AI based Maximum Power Point Tracking for Solar PV System working under Partial Shading Condition

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by

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UNDERTAKING

We declare that the work presented in this report titled **"AI based Maximum Power Point Tracking for Solar PV System working under Partial Shading Condition",** submitted to the **Department of Electrical Engineering, Rajkiya Engineering College, Ambedkar Nagar**, for the award of the **Bachelor of Technology degree**, is our original work. We have not **plagiarized or submitted** the same work for the award of any other degree. In case this undertaking is found **incorrect**, we **accept** that our degree may be **unconditionally withdrawn.**

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CERTIFICATE

This is to certify that **Mr. Deveshwar Nishad, Mr. Divyanshu Verma, & Mr. Pawan Kumar** have carried out the project work presented in this report entitled **"AI based Maximum Power Point Tracking for Solar PV System working under Partial Shading Condition"** 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.

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Dedicated to

our parents.....

for giving us a dream

And, to

our teachers.....

for helping us to realize that dream

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On the submission of our thesis entitled **"AI based Maximum Power Point Tracking for Solar PV System working under Partial Shading Condition",** we would like to extend my gratitude and sincere thanks to our supervisors ***Dr. Mohammed Aslam Husain*** *(Assistant Professor) and* ***Dr. Yudhisthir Pandey*** *(Assistant Professor),* Department of Electrical Engineering for their constant motivation and support during the course of our work. We truly appreciate and value their esteemed guidance and encouragement from the beginning to the end. Their knowledge and company at the time of crisis would be remembered lifelong.

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ABSTRACT

In today's world scenario, there is high need for renewable energy sources because of exhaustible fuels in conventional energy sources like coal, petroleum, etc. and also due to the increase in global warming and pollution level by mass combustion of these fuels. Renewable energy source es (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. India is a country which has a very large capacity to produce electrical energy through solar energy. Presently, India plans to produce 100 Gigawatts Solar power by the year 2022. The installed solar energy capacity has increased by 17 times in the last 7 years, and stands at 49.5 GW. Fifth-largest solar installed capacity in the world. Government commitments Reduce India's total projected carbon emission by 1 bn tones by 2030, reduce the carbon intensity of the nation's economy by less than 45% by the end of the decade, achieve net-zero carbon emissions by 2070 and expand India's renewable energy installed capacity to 500 GW by 2030. Proposed solar cities and parks: 1 solar city per state-approved and approval setting up 45 solar parks of 37 GW across the nation and so, it becomes essential to use the solar energy with high efficiency. For increasing the Power rating of the system, we have to connect multiple panels in series and parallel combination but due to partial shading condition solar panel are unable to operate at its maximum efficiency. Maximum power point tracking (MPPT) scheme is used to extract maximum power from solar PV cells under different atmospheric condition. 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 about the concept of Artificial Intelligence based Maximum Power Point Tracking (MPPT) which significantly increases the efficiency of the solar photovoltaic system working under partial shading condition.

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 the efficient techniques 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 and Proteus design suite along with the hardware implementation of the model for demonstration.

The MPPT Techniques that we have used during the simulation and on which we have tested our Solar PV system are Perturb and Observe (P&O) technique and Particle Swarm Optimization (PSO) technique which is an Artificial Intelligence method. Further, we want to improve and research the above-mentioned techniques and various new MPPT techniques in the higher studies.

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LIST OF SYMBOLS

$=$	Equal
$-$	Subtraction
$/$	Division
$+$	Addition
$\surd$	Square Root
$\approx$	Approximate
$>$	Greater Than
$\geq$	Greater than or equal to
$\times$	Multiplication
$\mid \; \mid$	Absolute value (Modulus)
Δ	Delta (for difference)
( )	Small bracket
[ ]	Big bracket
d/dx	Differentiation with respect to t.
$\int$	Integration
∂	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
uF	Micro Farad
KHz	Kilo Hertz

CHAPTER 1

INTRODUCTION

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. 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) 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 accessible in wind currents. Current day turbines go from around 600 kW to 5 MW 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 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 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. 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 and yield it on prerequisite.

1.2.5 GEOTHERMAL

Geothermal vitality is the warm vitality which is created and put away 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 .

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.

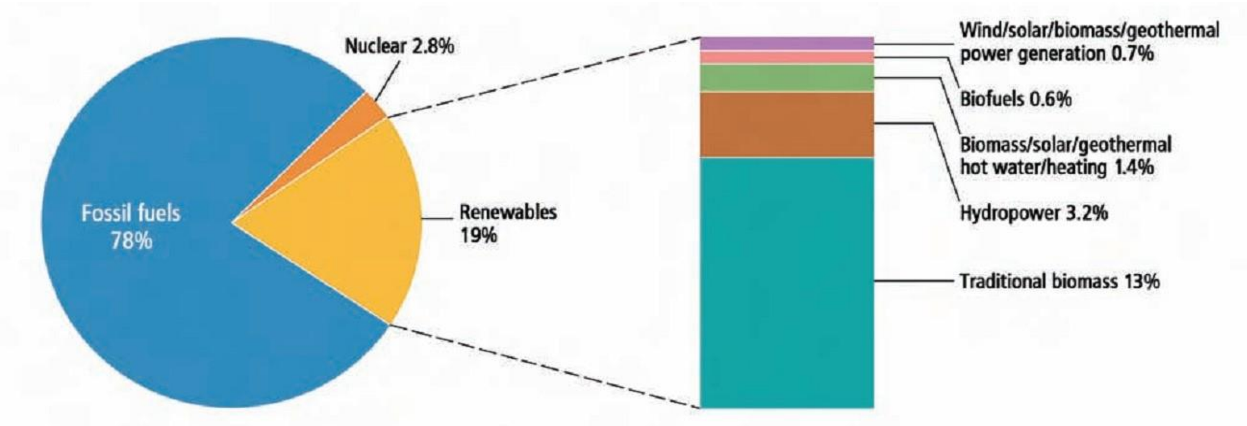


Figure 1.1 : Global energy consumption

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. 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. 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.

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 falls 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 to p intersection and equal obstruction is because of the spillage current.

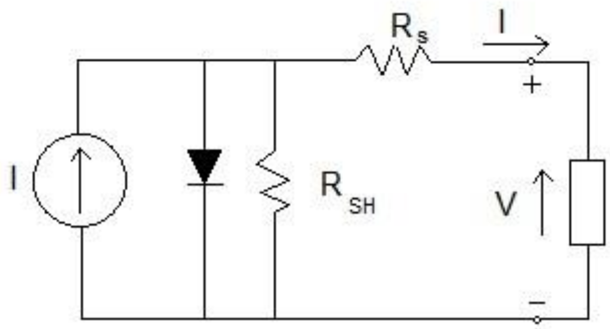


Figure 3.1: Single diode model of a PV cell

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

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

$$\mathbf{I_d= I_o (e^{qVd/kT} - 1)} \qquad \textbf{(3.2)}$$

where Io is the opposite immersion current of the diode, q is the electron charge, Vd is the voltage over the diode, 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

$$\mathbf{I = I_{sc} - I_o (e^{qVd/kT} - 1)} \qquad \textbf{(3.3)}$$

Using suitable approximations,

$$\mathbf{I = Isc - Io\ (eq((V+IRs)/nkT) - 1)} \qquad \textbf{(3.4)}$$

where, I is the photovoltaic cell current, V is the PV cell voltage, T is the temperature (in Kelvin) and n 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.

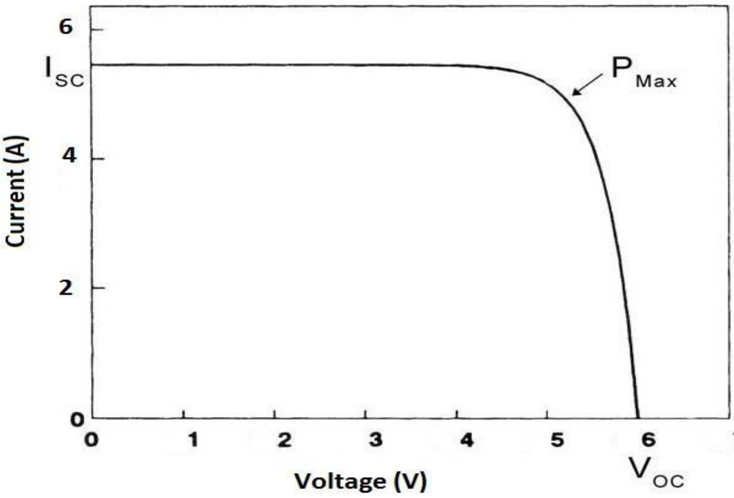


Figure 3.2 : I-V characteristics of a solar panel

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.

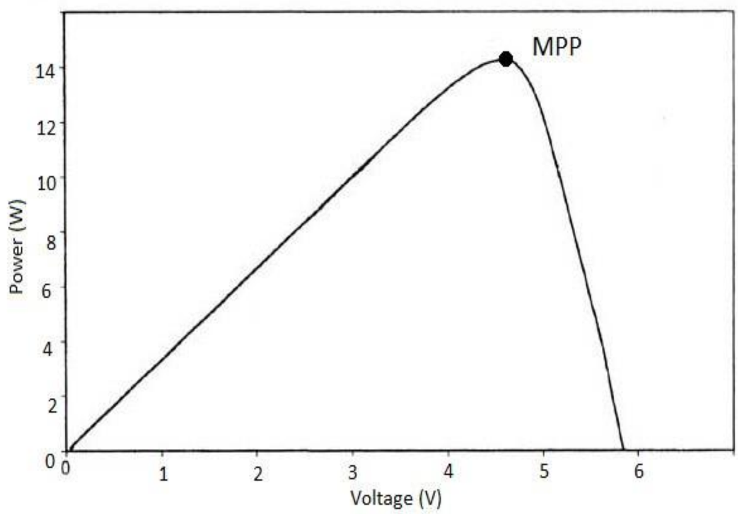


Figure 3.3 : P-V characteristics curve of photovoltaic cell

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.

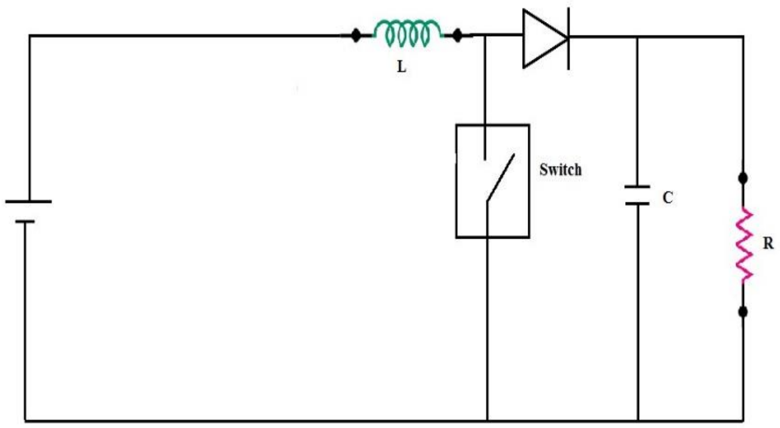


Figure 3.4 : Circuit diagram of a Boost Converter

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.

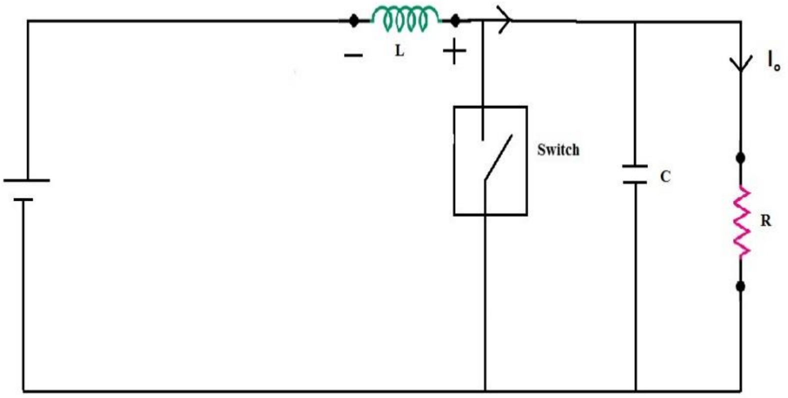


Figure 3.5 : Mode 1 operation of Boost Converter

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.

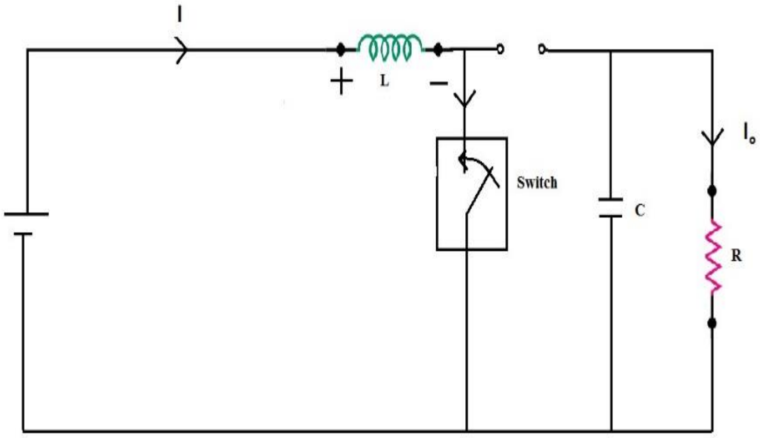


Figure 3.6 : Mode 2 operation of Boost Converter

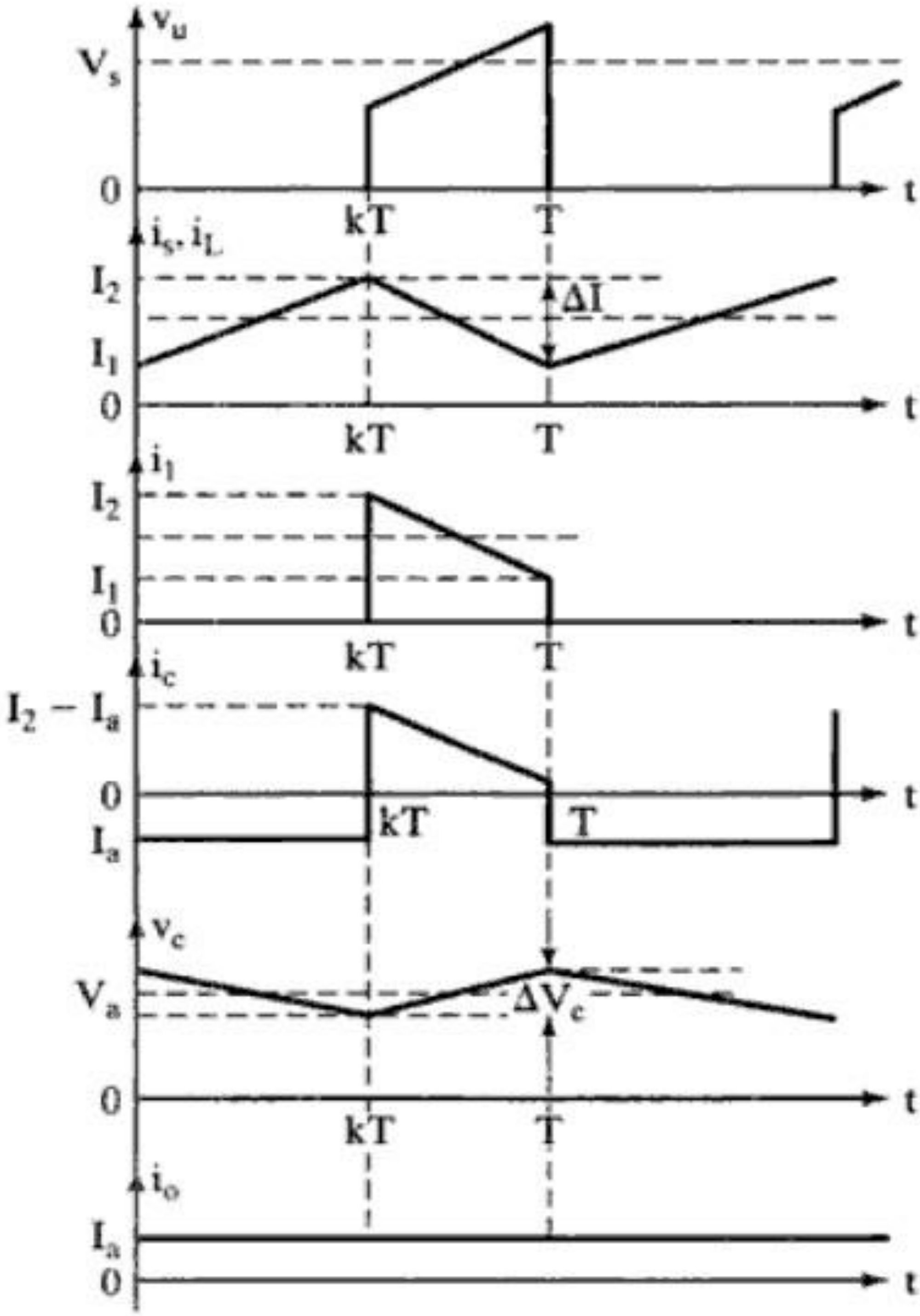


Figure 3.7 : Waveforms for a Boost Converter

CHAPTER 4

MODELING OF STANDALONE PV SYSTEM

4.1 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 1STH-245 W. The inputs to the solar PV panel are temperature, solar irradiation.

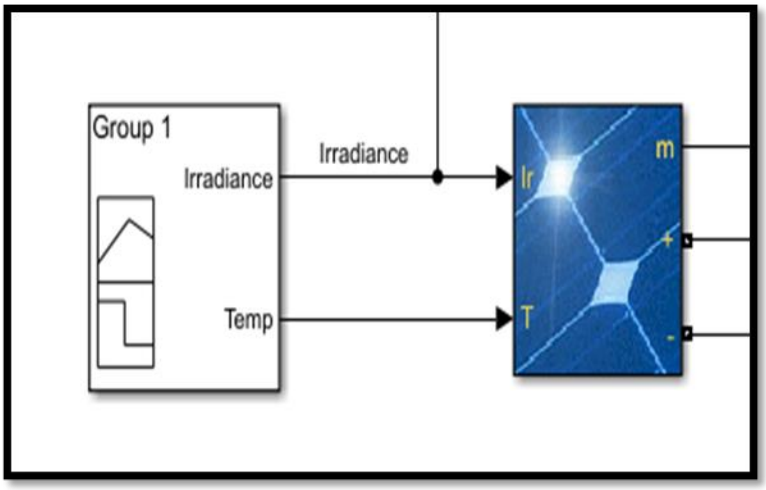


Figure 4.1 : PV Solar Panel

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.

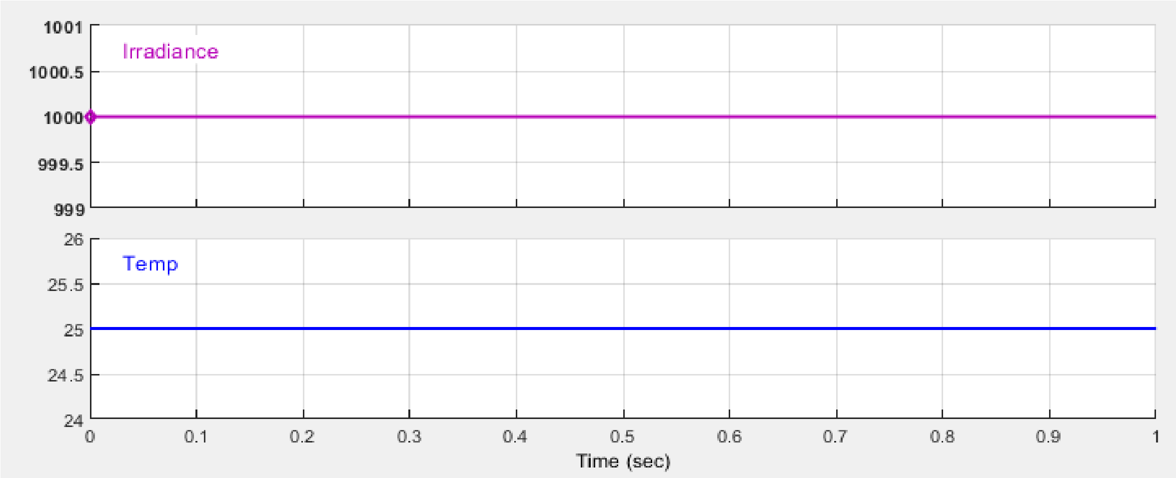


Figure 4.2 : Irradiation signal (Watt per sq. cm. versus time) and Temp signal (ºC vs Time)

4.2 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.

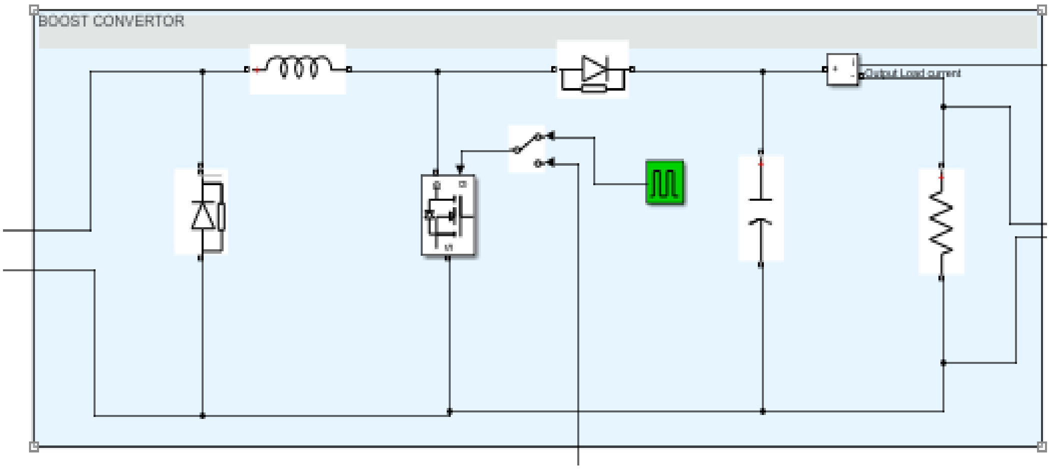


Figure 4.3 : Boost Convertor

4.3 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.

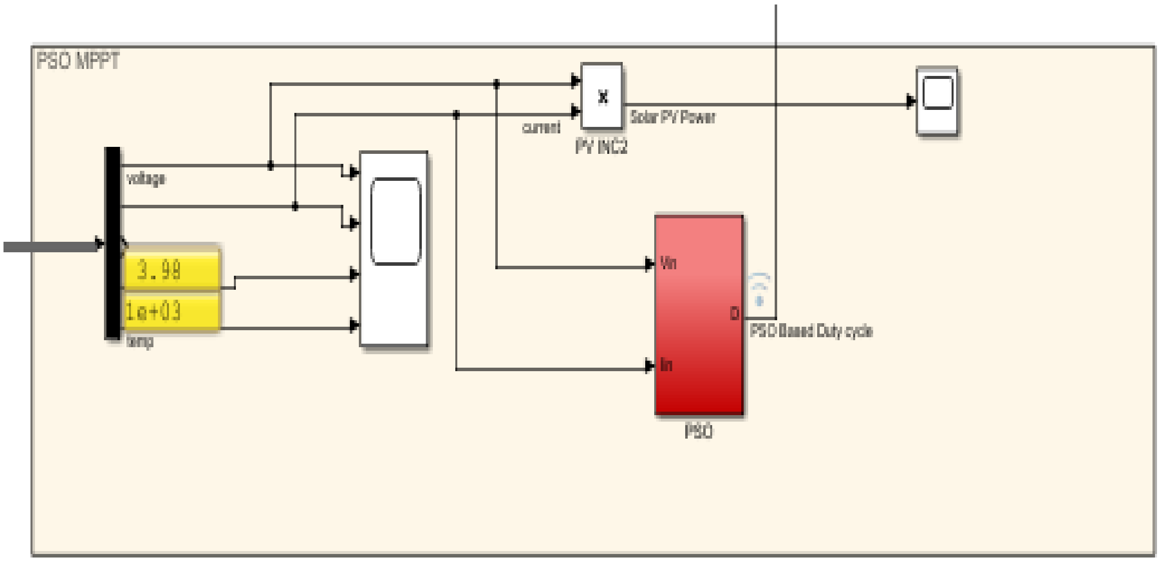


Figure 4.4 : SIMULINK™ Model of MPPT based on PSO Technique

Table 1 : 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

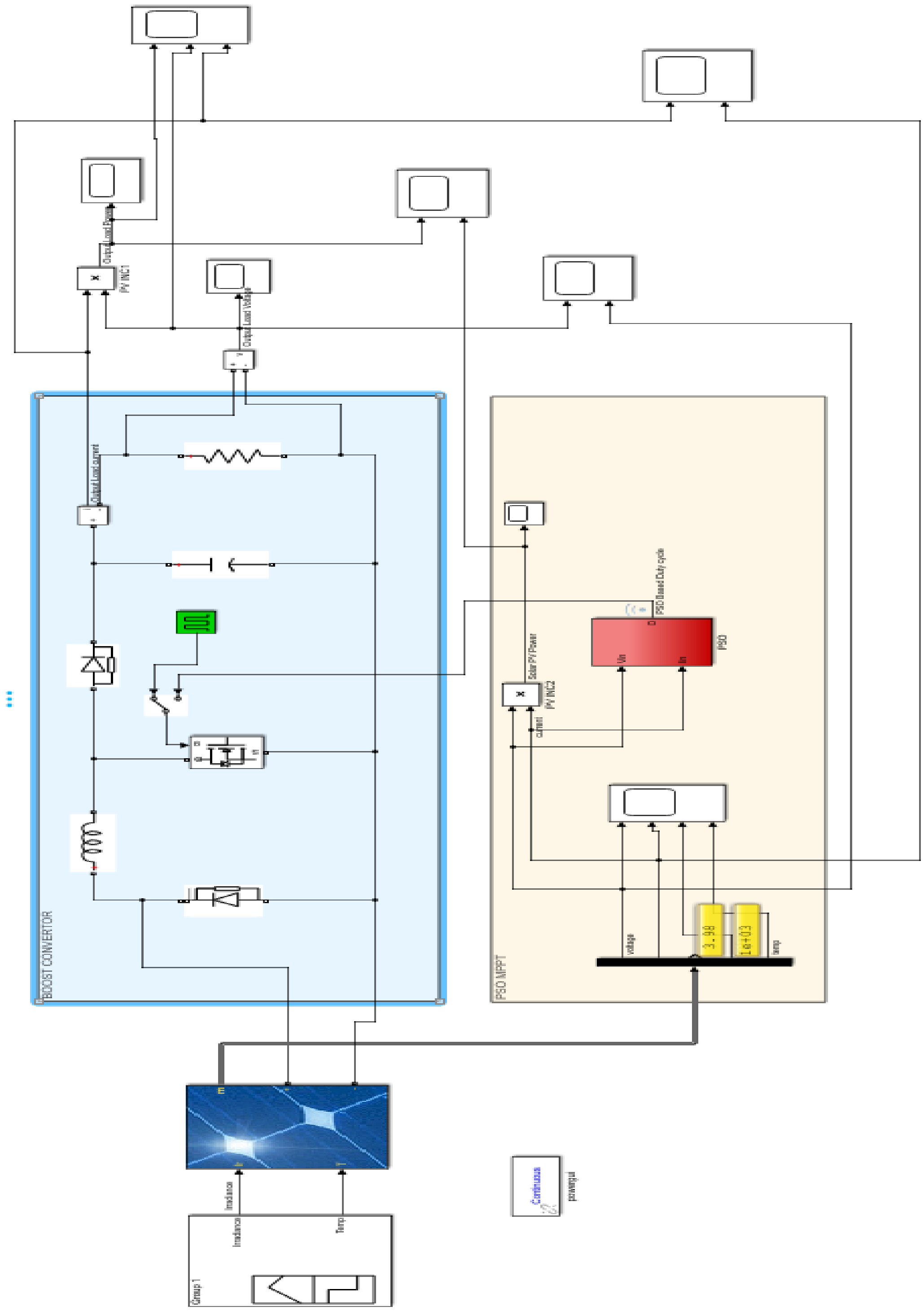


Figure. 4.5 Complete Simulation Model of MPPT PSO based Solar PV System

CHAPTER 5

PARTIAL SHADING CONDITION

5.1. OVERVIEW

The sun transmits energy in the form of electromagnetic radiation. The radiation can change in value based on the type of beam. The types of beams are divided into two types namely direct and diffuse. Direct radiation is solar radiation that comes directly taken by the earth without flattening on the surface of the atmosphere. Diffuse radiation is a type of solar radiation through the process of spreading to the atmosphere. The spread prompts the amount of irradiation that reaches the earth to be diminished.

Changes in irradiation values are determined by weather conditions experienced by the earth. In sunny conditions, there is direct radiation from the sun so that the amount of irradiation reaching the earth is> 900W / m2. In cloudy conditions, diffuse radiation occurs, which causes the value of irradiation taken by the earth to decrease in the range of 400-800W/m2 . In cloudy conditions, there is a diffusion of sunlight in the form of direct irradiation. The transmission undergoes a spread of irradiation on the surface of the atmosphere so that the obtained irradiation value decreases. The reduction encountered in this condition is worth 50% of the cloudy conditions. Solar irradiation given to the earth changes every time. These variations are caused by the position of the sun, based on the earth revolution that occurred. In this position, the sun can transmit maximum irradiation based on the irradiation time. The maximum optimal irradiation is during the daytime. The aforementioned happens due to the position of the sun perpendicular to the surface of the earth so that the irradiation value reaches> 1000W / m2.

Partial shading is the condition of the closed parts of the surface of a solar cell from sun exposure. The condition was caused by the presence of an object that is blocking the solar cells (Belhaouas, et al., 2017). By blocking the solar cells will result in a decrease in the power produced by solar cells. The decrease is affected by solar irradiation received by solar cells, thereby reducing the value of the output current generated

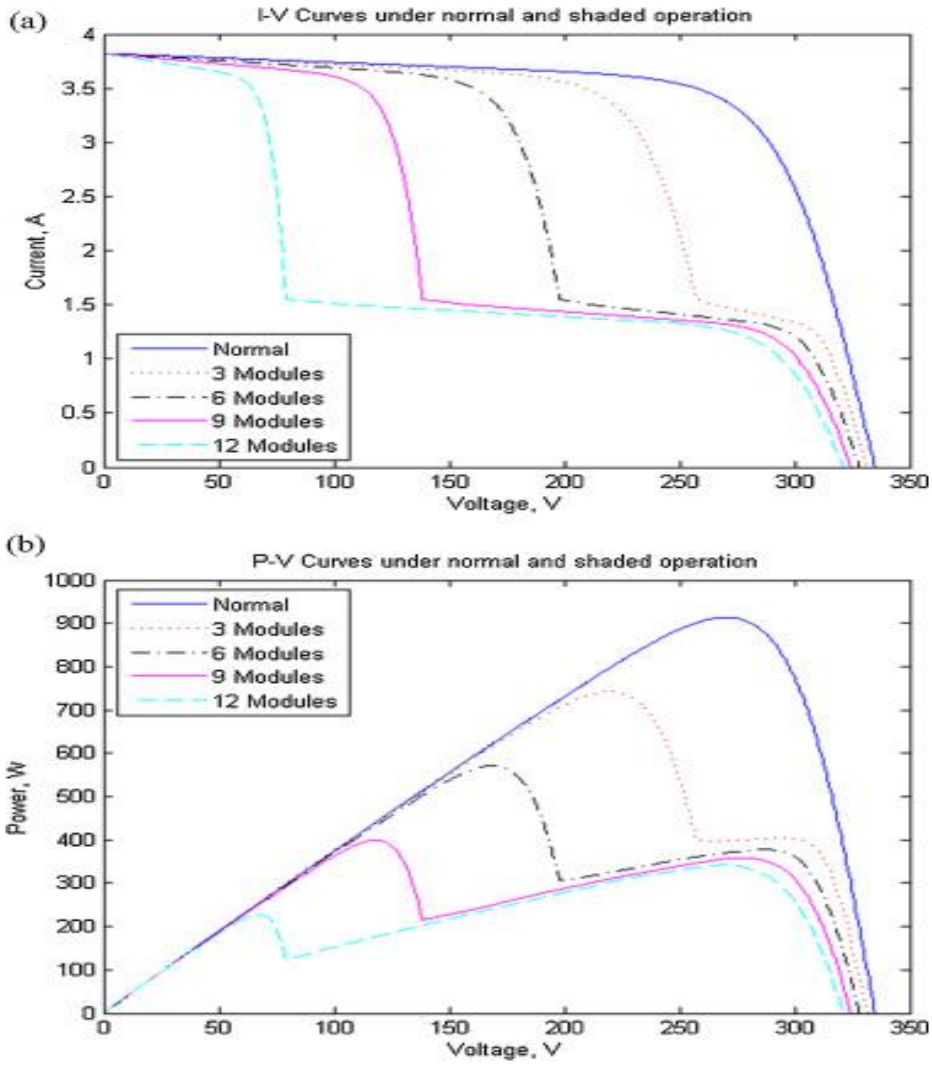


Figure 5.1: I-V& P-V Curve under Normal And Shaded Operation

5.2. EFFECTS

In order to scale up the PV power according to demand requirement, PV modules are connected in series and parallel fashion to form a PV array. Under such condition, the panels receive non-uniform irradiation will introduce shading effect to the panels. Specifically, in a cloudy day the panels may witness faster and dynamic insolation change. Under such circumstances, the nature of P-V curve distorting to produce multiple peaks is shown in figure. During this period, the panels receiving less irradiation introduce hotspots and act as a load to the panel. Further the shade condition increases the probability of damaging the panels and hence reduces the efficiency of power delivered by the panel. Hence to avoid the severity, each panel connected in PV array is connected with a bypass diode and it gets forward biased when any irradiation changes occur.

The occurrence of multiple peaks under partial shading condition is shown in Fig. From Fig, P-V characteristics with local and global peaks under partial shaded conditions are clearly mentioned where the significant power reduction is also clearly seen. It is also important to note that depending on the shade pattern, the GMPP is varying. Thus, the importance of tracking GMPP under shade conditions is mandatory to improve the efficiency of power generation.

CHAPTER 6

MAXIMUM POWER POINT TRACKING ALGORITHMS

6.1 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.

6.2 ARTIFICIAL INTELLIGENCE BASED MPPT TECHNIQUES

In the last decade, artificial intelligence (AI) techniques have been extensively used for maximum power point tracking (MPPT) in the solar power system. This is because conventional MPPT techniques are incapable of tracking the global maximum power point (GMPP) under partial shading condition (PSC). The selection of AI-based MPPT techniques is complicated because each technique has its own merits and demerits. In general, all of the AI-based MPPT techniques exhibit fast convergence speed, less steady-state oscillation and high efficiency, compared with the conventional MPPT techniques. However, the AI-based MPPT techniques are computationally intensive and costly to realize. The integration of various AI optimization techniques with MPPT is aimed to resolve and rectify the following limitations of a conventional HC MPPT:

- Lack of adaptive, robust and self-learning capabilities.
- High steady-state error, power oscillation at MPP and slow transient response.

Inability to find GMPP, trapping at local MPP and incorrect perturbation direction under PSC or sudden irradiance change due to MPPT failure. In general, the existing AI-based MPPT techniques utilize the sensory information including solar irradiance Ee, input voltage of solar power system VI, PV and input current II, PV measurements to predict and estimate the GMPP throughout the non-linear P−V curve.

MPPT techniques are categorized into two major groups: conventional HC MPPT and AI-based MPPT. AI-based MPPT term is known as computational intelligence (CI) based MPPT, soft-computing MPPT, modern MPPT or bio-inspired MPPT. It mainly consists of **Particle Swarm Optimization (PSO)**, fuzzy logic control (FLC), artificial neural network (ANN), differential evolution (DE), genetic algorithm (GA), Tabu search (TS), Cuckoo search (CS), firefly algorithm (FA) and hybrid algorithms. Conventional HC MPPT techniques consist of **P&O**, IC, HC, constant voltage, fractional short-circuit current, fractional open-circuit voltage, scanning-tracking of current-voltage (I−V) curve, Fibonacci searching, global MPPT (GMPPT) segmentation searching and extremum seeking control.

Table:2 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

Differentiation 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 or 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
Gauss-Newton 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.
There are different techniques used to track the maximum power point. The used technique in this project work is discussed below:

1) Perturb and Observe (hill climbing method)
2) Particle Swarm Optimization (PSO) Method

6.2.1 Perturbation &Observation (P&O)

In this approach, firstly we calculate the initial power *P***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***2** drawn by the PV array. If the new power *P***2** is more as compare to the *P***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. 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.

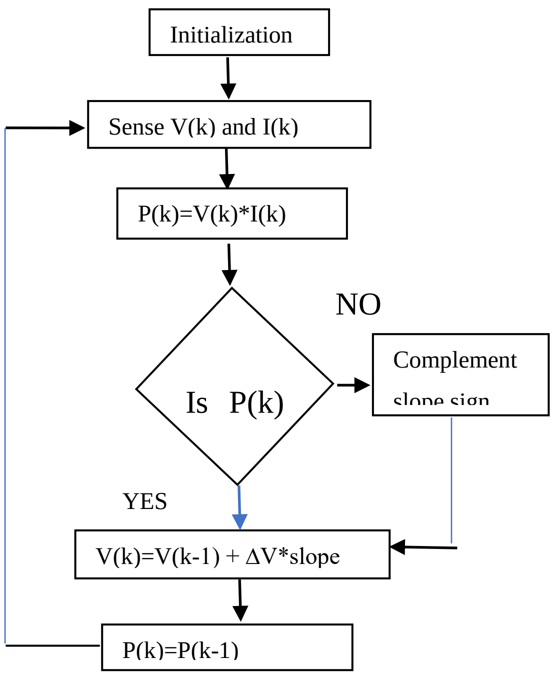


Figure 6.1. Simple P&O technique Algorithm

6.2.2 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. 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. the formula by which each particle updates its velocity is

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,

$$pbest_i = s^k_i \qquad \text{……(4.9)}$$

$$f(s^k_i) > f(pbest_i) \qquad \text{…….(4.10)}$$

and gbest represents the best position which is gained among all the agents.

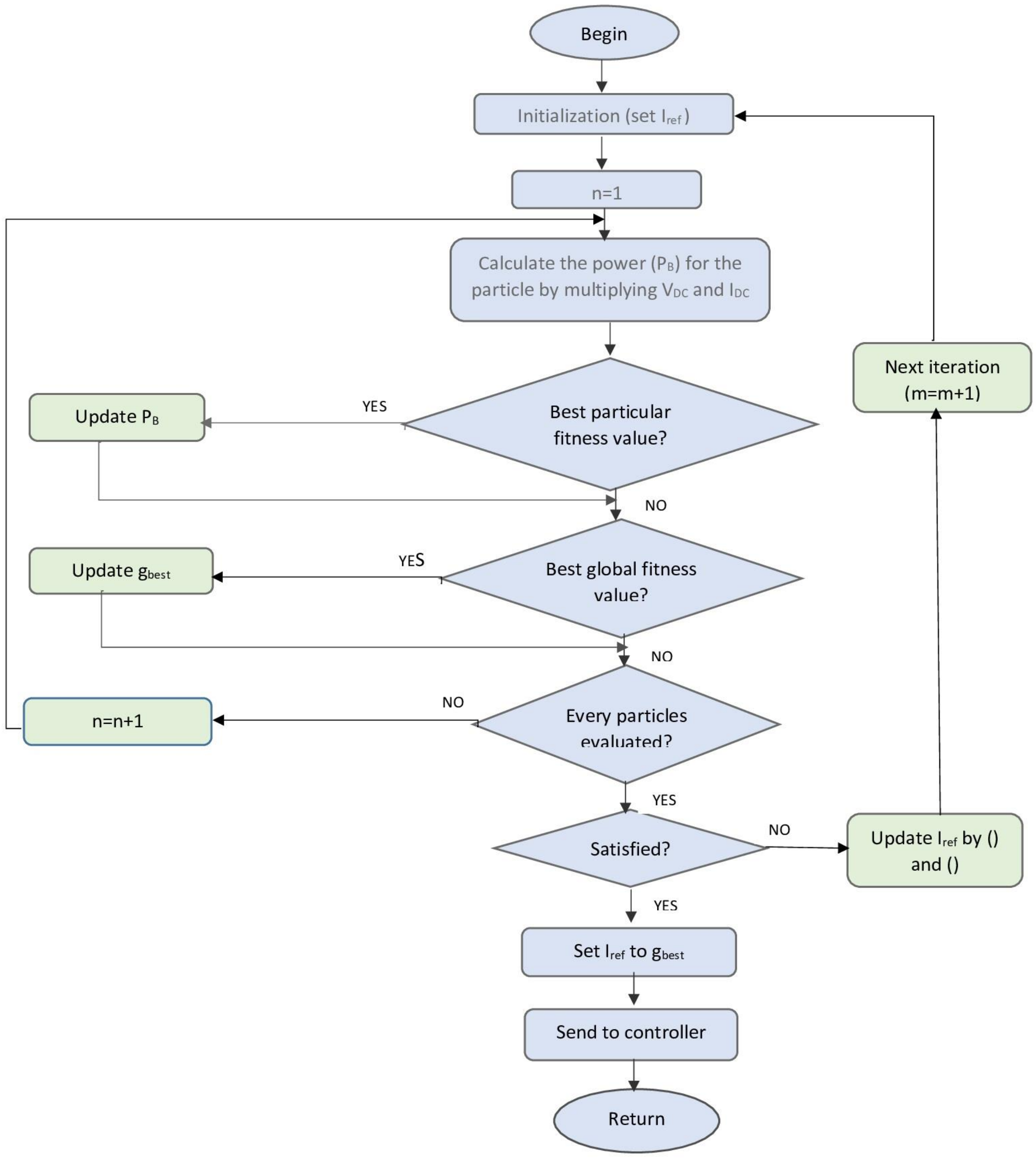


Figure:6.2 Flowchart for PSO algorithm

6.3 PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

6.3.1 THE BASIC PSO ALGORITHM

PSO method 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:

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

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad \ldots\ldots\ (4.14)$$

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

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.

6.3.2 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.

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

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

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.

6.3.3. 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.

6.4 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.

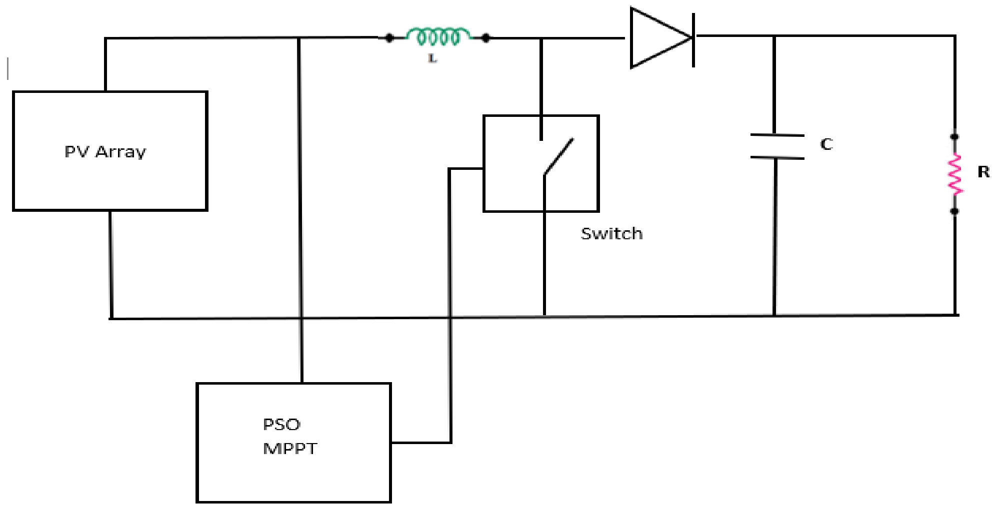


Figure 6.3 : Requisite implementation for MPPT system

CHAPTER 7

SIMULATION MODELS AND RESULTS

7.1. P&O METHOD

7.1.1. MATLAB SIMULINK SIMULATION AND RESULTS

Matlab Simulink Simulation Model are shown below, in which all the components of P&O MPPT are placed according to circuit configuration. P&O MPPT code are uploaded and the circuit will be simulated and corresponding results are also shown below.

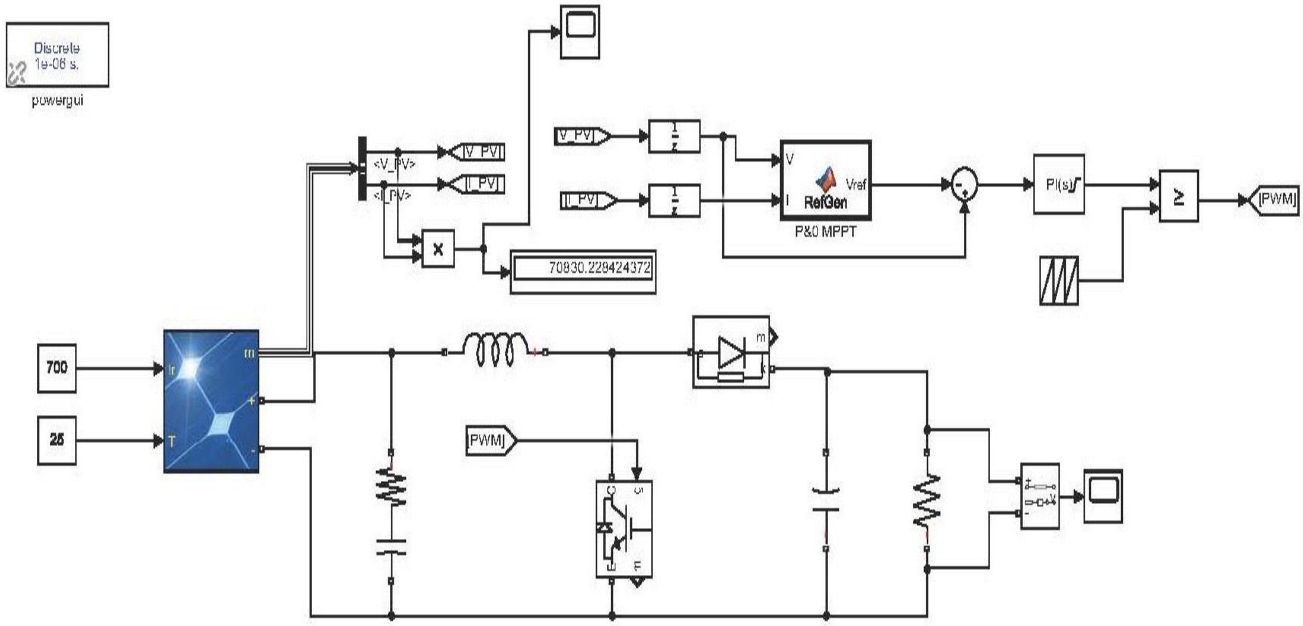


Figure 7.1: Matlab Simulink Simulation Model

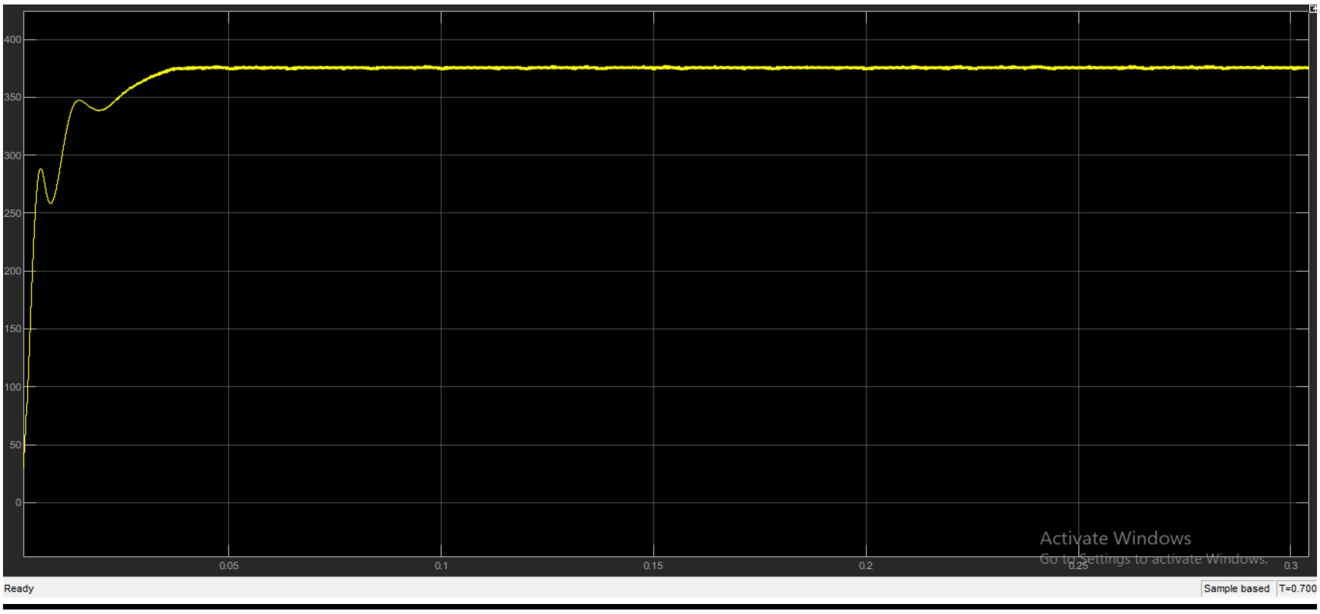
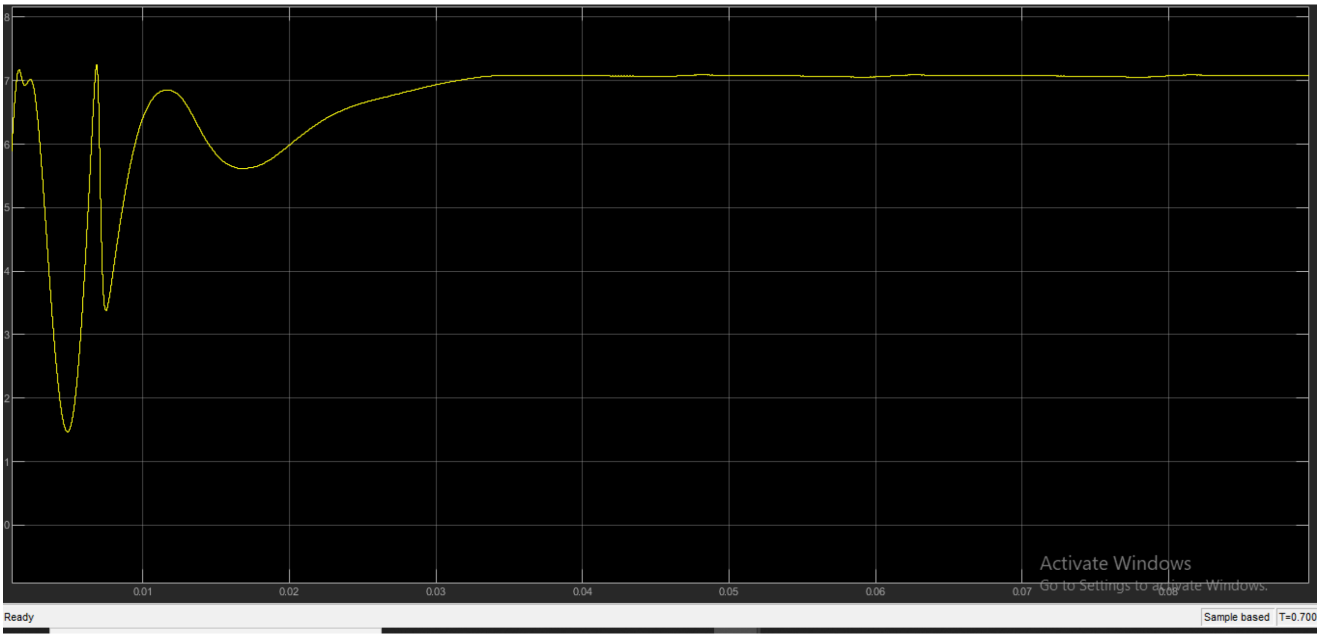


Figure 7.2: Result, Output Voltage Variation against time



Figur 7.3: Result, Power Variation against time

7.1.2. PROTEUS MODEL SIMULATION

The Circuit configuration of the Proteus model according to the actual circuit diagram is shown below, in which different components such as Arduino, solar panel, current sensor, voltage sensor, MOSFET, MOSFET Driver and LCD etc. are used. We can also control the irradiance of the solar Panel. The current sensor is used for sensing the current from the circuit and used in series of the circuit and sends the current value to the Arduino. The voltage sensor is placed in the parallel combination of the circuit and send signal to Arduino. LCD are placed for showing value of Power, Voltage and Current. Result is also attested below:

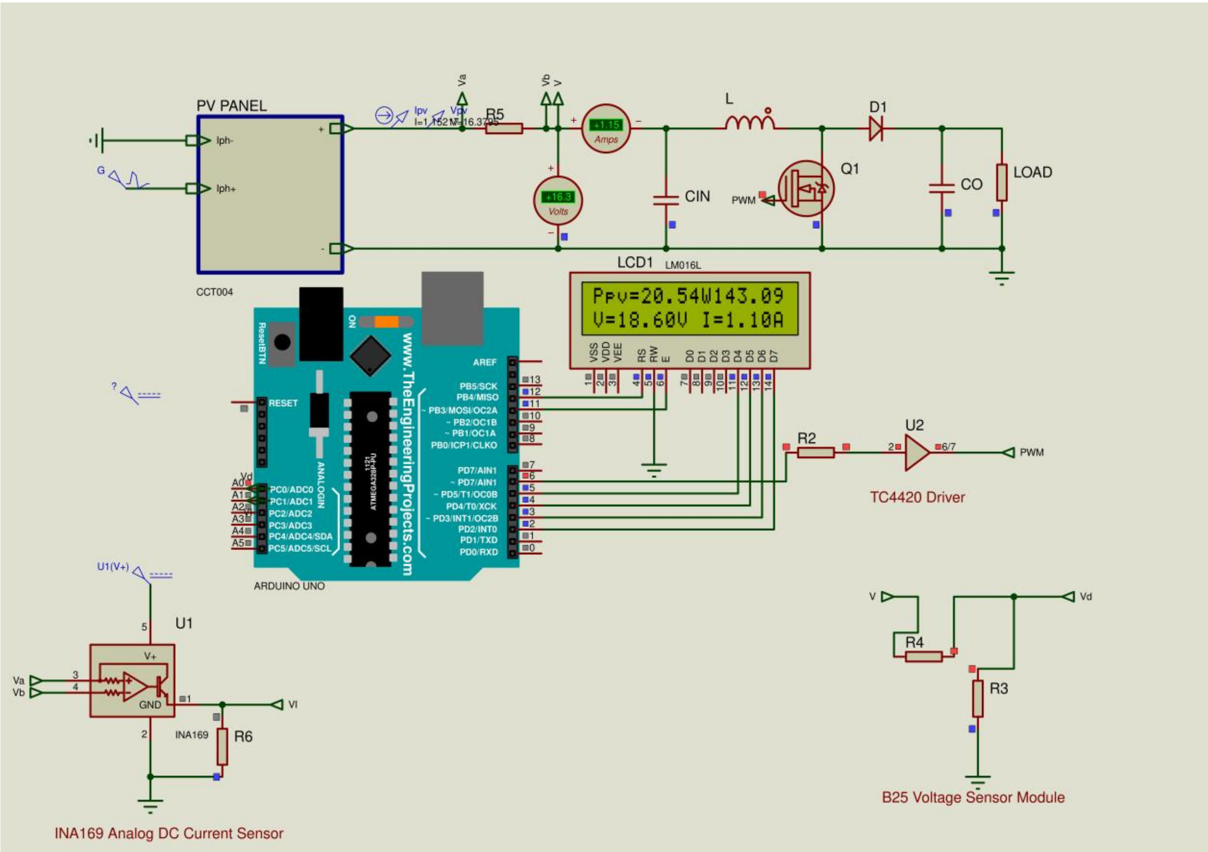


Figure 7.4: Proteus Simulation Model

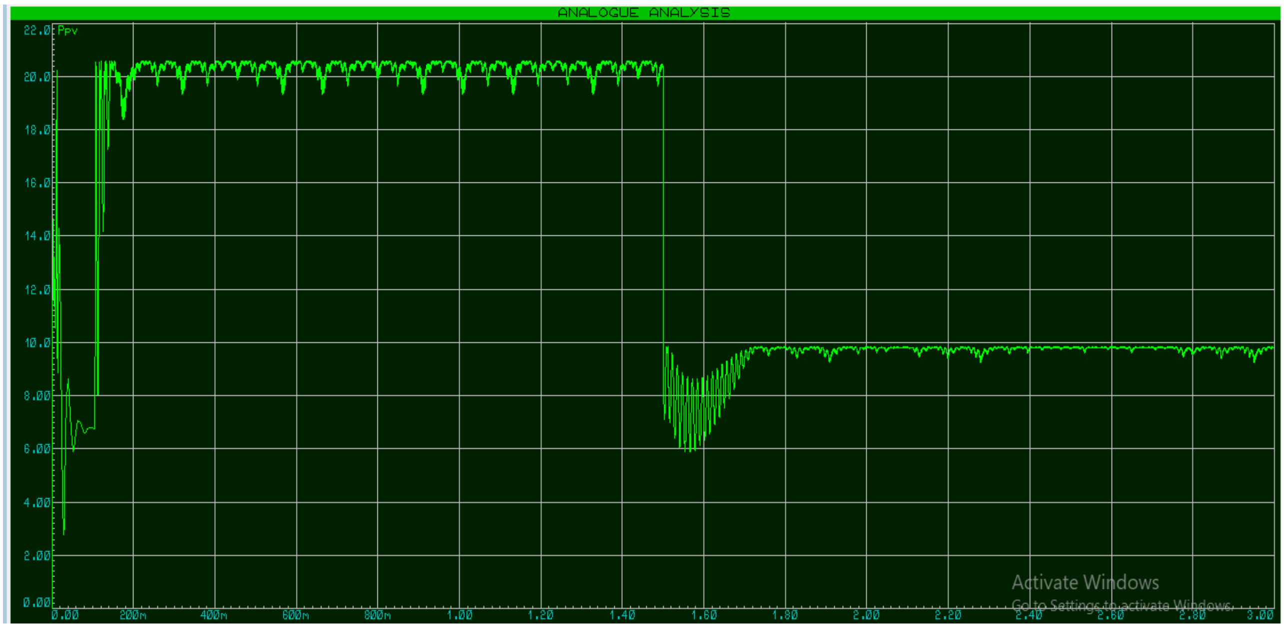


Figure 7.5: Result Power Variation against time

7.2. PSO METHOD (For Single Panel)

7.2.1. PROTEUS MODEL SIMULATION

The circuit diagram of PSO Method for single panel is same as the P&O method and also the same sensors are used. The controller is instructed in such a way to perform the tracking based on PSO algorithm which is an AI method.

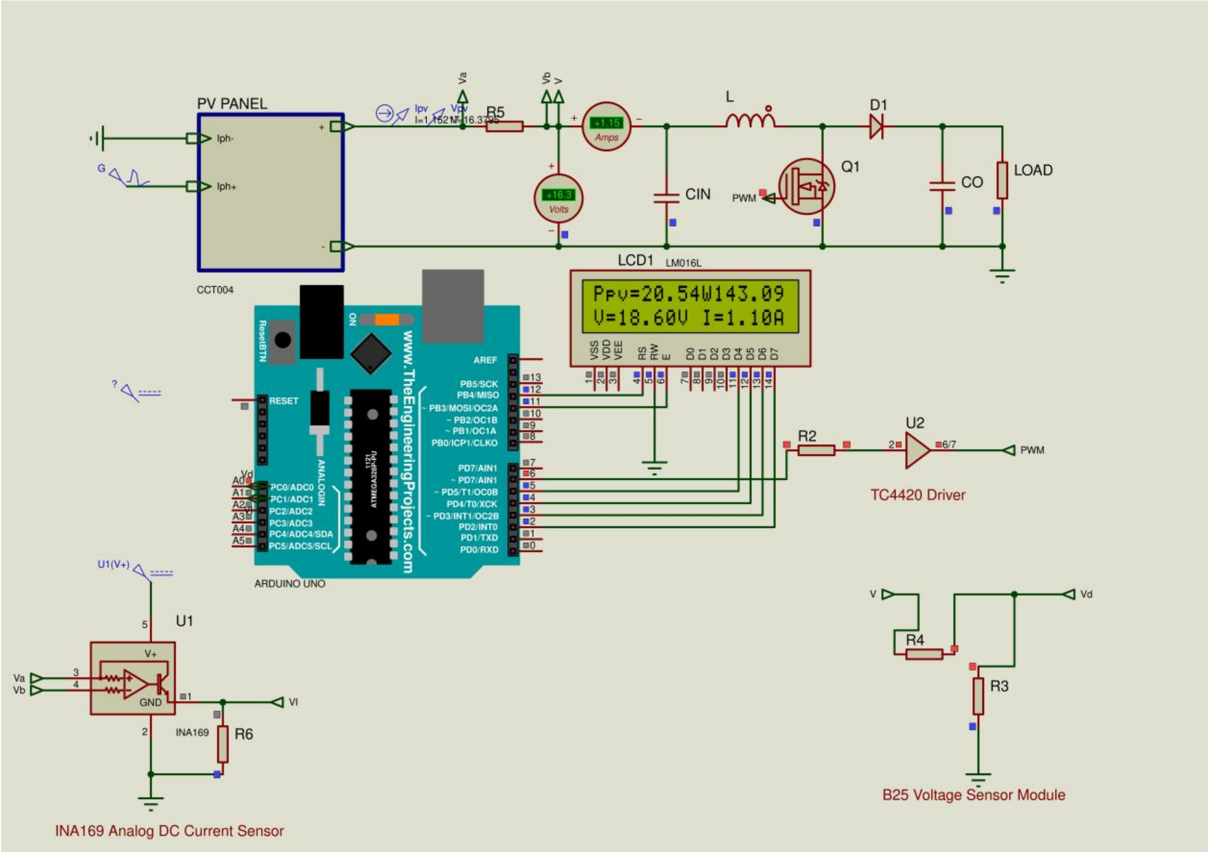


Figure 7.6: Proteus Simulation Model

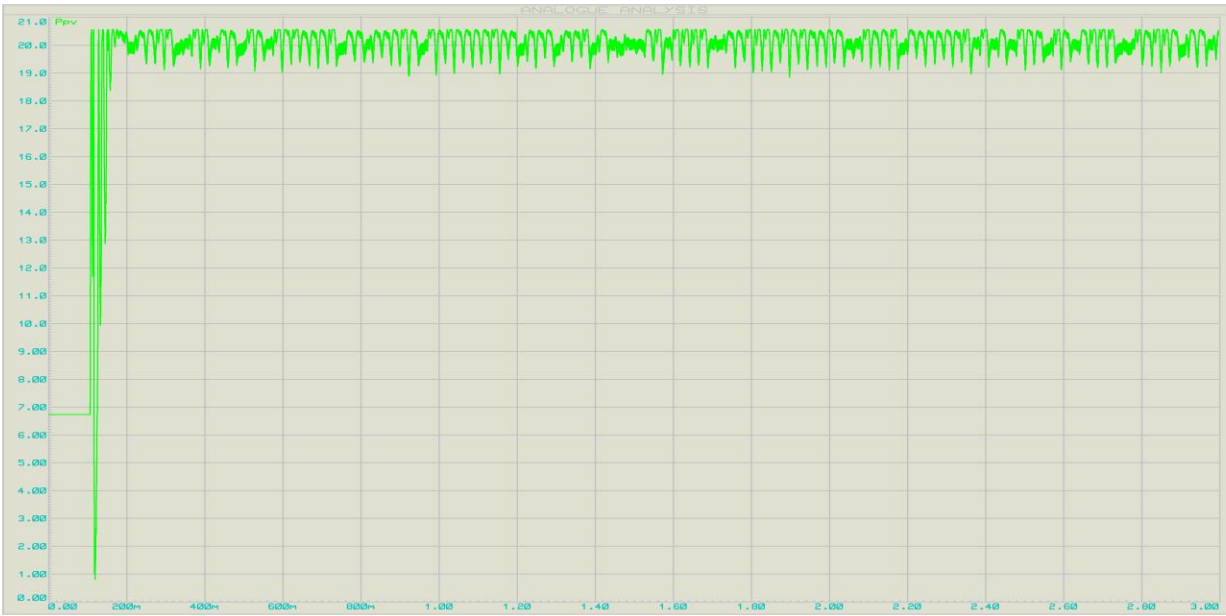


Figure 7.7: Result Power Variation against time.

7.3. PSO METHOD (For Multiple Panels)

7.3.1. MATLAB SIMULINK SIMULATION

MATLAB simulation Model by using different components of multiple panels is used in the circuit. Different graph plotting components are also placed and accordingly graphs are simulated and get the P-V, I-V and power against time are plotted.

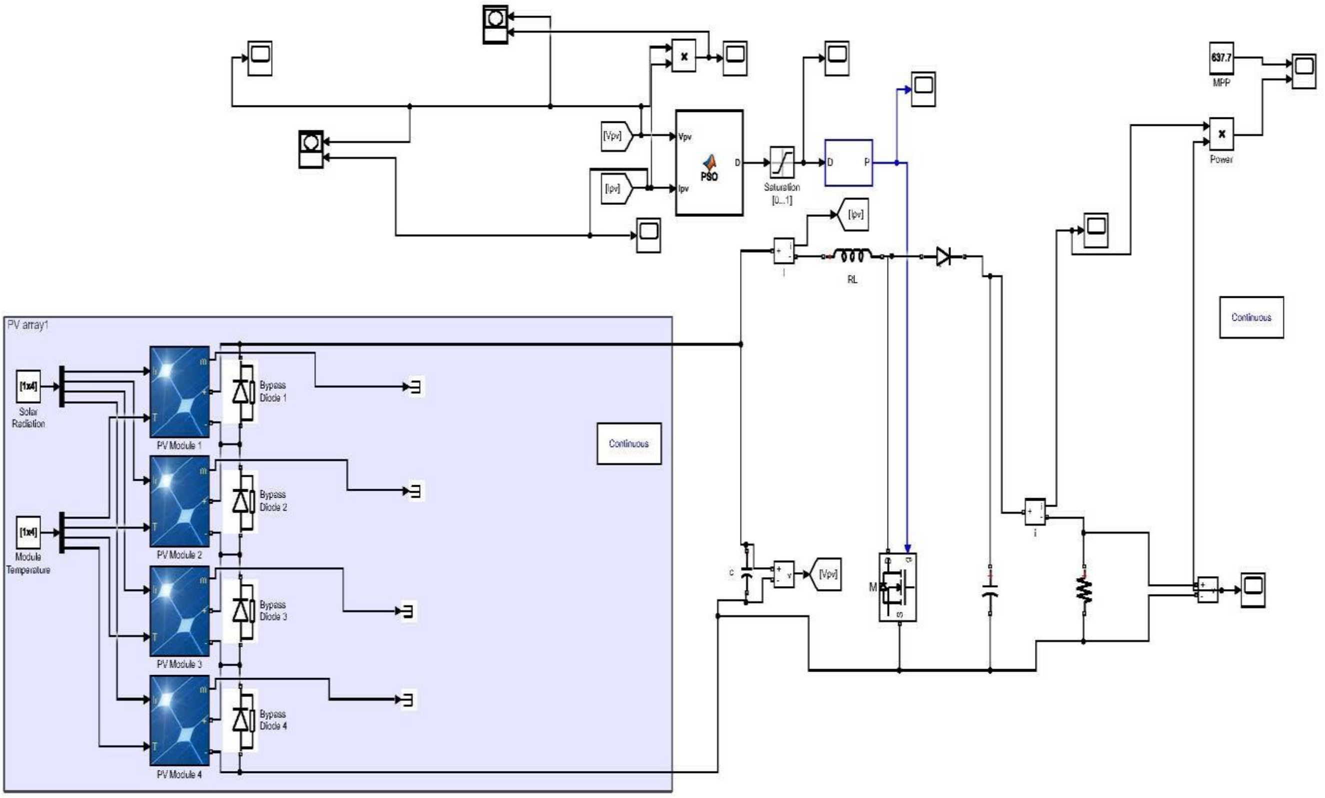


Figure 7.8: Matlab Simulink Simulation Model

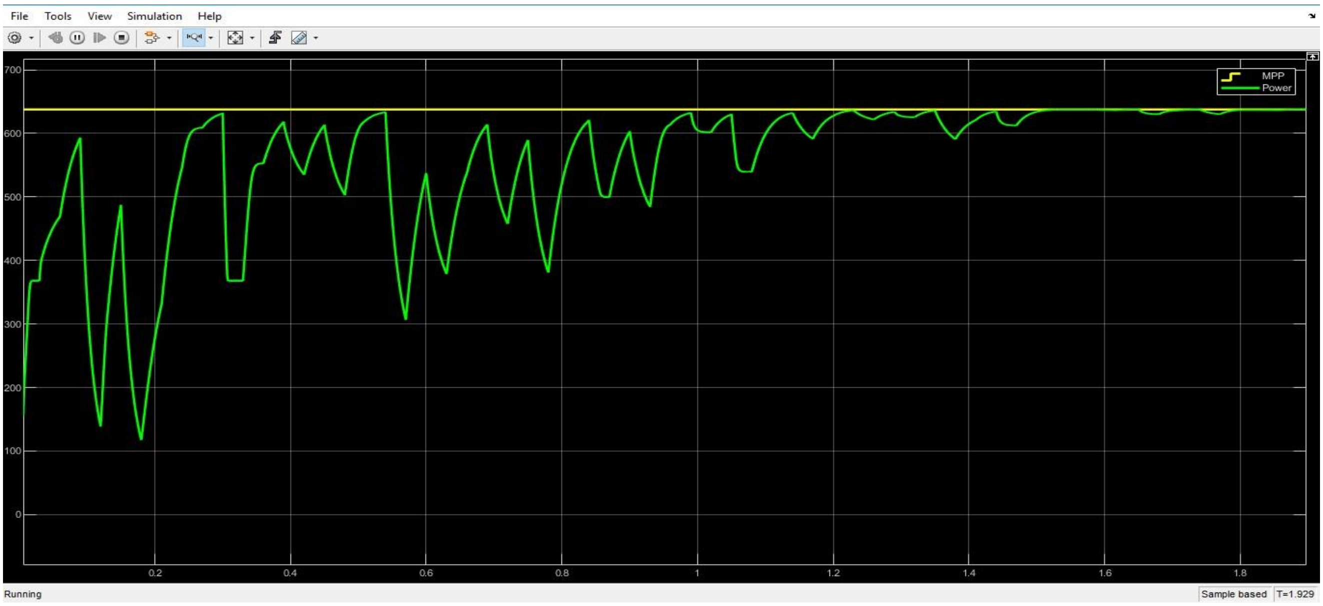


Figure 7.9: Result, Power Variation Against Time

7.3.2. PROTEUS MODEL SIMULATION

Proteus Model of Multiple panels are shown in the figure. Circuit diagram is same as the previous proteus model except the multiple panel and algorithm are also changed according to the PSO multiple panels.

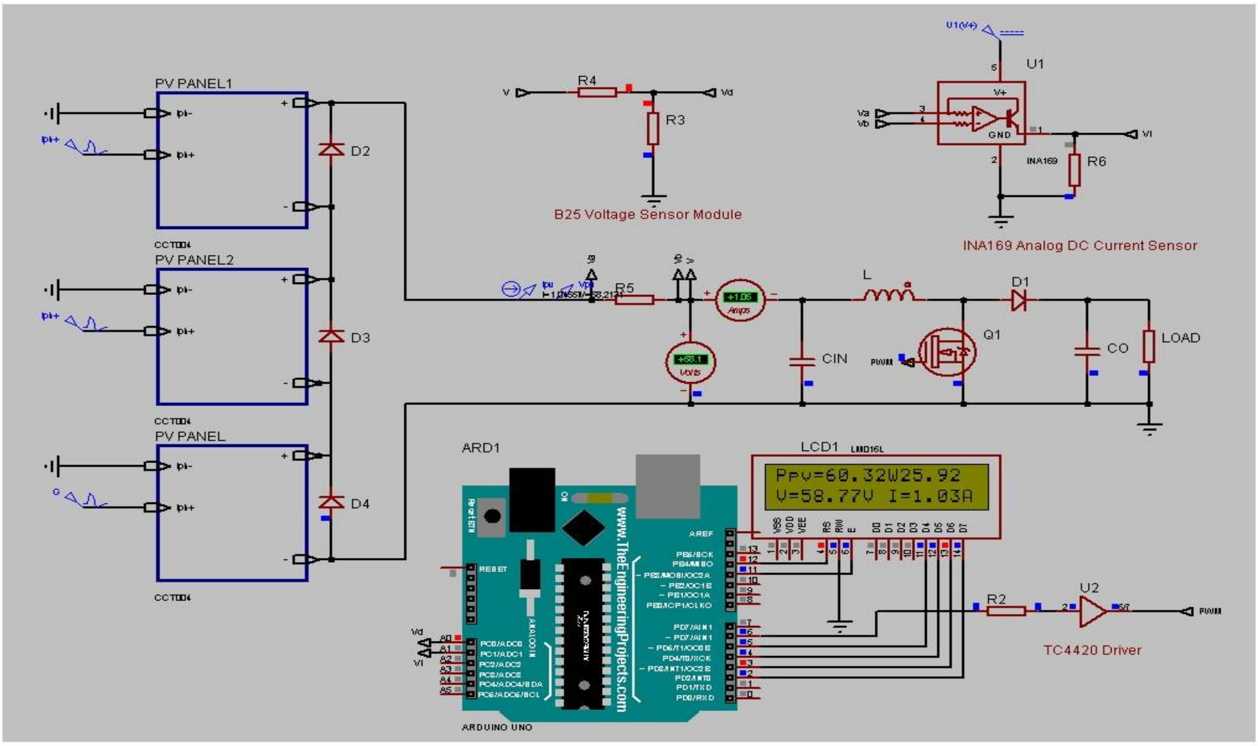


Figure 7.10: PROTEUS MODEL SIMULATION

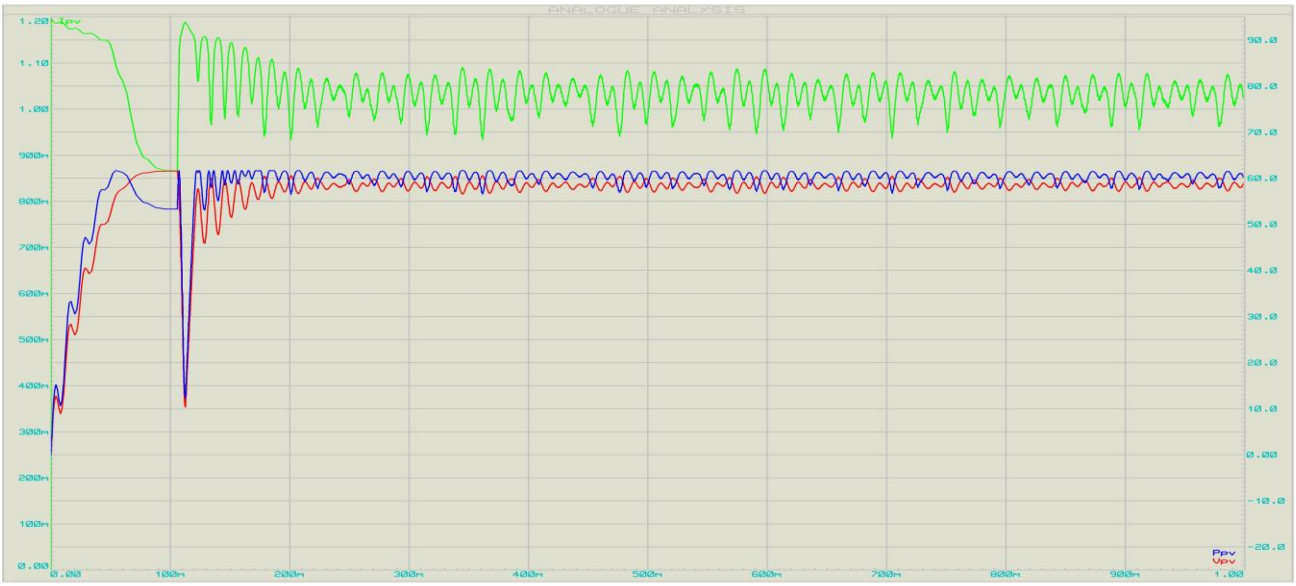


Figure 7.11: Power, Voltage and Current Variation against time

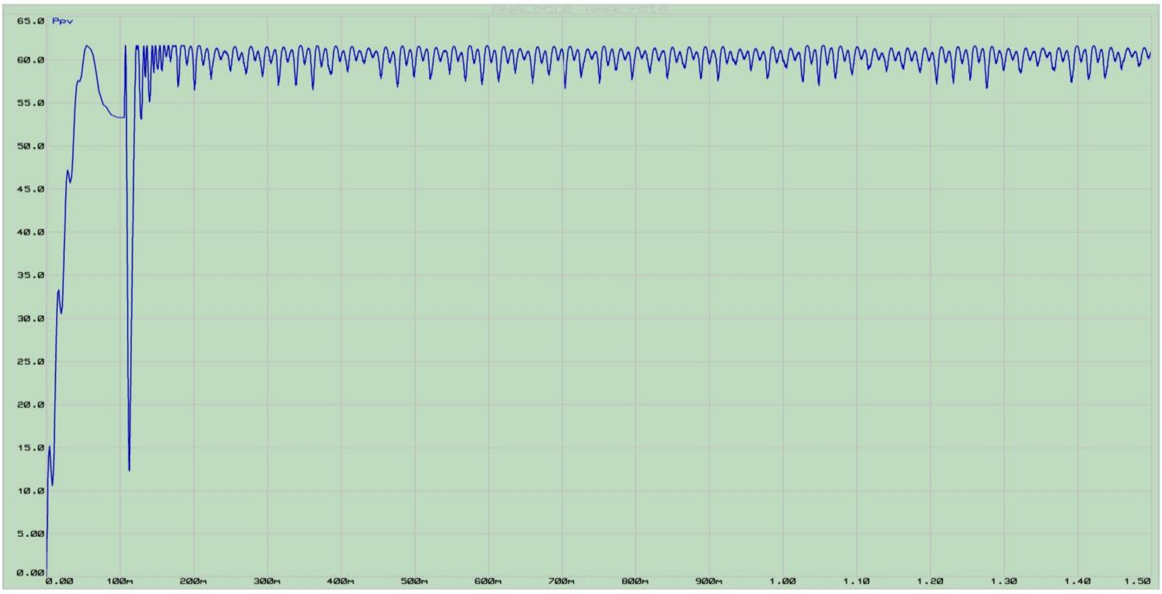


Figure 7.12: Power Variation against time

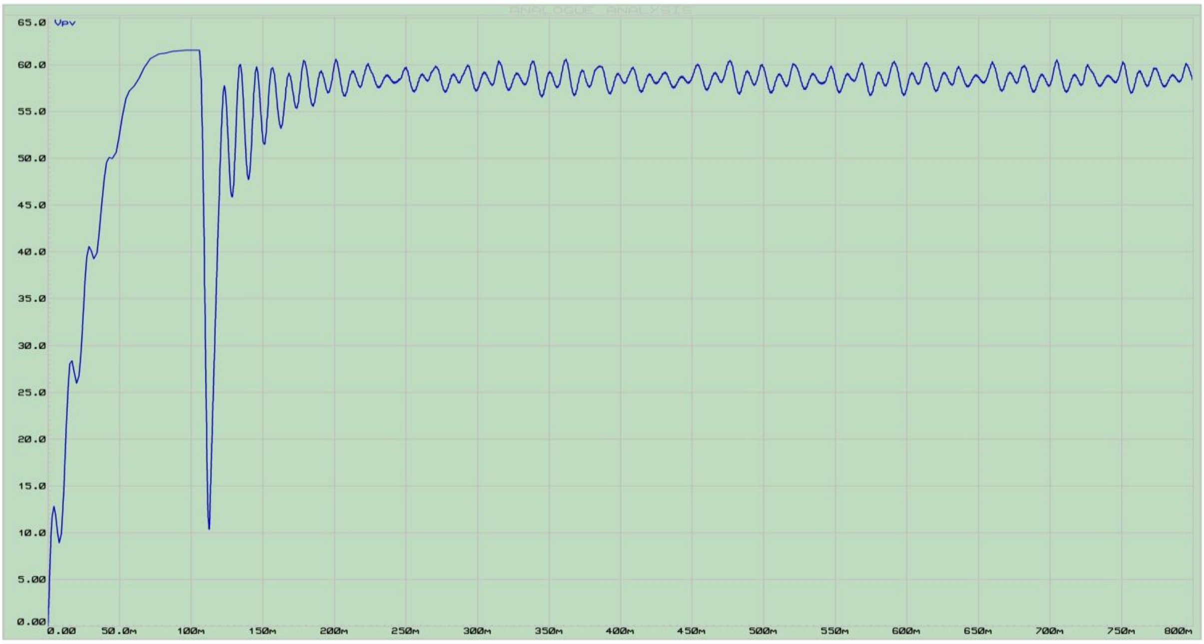


Figure 7.13: Voltage Variation against time

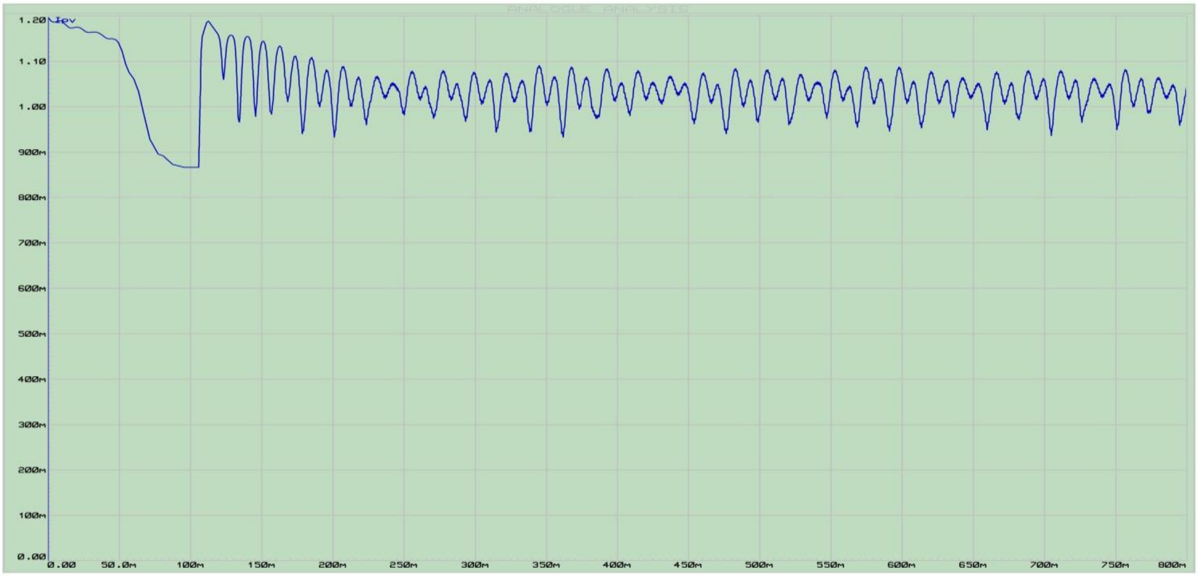


Figure 7.14: Current Variation against time

CHAPTER 8

HARDWARE IMPLEMENTATION

Project Hardware means all materials, supplies, apparatus, devices, equipment, machinery, tools, parts, components, instruments, and appliances that are to be incorporated into the Project.

8.1. Current sensor

A current sensor is a device that detects and converts current to an easily measurable output voltage, which is proportional to the current through the measured path. There are a wide variety of sensors, and each sensor is suitable for a specific current range and environmental condition.

Features & details

- IC: ACS712
- Product: Current sensor module
- Number of pins: 3
- Measure Current Range: 30A
- Low-noise analog signal path

8.2. Solar panel

Solar panel is radiant light and heat from the Sun that is harnessed using a range of technologies such as solar power to generate electricity, solar thermal energy including solar water heating, and solar architecture.

Features & details

- Application: Perfect for charging Power Bank/Mobile/Small Battery upto 20AH
- Dimension: (L*W*H) mm -450*350*22
- Outstanding Durability: With its newly reinforced frame design, Loom Solar 20W can endure a front load up to 6,000Pa, and a rear load up to 5,400Pa.
- Best in Class Efficiency: Innovative cell technology ensures optimum solar power generation providing high value for money upto16.5%.
- Technology: Poly Crystalline, PID Resistance Technology

Tempered Solar Glass

- The high light transmittance solar glass allows the solar cells to absorb more sunlight and increase 2%-3% power output. The tempered glass increases the ability to stand 2400 Pa wind and snow load.

8.3. Jumper wires

A jumper wire is an electric wire that connects remote electric circuits used for printed circuit boards. By attaching a jumper wire on the circuit, it can be short-circuited and short-cut (jump) to the electric circuit.

8.4. Diode

It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction. Diodes are also known as rectifiers because they change alternating current (ac) into pulsating direct current (dc). Diodes are rated according to their type, voltage, and current capacity.

Features & details

- Case: Molded plastic use UL 94V-0 recognized Flame retardant epoxy
- ZYME FR207 Fast Recovery Diode 2 A 1000 V DO-15 Axial 207 2-amp 1000 Volt Electronic Silicon Diodes
- Feature: Low forward voltage/High current capability/Low leakage.
- current/High surge capability
- FR207 Data: Forward rectified current:1A, Maximum recurrent peak reverse voltage:1000V
- Pack of 10
- Zyme diodes

8.5. Capacitor (220uF/100V Electrolytic Capacitor)

A capacitor (originally known as a condenser) is a passive two-terminal electrical component used to store energy electrostatically in an electric field. 220uF 100V Electrolytic Capacitor is a high-quality electrolytic capacitor that offers long life and high reliability. Electrolytic Capacitors are the most commonly used type of capacitors in Electronic Circuits.

Features & details

- Capacitance: 220uF;
- Voltage Rating:100V

- Tolerance: 20%;
- Termination: Radial
- Operating Temperatures: -40Œ_C to +85Œ_C

8.6. IRFP250N – N-Channel MOSFET

Benefit, combined with the fast-switching speed and ruggedized device design, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications. It has isolated mounting holes

Features & details

- Dynamic dV/dt rating; Isolated Central Mounting Hole
- N-Channel; Fast switching
- Max Drain-Source Voltage: 200V
- Max Gate-Source Voltage: + 20V
- Max Continuous Drain Current, VGS @ 10 V, TC = 25 deg C: 30A

8.7. TC4420 IC-6A High-speed MOSFET Driver IC

The TC4420/TC4429 are 6A (peak), single-output MOSFET drivers. The TC4429 is an inverting driver (pin-compatible with the TC429), while the TC4420 is a non-inverting driver. These drivers are fabricated in CMOS for lower power and more efficient operation versus bipolar drivers.

Features & details

- Maximum Supply Voltage: 20V
- Maximum Input voltage: 5V to VDD + 0.3V
- Maximum Input Current (VIN > VDD): 50mA

8.8. Common Mode Choke 20mH U core 3A

Common mode choke coils are used to suppress common mode noise. This type of coil is produced by winding the signal or supply wires one ferrite core. Since magnetic flux flows inside the ferrite core, common mode choke coils work as an inductor against common mode current.

EMI Filter for SMPS Power Supply 20mH 3 Amps 8.0mm X 7.0 mm Pitch

Features & details

- Common mode Choke for SMPS 3Amps

- Used in SMPS Input Circuit

8.9. LCD (Liquid Crystal Display)

LCD (Liquid Crystal Display) is a type of flat panel display which uses liquid
crystals in its primary form of operation. LEDs have a large and varying set of use cases for consumers and businesses, as they can be commonly found in smartphones, televisions, computer monitors and instrument panels.

Features & details

Below are some common resolutions for monitors: Desktop widescreen monitors are usually 1920 x 1080, though 2560 x 1440 and 3440 x 1440 are becoming more popular.

FHD	1920×1080
WUXGA	1920 X 1200Q
WXGA	2048 X 1152
WQHD	2560 X 1440

8.10. Arduino UNO

Arduino UNO is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. This board can be interfaced with other Arduino boards, Arduino shields, Raspberry Pi boards and can control relays, LEDs, servos, and motors as an output. This board contains a USB interface i.e. USB cable is used to connect the board with the computer and Arduino IDE (Integrated Development Environment) software is used to program the board.

Features & details

- The unit comes with 32KB flash memory that is used to store the
- number of instructions while the SRAM is 2KB and EEPROM is 1KB.
- The operating voltage of the unit is 5V which projects the microcontroller on the board and its associated circuitry operates at 5V while the input voltage ranges between 6V to 20V and the recommended input voltage ranges from 7V to 12V.

8.11. Resistance

A **resistor** is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

8.12. Bread board

A breadboard, or protoboard, is a construction base for prototyping of electronics. Originally the word referred to a literal bread board, a polished piece of wood used when slicing bread. In the 1970s the solderles breadboard (a.k.a. plugboard, a terminal array board) became available and nowadays the term "breadboard" is commonly used to refer to these.

8.13. Switch

A switch is an electrical component that can disconnect or connect the conducting path in an electrical circuit, interrupting the electric current or diverting it from one conductor to another.

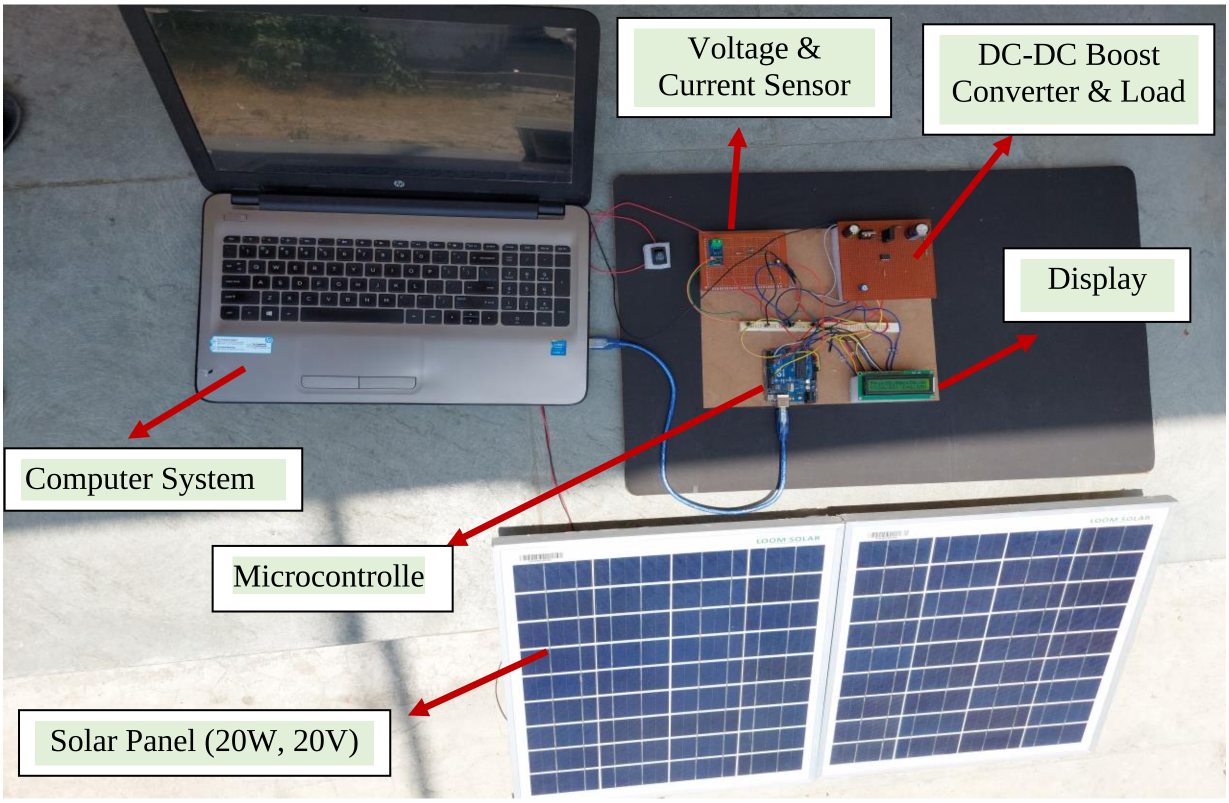


Figure 8.1. Hardware Implementation of PSO MPPT model for two panels

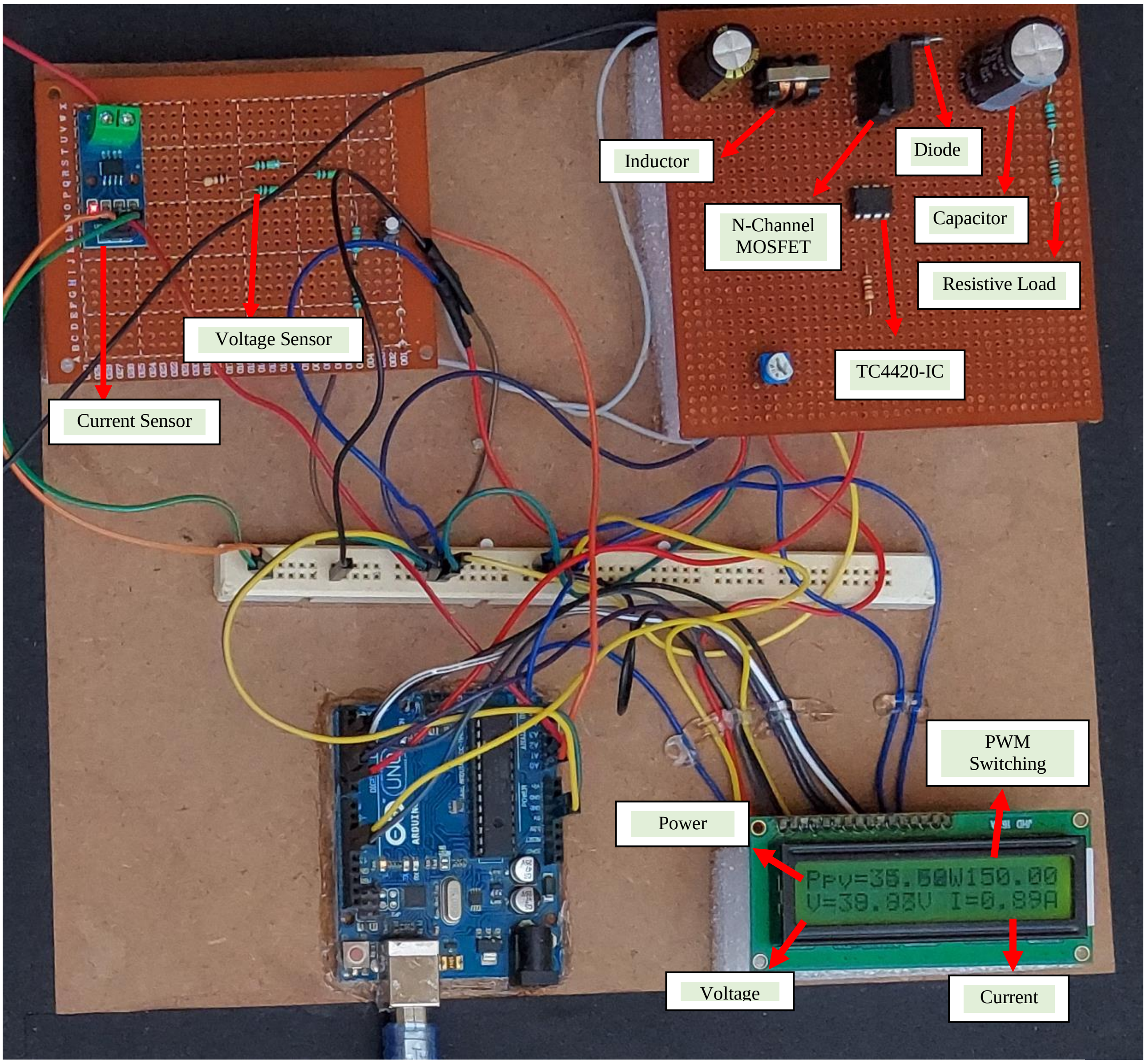


Figure 8.2. Circuit connection and output display of hardware model

CHAPTER 9

CONCLUSION

The model appeared in Figures 7.1, 7.4, 7.6, 7.8, and 7.10 were mimicked utilizing SIMULINK, MATLAB and PROTEUS Design Suite. The plots got in the various extensions have been appeared in Chapter 7.

The recreation was first simulated with the P&O algorithm MPPT on single panel mode, by using MATLAB Simulink and Proteus software. It was seen that when we implemented MPPT P&O algorithm on single panel on MATLAB Simulink, the output voltage and current against time are settled for operating at its Maximum Power condition in nearly 0.03 seconds which we can see in figure 7.2 and 7.3. The same model when simulated by Proteus software for the solar panel of rating 20 volts, 20 Watt the output Power curve is settled at 0.20 seconds for its Maximum Power operation, which we can see in figure 7.5.

The reproduction was then simulated with the AI based PSO algorithm MPPT mode. Firstly for single panel operation using Proteus software, we can see from the figure 7.7 that the output Power curve against time is settled at its peak value in 0.2 seconds. After that the simulation was incorporated under the Partial Shading Conditions for multiple panels. The result for Power variation against time for the 4 panels (each under different irradiance condition) of MATLAB simulation are shown in the figure 7.9, in which we can see the maximum Power that can be obtained for the condition under which simulation is performed is 637.7 Watt and the obtained Power curve is settled at this value. Proteus simulation for three panels under partial shading condition is also simulated and the corresponding results are shown in the figure 7.11, 7.12, 7.13, 7.14 in which Power Voltage and Current variation against time can be seen where the desired results of Maximum Power point is settled at slightly less than 0.2 sec.

After this a hardware model was implemented for the analysis of above-mentioned AI based PSO method in practical conditions. A total of two panels are used each of rating 20 Watts, 20 volts and the overall circuit is designed and the corresponding results for different irradiance condition under partial shading condition are obtained. For a specific case of irradiance () the obtained power, voltage and current are shown in the figure ().

In this way, it was seen that utilizing the Perturb & Observe and Particle Swarm Optimization (PSO) method expanded the proficiency of the photovoltaic framework in order to obtain Maximum Power point depending upon the given environmental conditions.

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