

**Design and Development of Hybrid Maximum Power Point Tracking Algorithm for  
Photovoltaic Cell**

By

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13447

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering  
in Partial Fulfillment of the Requirements  
for the Degree  
Bachelor of Engineering (Hons)  
(Electrical & Electronic Engineering)

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# **CERTIFICATION OF APPROVAL**

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2013

## **CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ahmed Fawad Ansari

Your Full Name

## **ABSTRACT**

Photovoltaic system (PV systems) uses solar panels to convert sunlight into electricity. Maximum Power Point Technique (MPPT) is mostly used to measure the efficiency PV system. The main objective of MPPT is to process data (Voltage and current) accumulated from the PV array and propose the proper resistance to get maximum power under any environmental conditions. In this paper we have designed and developed new algorithm for finding the Maximum Power Point of PV cell by hybridizing the usual techniques for finding the maximum power point that are “Perturb and Observe” and “Incremental conductance” to overcome their advantages and disadvantage which they have over each other. Moreover designed algorithm is developed using matlab and will be validate using real time data from the PV cell and the output will be compared with current algorithms.

## **ACKNOWLEDGEMENTS**

Foremost, I would like to express my sincere gratitude to my Supervisor: Dr. Nursyarizal Bin Mohd. Nor and Co- supervisor Dr. Balbir Singh Mahinder Singh, who have the attitude and the substance of a genius They continually and convincingly conveyed a spirit of adventure in regard to Final year Project, and an excitement in regard to teaching. Without their guidance and persistent help this dissertation would not have been possible.

Besides my advisor, I would like to thank Mr.Pervez Hameed Shaikh for his encouragement, insightful comments, and hard questions Moreover I would like to extend my gratitude for continuously helping me in coding in matlab.

I would like to thank my family who supported and encouraged me throughout my life. Last but not the least; I would like to thank all friends in UTP. In Particular I am grateful to my very good friend in UTP Miss Villasini Velautham for encouraging me and supporting during my stay in UTP.

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# CHAPTER 1

## INTRODUCTION

### 1. Background study

Renewable Energy is the energy extracted from natural resources such as sunlight, tidal energy, thermal, and heat. These sources are limitless so can be used without hurting the eco system unlike conventional fossil fuels. Moreover Clean Development Mechanisms (CDMs) has pushed the idea of green environment which leads to increasing usage of renewable energy sources [1].

Due to rise in cost of conventional energy, solar energy has been considered a good alternative. Since these sources are rich and available all around earth. Photovoltaic cells are connected in series usually called as PV arrays which generate electrical power depending on atmospheric conditions (i.e. temperature).

Photovoltaic system (PV systems) uses solar panels to convert sunlight into electricity. Maximum Power Point Technique (MPPT) is mostly used to measure the efficiency PV system. The main objective of MPPT is to process data (Voltage and current) accumulated from the PV array and propose the proper resistance to get maximum power under any environmental conditions.

Techniques used mostly for tracking the Maximum Power Point (MPP) of PV cell are “perturb and observe” and “Incremental Conductance”. They use voltage and current of the PV array and predict the position of MPP. Atmospheric conditions play an important role in the tracking; due to its rapid change it becomes difficult for tracker to predict MPP properly. The Figure.1 given below show the IV characteristics of PV cell at different irradiances.

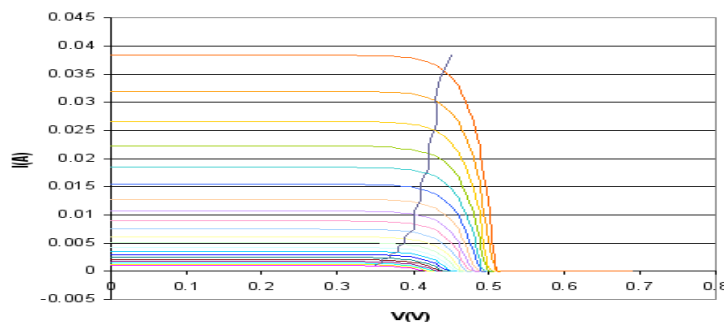


Figure 1: IV characteristics of PV cell

## **1.2 Problem statement:**

- Typical Maximum Power Point techniques (“Perturb and Observe” and “Incremental conductance”) have advantages and disadvantages over one and other.
- In PO major disadvantage is at MPP output power starts oscillating.
- For IC biggest disadvantage is its complexity

## **1.3 Objectives and Scope of study:**

### **1.3.1 Objectives:**

- To design individual algorithms for PO and IC.
- To hybridize both individual algorithms.
- To test the performance of designed algorithms on given data.

### **1.3.2 Scope of study:**

This project proposes idea of hybrid maximum power point tracking algorithm of solar cell using typical techniques “Perturb and observe” and “Incremental Conductance” to overcome difficulties faced in performing data processing.

This project is:

1. To design new hybrid Maximum Power Point Tracking algorithm
2. To reduce the computational time

## **1.4 Relevancy of topic:**

The algorithm designed will increase efficiency and accuracy of the Maximum Power Point tracking, because two algorithms are hybridized in one meaning it will decide the technique after analyzing the data provided (data depends on atmospheric conditions) for the best results. Results obtained can be compared with the results from available algorithms

## **1.5 Feasibility of project within timeframe:**

The project has been divided in two phases (FYP1 &FYP2). During FYP1 literature review and individual algorithms will be done while in FYP2 its hybridization and report will be done, and shown in proposed methodology and Gantt chart, the project can easily be completed in the given time frame.

## CHAPTER 2

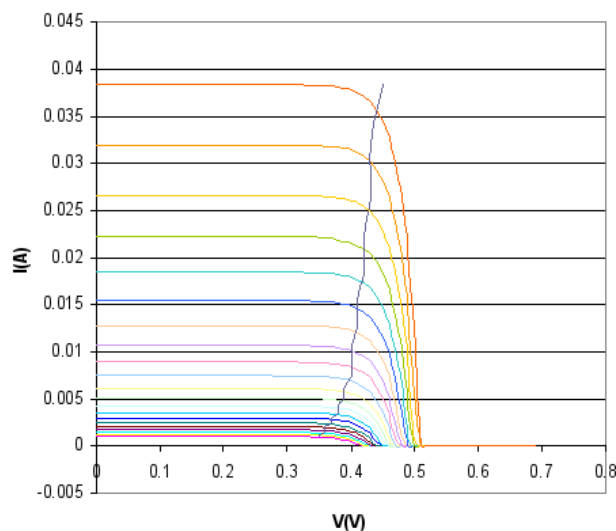
### LITERATURE REVIEW

#### 2.1 Photovoltaic Cell

The word Photovoltaic is a combination of two words “Photo” means “light” and “Volt” means an electrical potential. Sometimes photovoltaic cells are called PV cells are also referred to as solar cells [1].

Figure 2 and 3, Shows the nonlinear I-V characteristics of photovoltaic cells. This non-linear electrical behavior of the PV cell characterizes with a fill factor (FF) parameter which is ratio of the greatest power of PV cell to the product of  $V_{oc}$  and  $I_{sc}$ . Since, maximum power of shells depends on operating environment [2].

When power delivered from PV cells is raised until the derivative  $dI/dV$  of I-V characteristic curve becomes equal and opposite to the I/V ratio (where  $dP/dV=0$ ). This is called maximum power point (MPP), present at the knee of the curve. If the power extracted from the PV cell will be less than the maximum available, thus the cell will not be used proficiently as it could be [3].



**Figure 2: I-V curve at various Irradiance level along with their knee point [2].**

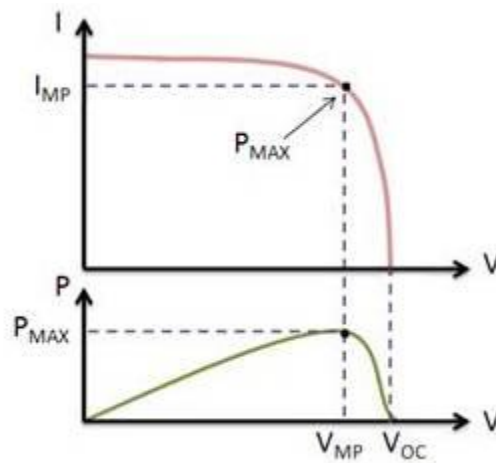


Figure 3: I-V and P-V curve of PV cell [2].

## 2.2 Maximum Power Point Tracking (MPPT)

The function of electronic MPPT is its capability to allow the modules to harvest the power. This device can vary the electrical operating point on PV cell and its subsequent load. Besides, in mechanical tracking method, the unit moves physically towards the sun. MPPT and Mechanical tracking system can be used in combination. However two systems have their own unique significance [2-5].

MPPT exploit several types of control or logic circuits to search for this operating point. MPPT uses logic and control circuits to find the operating points which permit the converter circuits to pull out the maximum power available from a PV cell.

To implement MPPT in the field, following factors need to be considered:

- MPPT should be capable of resisting with different weather conditions.
- MPPT must also be capable of monitoring different voltage and current readings from several sources
- Because of rapidly varying current and voltage values MPPT should be capable enough to read from the source and control the operating accordingly. Which leads to improvement of rate at which MPP reaches faster, moreover it makes solar energy system more efficient

## **2.3 Hill Climbing/Perturbation and Observation**

It is also well known as perturbation algorithm. The concept of this algorithm is to vary the operating current or voltage of PV cells until it reaches its MPP.

Power converter's duty ratio is perturbed when using Hill climbing, while only voltage of PV array is perturbed in PO. In Hill climbing, while perturbing the duty ratio power converter, also perturbs the current and voltage simultaneously of the PV array. Both methods have their own unique significance but following same basic idea [6].

Perturb and Observe is the commonly preferred technique because of its easily available applications. Its ability can be improved by using appropriate analytical and adaptive Hill climbing method.

### **2.3.1 Hill Climbing/ PO Algorithm**

The increment or decrement of voltage to a cell is increases or decreases the power when in operation at left of PV graph (as in Figure 1); At starting point voltage is raised till output power starts falling, then to achieve the maximum output power, voltage to the cell is decreased, this cycle is repeated till MPP is achieved as explained in flowchart given in Figure.4 After achieving MPP the output power starts oscillating around it [7].

The Table 1 shows the summary of algorithm, Show that it works when instantaneous PV voltage or current is used as long as sampling occurs. This cycle keeps on repeating periodically till MPP is attained. The output power then starts oscillating around MPP. Perturbation step size should be decreased to control the oscillations of output power, Moreover decreasing perturbation step size leads to slowing down of tracking action. This problem can be solved by having a constant perturbation size which starts decreasing as reaching the MPP [8].

Table 1. Summary of Hill Climbing/ PO Algorithm [6]

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

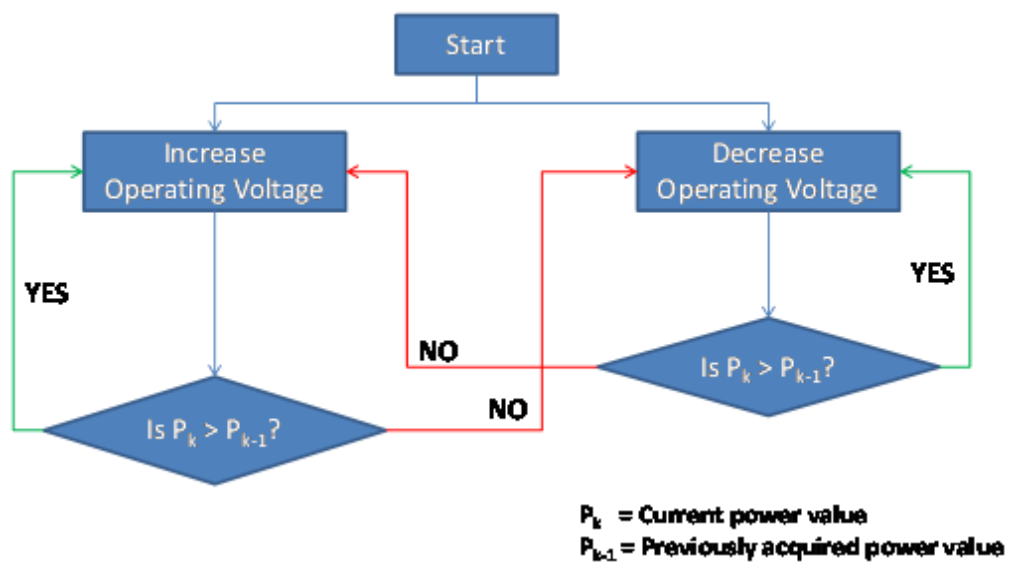


Figure 4: Algorithm for PO. [2]

Next perturbation magnitude can be modified using Fuzzy logic control, MPP tracking has been divided in two stages in some suggested algorithms, in first stage faster tracking should be carried out which will help in calculate initial operating point near to MPP and then finer tracking to reach MPP [6].

### 2.3.1.1 Drawbacks

The drawbacks of PO are described as below:

- Oscillations of power around MPP under steady state conditions in perturb and Observe method is one of the leading drawbacks.

- This algorithm tracks wrongly under rapidly varying irradiation conditions.
- Slow response time, due to which computations take longer time.

## 2.4 Incremental conductance (INC) method

Voltage sensor and Current sensor are used to calculate the output voltage and current of PV array in Incremental Conductance technique (IC). Power voltage slope is zero at MPP. P-V curve have been bifurcated in two sides left and right, at left side MPP is positive and at the right side its negative as shown in figure 1 [10]. Mathematically it is written as:

$$\begin{cases} dP/dV = 0, & \text{at MPP} \\ dP/dV > 0, & \text{left of MPP} \\ dP/dV < 0, & \text{right of MPP.} \end{cases} \dots\dots\dots (1)$$

The above equation:1 can be rewritten as,

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V \frac{dI}{dV} \approx I + V \frac{\Delta I}{\Delta V} \dots\dots\dots (2)$$

Therefore,

$$\begin{cases} \Delta I/\Delta V = -I/V, & \text{at MPP} \\ \Delta I/\Delta V > -I/V, & \text{left of MPP} \\ \Delta I/\Delta V < -I/V, & \text{right of MPP.} \end{cases} \dots\dots\dots (3)$$

### 2.4.1 Incremental conductance (INC) Algorithm

Flowchart given in Figure.5 shows that by comparing Instantaneous Conductance to the increased Conductance MPP can be tracked, the voltage at which PV array functions is known as reference voltage ( $V_{ref}$ ), as MPP is reached  $V_{ref}$  becomes equal to  $V_{MPP}$ . After attaining MPP only changes in current  $\Delta I$  is noted which are due to changes atmospheric conditions or MPP while PV array is constant at this point. New MPP can be tracked by varying  $V_{ref}$  [6].



Speed of tracking MPP is defined by increment in size. Using larger increments can speed up tracking but system becomes unstable and starts oscillating at the MPP, that's where delay is.

Some methods suggest for dividing tracking in two stages, which means in first stage getting the operating point of PV array closer to MPP, then in second stage IC is used to track MPP. By controlling power converter, initial operating point can be placed to equivalent load (resistance) relative to the ratio of open circuit voltage to short circuit current of PV array. This two-stage method also works multiple local maxima [12-13].

A linear function which bifurcate the I–V plane is exploited, during first stage operating point is brought in fraction having potential MPPs changing due to atmospheric conditions and then in second stage by the use IC MPP is obtained [14].

To obtain good results from IC technique, error signal can be generated using instantaneous conductance and the incremental conductance [10] - [11]. This is represented in equation (4).

$$e = \frac{I}{V} + \frac{dI}{dV} \dots \dots \dots (4)$$

In equation (4) it is proved that error becomes zero at MPP. Error can be made zero by using proportional integral (PI) control. Values of instantaneous PV array voltage and current are measured by using two other sensors.

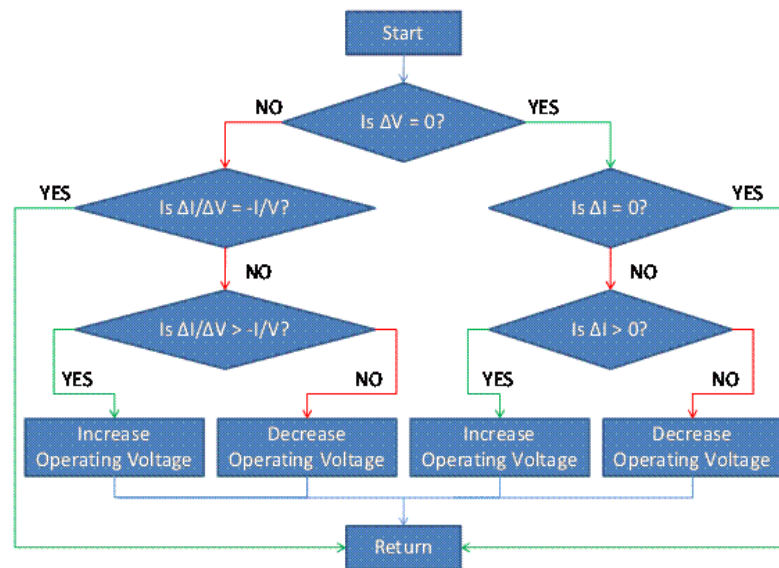


Figure 5: Flow Chart for Incremental Conductance Algorithm [2]

IC technique has advantage over P&O method because MPP can be achieved easily without even oscillating around it value. IC also shows higher accuracy in tracking under quickly changing atmospheric conditions.  $dP/dV$  is calculated by using the incremental conductance  $dI/dV$  of PV arrays [6].

#### *2.4.1.1 Drawbacks*

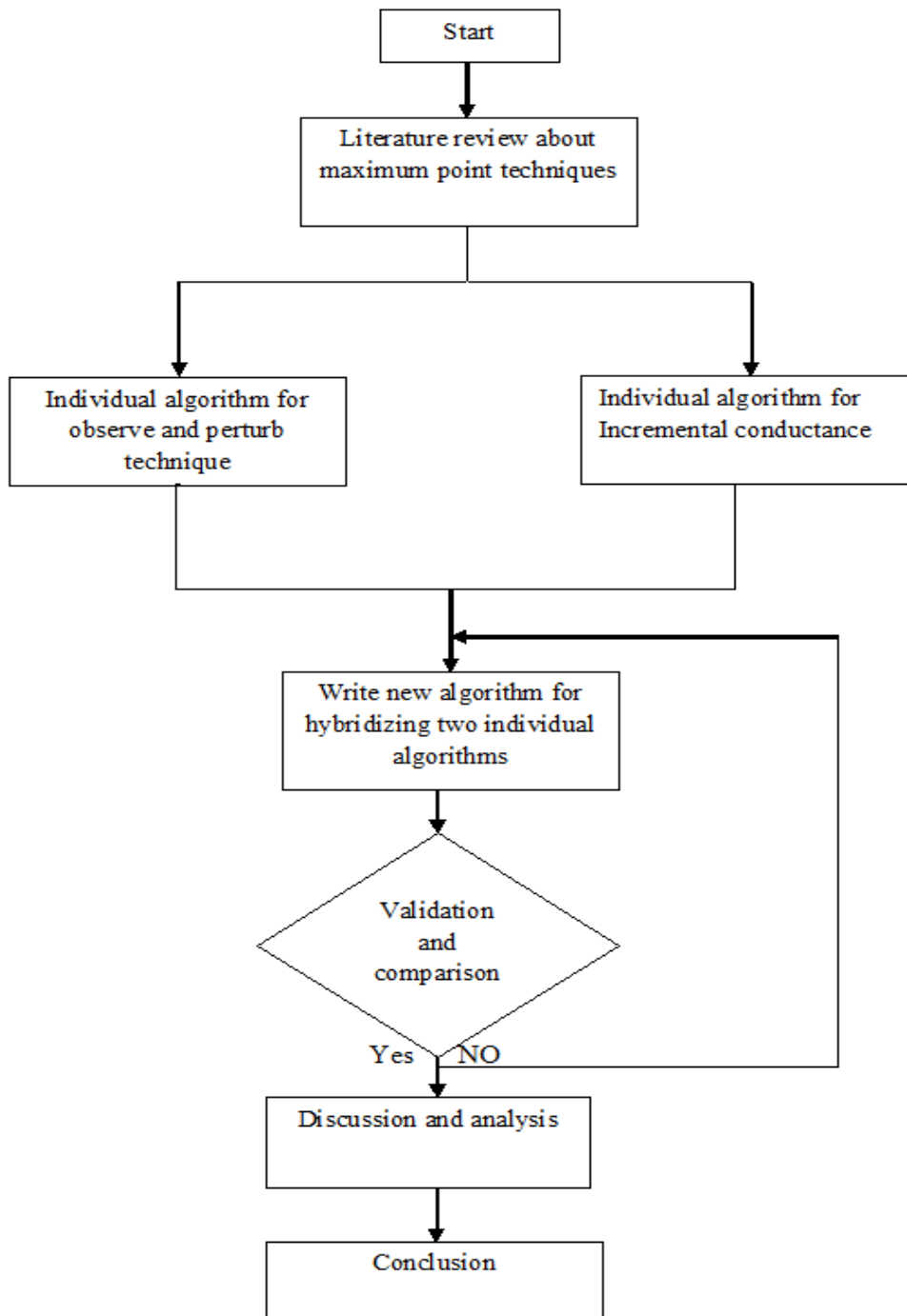
The drawbacks of PO are described as below:

- System becomes unstable when step size is increased, and starts oscillating at MPP.
- As sampling frequency slows down, system takes a lot of time for computation
- Increased system complexity.

## CHAPTER 3

### RESEARCH METHODOLOGY

#### 3.1 Research Methodology Flow Chart



For doing this project its very necessary to need to know about the work done on MPPT before and ongoing work, available algorithms should be studied in order to know there drawbacks, it will be helpful in designing the individual algorithms, once literature review and data is collected, we will proceed to individual designing of algorithms for PO and IC, after receiving positive results then both algorithms will be hybridized, the new hybrid algorithm will then be validated by comparing results with individual one, if results are positive then only we can proceed to discussion, analysis and thesis writing, if not then have to recheck the algorithm.

### 3.3 Proposed System

PO and IC algorithms for maximum point tracking will be hybridized and a new algorithm will be designed, which will perform tracking based on given data. Hybrid algorithm will have two loops one for Voltage and another for current. At first when data is injected for processing it will check the value of voltage ( $\Delta V$ ), it will check for two conditions for that either  $\Delta V = 0$  or  $\Delta V \neq 0$ . That's where it will be divided in two loops, if in the first loop  $\Delta V \neq 0$  it will check for another condition mentioned in equation 5.

$$dI/dV = -I/V \dots \dots \dots (5)$$

Which means if incremental Conductance is equal to ratio of short circuit current and voltage it means it has reached MPP and repeats the loop, if this condition is not satisfied it will proceed for another condition as in equation(6)

$$\Delta I/\Delta V > -I/V \dots \dots \dots (6)$$

If condition in equation six is satisfied it will increase voltage and if not it will decrease voltage until it satisfies the condition in equation (7), which is checking its power until it reaches maximum. Once its satisfied MPP is obtained and loop starts repeating itself.

$$P_k > P_{k-1} \dots \dots \dots (7)$$

For the second loop if  $\Delta V = 0$  it checks for condition in equation (8),

$$\Delta I = 0 \dots \dots \dots (8)$$

If the condition in equation (8) is satisfied, then the loop will repeat itself. If not then it will proceed to another condition given in equation (9).

$$\Delta I > 0 \dots \dots \dots (9)$$

If condition given in equation (9) is satisfied it will proceed to increasing of voltage if not then decreasing of voltage until it satisfies the condition in equation(7), when condition in equation(7) is achieved that's when MPP is reached.

### 3.4 Project Activities

#### 3.4.1.Literature review and Data collection:

This project needs deep knowledge about Photovoltaic systems and MPPT techniques and the latest work being done by other scholars, also about the algorithms and data available. Data collection will be one of major task also which will be use for checking and validation of the designed algorithm.

#### 3.4.2 Algorithm Design:

After reading and understanding the parameters and equations of PV system and MPPT, Individual algorithms for PO and IC techniques will be developed, after that have to design and develop new algorithm hybridizing the two individual algorithms

#### 3.4.3 Validation and Comparison of results:

The designed algorithm's performance will be tested with different data (extracted under different weather conditions), and then results will be compared.

### 3.5 key milestone:

The key milestones are described in the table below:

Table 2: key Milestones

<b>TASK</b>	<b>TIME PERIOD</b>
Research Phase and Data Collection	March 2013
Design and simulation phase	July 2013
Optimization and Validation of design	Aug 2013
Presentation phase and Thesis writing	September 2013

### 3.6 Gantt chart

Project Title: Designing and Development of Hybrid Maximum Power Point Tracking algorithm for Photovoltaic Cell									
Project Tasks	Project								
	2013								
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
<b>Project Title Selection</b>									
<b>Research phase and Data collection</b>									
Literature review and collecting of data									
<b>Design and simulation phase</b>									
Proposing design, simulating and analyzing									
<b>Optimization and Validation of design</b>									
Optimization of design if it's necessary									
<b>Presentation phase</b>									
Submission of Progress Report									
Pre-EDX									
Submission of Draft Report									
Submission of Dissertation									
Submission of Technical Paper									
Oral Presentation									
Submission of Project Dissertation									

### 3.7 Tools:

Tools required are listed in table.2

Table 3:Tools

Matlab Software	For Coding
C Programming language software	Coding
Microsoft word	Thesis writing
Microsoft Excel	Comparing results and making graphs

# CHAPTER 4

## Results and Discussion

### 4.1 Hybrid Algorithm Flowchart

The new hybrid algorithm for MPPT is designed by combining the two techniques “Perturb and Observe” and “Incremental Conductance” the flow chart of new design is given below:

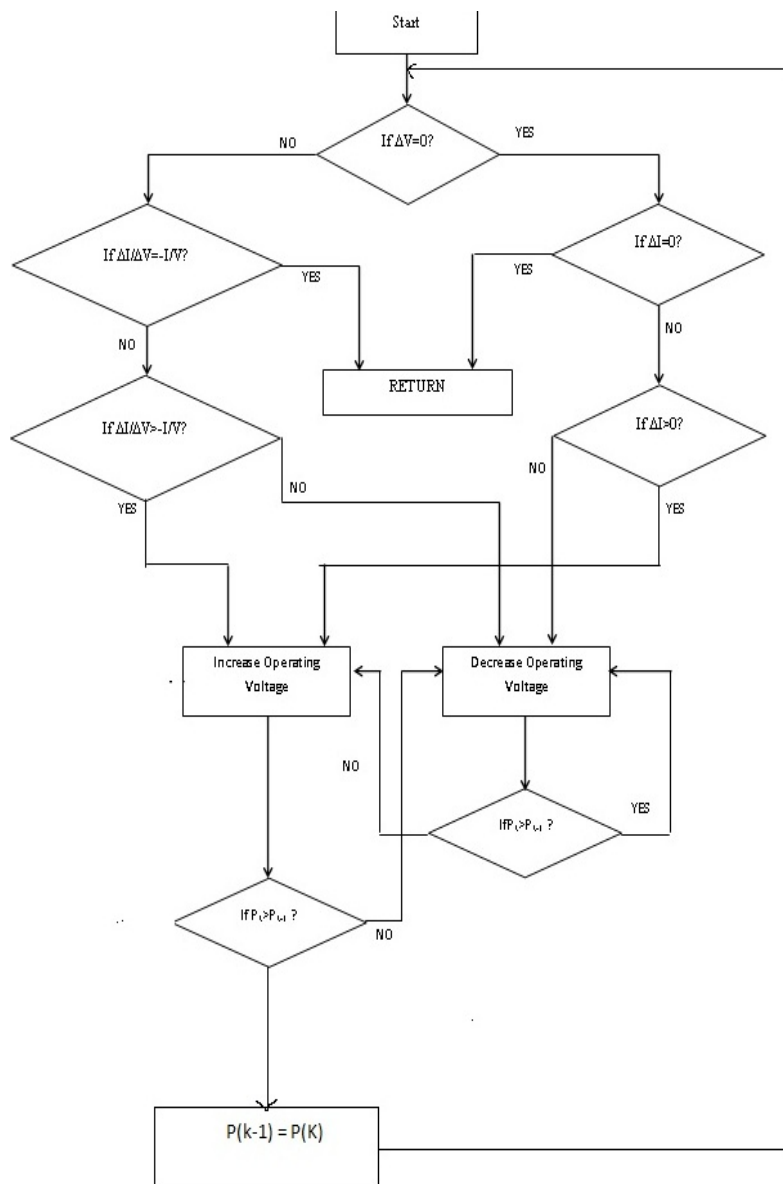


Figure 6: Hybrid algorithm of MPPT

## 4.2 Coding of Hybrid Algorithm:

Coding has been divided in few programs, for less complexity and is also helpful in modifying and debugging, they are explained below:

### Main Program

```
close all
clear all
clc
Vi=input('Enter atleast 2 values of Voltage (V) : ')
Ii=input('Enter atleast 2 values of Current (I) : ')
pows(1)=Vi(1)*Ii(1);
for i=2:length(Vi)
[pow, V, I] = maxpowpoint(Vi,Ii,i)
Vi(i)=V(i);
pows(i) = pow(i);
maxpow = max(pows)
plot(maxpow, '*')
xlabel('Current in amps');
ylabel('Power in watts');
end
```

### Voltage Increase Function

```
function [pow V] = increase (V,pow,I,i)
V(i)=pow(i-1)/I(i);
pow(i)=V(i)*I(i);
```

### Voltage Decrease Function

```
function [pow V] = decrease (V,pow,I,i)
V(i)=pow(i-1)/I(i);
pow(i)=V(i)*I(i);
```

### Maximum Power Point tracking Algorithm:

```
function [pow, V, I] = maxpowpoint(V,I,i) % Calling main function
pow(i-1)= V(i-1)*I(i-1); %Calculating Old value of power
pow(i) = V(i)*I(i); %Calculating New value of power
if V(i)-V(i-1) == 0 %if difference between Old Voltage and New Voltage is
zero
if I(i)-I(i-1) == 0 %%if difference between Old Current and New Current is
zero
return%Return Back and start
else
while (1)
if pow(i)< pow(i-1) %if Old Power is less then New Power
[pow V] = increase (V,pow,I,i); %Calling Voltage increase
Function
```



```

elseif pow(i)> pow(i-1) %if Old Power is greater then New Power
    [pow V] = decrease (V,pow,I,i); %Calling Voltage Decrease
Function
else
return%Return Back and start
end
end
end
% Another Part of Algorithm
else
if (I(i)-I(i-1))/ (V(i)-V(i-1)) == -(I(i)/V(i)) %if incremental Conductance
is equal to ratio of short circuit current and voltage means MPP is
achieved
return%Return Back and start
else
while (1)
if pow(i)< pow(i-1)%if Old Power is less then New Power
    [pow V] = increase (V,pow,I,i);%Calling Voltage increase
Function
elseif pow(i)> pow(i-1)%if Old Power is greater then New Power
    [pow V] = decrease (V,pow,I,i);%Calling Voltage Decrease
Function
else
return
end
end
end
end
end

```

Some of the results were obtained after running algorithm (real data was used for this computation which was collected in lab). Which are given as:

## 4.3 Results

### 4.3.1 Result of First Experiment:

#### Input

Enter atleast 2 values of Voltage (V) : [2.00 3.00 4.00 5.00 6.00 ]

$V_i = 2 \quad 3 \quad 4 \quad 5 \quad 6$

Enter atleast 2 values of Current (I) : [0.10 0.20 0.30 0.40 0.50 0.60]

$I_i = 0.1000 \quad 0.2000 \quad 0.3000 \quad 0.4000 \quad 0.5000 \quad 0.6000$

pow = 0.2000 0.2000

V = 2 1 4 5 6

I = 0.1000 0.2000 0.3000 0.4000 0.5000 0.6000

**MaxPowerPoint** = 0.2000

pow = 0 0.2000 0.2000

V = 2.0000 1.0000 0.6667 5.0000 6.0000

I = 0.1000 0.2000 0.3000 0.4000 0.5000 0.6000

**MaxPowerPoint** = 0.2000

pow = 0 0 0.2000 0.2000

V = 2.0000 1.0000 0.6667 0.5000 6.0000

I = 0.1000 0.2000 0.3000 0.4000 0.5000 0.6000

**MaxPowerPoint** = 0.2000

pow = 0 0 0 0.2000 0.2000

V = 2.0000 1.0000 0.6667 0.5000 0.4000

I = 0.1000 0.2000 0.3000 0.4000 0.5000 0.6000

**MaxPowerPoint** =0.2000

#### **4.3.2 Result of Second Experiment (Straight data from PV cell):**

##### **Input**

Enter atleast 2 values of Voltage (V) : 5.00 6.00 7.00

V<sub>i</sub> =

5.0000 6.0000 7.0000

Enter atleast 2 values of Current (I) : [0.50 0.60 0.65 0.675 0.70 0.80 ]

Ii =

0.5000 0.6000 0.6500 0.7000 0.8000

### Output

**MaxPowerPoint** = 4.9000 4.9000

### 4.3.3 Results of Third Experiment

Enter atleast 2 values of Voltage (V): [9.00 10.00 11.02 14.69 15.62]

Vi = 9.00 10.00 11.02 14.69 15.62

Enter atleast 2 values of Current (I): [0.80 0.90 1.00 1.100 1.20 1.30]

Ii = 0.80000 0.90000 1.0000 1.1000 1.2000 1.3000

**MaxPowerPoint**= 17.6280 17.6280

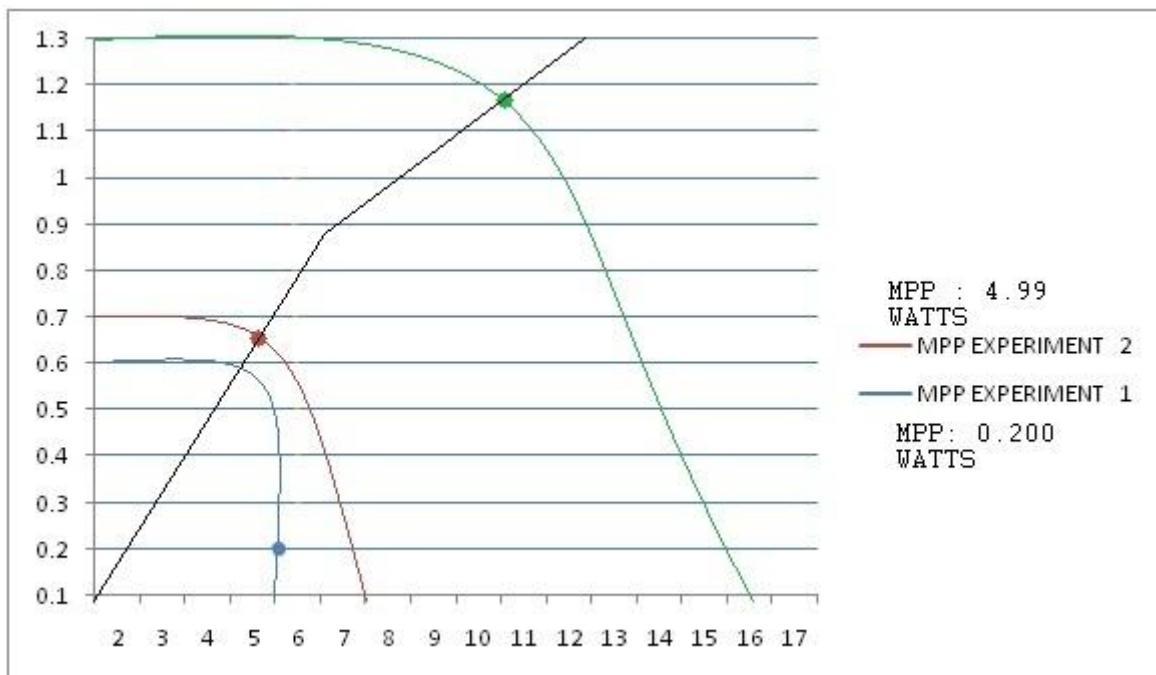


Figure 7 Results of Experiment one two and three.

### 4.3.3 Result of Fourth Experiment:

#### Input

Enter atleast 2 values of Voltage (V) : [14.69 15.62 17.35 17.53 17.71 ]

$V_i = 14.6900 \ 15.6200 \ 17.3500 \ 17.5300 \ 17.7100$

Enter atleast 2 values of Current (I): [1.00 1.100 1.20 1.30 1.40 1.50 1.90 2.00 2.10]

$I_i = 1.0000 \ 1.1000 \ 1.2000 \ 1.3000 \ 1.4000 \ 1.5000 \ 1.9000 \ 2.0000 \ 2.1000$

**MaxPowerPoint** = 32.9650 32.9650

### 4.3.5 Results of 5<sup>th</sup> Experiment (data during Rainy season)

#### Input

Enter atleast 2 values of Voltage (V) : [15.62 17.35 17.53 17.71 18.40 18.50 ]

$V_i = 15.6200 \ 17.3500 \ 17.5300 \ 17.7100 \ 18.4000 \ 18.5000$

Enter atleast 2 values of Current (I) : [ 1.40 1.50 1.90 2.00 2.10 2.60]

$I_i =$

1.4000 1.5000 1.9000 2.0000 2.1000 2.6000

#### Output

**MaxPowerPoint** = 47.8400 47.8400

### 4.3.6 Results of 6<sup>th</sup> Experiment

#### Input

Enter atleast 2 values of Voltage (V) : [17.35 17.53 17.71 18.40 18.50 19.15 19.19 19.33]

$V_i = 15.6200 \ 17.3500 \ 17.5300 \ 17.7100 \ 18.4000 \ 18.5000 \ 19.1500 \ 19.1900 \ 19.3300$

Enter atleast 2 values of Current (I) : [2.60 2.75 2.800 2.85 2.95 3.00 3.10 3.15 3.20]

Ii =

Columns 1 through 9

2.60000 2.7500 2.8000 2.8500 2.9500 3.0000 3.1000

Columns 10 through 12

3.1500 3.2000

**MaxPowerPoint** = 59.3650 59.3650

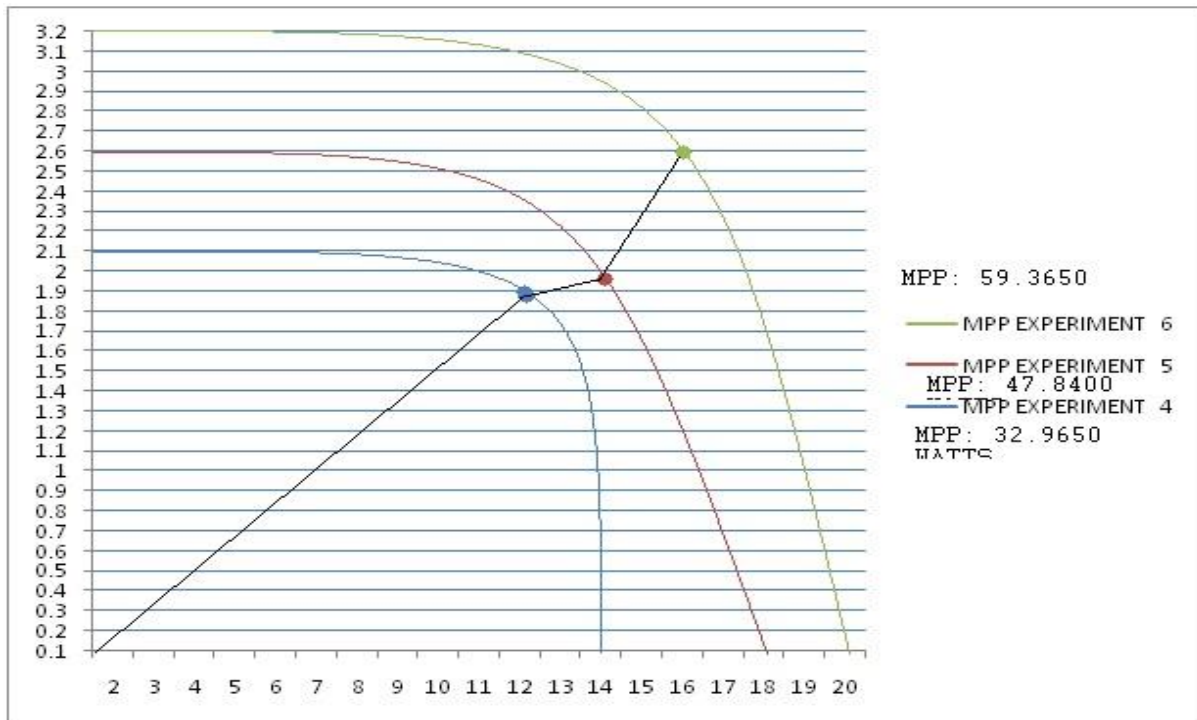


Figure 8 Results of experiment four five and six

#### 4.3.7 Result of 7<sup>th</sup> Experiment (Partial Shading data)

V =

Columns 1 through 9

17.8454 18.8460 19.3300 19.4400 19.5500 19.6200 19.7300 19.8000 19.9100

Columns 10 through 12

19.9800 20.0500 20.1200

I =

Columns 1 through 9

3.1000 3.1500 3.2000 3.2500 3.3000 3.3500 3.4000 3.4500 3.5000

Columns 10 through 12

3.5500 3.6000 3.6500

**MaxPowerPoint = 59.3650**

#### 4.3.8 Result of 8<sup>th</sup> Experiment

**Input**

V =

Columns 1 through 9

20.2300 19.6976 19.6976 19.6976 19.6976 19.6976 19.6976 19.6459 19.6459

Columns 10 through 15

19.6459 19.6459 19.6459 20.9900 21.0200 21.1000

I =

Columns 1 through 9

3.7000 3.8000 3.8000 3.8000 3.8000 3.8000 3.8000 3.8100 3.8100

Columns 10 through 12

3.8100 3.8100 3.8100

## Output

maxpow = 74.8510

??? Attempted to access I(13); index out of bounds because numel(I)=12.

Error in ==> maxpowpoint at 3

pow(i) = V(i)\*I(i);

Error in ==> mainprog at 8

[pow, V, I] = maxpowpoint(Vi, Ii, i)

## 4.3.9 Result of 9<sup>th</sup> Experiment

### Input

Current I

[2.10 2.20 2.30 2.40 2.50 2.55 2.60 2.65 2.70 2.75 2.80 2.85 2.90 2.95 3.00  
3.05 3.10 3.15 3.20 3.25 3.30 3.35 3.40 3.45 3.50 3.55 3.60 3.65 3.70 3.80  
3.80 3.80 3.80 3.80 3.80 3.81 3.81 3.81 3.81 3.81]

Voltage:

V exp=

[17.14 17.35 17.53 17.71 17.82 17.96 18.11 18.22 18.29 18.40 18.50 18.58  
18.65 18.76 18.83 18.90 18.94 19.04 19.08 19.15 19.19 19.33 19.44 19.55  
19.62 19.73 19.80 19.91 19.98 20.05 20.12 20.23 20.27 20.34 20.41 20.48  
20.56 20.63 20.70 20.74 20.81 20.88 20.92 20.99 21.02 21.10]

### Output

V =

Columns 1 through 9

17.5300 16.7332 16.0057 15.3388 14.7252 14.4365 14.1588  
13.8917 13.6344

```

Columns 10 through 18
13.3865 13.1475 12.9168 12.6941 12.4790 12.2710 12.0698
11.8752 11.6867
Columns 19 through 27
11.5041 11.3271 11.1555 10.9890 10.8274 10.6704 10.5180
10.3699 10.2258
Columns 28 through 36
10.0858 9.9495 9.6876 9.6876 9.6876 9.6876 9.6876
9.6876 9.6622
Columns 37 through 44
9.6622 9.6622 9.6622 9.6622 20.9200 20.9900 21.0200
21.1000
I =
Columns 1 through 9
2.1000 2.2000 2.3000 2.4000 2.5000 2.5500 2.6000
2.6500 2.7000
Columns 10 through 18
2.7500 2.8000 2.8500 2.9000 2.9500 3.0000 3.0500
3.1000 3.1500
Columns 19 through 27
3.2000 3.2500 3.3000 3.3500 3.4000 3.4500 3.5000
3.5500 3.6000
Columns 28 through 36
3.6500 3.7000 3.8000 3.8000 3.8000 3.8000 3.8000
3.8000 3.8100
Columns 37 through 40
3.8100 3.8100 3.8100 3.8100

```

maxpow =  
36.8130

??? Attempted to access I(41); index out of bounds because numel(I)=40.  
Error in ==> maxpowpoint at 3  
pow(i) = V(i)\*I(i);

Error in ==> mainprog at 8  
[pow, V, I] = maxpowpoint(Vi,Ii,i)

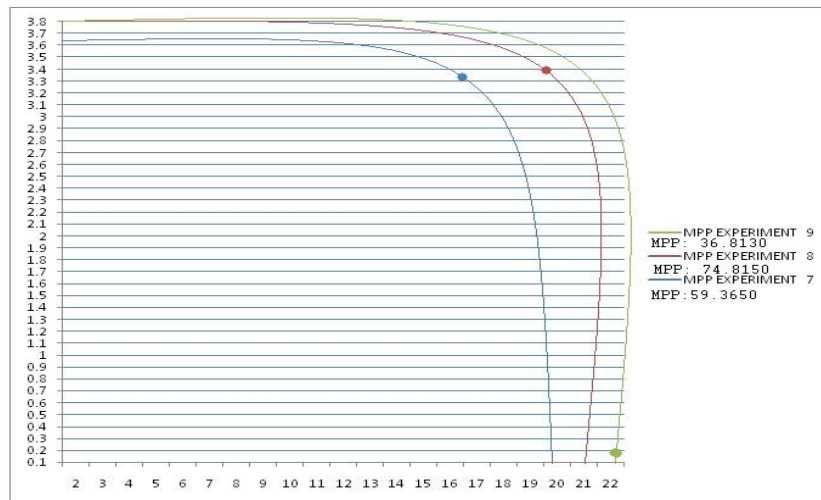


Figure 9: Results of experiment seven eight and nine



#### 4.4 Validation of Results:

Table 4:Results validation

Experiment Number	Obtained Results from Hybrid Algorithm	Calculated manually
1	MPP: 0.200 watts	MPP:36.5
2	MPP: 4.99 watts	MPP:5.6
3	MPP:17.6280	MPP:20.306
4	MPP:32.9650	MPP:37.191
5	MPP:47.84	MPP:48.1
6	MPP:59.3650	MPP:61.85
7	MPP:72.389	MPP:73.1825
8	MPP:74.8510	MPP:80.391
9	MPP:36.8130	MPP:81.2

After Performing Experiments, MPP was located in 1<sup>st</sup> experiment it can be noticed that it algorithm did not work well, because there were some problems with the equations of incremental conductance after that in 2<sup>nd</sup> to 7<sup>th</sup> it showed good results with no complication or difficulty in following MPP, while in 8<sup>TH</sup> and 9<sup>th</sup> experiment it can be noticed that with that with no rapid change in data algorithm gets stuck and is unable to follow MPP after some iterations because the data might have been taken during the cloudy season or in such atmosphere where there is very less change.

Since data collection is the important part of FYP, and varying data from the PV cell is needed for verifying the results from the designed algorithm, therefore after reading the properties of PV cell, PV cell was generated in the matlab, given below is the code that has been used for generation of the output Power, Voltage and Current of the PV cell.

## SIMULATION OF PV ARRAY IN MATLAB<sup>®</sup>

```
T=28+273;
Tr1=40; % Reference temperature in degree Fahrenheit
Tr=(Tr1-32)+273; % Reference temperature in kelvin
S=[100 80 60 40 20]; % Solar radiation in mW/sq.cm
%S=70;
ki=0.00023; % in A/K
Iscr=3.75; % SC Current at ref. temp. in A
Irr=0.000021; % in A
k=1.38065*10^(-23); % Boltzmann constant
q=1.6022*10^(-19); % charge of an electron
A=2.15;
Eg0=1.166;
alpha=0.473;
beta=636;
Eg=Eg0-(alpha*T)/ (T+beta)+q; % band gap energy of semiconductor used
cell in joules
Np=4;
Ns=60;
V0=[0:1:300];
for i=1:5
Iph=(Iscr+ki*(T-Tr))*((S(i))/100);
Irs=Irr*((T/Tr)^3)+exp(q*Eg/(k*A))*((1/Tr)-(1/T));
I0=Np*Iph-Np*Irs*(exp(q/(k*T*A))*V0./Ns)-1);
P0 = V0.*I0;
figure(1)
plot(V0,I0);
axis([0 50 0 20]);
xlabel('Voltage in volt');
ylabel('Current in amp');
hold on;
figure(2)
plot(V0,P0);
axis([0 50 0 400]);
xlabel('Voltage in volt');
ylabel('Power in watt');
hold on;
figure(3)
plot(I0,P0);
axis([0 20 0 400]);
xlabel('Current in amp');
ylabel('Power in watt');
hold on;
end
end
```

After running the code, following results were obtained:

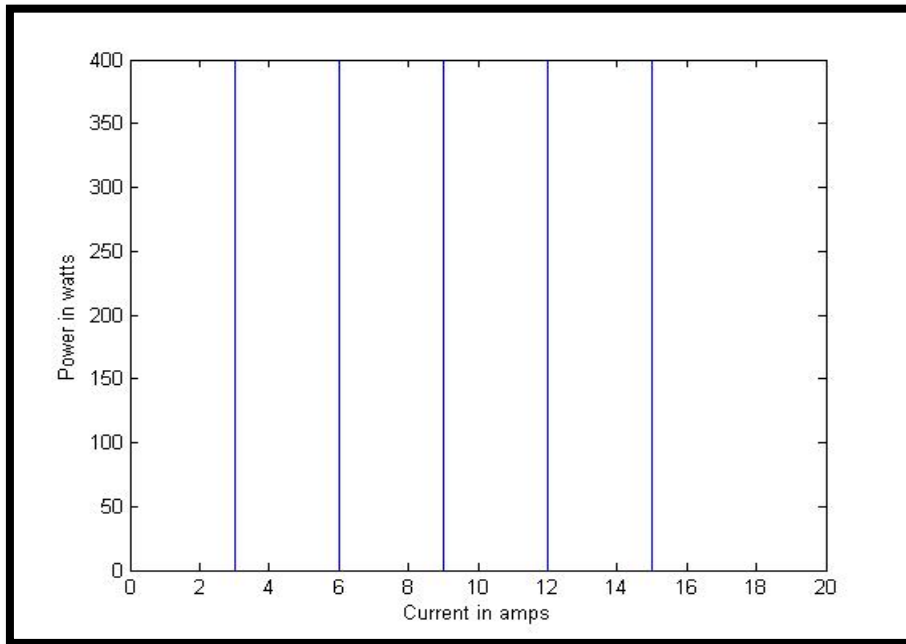


Figure 10: Output Power Vs current graph

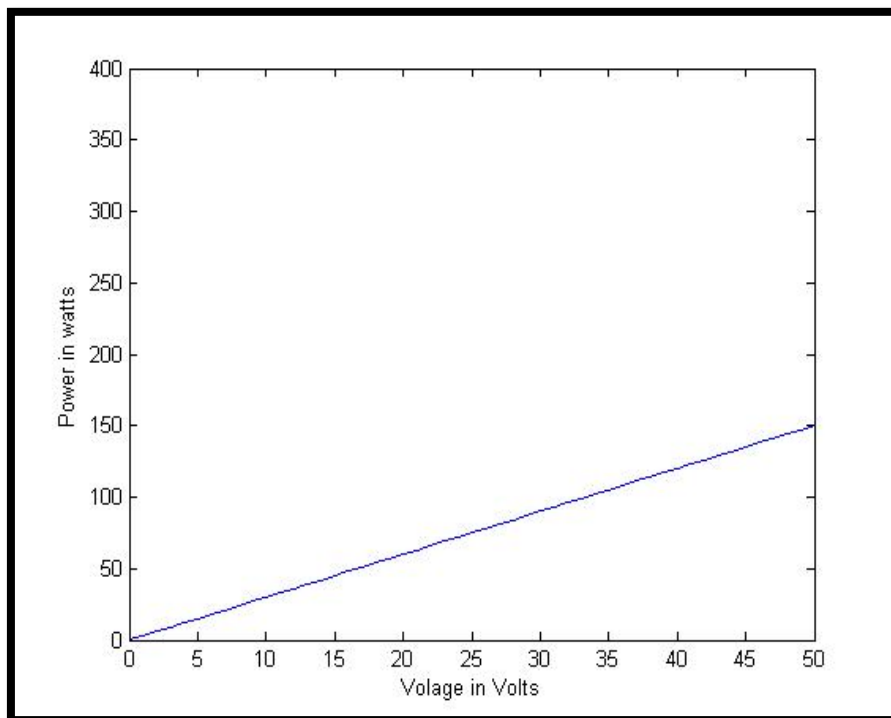
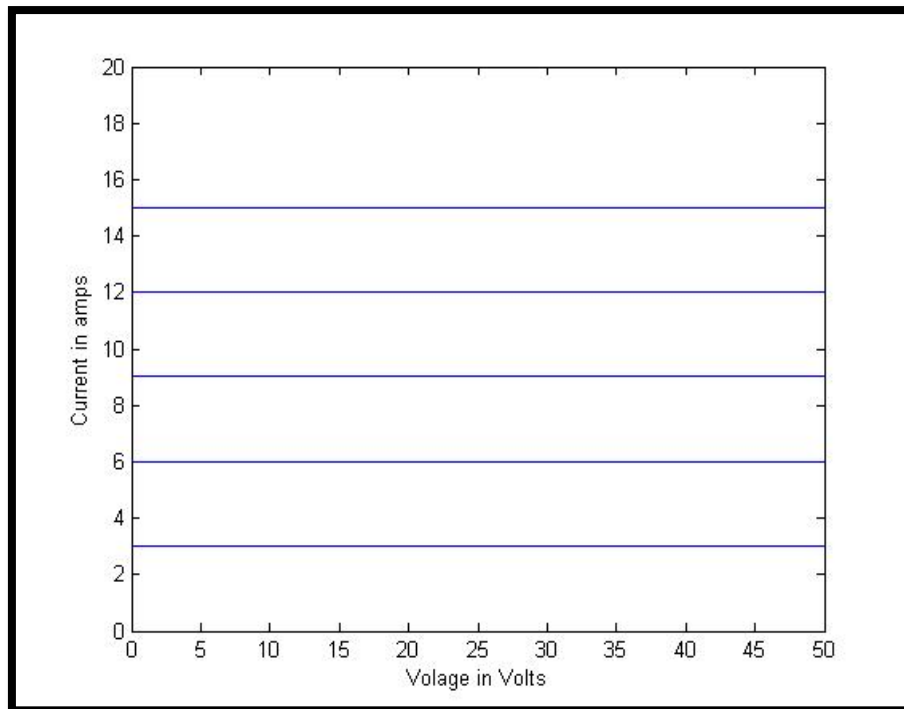


Figure 11: Output power Vs Voltage graph



**Figure 12: Output current Vs voltage**

## 4.5 Discussion

### 4.5.1 HYBRID ALGORITHM

The new designed algorithm is hybridizing Perturb and Observe technique and Incremental conductance; it is expected to give positive and fast results than the other available algorithms. The designed algorithm is very easy to implement and troubleshoot.

### 4.5.2 PHOTOVOLTAIC ARRAY:

Again the power produced by a single module is not sufficient to meet the power demands for most of the practical purposes. PV arrays can use inverters to convert the dc output into ac and use it for motors, lighting and other loads. The modules are connected in series for more voltage and then in parallel to meet the current specifications.

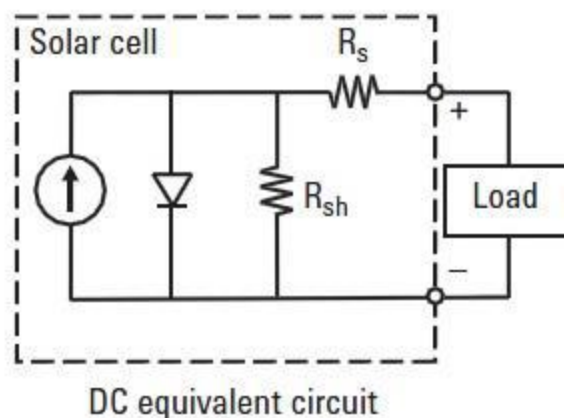


Figure 13: Simplified circuit diagram of a solar PV cell

The photovoltaic cell output voltage is basically a function of the photocurrent which is mainly determined by load current depending on the solar irradiation level during the operation.

$$V_c = (A * k * T_c / e) \ln ((I_{ph} + I_0 - I_c) / I_0) - R_s * I_c$$

The symbols used are

**V<sub>c</sub>**: cell output voltage, V.

**T<sub>c</sub>**: reference cell operating temperature (20 °C).

**Rs:** series resistance of cell (0.001  $\Omega$ ).

**I<sub>ph</sub>:** photocurrent, function of irradiation level and junction temperature (5 A).

**I<sub>0</sub>:** reverse saturation current of the diode ( $2 \times 10^{-4}$  A).

**I<sub>c</sub>:** cell output current, A.

**k:** Boltzmann constant ( $1.38 \times 10^{-23}$  J/K).

**e:** electron charge ( $1.602 \times 10^{-19}$  C).

For accurate modeling of the solar panel, two diode circuits could have been used. But our scope of study is limited to single diode model. Following are the ideal characteristics of a solar array which show the variation of current and voltage with respect to voltage. [15]

Simulated PV cell can be very useful for creating own data under desired conditions and it can be used for experimentation. Parameters in the code can be varied, the intensity of Sun as well as the outside temperature and different kind of data can be obtained. The output graphs can be used for finding the Maximum power Point of the PV cell.

#### **4.6 Optimization and Future work:**

From the new algorithm produced and available algorithms it can be concluded that the new designed algorithm is very unique work in this area of research. It can be optimized for better results in future; there are few optimization techniques that are listed below:

1. **Fuzzy Logics:** An adaptive P&O MPPT has been proposed and evaluated using fuzzy logic control to give variable step-size convergence to improve the efficiency of the PV system. [16] The same technique has been used by Trishan Eswam and Patrick L. Chapman in which perturbation size has been controlled by using fuzzy logics and algorithm is divided in two parts in first part points near MPP are attained and in second MPP itself. [6]
2. **Constant Perturbation size:** Proposed idea of having constant perturbation size which will stop the oscillation of the power around the MPP [8].

- 3. Fractional Open Circuit Voltage:** Proposed technique is designed with more emphasis is put on P&O while taking help from FOCV method during confusing and critical situations. FOCV should only be used when very much necessary as measuring open circuit voltage leads towards the temporarily power loss.[17]

## **CHAPTER 5**

### **CONCLUSION**

#### **5.1 Conclusion**

Designing Hybrid algorithm is a new research in the area of MPPT which will be helpful in simplifying and faster computational of the Maximum Power Point of the PV cell. Due to its less complexity it's very easy to implement and troubleshoot. The designed algorithm will be tested under different data collected in the different weather conditions.

Simulated PV array is going to be very useful to create our own data under different conditions and use it for the validation of the algorithm. Furthermore it can be modified more the give better results and can be used widely.



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