the dP/dV technique is that instead power variation with voltage here the variation in power is seen with respect to the current i.e., dP/dI fig. 4 and it is made equal to zero to get the condition for MPP. Here also, duty cycle is change till we get the dP/dI equal to zero to have the maximum power.

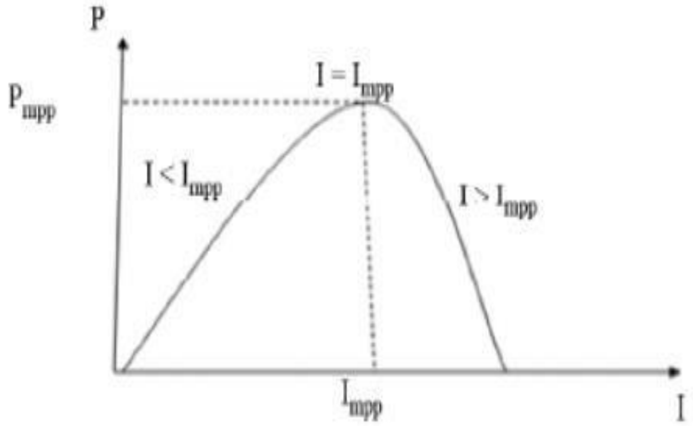

Figure 4.4. P-V curve explaining feedback variation of power with current

4.2.10 Gauss-Newton Technique

The fastest algorithm technique of MPPT is *Gauss-Newton Technique* [24]. This is used for the finding out the root by algorithm. This algorithm is also used to find out the non-linear least square problem.

In this algorithm, the change in power is used in first and second order derivatives to find out the number of iterations of convergence and direction when we are going to solve the following equation:

$$V(k+1) = v(k)\frac{\frac{dP}{dv}\mid v = v(k)}{\frac{\partial^2 p}{\partial v^2}\mid v = v(k)} \tag{4.8}$$

4.2.11 Perturbation & Observation (P&O)

In this approach, firstly we calculate the initial power $P\mathbf{1}$ by measuring the initial voltage and initial current of the PV array. Then, we take a small voltage perturbation (ΔV) by taking a small duty-cycle perturbation (Δd) in any one direction and calculate the power $P\mathbf{2}$ drawn by the PV array [25]. If the new power $P\mathbf{2}$ is more as compare to the $P\mathbf{1}$**,** then the next perturbation is carried out in the same direction else the perturbation is done in the reversed direction. Voltage perturbations deicides the successive rise or fall of the output power. By performing the perturbation in this manner, we can find out the Peak Power point (Vmpp). as this method can be easily implemented, it is used widely [26]. Algorithm flowchart is shown in fig 5.

Deviation from the MPP during the continuous change in environment conditions, like broken clouds, is one major drawback of this technique. Further, deciding the perturbation size is somewhat difficult which also come under its drawbacks. Updated version of this technique is Adaptive Hill climbing, which uses controller for automatic tuning of perturbation size according to the change in output power because of change in atmospheric condition [14].

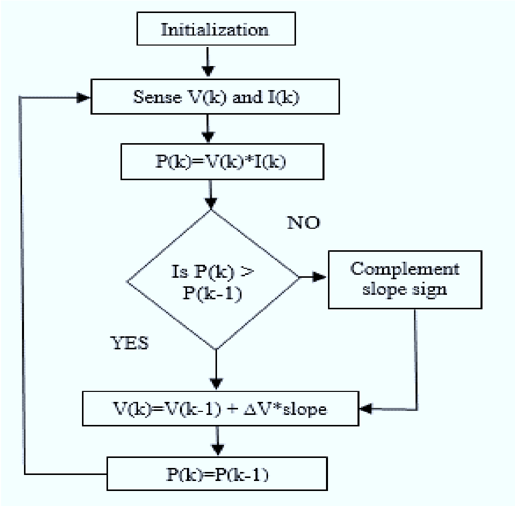

Fig 5. Simple P&O technique Algorithm

4.2.12 Particle Swarm Optimization (PSO)-Based MPPT Technique

PSO techniques is better suited for the partially shaded atmospheric condition as PSO has better robustness characteristics, parallel processing, smooth and agile convergence, easy realization and intense probability of searching global optimal solution. It has higher efficiency ass it gives better result for the multi-peak function optimization [27], [14]. The concept of this technique is derived from the flocking of birds, the way they move in the space and communicate with each other, in the similar way the different agents also known as particles keep the track of the movement and communicate intelligently with each other to provide their individual local best location. Thus, they keep on updating their position and the velocity based on their individual's previous velocity and its group's best velocity [28], [29].
The formula by which each particle updates its velocity is [29]

$$v_i^{k+1} = \omega v_i^{k} + c_1 r_1 (p_{best_i} - s_i^{k}) + c_2 r_2 (g_{best} - s_i^{k}) \qquad (9)$$

$$s_i^{k+1} = s_i^{k} + v_i^{k+1} \qquad (10)$$

Where ω denotes momentum factor, c_1 and c_2 denotes positive constants, r_1 and r_2 denotes random numbers and have values between (0-1), *pbest* represents the i^{th} agent's best position so far and is given by (3) only if condition (4) satisfies,

$$p_{best_i} = s^{k}{}_{i} \qquad (4.9)$$

$$f(s^{k}{}_{i}) > f(p_{best_i}) \qquad (4.10)$$

and *gbest* represents the best position which is gained among all the agents [29].

4.2.13 Artificial Neural Network (ANN)-Based MPPT Technique

Reason why the ANN is one of best suited technique for MPPT is due to its robustness and ability to intelligently map up the nonlinear relationship among the input variables and the output variables under any atmospheric condition automatically. Firstly, Neural Networks are tamped offline with the various kinds of non-linear relationships to make them literate enough that later on when they are actually connected online with the PV system, they would efficiently perform their function. This helps in providing the right duty cycle that would be suited to get the MPP and to generate the data required for ANN model, P&O method is used and after that a logic table is developed from this data by the means of sign function. There are two input variables for the ANN model, (*dP*) which represents the output power derivative and other one is (*dV*) which represents the voltage derivative [30].

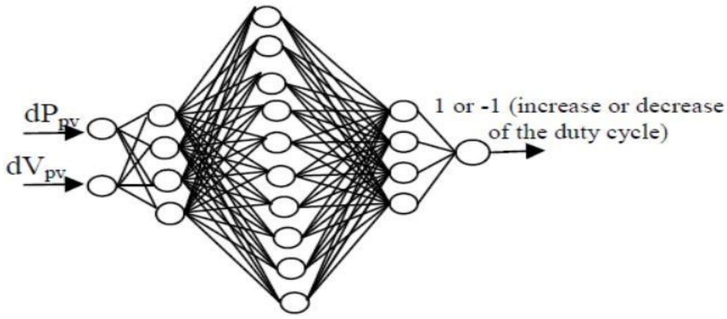

Figure 4.6: The ANN configuration used to determine duty cycle for MPP.

4.2.14 Fuzzy Logic (FL)-Based MPPT Technique

This technique can be used due to its firmness to solve the problem of non-linear optimization with a rule-based algorithm. The other best advantage of this technique is that using this technique we do not need to know the exact model on which we are using the technique. Regardless of this, designer need to have the complete understanding of the working of the PV system [31]. It requires some variables: two input variables, error(E) and change of error (CE), and an output variable, duty cycle(D) and the way of calculating them is shown below:

$$E(k) = \frac{dP}{dV}(k) - \frac{dP}{dV}(k-1) \qquad \ldots\ldots \quad (4.11)$$

$$C(k) = E(k) - E(k-1) \quad \ldots\ldots (4.12)$$

E(k) expresses the error in the position of operating point of the applied load at the time of kth instant, whereas C(k) talks about the direction in which the point is moving. FL is performed using the Mamdani's method and output is calculated using the center of gravity through the process of defuzzification [15].

4.2.15 Hybrid MPPT Technique

Using two different techniques together to change the duty cycle so as to get the MPP more efficiently under all atmospheric conditions is termed as Hybrid MPPT. Most commonly used MPPT technique is the P&O technique due to its easy implantation, accuracy, simplicity. And using it with other techniques like ANN, Fuzzy logic etc., to change the perturbation size can results in higher efficiency and accuracy [32]. High nonlinear nature in the PV characteristics of simple P&O which results in power fluctuations and low stability can be eliminated removed using Adaptive Neuro-Fuzzy Inference System (ANFIS) [33], [34]. Many more Hybrid techniques are proposed in [32], [35].

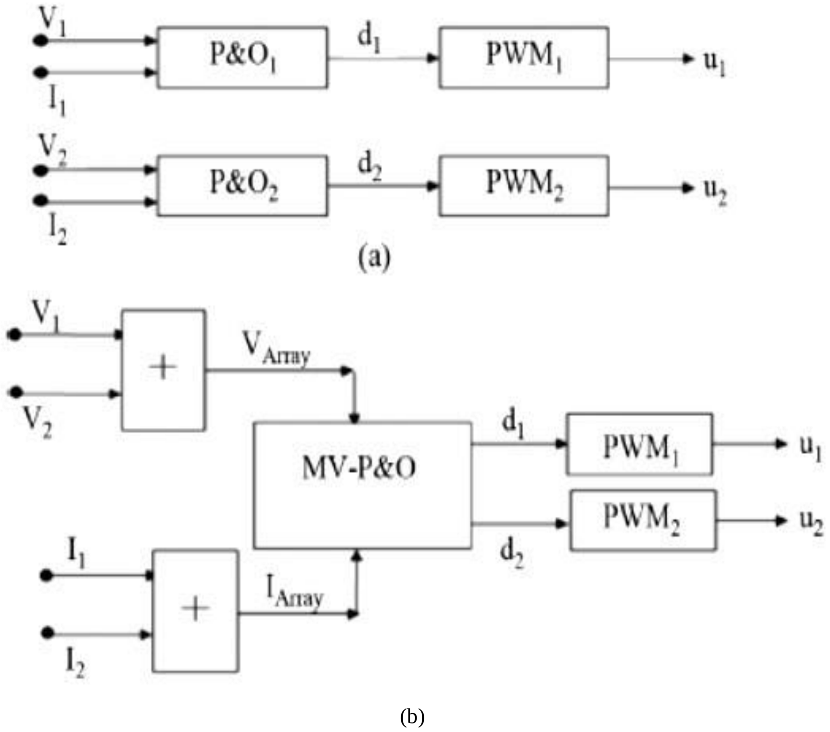

Figure 4.7. Comparison Between (a) traditional P&O and (b) multivariable P&O structure

4.2.16 Other MPPT Techniques

Different Distributed MPPT (DMPPT) methods are illustrated in [36], [37]. State space representation is used to show the nonlinear relation of the dynamic feedback controller in the state-based MPPT [35]. In [38], using the irradiation and temperature, solar cell voltage and current are calculated using which MPP is directly tracked. In [39], the technique used is Cuckoo search (CS). In [40], MPP is achieved by using the data of temperature and irradiation collected during a time period and control are according to the value closest to the MPP.

4.3. COMPARISON AMONG DIFFERENT TECHNIQUES

Each technique has its own feature and therefore a comparison between them would help us to decide which technique is suitable for getting the proper outcome.

4.3.1 BASED ON CONTROL STRATEGIES

The technique which is used to find the solution to the MPP is termed as control strategy. The different control strategies used in the MPPT are: Indirect Control, Direct Control, and probabilistic control. In indirect control we gather the different data and parameters including characteristics curves from the PV module and use this database to find the MPP. This control strategy is again divided into two types which are modulation method [35] and sampling method [41], [42]. In direct control there is no need of knowing the characteristic curves as it directly achieves the MPP with the help of variations in the operating points of the PV module. In probabilistic, formulas and rules of probability are used to get the MPP [35].

4.3.2 BASED ON TYPE OF CIRCUITRY

Circuitry is based on the type of components installed in the circuits. Basically, they are three types of circuits, one which have only digital components, second one is those having only analog components, and third one is those having both analog and digital components. This is decided by the user, as everyone selects the type on which they can comfortably work[14].

4.3.3 BASED ON CONTROL VARAIABLE

Choosing the number of variables depend on the techniques used for the PV module. Generally, the variables used are current, voltage, irradiance, temperature etc. Based on the variables chosen there are two classifications of MPPT techniques, one-variable technique and two-variable technique. Due to easy implementation and simple structure the voltage sensor based MPPT is commonly used [14]

Table:1 CHARACTERTICS OF DIFFERENT MPPT TECHNIQUES

MPPT Technique	Convergence Speed	Control Strategy	Control Variable	Circuitry (A/D)	Parameter Tuning	Converter Used (DC/DC or DC/AC)
Curve-Fitting Technique	low	INC	V	D	Yes	DC/DC
Fractional short circuit current	medium	INC	V or I	Both	Yes	DC/DC
Fractional open circuit voltage	low	INC	V or I	Both	Yes	DC/DC
One-Cycle Control(OCC) Technique	medium	SM	I	Both	Yes	DC/AC
Differentiatio n Technique	low	SM	V or I	D	Yes	DC/DC
Load Current/Load Voltage Maximization Technique	medium	MM	V	A	No	DC/DC
Feedback volatge/ Current Technique	medium	SM	V or I	Both	No	Both

Feedback of Power Variation with Volatge Technique	low	SM	V, I	D	No	Both
Feedback of Power Variation with Current Technique	low	SM	V, I	D	No	Both
GaussNewton Technique	medium	SM	V or I	D	No	DC/DC
Perturb and Observe (hill climbing method)	medium	SM	V, I	Both	No	DC/DC
Particle Swarm Optimization (PSO) Method	fast	INT	V or I	D	Yes	Both
Artifical Neural Network (ANN)-Based MPPT	fast	INT	V or I	D	Yes	Both
Fuzzy Logic (FL)-Based MPPT	medium	INT	V or I	D	Yes	Both
Hybrid MPPT	fast	SM	V or I	D	Yes	Both

Note: INC: Indirect Control, **SM:** Sampling Method, **MM:** Modulation Method, **INT**: Intelligent or Probabilistic Control, **V:** Voltage, **I:** Current, **A:** Analog, **D:** Digital, & **Tech A-O** are MPPT Techniques described in section -II & subsections A-O respectively.

4.4 PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

4.4.1 THE BASIC PSO ALGORITHM

PSO method [14] [15] is a hearty stochastic streamlining strategy dependent on the development and insight of multitudes. It applies the idea of social collaboration to critical thinking. It utilizes various operators (particles) that establish a multitude moving around in the quest space searching for the best arrangement.

Every molecule monitors its directions in the arrangement space which are related with the best arrangement (wellness) that has accomplished so far by that molecule. This worth is called individual best, pbest. Another best worth that is followed by the pso is the best worth acquired so far by any molecule in the neighborhood of that particle. This value is called gbest. During the optimization process, the particles take up the objective function's values, while their gbest and pbesti are saved. The basic pso algorithm which determines the next velocity and position of the candidate solution can be given mathematically as:

$$v_i^{k+1} = w \times v_i^k + r_1 \times c_1 \times \left(P_{besti} - x_i^k\right) + r_2 \times c_2 \times \left(G_{best} - x_i^k\right) \qquad \text{.......} (4.13)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad \text{.......} (4.14)$$

the before referenced articulation, I speaks to the variable of the improvement vector, k is the quantity of emphases, vik and xik individually the speed and position of the ith variable inside k cycles, the boundary w is known as latency that keeps up a harmony between the nearby and worldwide inquiry. C1 and c2 are increasing speed constants. R1 and r2 are two produced arbitrary numbers which are consistently circulated in the span [−1, 1].

The variable pbesti records the best position influenced by the ith molecule up to the specific season of estimation. The accompanying condition shows that this position is possibly recorded as pbesti if the condition expressed underneath is fulfilled.

$$x_i^k = \left[x_1^k, x_2^k, x_3^k, \cdots, x_i^k, \cdots, x_{(n-1)}^k, x_n^k\right] \qquad \text{.......} (4.15)$$

4.4.2 CONFIGURATION OF PSO PARAMETERS

The pursuit space of the issue in which each position speaks to a yield voltage esteem as an answer for the mppt issue. The assessment of the particles depends on the yield intensity of the pv board separate to the last voltage esteem which is shown by fit as the wellness evaluator for the particles. The accompanying condition shows the position lattice of the n particles which speaks to n answers for the mppt issue.

$$P_{besti} = x_i^k \text{ if } fit\left(x_i^k\right) \geq fit\left(P_i\right) \quad \text{....... (4.16)}$$

where x_i^k is the position of i_{th} particle at k_{th} iteration. Therefore, the algorithm must be initialized when the following equation is satisfied.

$$\left|\frac{fit\left(x_{i+1}\right) - fit\left(x_i\right)}{fit\left(x_i\right)}\right| > \Delta P \quad \text{....... (4.17)}$$

4.4.3. PSO ALGORITHM IMPLEMENTATION

i. initialize the size of swarm, dimension of search space, maximum number of iterations, and the pso constants w, c 1 and c 2. Define the random numbers r1 and r2.

ii. find out the current fitness of each particle in the population. iii. attribute the particles with random initial positions and velocities. iv. evaluate fitness value of each particle.

v. calculate the global best fitness value: current global best fitness = min (local best fitness).

vi. update the particle velocity and position for next iteration. Find out the current fitness of each particle: if current fitness < local best fitness, set local best fitness = current fitness.

vii. determinate the current global best fitness (current global best fitness = min (local best fitness)): if current global best fitness < global best fitness, then global best fitness = current global best fitness. The position corresponding to global best fitness is assigned to gbest.

viii. repeat steps 6 and 7 until achieved the maximum number of iterations or there is no improvement of the global best fitness value.

ix. determine the duty cycle for the dc-dc convertor.

x. terminate the iterative algorithm when the criterion is reached.

4.5 IMPLEMENTATION OF MPPT USING A BOOST CONVERTER

The system uses a boost converter to obtain more practical uses out of the solar panel. The initially low voltage output is stepped up to a higher level using the boost converter, though the use of the converter does tend to introduce switching losses. The block diagram shown in figure 4.4 gives an overview of the required implementation.

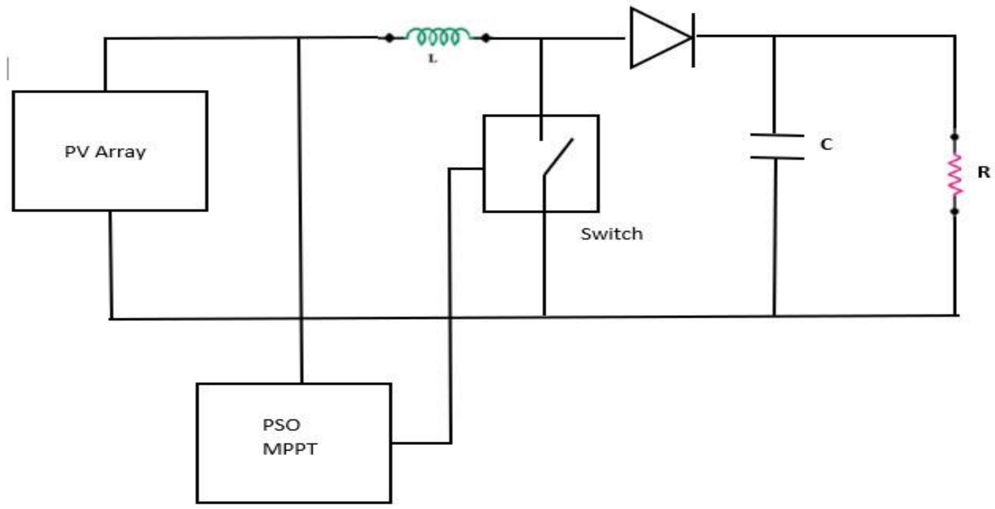

Figure 4.8: Requisite implementation for MPPT system

CHAPTER 5

MODELING OF STANDALONE PV SYSTEM

5.1 SOLAR PANEL

The entire system has been modeled on MATLAB™ 201ab and Simulink™. The PV Panel used here is the PV panel available in the Simulink library. The Panel used is Soltech 1STH245 W. The inputs to the solar PV panel are temperature, solar irradiation.

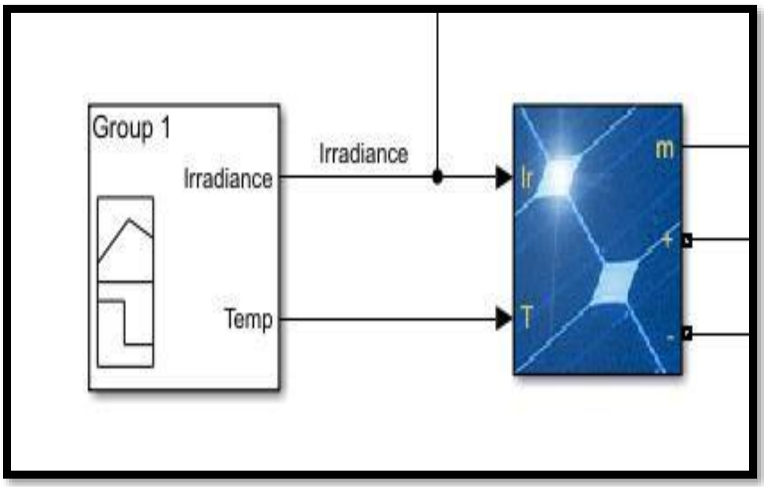

Figure 5.1 : PV Solar Panel

The simulation is carried out for a cell surface temperature of 25° C, 6 solar cells in series and 1 rows of solar cells in parallel. The irradiation (shown in Figure 5.1) is taken to be 1000 W/cm^2 which is the maximum irradiance that the earth surface receives, to reflect maximum conditions and effectively show the use of an MPPT algorithm in field runs. The simulation is run for a total of 0.8 seconds.

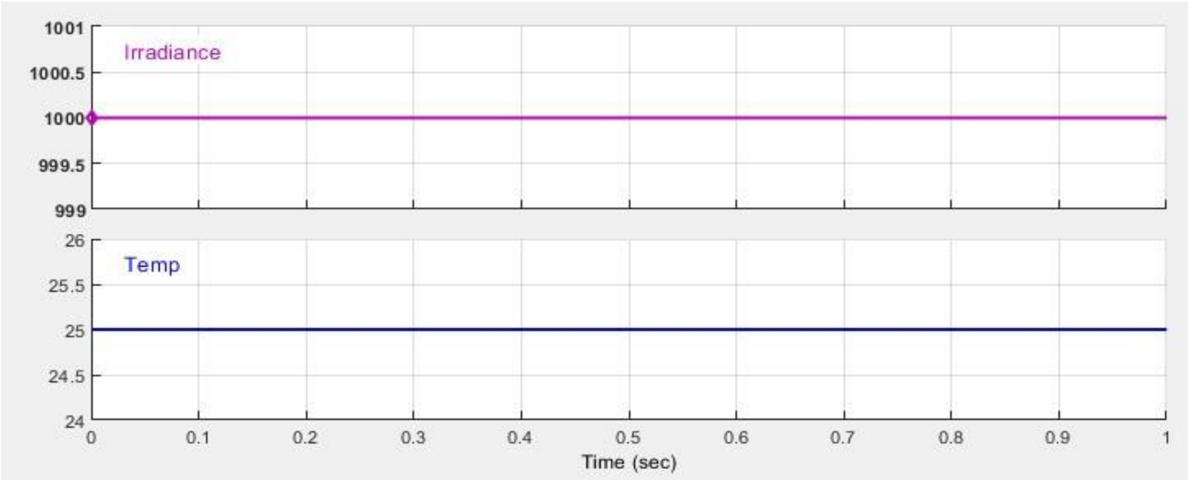

Figure 5.2: Irradiation signal (Watt per sq. cm. versus time) and Temp signal (ºC vs Time)

5.2 BOOST CONVERTER

A boost converter has been used in our simulation. It finds applications in various real-life scenarios like charging of battery bank, running of DC motors, solar water pumping etc. The simulation has been done for a resistive load of 300Ω. For efficient running of a motor, we should undergo load resistance matching techniques. In the boost converter circuit, the inductor has been chosen to be 6.37 mH and the capacitance is taken to be 250 µF for a ripple free current. The switch is physically realized by using a MOSFET with the gate voltage controlled by the duty cycle through the pulse generator having switching frequency of 25 KHz.

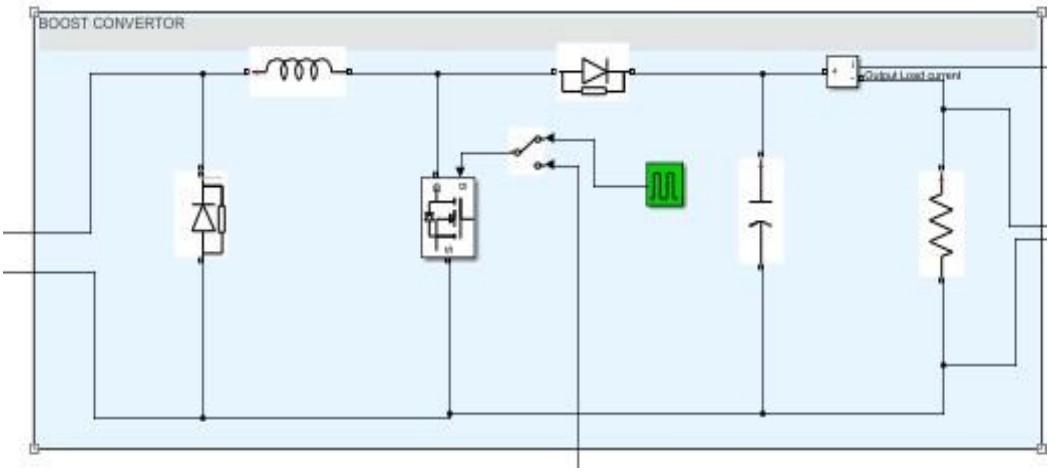

Figure 5.3: Boost Convertor

5.3 MPPT INTERFACING

The Solar PV board and the lift converter which is fabricated utilizing the Sim Power Systems module of MATLAB, are associated. The square outline for the model appeared in Figure 5.4 is a recreation for the situation where we get a differing voltage yield. This model is utilized to feature the contrast between the force acquired on utilizing a MPPT calculation and the force got without utilizing a MPPT calculation.

To look at the force yield in both the cases expressed over, the model is outfitted with a manual switch as appeared. At the point when the switch is tossed to one side the circuit sidesteps the MPPT calculation and we get the ideal force, voltage and current yields through the separate extensions. Oppositely when the switch is tossed to one side, the installed MPPT work square is remembered for the circuit and we get the ideal yields through the individual extensions.

Figure 5.4: SIMULINK™ Model of MPPT based on PSO Technique

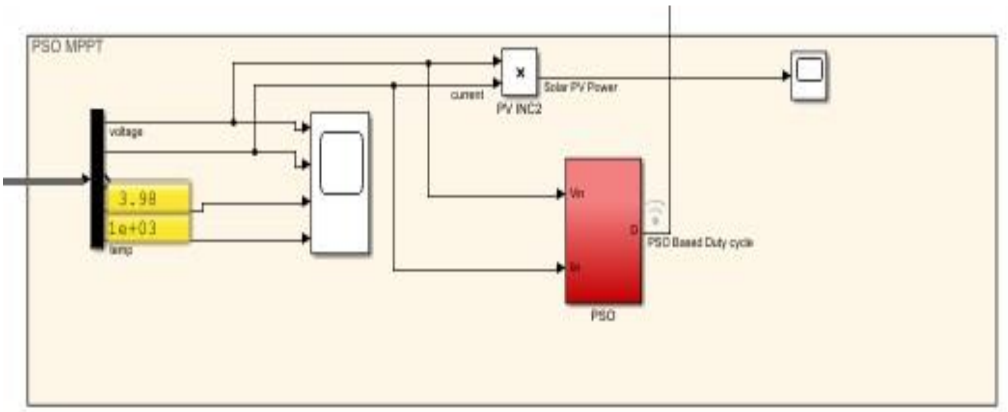

Table 2: Different parameters of the standalone PV system

Parameter	***Value taken for simulation***
Irradiance	1000 W/cm^2
Solar Module Temperature ***(T)***	25°C
No of solar cells in series ***(N_S)***	6
No of rows of solar cells in parallel ***(N_P)***	1

Total Power Of PV array	1500 W
Maximum Power Output of PV array	1500 W
*Resistance of load **(R)***	45 Ω
*Capacitance of boost converter **(C)***	250 µF
*Inductance of boost converter **(L)***	6.73 mH
Switching frequency of PWM	25 KHz

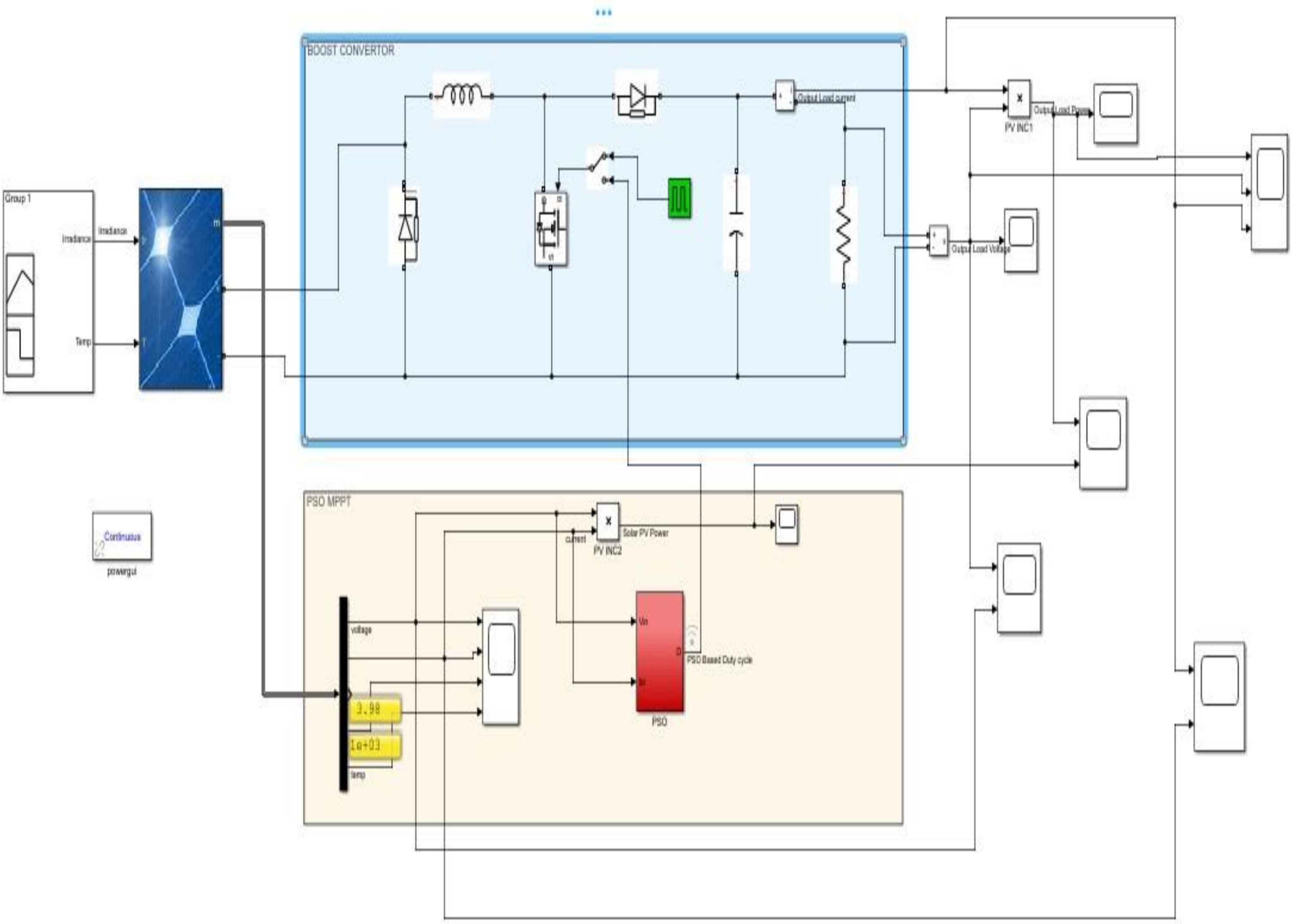

Figure. 5.5 Complete Simulation Model of MPPT PSO based Solar PV System

CHAPTER 6

RESULTS

6.1 Case 1: Running the system without MPPT

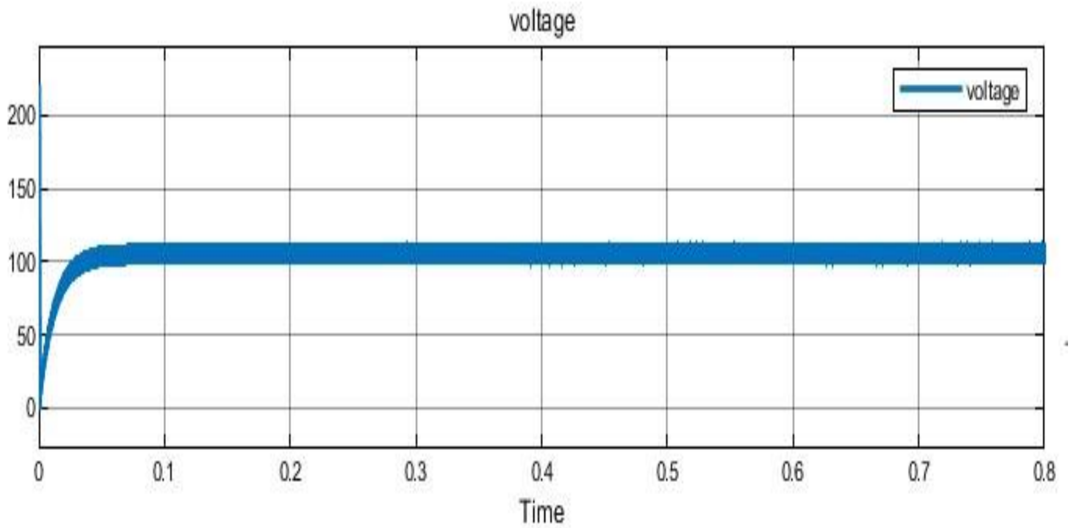

Figure 6.1: Plot of Output voltage of PV panel v/s time without MPPT

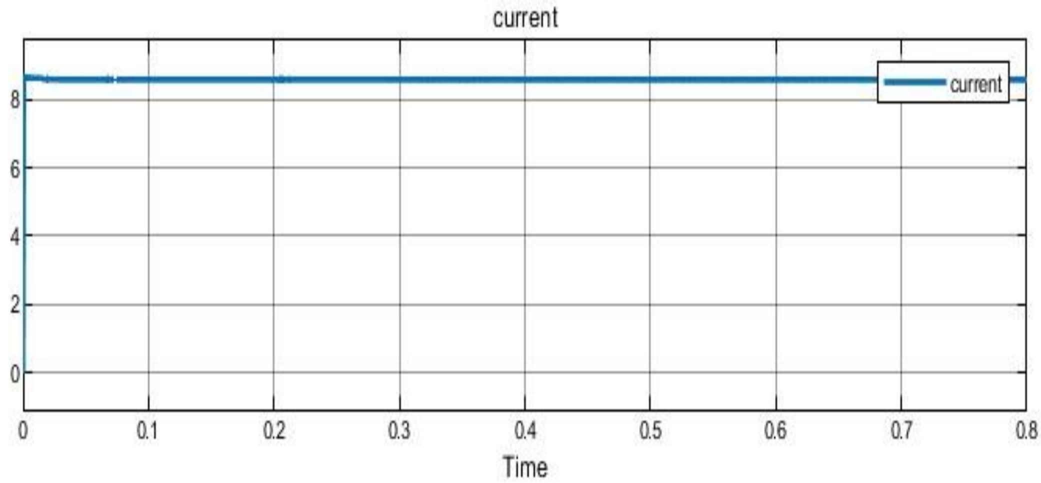

Figure 6.2: Plot of Output Current of PV panel v/s time without MPPT

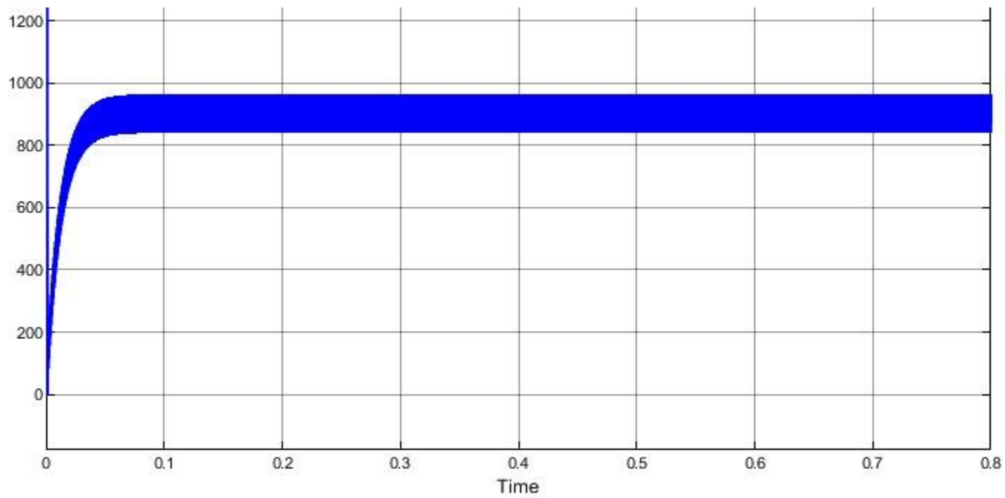

Figure 6.3: Plot of Output Power of PV panel v/s time without MPPT

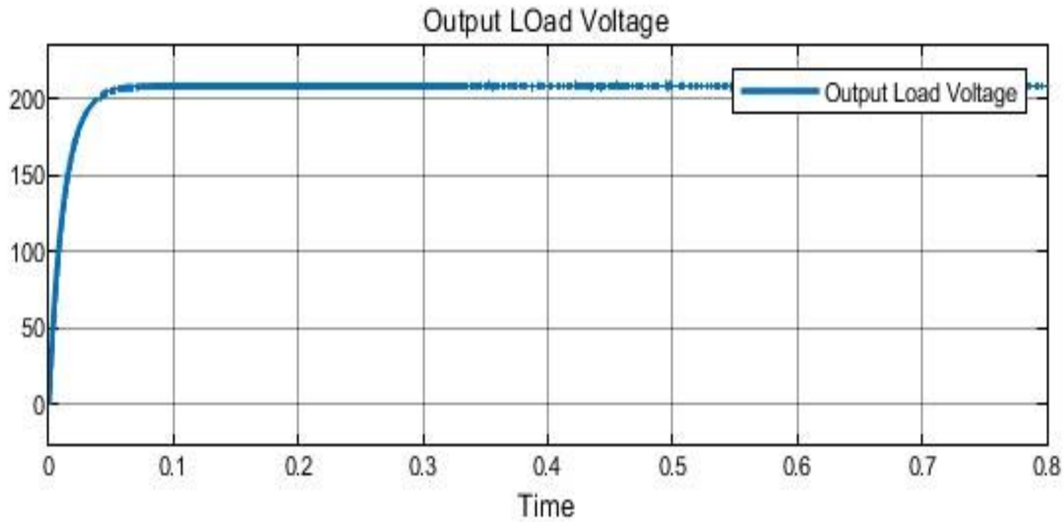

Figure 6.4: Plot of Output Voltage at load side v/s time without MPPT

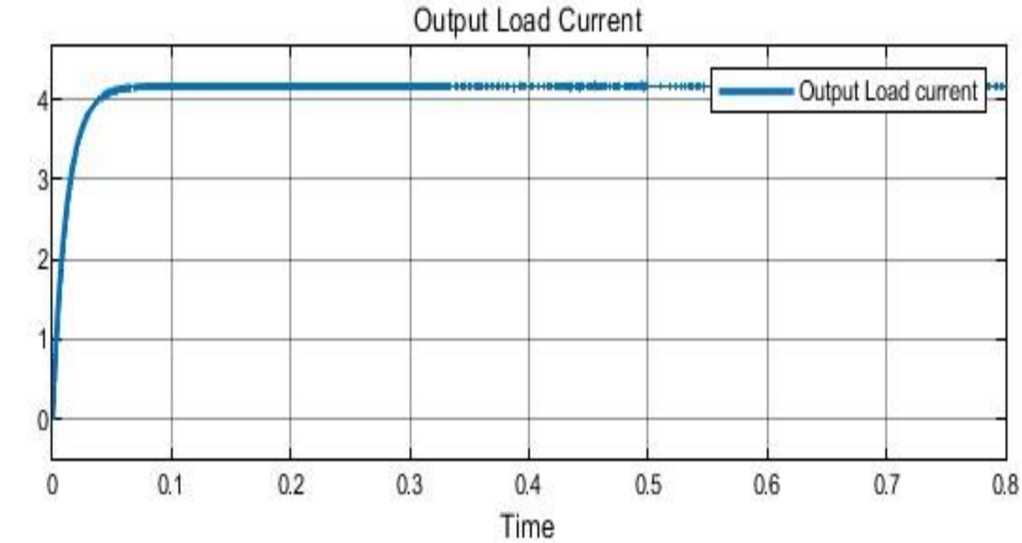

Figure 6.5: Plot of Current obtained at load side v/s time without MPPT

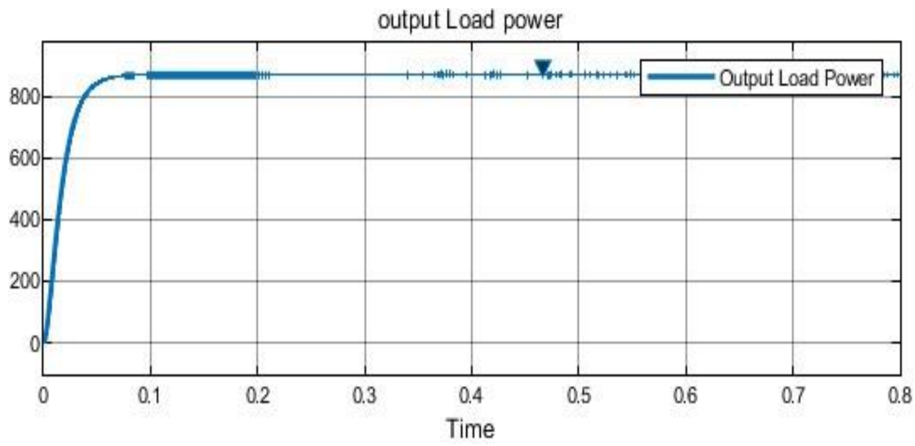

Figure 6.6: Plot of Power obtained at load side v/s time without MPPT

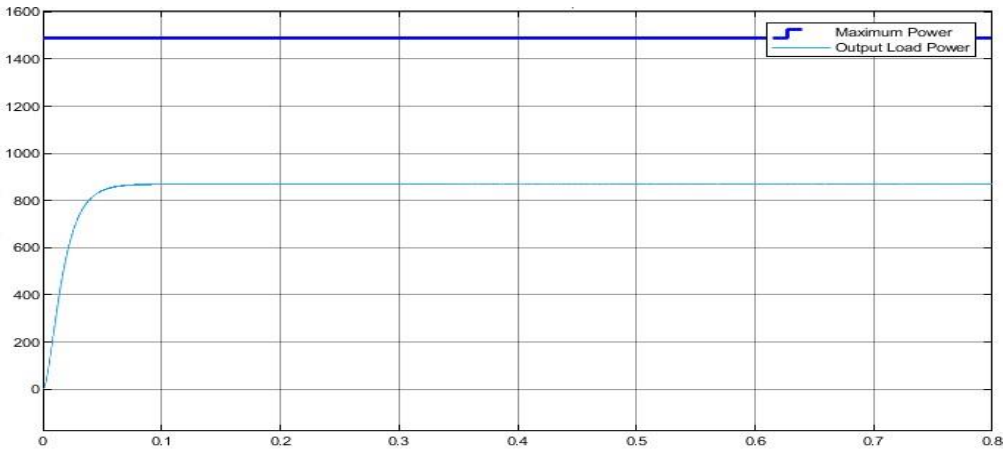

Figure 6.7: Plot of Power obtained at load side and Maximum Power v/s Time with MPPT

CASE 2: RUNNING THE SYSTEM WITH MPPT

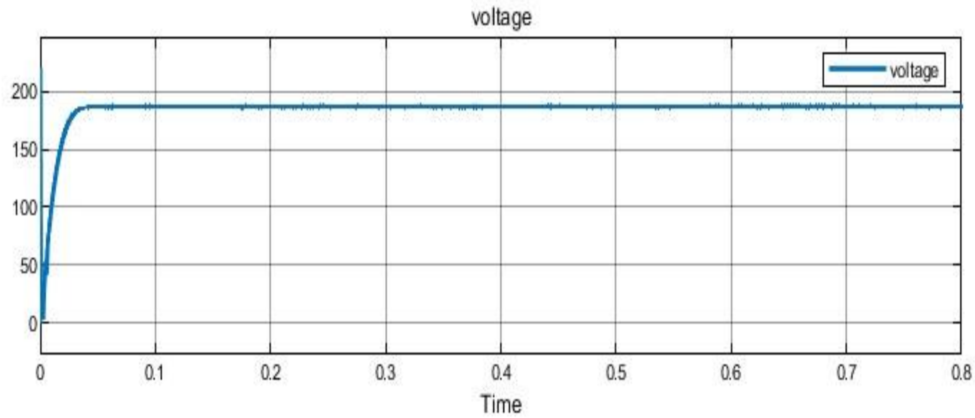

Figure 6.8: Plot of Output voltage of PV panel v/s time with MPPT

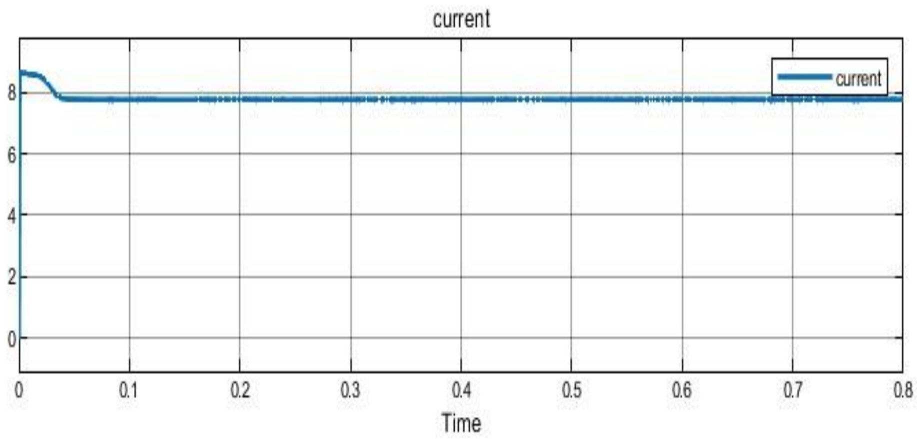

Figure 6.9: Plot of Output Current of PV panel v/s time with MPPT

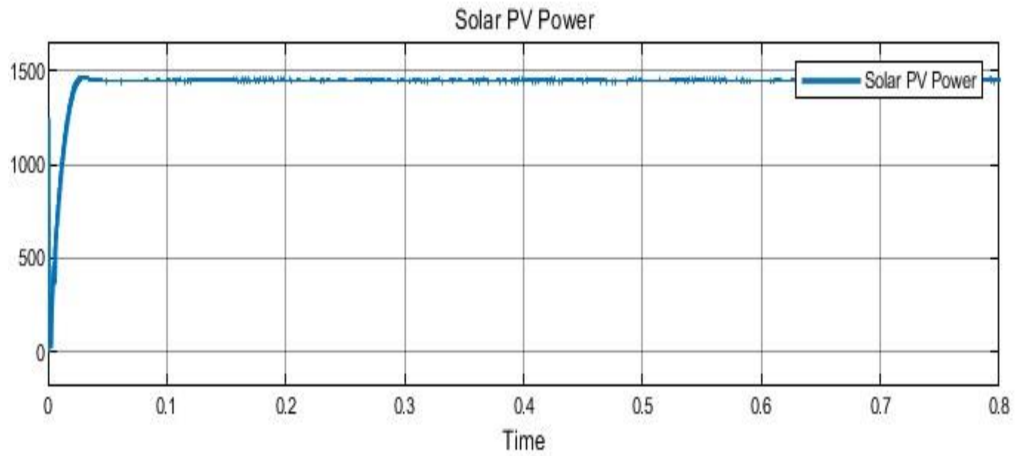

Figure 6.10: Plot of Power output of PV panel v/s time with MPPT

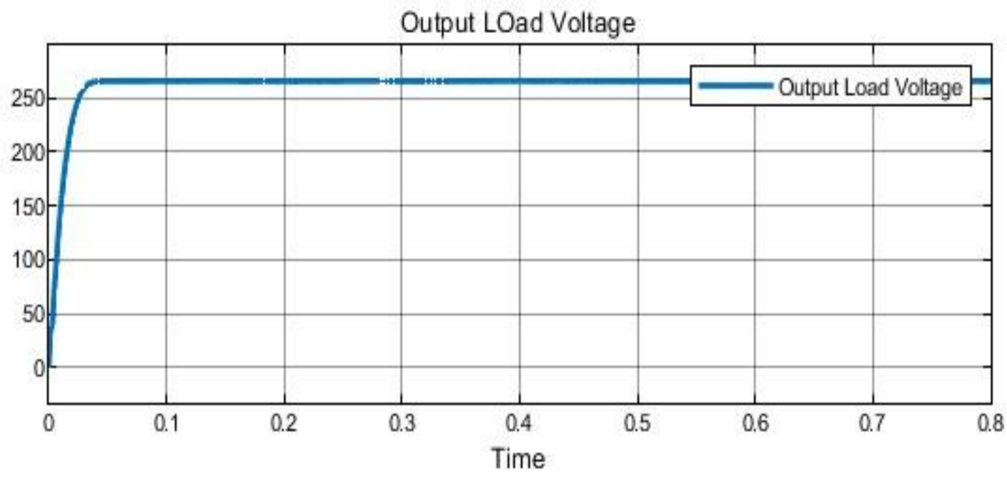

Figure 6.11: Plot of Output Voltage at load side v/s time with MPPT

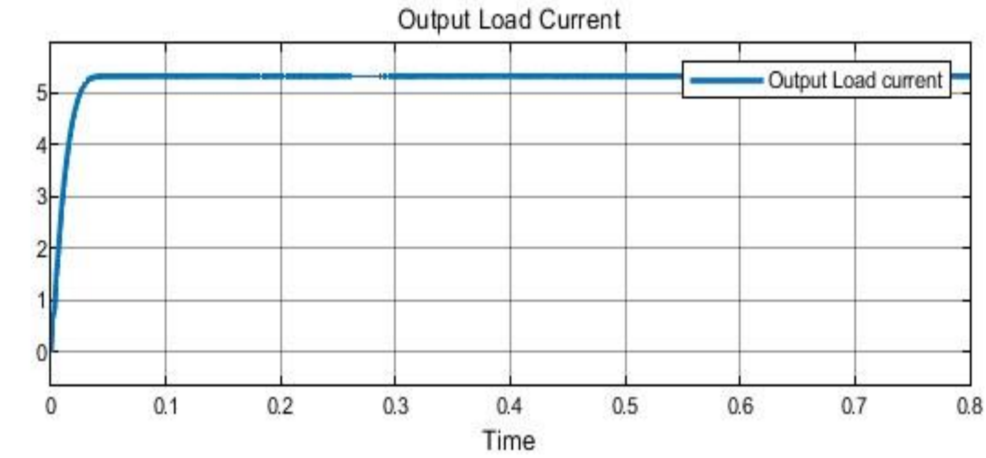

Figure 6.12: Plot of Output current at load side v/s time with MPPT

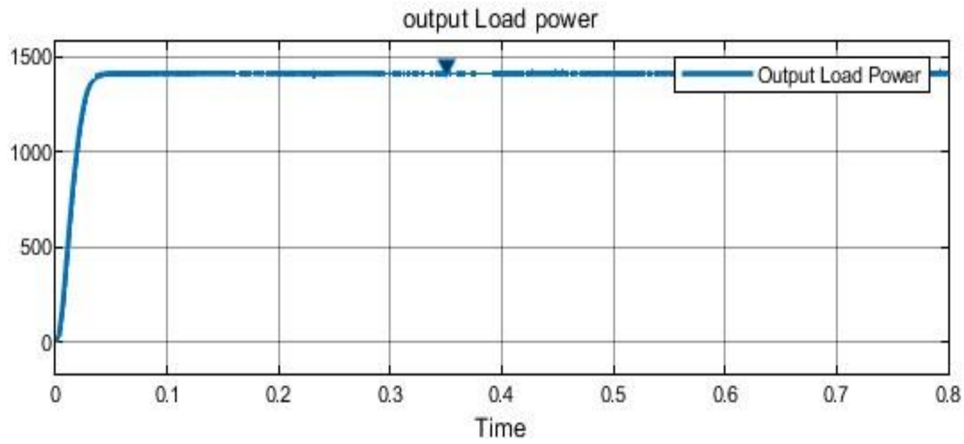

Figure 6.13: Plot of Power obtained at load side v/s time with MPPT

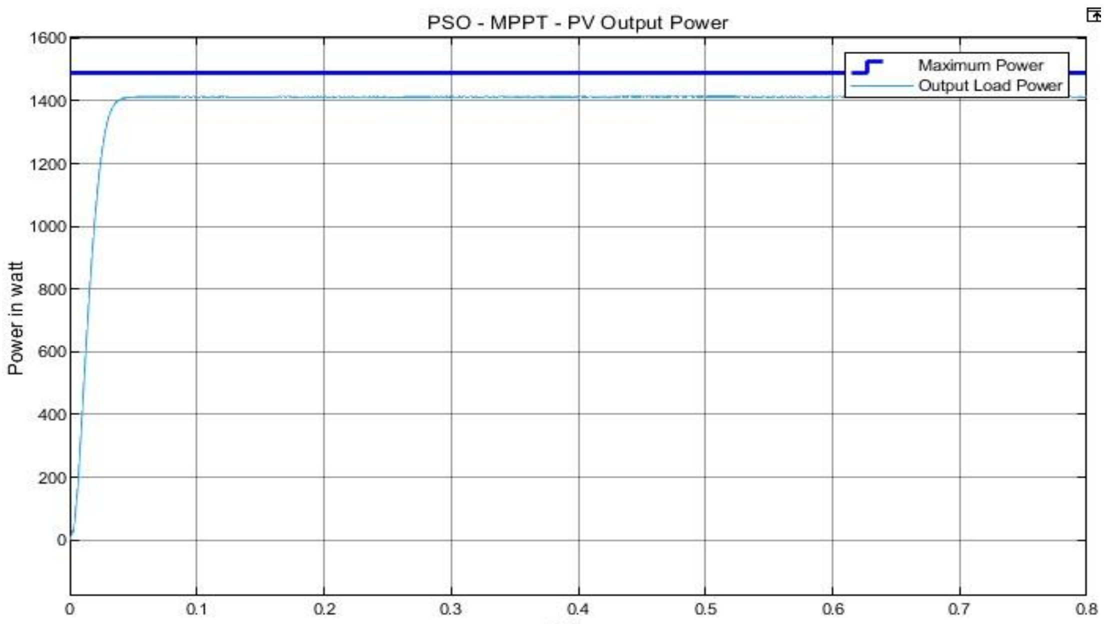

Figure 6.14: Plot of Power obtained at load side and Maximum Power v/s Time with MPPT

CHAPTER 7

CONCLUSION

The model appeared in Figure 5.4 was mimicked utilizing SIMULINK and MATLAB. The plots got in the various extensions have been appeared in Chapter 6.

The recreation was first run with the switch on no MPPT mode, bypassing the MPPT calculation obstruct in the circuit. It was seen that when we don't utilize a MPPT calculation, the force acquired at the heap side was around 850 Watts (Figure 6.6) for a sun-oriented illumination estimation of 1000 Watts for every sq. cm. It must be noticed that the PV board produced around 950 Watts power (Figure 6.3) for this degree of sunlight-based illumination.

The reproduction was then run with the switch on MPPT mode. This incorporated the MPPT obstruct in the circuit. Under a similar light conditions, the PV board created around 1450 Watts power (Figure 6.8) on account of the adjustment in the irradiance and temperature of the board. For this situation, be that as it may, the force acquired at the heap side was seen as around 1410 Watts (Figure 6.12), therefore expanding the change effectiveness of the photovoltaic framework all in all.

The loss of intensity from the most extreme force for example 1500 Watts of the PV board can be clarified by exchanging misfortunes in the high recurrence PWM exchanging circuit and the inductive and capacitive misfortunes in the Boost Converter circuit.

In this way, it was seen that utilizing the Particle Swarm Optimization (PSO) method expanded the proficiency of the photovoltaic framework (figure 6.14) by roughly 165% from a prior yield intensity of around 850 Watts to an acquired yield intensity of around 1410 Watts.

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