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Optimization of Maximum Power Point Tracking (MPPT) of
Photovoltaic System using Artificial Intelligence (AI) Algorithms

by

Raal Mandour

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Electrical and Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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AP. Dr. Irraivan Elamvazuthi

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 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.

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RAAL MANDOUR

Abstract:

Although solar energy is one of the most available renewable energy resources, its usage is strongly influenced by environmental and technological aspects. Photovoltaic (PV) offers an environmentally friendly source of electricity, which is however still relatively costly today. In order to minimize the output power cost, the maximum power point tracking (MPPT) of the PV output for all sunshine conditions is a key factor to maximize the power output of a PV system for assigned conditions of radiation and temperature. The core of the MPPT is represented by the implemented algorithm devoted to find and maintain the operation near to the Maximum Power Point (MPP). In this paper, starting from the set of equations modeling a PV module, an innovative procedure to optimize the performance and efficiency of the MPPT algorithms is presented, simulated and verified. Artificial intelligence algorithms, specifically PSO and PSO combined with Incremental conductance algorithm, are used to achieve the stated goals. Studies on the conventional and intelligent algorithms are conducted and a comparison between their efficiencies and drawbacks is presented. Flowcharts are developed and simulation tools are identified. MATLAB simulations are shown and resulting graph and efficiencies under several irradiance values are specified along with comparison with the previously achieved performance of MPPT algorithms and different set of Data.

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Contents

List of figures:

List of tables:

CHAPTER 1: Introduction

1.1.Project Background

Today's world is developing at an extremely rapid pace requiring more energy every day. This growing energy demand, tied with the decrease of conventional energy sources have urged researchers to turn to the renewable ones.

One of the alternatives is solar energy. However, solar panel efficiency of energy conversion is not high [1]. This limitation has encouraged research works aiming to extract the maximum power and optimize the power output from these panels to achieve optimum efficiency in operation.

When mentioning solar energy harvesting, there are two distinctive and only lightly related concepts called tracking. It is important to differentiate between the two. The two concepts are:

- Maximum Power Point Tracking (MPPT): an electronic function that regulates voltage / current parameters to allows the modules to produce all the power they are capable of out of a solar panel. Additional power harvested from the modules is then made available as increased battery charge current

- Mechanical Tracking: a method to physically move the solar panels to keep them facing the sun at an angle that changes with time depending on the sun position.

Maximum Power Point Tracking, abbreviated as MPPT, is an inverter based electronic architecture that controls the Photovoltaic (PV) modules in a way that ensures the solar panels will produce all the power they are capable of [2].

As discussed briefly above, electronic MPPT is a completely different approach from mechanical tracking systems that physically move the modules to make them point to the sun, but they could be used together.

Electronics and programming are used in MPPT to change the electrical operating point (usually the voltage) of the modules so that the modules are able to deliver maximum available power. Monitoring the Current (I) vs. Voltage (V)

curve also known as the IV curve that is knee shaped, by slightly moving the voltage level a significantly higher current can be achieved.

Since Maximum Power Point Tracking (MPPT) is developed to get the maximum possible power from one or more solar panels, several algorithms and techniques have been proposed for MPPT. Most commonly used techniques of MPPT are Perturb and Observation (P&O), Constant Voltage and Current, Hill-climbing method, Incremental Conductance, Parasitic Capacitance along with some DSP based methods[2]. Each of the above techniques is accompanied with problems. For instance, P&O method is simple but has a large steady state error accompanied with oscillation at the maximum power point [3]. In Incremental conductance method, the power of solar panel is a non-linear function of duty cycle. Hill climbing algorithm suffers from getting stuck at local maxima or minima. Also, the modified algorithms based of the earlier mentioned ones were able to improve some of the drawbacks but not the efficiency such as the modified P&O technique that improved the convergence problem at rapidly changing weather but couldn't increase the efficiency[1][4][5].

Similarly, Artificial intelligence algorithms are used to improve MPPT and it began to increase the efficiency of the solar panels while presenting other trade-offs and disadvantages. Algorithms such as Stimulated Annealing (SA) technique will eliminate stability problems and getting stuck in maxima or minima. On the other hand, there is a trade-off between quick settling time and steady state error. Other problems and drawbacks are present to other AI algorithms such as Fuzzy logic and PSO [1]. Nevertheless, AI algorithms can be improved further.

1.2.Problem Statement and identification

As seen from the background, efforts are deployed in order to improve the efficiency of the solar panels by developing algorithms and techniques for MPPT and improving the existing ones. However, drawbacks arise and a need to increased efficiency is still present. There is a necessity to overcome compromises between efficiency and steady state error and rapid response in

order to maximize the output power and thus reliability on solar energy as a renewable and efficient source of energy replacing conventional energy sources.

1.3. Objective

The objectives of this project are as follows:

i.   To enhance MPPT efficiency using AI algorithm
ii.   To explore the use of AI techniques in MPPT such as PSO
iii. To validate the results

1.4. Scope of Study

i.   To Study MPPT algorithms and AI algorithms
ii.   To simulate Algorithms using MATLAB
iii. To combine AI and MPPT algorithm
iv.   To simulate improved algorithms
v.   To evaluate the efficiency of the developed algorithms
vi.   To validate and verify the developed algorithms

1.5. The Relevancy of the Project

There is a global need to develop better solar cell materials and efficient control mechanisms and thus better, cleaner reliable and renewable energy source. Developing improved and efficient MPPT algorithm will enable increasing output power and thus reducing electricity generation cost. Therefore the growth in use of solar energy systems will be possible.

1.6. Feasibility of the Project within the Scope and Time frame

It is crucial that the objectives are realized by completing all the stages of the project in the allocated time.

Time management is a main element in this project to achieve the aimed results. The basic steps in order to successfully achieve the objective of this project ion time are as follows:

1. Defining Activities:

When it comes to a project, activities should be prioritized.

First of all, the high-level requirements are divided into high-level tasks or deliverables. Then, they are further broken down into activities

2. **Sequencing Activities:**

    In order to manage the project time, it is critical to identify the activity sequence. The activities identified in the previous step should be sequenced based on the execution order.

    When sequencing, the activity interdependencies should be considered.

3. **Resource Estimating for Activities:**

    The estimation of amount and the types of resources required for activities is done in this step. Depending on the number of resources allocated for an activity, its duration varies.

4. **Duration and Effort Estimation:**

    A key step in the project planning process is time and effort estimation. Higher accuracy is needed in this step.

5. **Development of the Schedule or Gantt chart:**

    In order to create a precise schedule, previous parameters are put in a visual form to monitor the activities and milestones [7].

    The Gantt chart in Appendix A will explain further about the tasks and the assigned time for them.

CHAPTER 2: Literature Review

2.1 PV Array Model

An electrical equivalent circuit of solar cell can be obtained as shown in Figure 1. The circuit contains a current source with a diode, a shunt resistance and a series resistance as shown below [6].
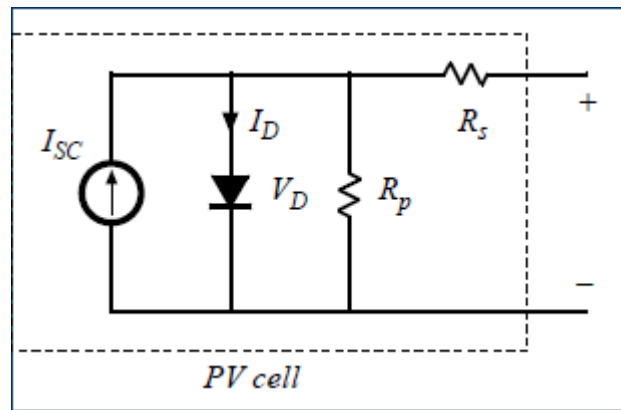
Figure 1: PV cell equivalent circuit

The current Id is mainly responsible for producing the nonlinear I-V characteristics of the PV cell. The PV cell model can be more developed by including a second diode as shown connected by the dotted lines. The second diode provides a more accurate I-V curve that takes in consideration for the difference in current [6][7].

Using KCL:

$$I_{sc} - I_D - \frac{V_D}{R_P} - I_{PV} = 0 \tag{1}$$

Diode characteristic:

$$I_D = I_O \left(e^{V_D/V_T} - 1 \right) \tag{2}$$

KVL:

$$V_{PVcell} = V_D - R_s I_{PV} \tag{3}$$

Where:

I_{sc}: Short circuit current of PV cell

I_D: Diode current

I_O: pn junction reverse saturation current

I_{PV}: PV current

V_{PV}: PV voltage

V_D: Diode voltage

R_s: Series resistance

R_p: Parallel resistance

A group of current-voltage characteristics defines the behaviour of a PV. Every curve is plotted for a constant uniform irradiance and a given temperature. Figure 2 shows V-I curve of a PV module for different sun irradiations [8].
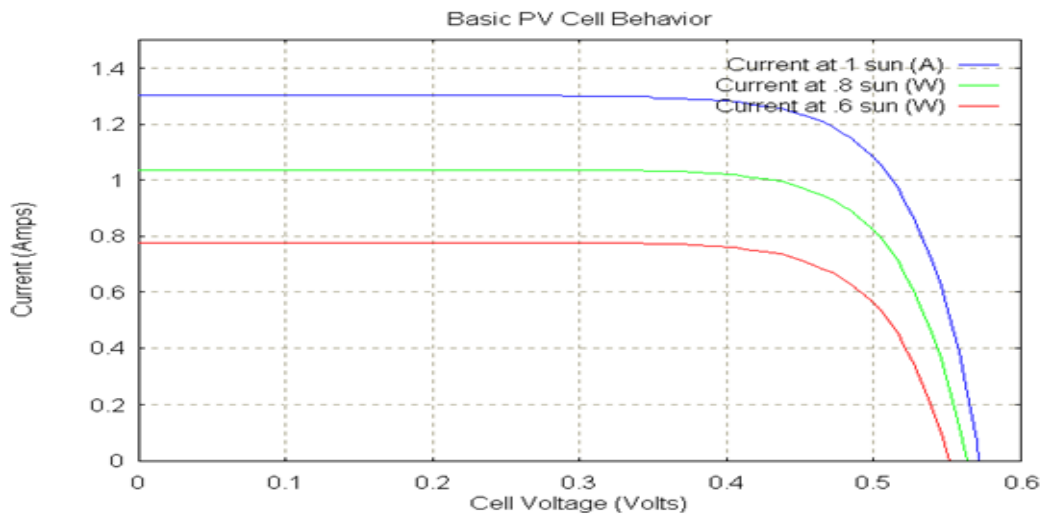
Figure 2: V-I curves of a PV module for different sun irradiations.

MPP is the point on the curve where the PV module operates with maximum efficiency and produces the maximum power output: every curve has a single MPP.
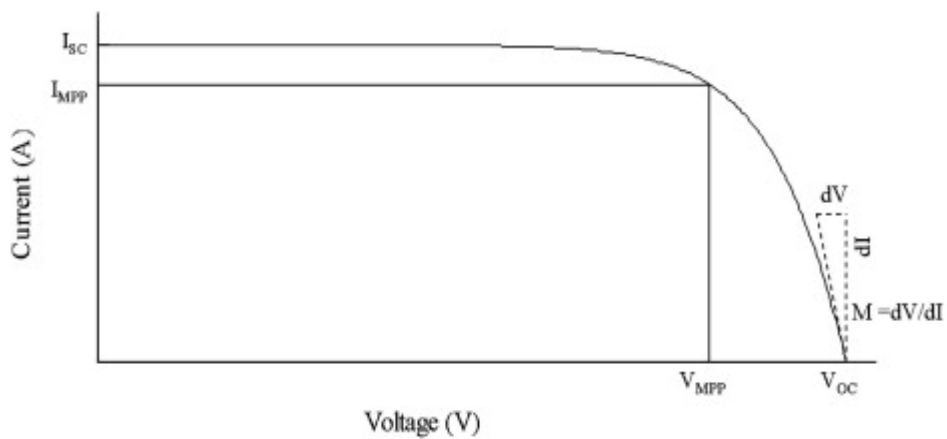
Figure 3: Typical V-I curve of a PV module

Figure 3 shows that at voltage V_{MPP} and current I_{MPP}, the PV module outputs the maximum possible power. The slope M corresponds to the Power.

6

The aim of current researches is to operate the PV module at the MPP. To achieve that, several algorithms were developed as mentioned earlier.

In research, MPPT algorithms will be categorized into two categories:

1. Conventional algorithms
2. Intelligent algorithms (AI)

2.2. Conventional MPPT algorithms:

2.2.1. Perturb and observe Algorithm (P&O)

The perturb and observe (P&O) algorithm is the most commonly used in practice because of its simplicity and ease of implementation in addition to its high reliability and tracking efficiency.

The most basic form of the P&O algorithm operates as shown in Figure 4.
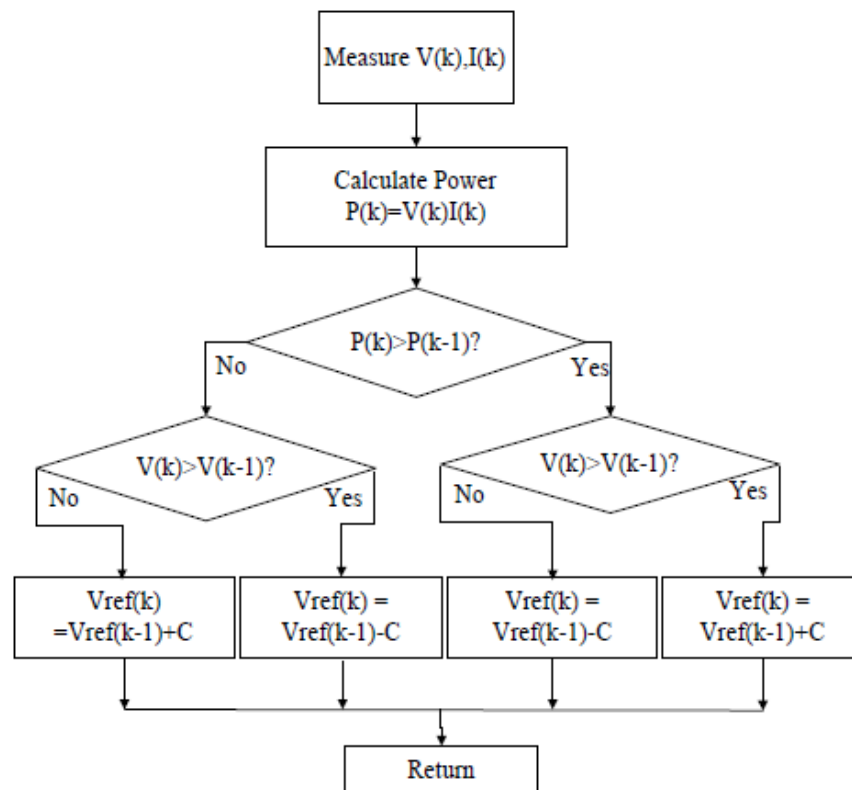
Figure 4: P&O flowchart

From figure 4, it is seen that P&O is founded on the calculation of the PV array output power and the power change by detecting both the PV current and

voltage. The controller functions regularly by comparing the present value of the power output with the previous value to determine the change on the solar array voltage or current. Power is calculated from the measured voltage and current. The magnitude of voltage and power at k^{th} instant are stored. Then the magnitude of power and voltage at $(k-1)^{th}$ instant are measured again and power is calculated from themeasured values.If the magnitude of power is growing, the perturbation will continue in the same direction in the next cycle, else the perturbation direction is reversed. When the MPP is reached, the system then oscillates around the MPP [5].

P&O has drawbacks that reduce its MPPT efficiency such as large steady state error and the oscillations at the MPP.

To try to overcome these drawbacks, a modified P&O algorithm is created. Figure 5 shows the Modified P&O:
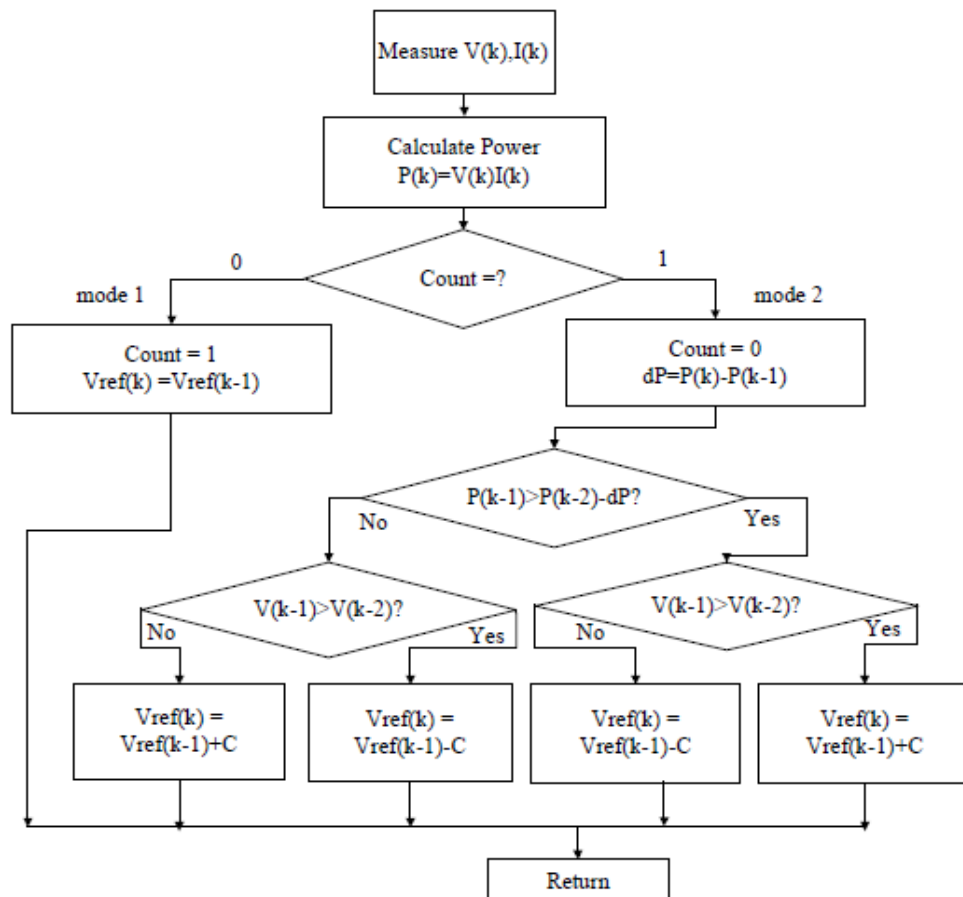
Figure 5: Modified P&O algorithm flow chart

There are two operation modes: Mode 1 for approximation process; and Mode 2 for perturb process. Mode 1 measures the power variation due to the previous

8

voltage change and atmosphere change, and retains the PV voltage constant for the next control stage. Mode 2 measures the power difference and determines the new PV voltage based on the present and the previous power variations. This algorithm overcomes the oscillation problem. However, it consumes double the time P&O algorithm uses [5].

2.2.2. The Incremental Conductance (INC) Algorithm

In this algorithm, the PV array's incremental conductance is used to determine the direction of perturbation. It compares the incremental conductance (dI/dV) with the instantaneous conductance (I/V). From figure below, at the MPP, dp/dv = 0
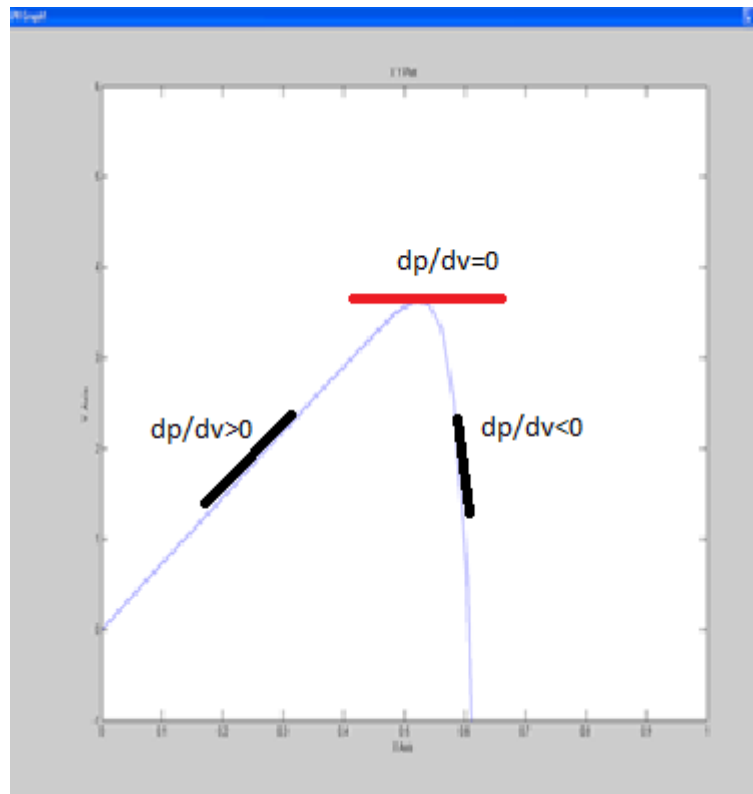
Figure 6: dp/dv at MPP

When dp/dv=0, PV array is operating at its maximum power point and no perturbation occurs. However, if it is not equal to zero a decision has to be made as to which direction the next perturbation will happen based on the value of the dp/dv [9].

Applying the chain rule for the derivative of products yields to
The following equations explained in Figure 6.

9

$$\frac{dI_{PV}}{dV_{PV}} = -\frac{I}{V} \text{ at MPP} \tag{4}$$

$$\frac{dI_{PV}}{dV_{PV}} > -\frac{I}{V} \text{ Left of MPP} \tag{5}$$

$$\frac{dI_{PV}}{dV_{PV}} < -\frac{I}{V} \text{ Right of MPP} \tag{6}$$

The major drawbacks of this algorithm since it uses a fixed step size (duty cycle) are excessive steady state oscillations resulting in a relatively low efficiency. A trade-off between dynamics and oscillations is always present.

A modification was done to this algorithm by introducing a variable step size. Figure 7 indicates the algorithm developed.
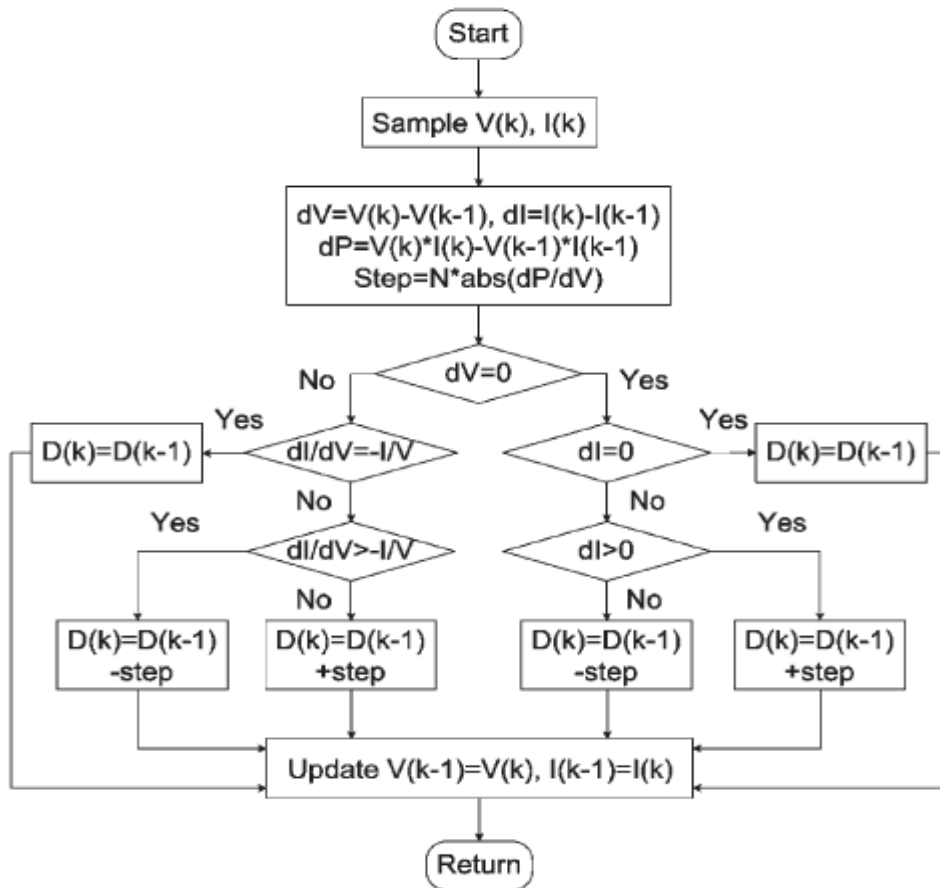
Figure 7: Variable step size INC flowchart [9]

In the flow chart, it is seen that the converter duty cycle iteration step size is automatically tuned allowing better performance.

2.3. Artificial intelligence (AI) Algorithms:

In order to improve the currently used algorithms, criteria that are to be enhanced have to be defined.

Among these criteria:

1. The Algorithm efficiency:

    In order to reduce the energy generation cost and acquire better energy generation, efficiency should be increased [10].

2. Recognition of Tracking Direction:

    In order to respond to rapidly changing environment, the MPPT controller should keep the correct sense of direction [10].

3. Reduction of steady state errors.

So as to be able to improve the above mentioned, AI algorithms are to be explored further in MPPT domain but first of all studied to be able to formulate their use.

2.3.1. Overview on Artificial intelligence:

Computational intelligence also known as artificial intelligence is the study of the design of intelligent agents [11].

An agent is something that acts in an environment. The world can be seen as a number of agents in an environment. The agent's environment may well include other agents. Each agent has some internal state that can decrypt theories about its environment and itself. It may have goals to achieve ways to achieve them, and several methods to alter its beliefs by analysis, assessment, and learning [11].

Artificial intelligence algorithms cover numerous and diverse branches of computer science and mathematics including: pattern recognition, predictive modelling, text mining and search, genetic programming, heuristics, inference, ontology and data analytics.

Artificial intelligence is commonly referred to as machine learning. It is used today for optimization, regression and classification [12].

2.3.2. Particle Swarm Optimization (PSO)

To optimize complex problems with multivariable objective function, PSO method is always used. This method is effective in the case of the presence of multiple local maximum power points.

PSO adapts the behaviour and searches for the best solution-vector in the search space. A single solution is called particle. Each particle has a fitness/cost value that is evaluated by the function to be minimized, and each particle has a velocity that directs the flying of the particles. The particles fly through the search space by following the optimum particles.

The algorithm is initialized with particles at random positions, and then it explores the search space to find better solutions. In every iteration, each particle adjusts its velocity to follow two best solutions. The first is the cognitive part, where the particle follows its own best solution found so far. This is the solution that produces the lowest cost (has the highest fitness). This value is called pBest (particle best). The other best value is the current best solution of the swarm.

The PSO algorithm is based on the cooperation of multiple agents that exchange information obtained in their respective search process [11][12].

Since MPPT algorithm algorithms get stuck in local minima and maxima, PSO can help overcome the problem as well as decrease steady state error and increase the efficiency.

The velocity and position update follows the below equations:

$$V_i^{k+1} = wV_i^k + c_1 r_1 (P_l^k - X_l^k) + c_2 r_2 (P_g^k - X_l^k) \qquad (7)$$

$$X_i^{k+1} = X_i^K + V_i^{k+1} \qquad (8)$$

Where

V_i^{k+1}: particle velocity,

X_i^{k+1} : current Position of a particle,

P_l^k: local best position

P_g^k: global best position

$r1,r2$: random number between 0 & 1

$c1,c2$: learning factors.

The above equations are used in the developed algorithm as show in the methodology section.

2.4.Related Work:

Table 1 show the efficiency of each algorithm and their drawbacks:

Table 1: MPPT algorithms efficiency

Reference	Reported MPPT Efficiency				
	Perturb and Observe	Incremental conductance	Constant Voltage	AI techniques	
[1] [10] [11]				98% 98.7% 99.2%	(PSO) (ANN-P&O) (Fuzzy Logic)
[1][2]			99%		
[2] [12]		98% 98.2%			
[8] [4]			95% 98.7%		
[3][12]	98.1%				

The recorded efficiencies are considered high. However for each case, few drawbacks arise such as getting caught in maxima, high steady state error and inability to follow the direction of change in perturbation in which hinders the overall performance of the MPPT.

Table 2: Reported MPPT Algorithms drawbacks

MPPT Algorithms Drawbacks			
Perturb-and-observe	Incremental conductance	Parasitic capacitance	AI techniques
• Large steady state error • Oscillation at the maximum power point	• Power of solar panel is a non-linear function of duty cycle	• Get stuck at local maxima or minima	• Trade-off between settling time and steady state error • Slow response

Table 2 shows some of the drawbacks that each algorithm experience. That is why more improvement should be performed.

2.5. Summary of Chapter 2:

The photovoltaic cells were explained and, its related graphs and equations. Maximum power point tracking algorithm was described along with their efficiencies and drawbacks. MPPT algorithms are divided into two groups; conventional and intelligent algorithms. Each algorithm is discussed briefly showing its flow chart and the drawbacks and efficiency and modifications already developed to improve it. Study of the AI algorithms, specifically, PSO, is shown as well as its potential use in the MPPT field. Comparison tables between various algorithms are developed paralleling the efficiency and drawback of each.

CHAPTER 3: Methodology

3.1. Research Methodology

Simulation is an increasingly significant methodological approach yielding to new prototypes and thus products. In this project simulation of MPPT algorithms and development of AI based MPPT algorithms are achieved using MATLAB. The simulation requires creation of flow charts and diagrams of the targeted algorithms.

3.2. Project Activities

Project Background
- Study of MPPT algorithm
- Study of AI algorithm

Development of algorithm
- Selection of algorithms
- Development of flow chart

Coding and implementation
- Code flow chart
- Selection of software and coding language
- Implementation

Analysis and enhancemet
- Analysis of obtained results
- Improvements
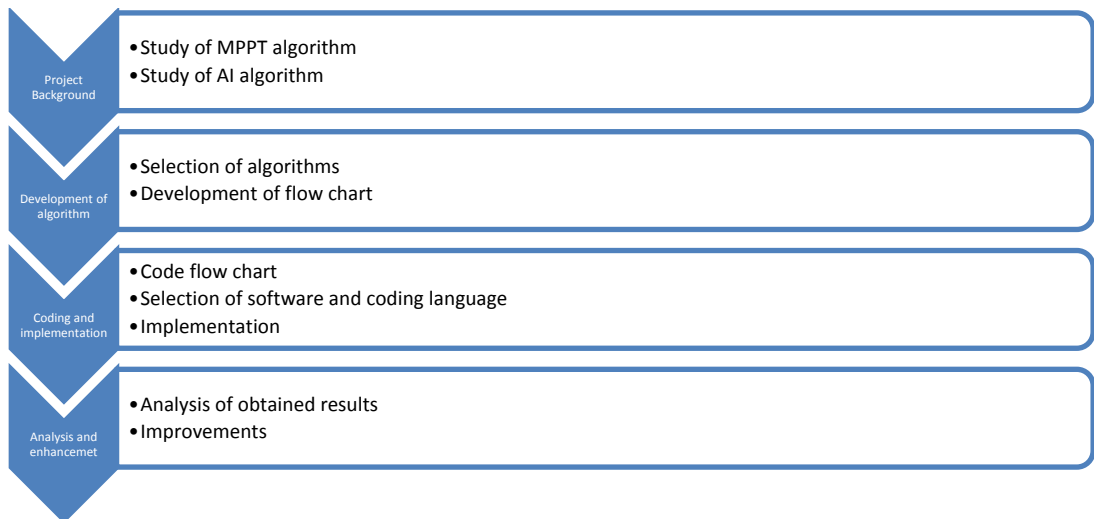
3.3. Outline and structure of the developed algorithms:

As per the literature review, the main focus of this paper is Particle swarm optimization.

Two algorithms using the later are developed: PSO and PSO-INC (Particle Swarm Optimization-incremental conductance). Figure 8 shows the general outline followed while developing the algorithms.
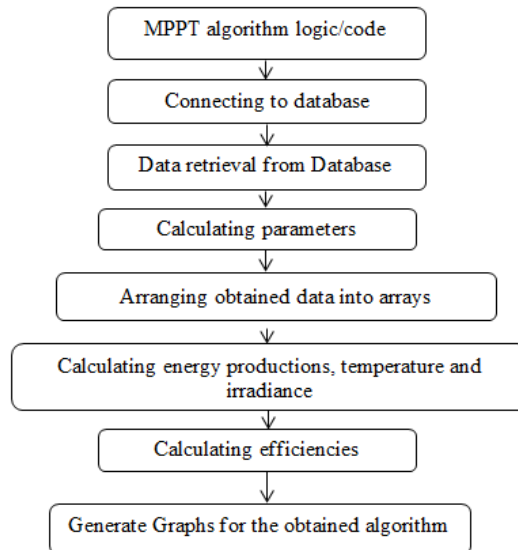
Figure 8: General Algorithm flow chart

3.3.1. Suggested Method 1 PSO Flow Chart:
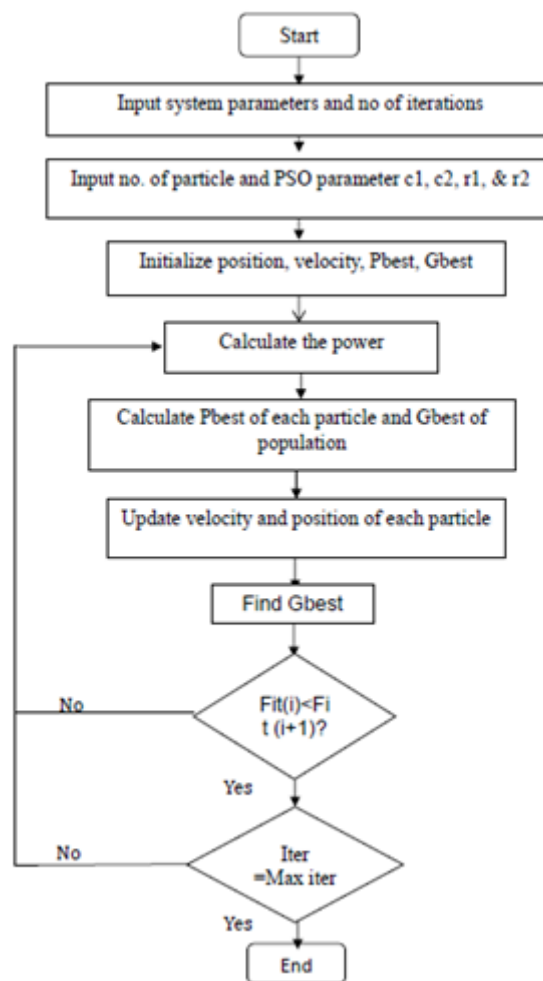
Figure 9: Suggested Method 1(PSO) flowchart

As shown in Figure 9, PSO algorithm is very simple yet it offers a great deal of flexibility to suit changing weather conditions by adjusting few parameters. Here two parameters defined as position and velocity are updated at each iteration the fitness function is the maximum power. As the iteration number increases the maximum power is updated and output the maximum power obtained until the reached iteration.

3.3.2. Structure of suggested Method 2 PSO-INC algorithm:

The PSO-INC algorithm uses the same block for the PSO section. In addition to this, a derivative block that takes the derivative of the output PV power is added to produce a pulse width modulation (PWM) signal. The later serves as a duty cycle tuner and one of the inputs to a DC-DC converter that generates the adequate input voltage to the PV module. Figure 10 shows the structure of the suggested method.
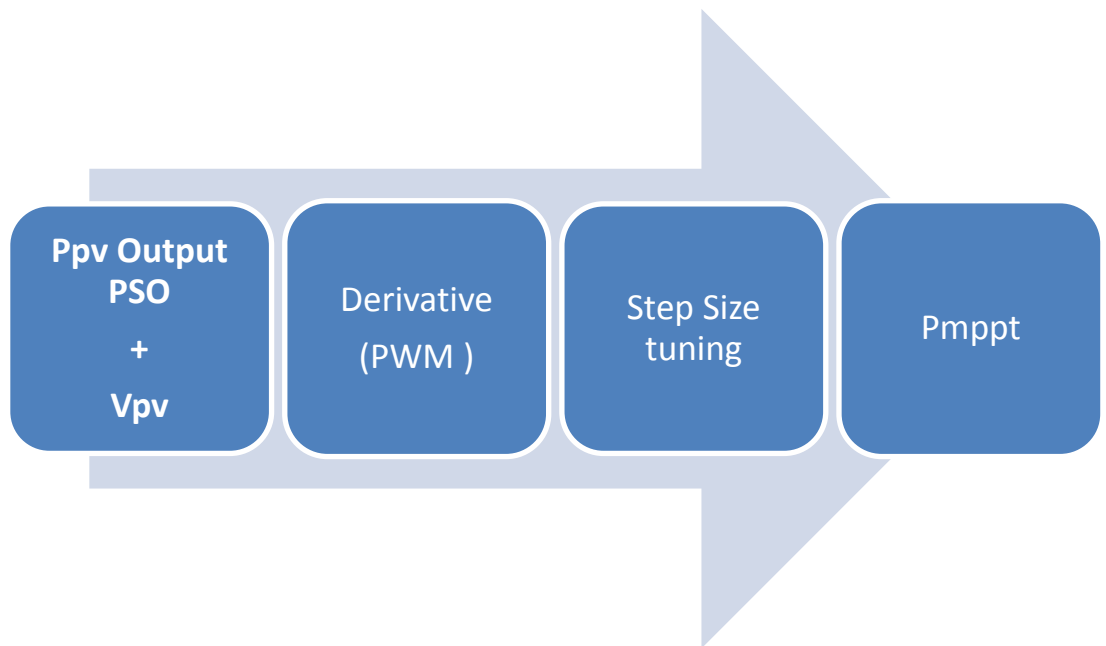
Figure 10: Suggested Method 2 (PSO-INC) structure

Where:

Ppv output PSO: The output from PSO block

Pmppt: Power output at maximum power point tracker.

3.4. Tools and materials:

3.4.1. MATLAB

MATLAB offers a set of tool that is very useful simulating MPPT algorithms. A block diagram environment known as SIMULINK for multidomain simulation and Model-Based Design is offered in MATLAB. It serves as a foundation for system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems [13].

This tool is used to simulate PV arrays and MPPT algorithms.

3.4.2. Irradiation databases

The data fed into the algorithms (irradiance) to which the PV is subject to, as mentioned above, are extracted from available meteorological databases.

In the databases, the monthly average daily values were compiled for each site and presented in tabular forms if at least 80% of the days for a particular month had complete data (i.e. six or fewer days missing).

The annual average daily values for a particular year are listed.

Table 3 shows a sample data from the Abilene, Texas database:

Table 3: Alpine Texas database sample data[16]

Year	Month	GHI	DNI	DHI	Temp.
2001	1	2.8	4.62	0.76	6.1
2001	2	3.31	3.66	1.42	9.8
2001	3	4.19	4.2	1.76	11.4
2001	4	5.87	5.23	2.38	19.9
2001	5	6.67	6.51	2.03	24
2001	6	7.54	8.23	1.75	28.2
2001	7	7.46	8.38	1.58	31.5
2001	8	6.01	5.95	1.93	28.8
2001	9	5.76	6.77	1.54	24.1
2001	10	4.81	6.95	1.05	19
2001	11	3.07	4.13	1.12	14.6
2001	12	2.8	4.56	0.92	9.4
2001	Averge	5.02	5.77	1.52	18.9
2002	1	3.22	5.2	0.91	9
2002	2	4.47	6.75	1.12	8.5
2002	3	5.03	5.87	1.6	12.3
2002	4	5.41	4.62	2.21	20.1
2002	5	6.69	5.97	2.44	22.9
2002	6	6.98	6.47	2.34	26.8
2002	7	6.48	6.17	2.12	27.2
2002	8	6.9	7.27	1.84	29.3
2002	9	5.63	6.42	1.67	25
2002	10	2.91	2.84	1.37	16.3
2002	11	3.4	5.58	0.9	11.5
2002	12	2.89	4.92	0.84	8.6
2002	Average	5	5.67	1.61	18.1
2003	1	3.39	6.12	0.74	7.3
2003	2	3.34	4.05	1.32	8.2
2003	3	5.28	6.26	1.48	14.1
2003	4	6.64	7.52	1.69	20.3

Where:

GHI: Global Horizon Irradiation

DNI: Direct Normal Irradiation

DHI: Diffuse Horizon Irradiation

Temp: Average temperature

The values used from this database are GHI values.

Another data sample is from NASA climatology Resource For Agroclimatology.

Daily Averaged Data (Evaluation Version) for Kuala Lumpur in 2012 is shown Table 4.

Table 4: Kuala Lumpur meterological data[17]

WEYR	WEDAY	SRAD	TMAX	TMIN	RAIN	WIND	TDEW	T2M	RH2M
2012	1	16.5	28.3	26.3	-99	2.2	24.1	27.2	82.7
2012	2	20.6	30.2	25.1	-99	1.4	23.6	27.7	78.0
2012	3	17.5	29.4	25.6	-99	1.8	23.9	27.5	80.3
2012	4	21.0	29.5	25.1	-99	2.8	23.4	27.2	79.1
2012	5	21.1	29.9	24.3	-99	2.1	22.6	27.3	75.3
2012	6	20.4	29.3	25.1	-99	2.2	23.3	27.3	78.4
2012	7	22.1	29.9	24.3	-99	2.7	22.5	27.1	75.8
2012	8	15.5	29.3	25.6	-99	2.0	23.2	27.2	78.6
2012	9	13.1	28.1	24.5	-99	1.9	23.0	26.4	81.3
2012	10	14.8	28.9	25.5	-99	2.0	23.7	27.3	80.6
2012	11	13.3	28.5	25.4	-99	2.1	23.8	27.1	81.8
2012	12	7.6	28.0	25.6	-99	2.4	23.8	26.9	82.9
2012	13	12.3	28.9	26.5	-99	1.9	24.1	27.5	81.5
2012	14	-99	28.3	26.4	-99	1.7	24.0	27.4	81.5
2012	15	15.9	28.6	25.9	-99	2.6	23.8	27.2	81.5
2012	16	20.6	29.6	27.1	-99	2.0	23.9	28.3	76.7
2012	17	20.8	28.5	26.1	-99	2.9	24.2	27.3	82.9
2012	18	15.3	28.2	26.1	-99	2.4	24.3	27.2	84.1
2012	19	18.6	29.2	26.3	-99	1.3	23.8	27.7	79.0
2012	20	18.1	28.2	26.5	-99	2.5	23.9	27.3	81.5
2012	21	18.5	28.4	26.2	-99	3.4	23.9	27.1	82.8
2012	22	18.6	27.9	26.2	-99	2.8	24.1	26.9	84.4
2012	23	18.4	28.6	26.2	-99	2.5	23.8	27.1	82.2
2012	24	22.6	29.3	26.0	-99	2.2	23.9	27.7	79.7
2012	25	20.9	30.6	26.2	-99	2.1	23.5	28.3	74.7
2012	26	20.7	29.7	24.6	-99	2.6	22.7	27.5	74.7
2012	27	18.5	30.4	24.5	-99	2.4	23.2	27.5	77.2
2012	28	13.4	28.4	25.5	-99	1.6	23.8	26.9	82.5
2012	29	16.7	28.7	26.0	-99	1.4	23.6	27.5	79.1
2012	30	-99	29.1	26.2	-99	1.8	24.1	27.7	80.4
2012	31	13.9	29.1	27.0	-99	1.3	24.3	27.8	81.0
2012	32	19.7	29.3	25.6	-99	2.5	23.8	27.2	81.8
2012	33	19.5	28.4	24.8	-99	2.5	23.6	26.6	83.6
2012	34	15.4	27.4	25.4	-99	2.2	23.5	26.4	83.8
2012	35	17.2	28.6	24.7	-99	2.2	23.4	26.5	82.8
2012	36	22.4	30.1	25.1	-99	2.0	23.4	27.6	77.7
2012	37	21.4	28.8	26.8	-99	2.5	24.3	27.7	81.7

Where:

```
SRAD      daily Insolation Incident On A Horizontal Surface (MJ/m^2/day)
T2M       Average Air Temperature At 2 m Above The Surface Of The Earth (degrees C)
TMIN      Minimum Air Temperature At 2 m Above The Surface Of The Earth (degrees C)
TMAX      Maximum Air Temperature At 2 m Above The Surface Of The Earth (degrees C)
RH2M      Relative Humidity At 2 m (%)
TDEW      Dew/Frost Point Temperature At 2 m (degrees C)
RAIN      Average Precipitation (mm/day)
WIND      Wind Speed At 10 m Above The Surface Of The Earth (m/s)
```

Data in SRAD is used as input to the PV module but after converting I into watt per meters square.

Appendix B shows more data samples from the above stated source in addition to others.

Another database from Saudi Arabia, used to compare the results obtained is shown in Table 5.

Table 5: Long-term daily mean values of sunshine duration and global solar radiation in KSA

#	City	Lat (Deg.)	Lon (Deg.)	Alt (m)	S (Hours)	GSR W/ m^2
1	Sakaka	29.97	40.20	574	9.0	5315
2	Tayma	27.63	38.48	820	9.2	5589
3	Hail	27.47	41.63	1010	9.4	5233
4	Sarrar	26.98	48.38	75	8.7	4548
5	Al-Ula	26.62	37.85	681	9.1	5808
6	Qatif	26.55	50.00	8	8.4	4740
7	Maaqala	26.37	47.37	450	8.9	4877
8	Zilfi	26.30	44.80	605	8.9	5589
9	Unayzah	26.07	43.98	724	9.3	5479
10	Uqtalas-Suqur	25.83	42.18	740	9.1	6110
11	Hutatsudair	25.53	45.62	665	9.0	5890
12	Al-Hofuf	25.50	49.57	160	8.7	5671
13	Shaqra	25.25	45.25	730	9.2	6055
14	Hanakiya	24.85	40.50	840	9.1	6055
15	Riyadh	24.57	46.72	564	9.2	5123
16	Madina	24.52	39.58	590	9.1	6356
17	Dawdami	24.48	44.37	0	8.8	5945
18	Derab	24.42	46.57	0	8.7	6192
19	Al-Kharj	24.17	47.40	430	9.1	5562
20	Harad	24.07	49.02	300	9.0	4685
21	Yabrin	23.32	48.95	200	9.1	5644
22	Al-Aflat	22.28	46.73	539	9.0	6000
23	Khulays	22.13	39.43	60	8.9	5973
24	Sayl Kabir	21.62	40.42	1230	8.9	6740
25	Turbah	21.40	40.45	1130	9.0	5726
26	Taif	21.23	40.35	1530	8.9	5425
27	Sulayyil	20.47	45.57	600	9.0	6575
28	Bisha	20.02	42.60	1020	9.2	7014

29	Heifa	19.87	42.53	1090	9.1	6082
30	Juarshy	19.85	41.57	2040	8.5	5425
31	Modaylif	19.53	41.05	53	8.5	6356
32	Kiyad	18.73	41.40	30	8.4	5123
33	Sirr-Lasan	18.25	42.60	2100	8.7	5041
34	Abha	18.22	42.48	2200	8.7	5836
35	Sabya	17.17	42.62	40	8.5	5014

Where:

Lon: longitude

Lat: latitude

Alt: Altitude

S: sunshine duration

GSR: global solar radiation

3.5. Algorithms Development:

The algorithms development is made on several stages, starting from the creation of the PV module acting as a platform to embed the proposed algorithms until obtaining the results.

3.5.1. PV module simulation:

As seen in section 2.1, the single diode model of solar cell is utilized.

The simulation of the PV module is done in steps starting from the model discussed above until the creation of the module. PV module models are implemented as masked subsystems in Simulink.

Figure 11 shows the solar cell:
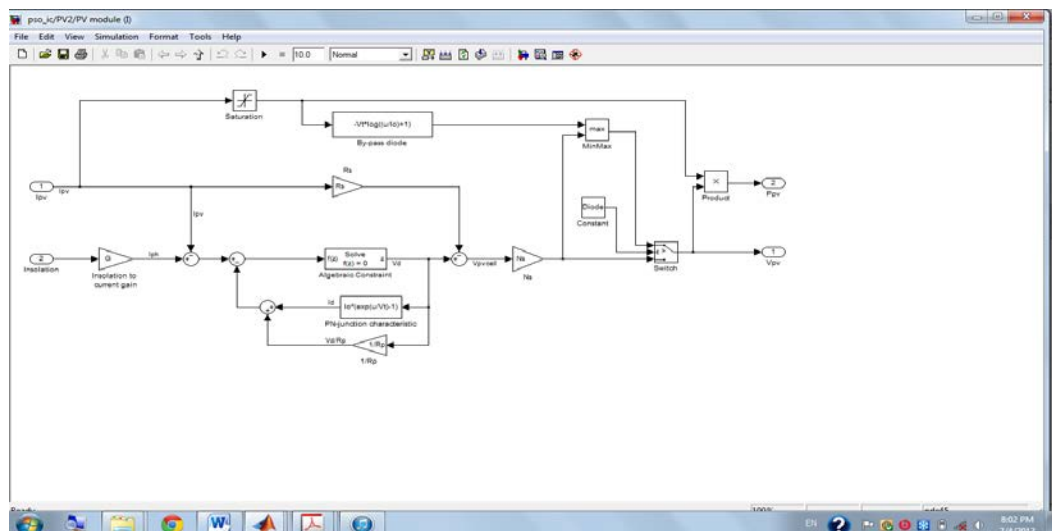
Figure 11: Solar cell submask in Simulink

21

In Figure 11, the inputs are the PV current and insolation and the outputs are the PV voltage and PV power.

The upper sub mask, shown in Figure 12, is a Current-input PV module with an algebraic constraint. The inputs are the PV voltage and the insolation. The outputs are the PV current and PV power.
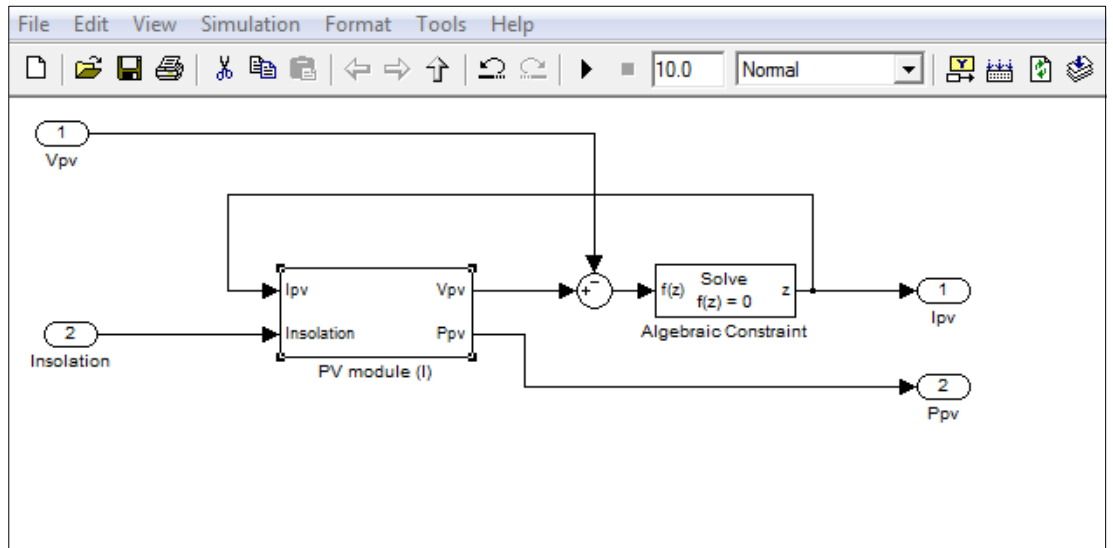
Figure 12: Current input PV module

This leads to the final PV module that is seen in the overall algorithm developed. The module is shown in Figure 13.
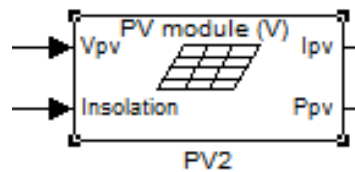
Figure 13: PV module

The solar cell parameters of the equations (1), (2) and (3) in section 2.1. should be initialized by editing the Mask as presented in Figure 14:

22
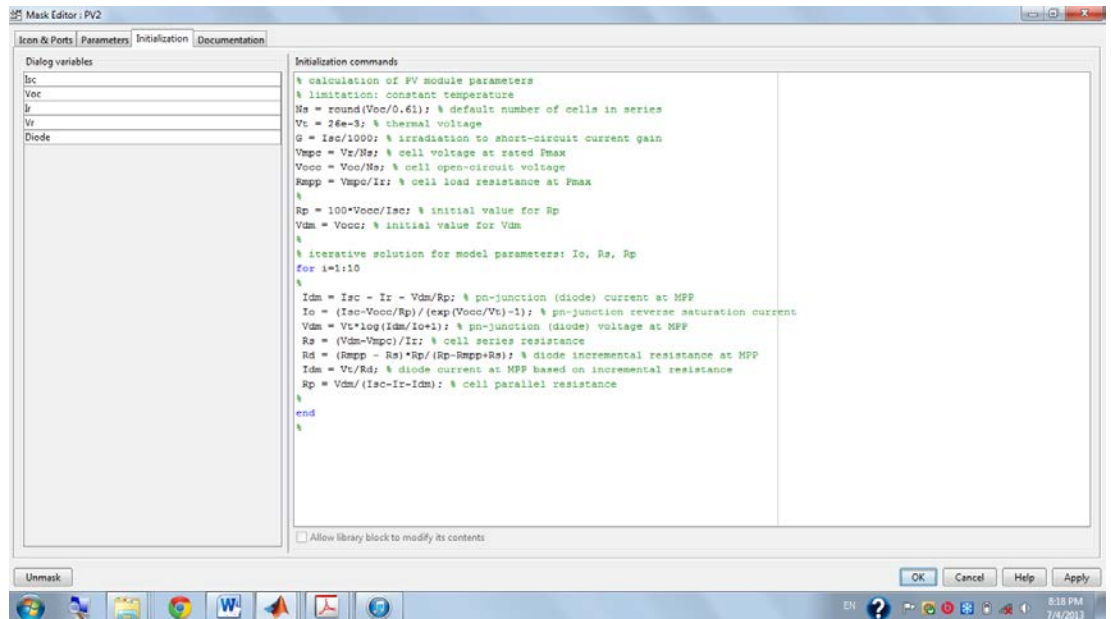
Figure 14: PV module Parameters initialization

Figure 15 shows the complete PV module with the inputs representing the voltage and irradiance are set to be a repeating sequence
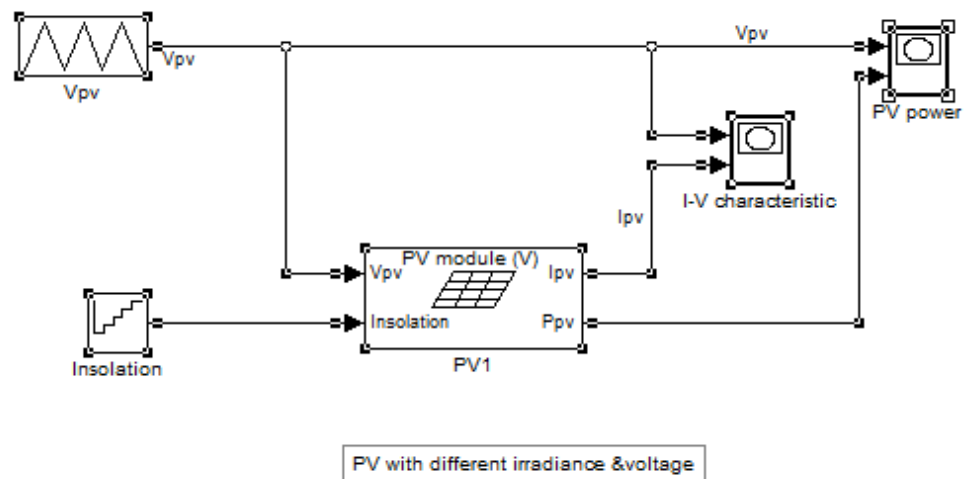
Figure 15: PV module Simulation In Simulink

The above model is further developed to include the MPPT algorithm which is created in Simulink using MATLAB function blocks. Chapter 4 clarifies more details concerning the simulation of the model and the results obtained.

3.5.2. Suggested Method 1 PSO Algorithm Development:

In order to develop the suggested algorithms in MATLAB Simulink, MATLAB Function block is used since it enables coding user's functions. The function is executed while running the simulation.

For the PSO algorithm, a MATLAB function block is created. Its inputs are Current and Irradiance and outputs are PV current and PV power.
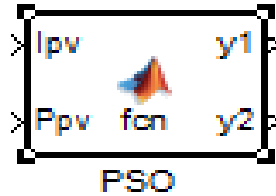
Figure 16: PSO MATLAB function block

Refer to appendix C for the complete code.

3.5.3. Suggested Method 2 PSO-INC Algorithm Development:

Following the same method, in PSO-INC algorithm, Pulse width modulation block and DC-DC converter are developed.

1. DC-DC converter Block:

To control the photovoltaic power system is necessary to use a DC-DC converter; the most adequate is the Buck converter. It reduces the input voltage. Figure17 shows the topology used [20].
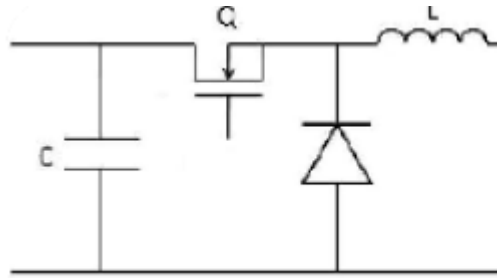
Figure 17: Buck converter topology used in DC-DC converter

The Simulink Model was created using the following differential equations that define the behaviour of the buck converter of Figure 17. Figure 18 shows the model.

$$L\frac{di_l}{dt} = V_{PV}.D - V_{BAT} \tag{9}$$

$$L\frac{dV_{PV}}{dt} = I_{PV} - i_l.D \tag{10}$$

24

Where:

i_l: Current of the battery

D: PWM parameter Control {0, 1}
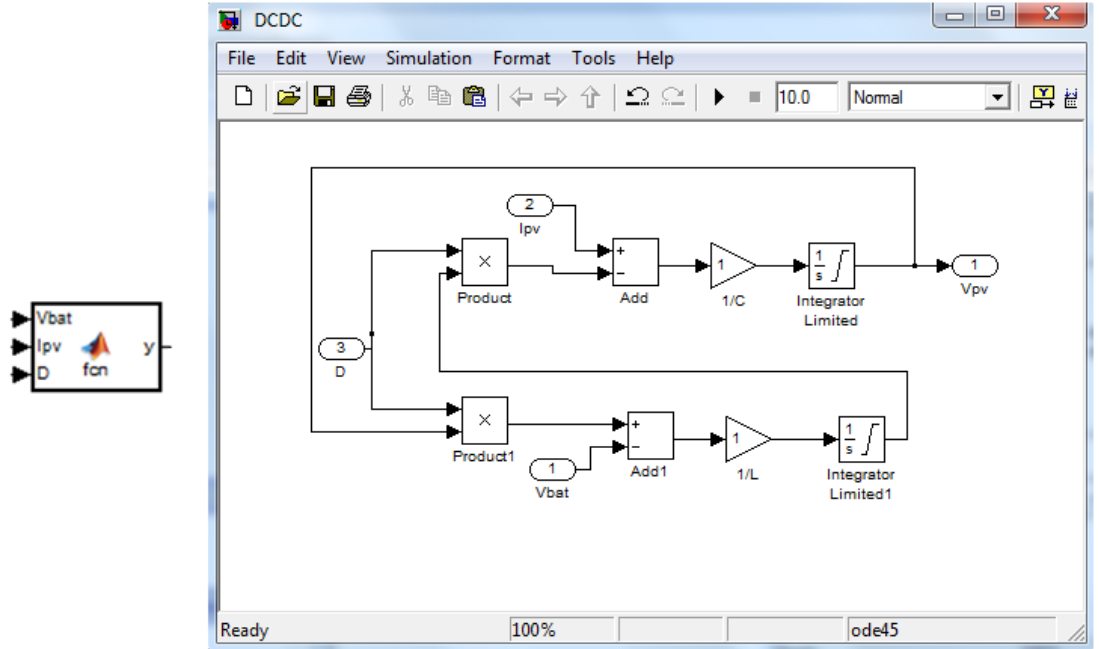
Figure 18: DC-DC Simulink Model

The capacitor needed in this converter has to be a power capacitor in order to be able to support large currents.

$$I_C = \frac{P}{N_S.V_{PV}} = \frac{1600}{32.9} = 48.6 \ A \tag{11}$$

The efficacy value is expressed as follows:

$$I_{Ceff}\sqrt{\frac{1}{T}\int I^2} = \frac{1}{3}I_C = 16.2 \ A \tag{12}$$

The value of the capacitor is 33mF.

As for the inductor, the equation to model the function of inductor is:

$$L = \frac{Vbat\Delta T}{\Delta i_l} = \frac{24\times25\times10^{-6}}{5} = 125\mu H \tag{13}$$

1. **PWM controller Block:**

The PWM controller is based on the Incremental conductance section of the algorithm where the change in the output power of PV panel result in changes in the voltage of the panel and therefore a change in the pulse width (duty cycle). Figure 19 describes the PWM model.

25
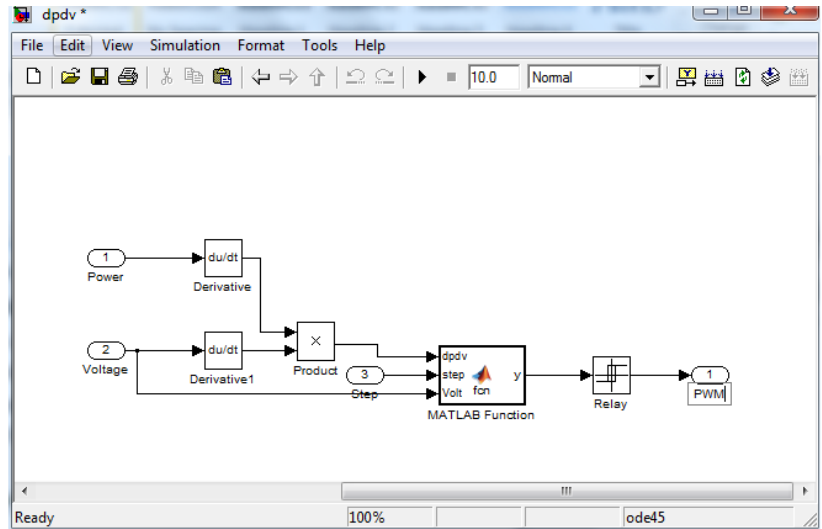
Figure 19: PWM controller Simulink Model

3.6. Gantt chart

Appendix A shows the Gantt chart for the project showing the project activities and time allocation for each task.

CHAPTER 4: Results, Discussion and Validation

4.1. PSO results:

The PSO model developed is shown in Figure 20:
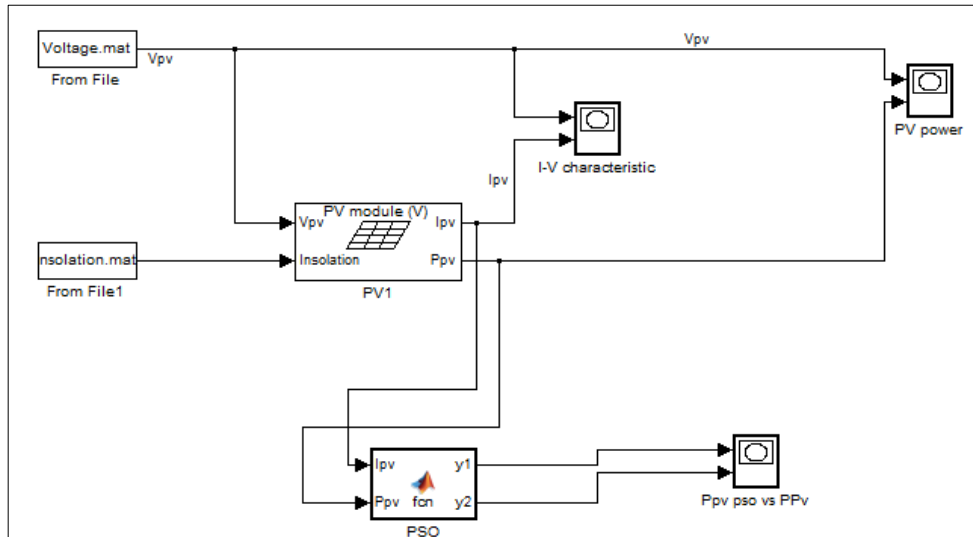
Figure 20: PSO Simulink Model

As previously discussed, the PV module is used as a platform to be able to test the algorithm. The MATLAB function block named PSO is the main section of the model.

The model is fed with two different sets of irradiance data; Kuala Lumpur and Saudi Arabia.

4.1.1. Case study 1- Kuala Lumpur Results:

The Output from the PV model is shown using scope named PV power in Figure 21.

Also the characteristic curves of Current vs, voltage at different irradiance are displayed using Scope I-V characteristic in Figure 22.

The fitness function (maximum power) vs. PV Power is displayed using Ppv pso vs PPv scope in Figure 23.

The resulting graphs are displayed in Figure 21, 22 and 23.
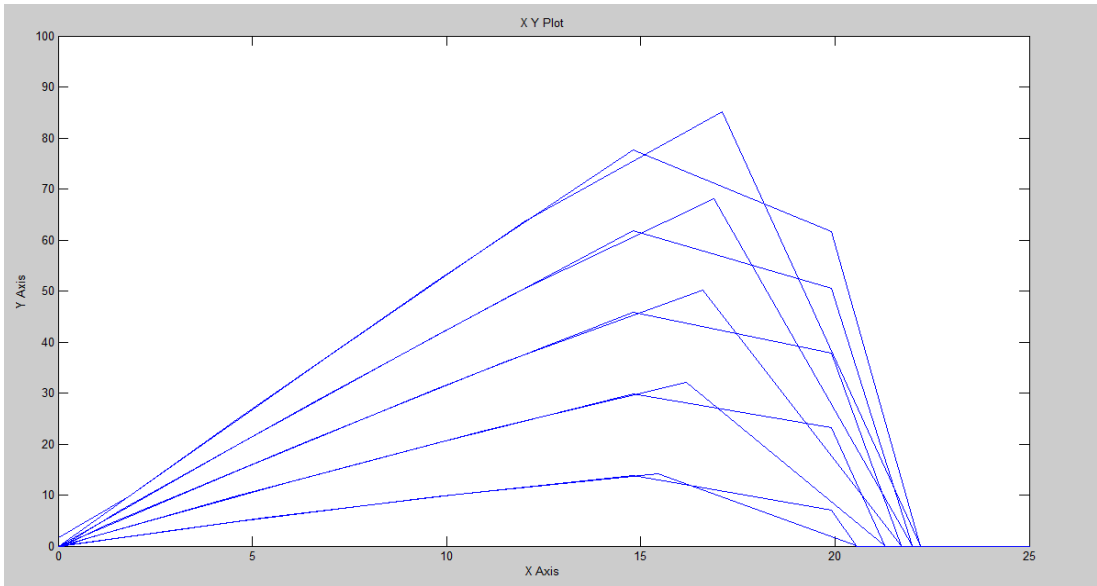
Figure 21: Power vs. Voltage at different irradiance
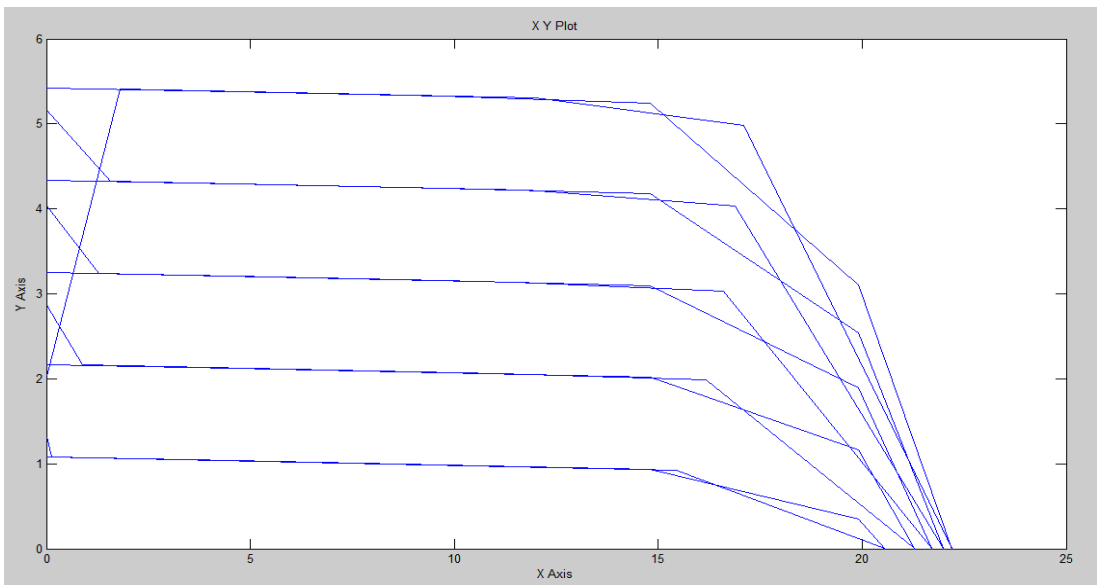
Figure 22: I-V Characteristic at different irradiance

28
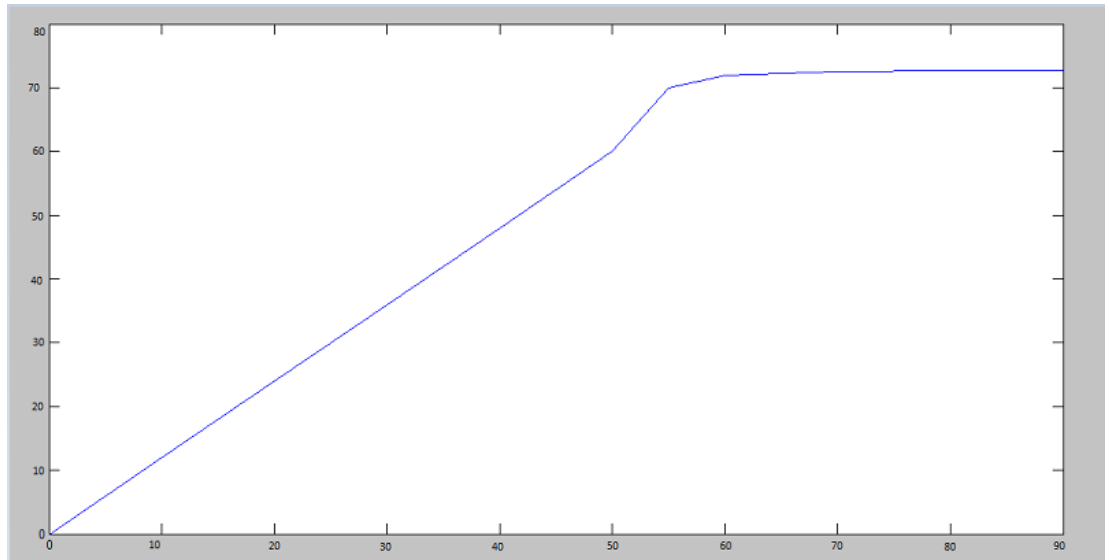
Figure 23: Fitness function (Ppso) vs. Ppv

The efficiency is calculated and tabulated. Table 6 shows the results for Kuala Lumpur.

Table 6: Efficiency of Proposed Method 1 PSO algorithm

G W/m2	Theoretical Output of PV panel [1]			Output of PV panel using PSO (Proposed Method 1)			Efficiency (%)
	Voltage V(volts)	Current I (Amps)	Power P (watts)	Voltage V(volts)	Current I (Amps)	Power P (watts)	
200	13.9	1	13.9	15.42	0.9	14.08	98.74
400	14.14	2.27	32.1	13.91	2.3	31.2	97.4
600	14.83	3.08	45.8	15.14	3.02	45.2	98.6
800	16.8	4.3	68.09	17	4	67.93	98.7
1000	14.9	5.3	79	15.2	5	78	99.5
200	13.9	1	13.9	15.43	0.89	14.09	98.79
400	14.14	2.27	32.1	13.91	2.3	32	99.6
600	14.83	3.08	45.8	15.14	3.02	45.68	98.2
800	16.8	4.3	68.09	17	4	67.9	98.65
1000	14.9	5.3	79	15.2	5.07	79.92	99.45

29

The mean efficiency for PSO algorithm is 98.7%

4.1.2. Case study 2-Saudi Arabia Results:

Similarly, the results are shown in Figure: 24, 25 and 26
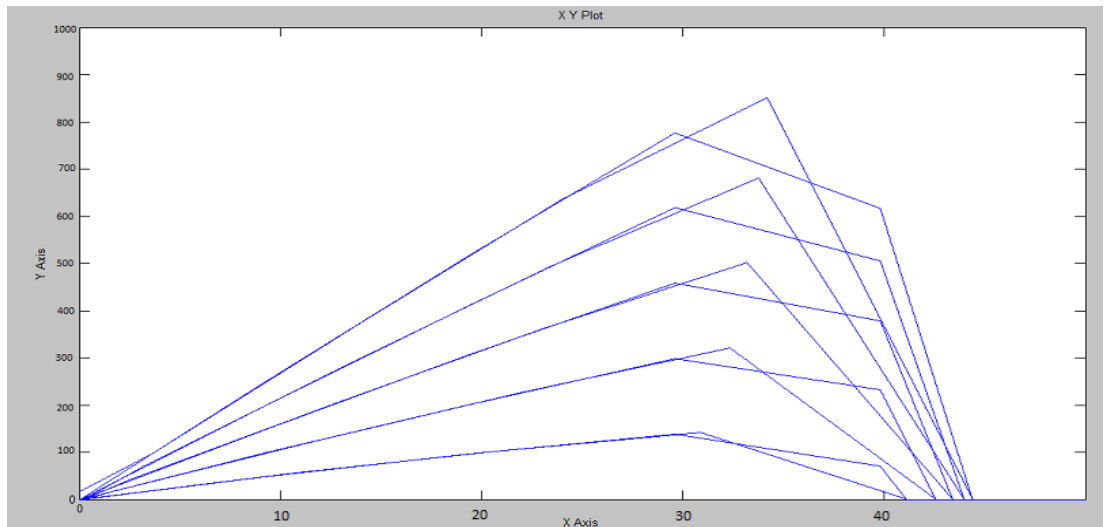
Figure 24: Power vs. Voltage at different irradiance
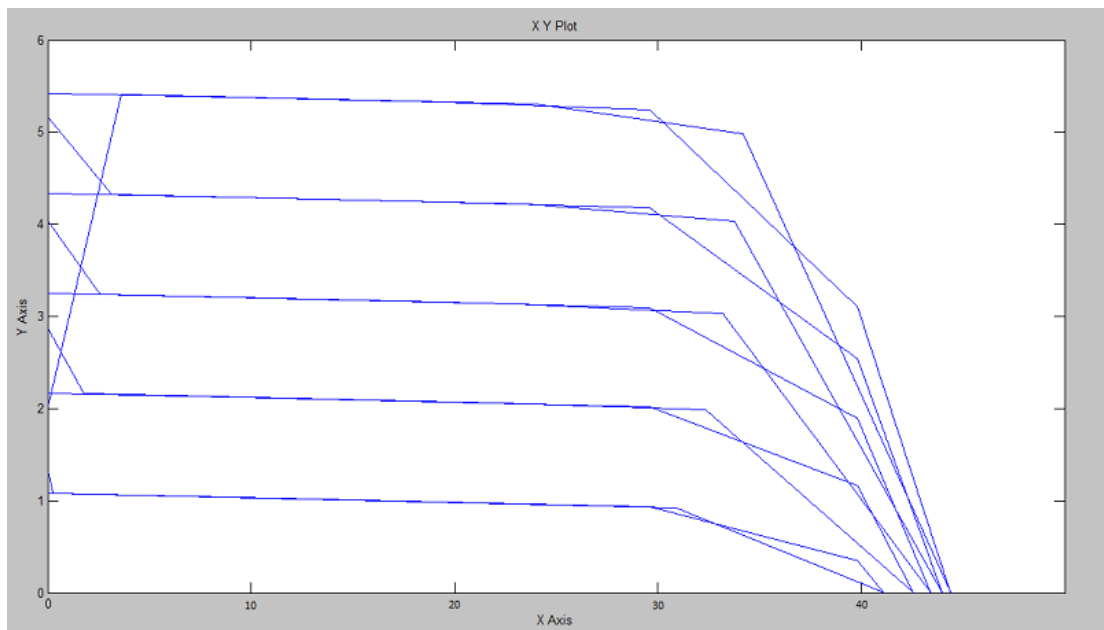
Figure 25: I-V Characteristic at different irradiance
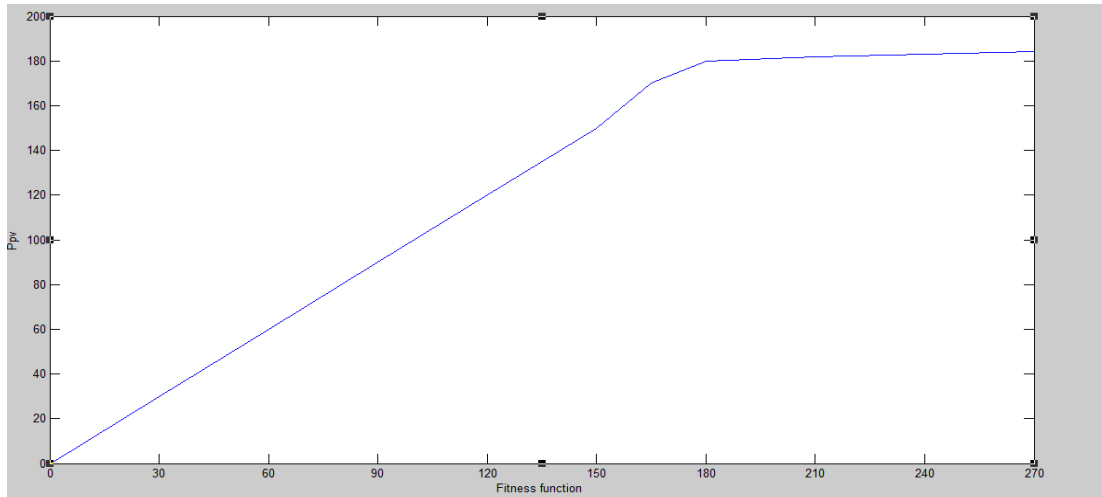
Figure 26: Fitness function (Ppso) vs. Ppv

The efficiency is calculated and tabulated. Table 7 shows the results for KSA for one iteration

Table 7: Efficiency of Proposed Method 1 PSO algorithm

G W/m2	Theoretical Output of PV panel [1]			Output of PV panel using PSO (Proposed Method 1)			Efficiency (%)
	Voltage V(volts)	Current I (Amps)	Power P (watts)	Voltage V(volts)	Current I (Amps)	Power P (watts)	
200	33.9	1	33.9	32.3	1.04	33.5	98.74
400	34.14	2.27	77.5	33.1	2.3	31.2	98.2
600	34.83	3.08	107.2	35	3.02	105.7	98.6
800	36.8	4.3	158.2	39.2	4	67.93	98.2
1000	37	5.3	184.97	36.8	5	78	99.5

The mean efficiency for PSO algorithm is 98.7%

As seen from the different set of results obtained, for a certain value of voltage and current the panel provides a maximum output. The output power of the panel increases as the module voltage increases, it reaches to a peak and drops as the voltage approaches to the open circuit voltage. In addition to this, the output current and the voltage are affected by the

31

variations in the irradiation as observed in Figure 21 and Figure 22 as well as Figure 24 and Figure 25

From Figure 23 and Figure 26, it is seen that the PSO algorithm is able to track the maximum power point. The graph shows an increasing curve until reaching the maximum power then instead of decreasing, the value of the power is sustained at the maximum.

The algorithm developed is able to track the direction of change, overcoming one of the problems in the earlier developed algorithms.

Also, the efficiency is increased.

4.2. PSO – INC results:

The PSO-INC model developed is shown in Figure 27:
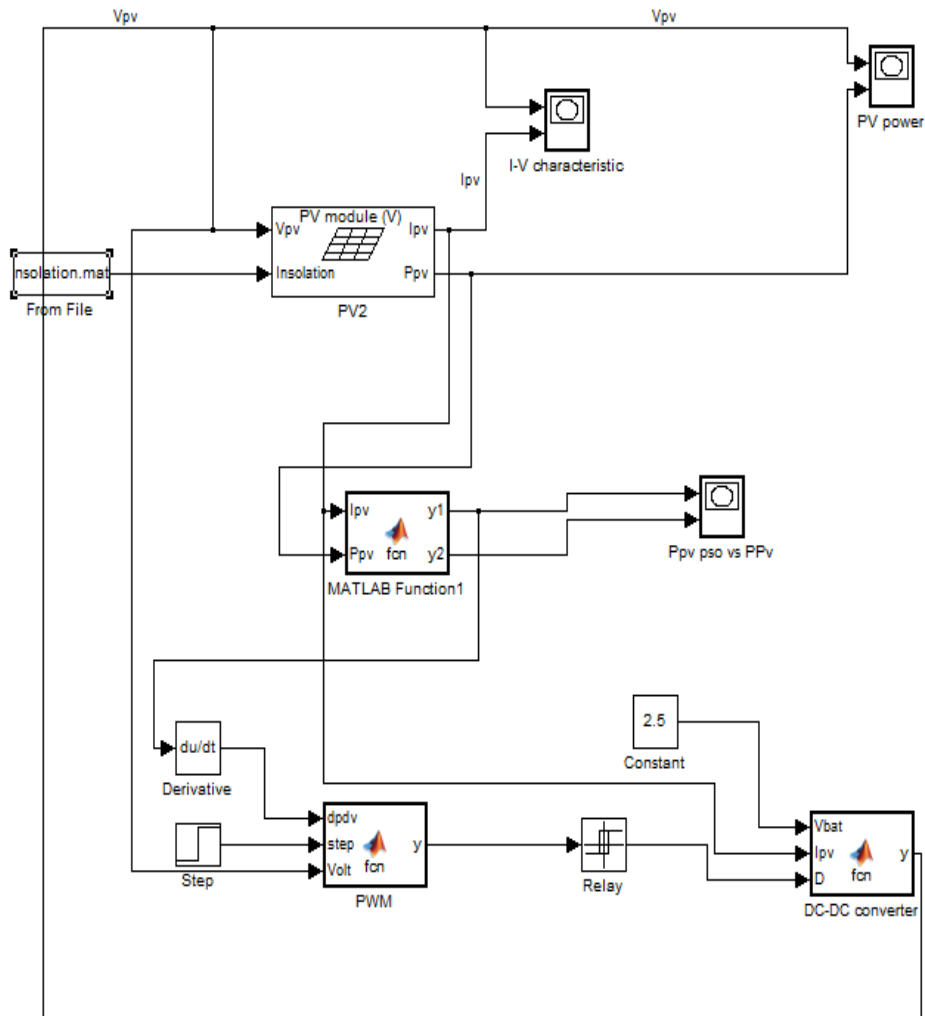
Figure 27: PSO-INC Simulink model

32

As explained in section 3.5.3, all the blocks in Figure 27 are developed in order to enable tracking of Maximum Power Point.

The resulting graphs are shown below.

4.2.1. Case study 1-Kuala Lumpur Results:
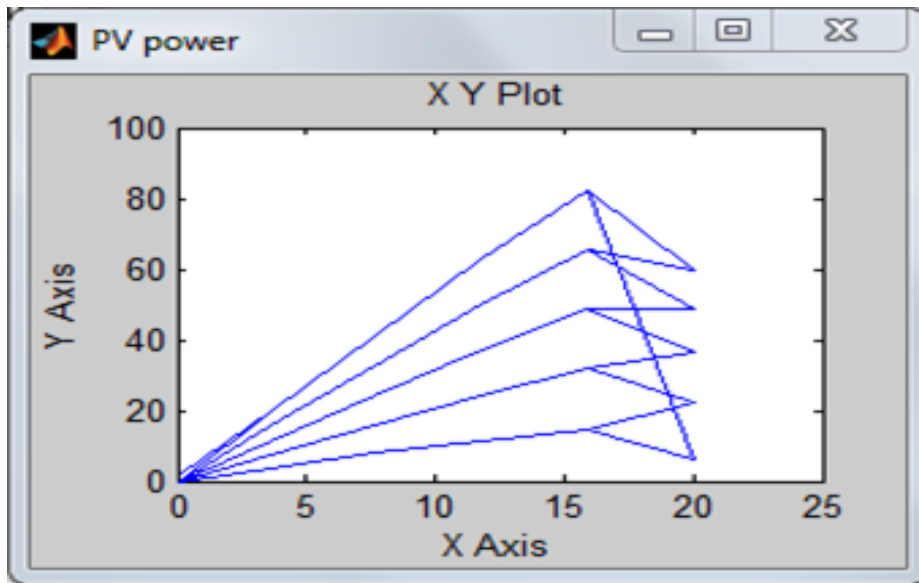
Figure 28: Power vs. Voltage at different irradiance
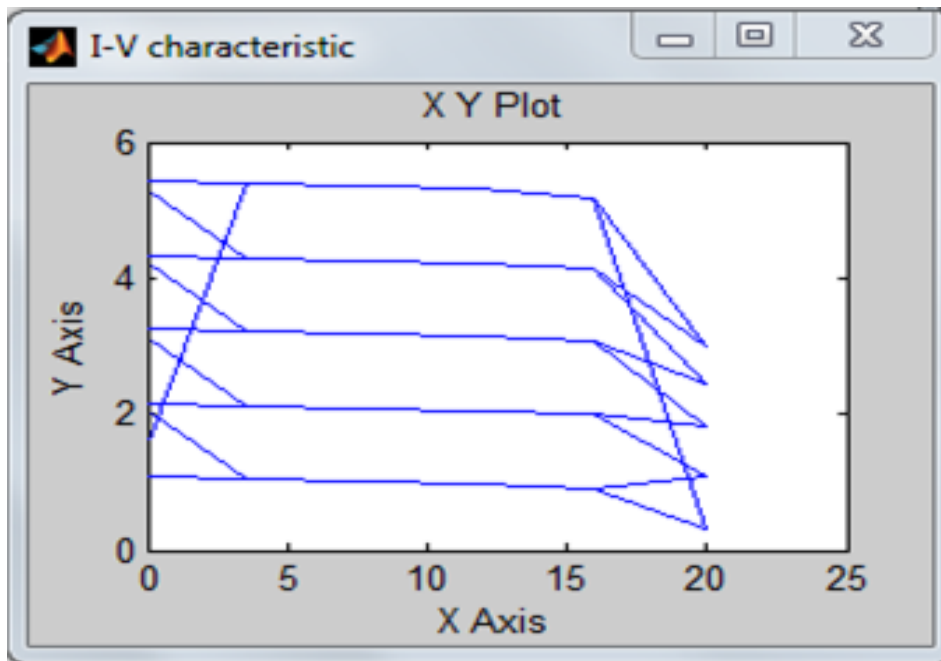
Figure 29: I-V Characteristic at different irradiance
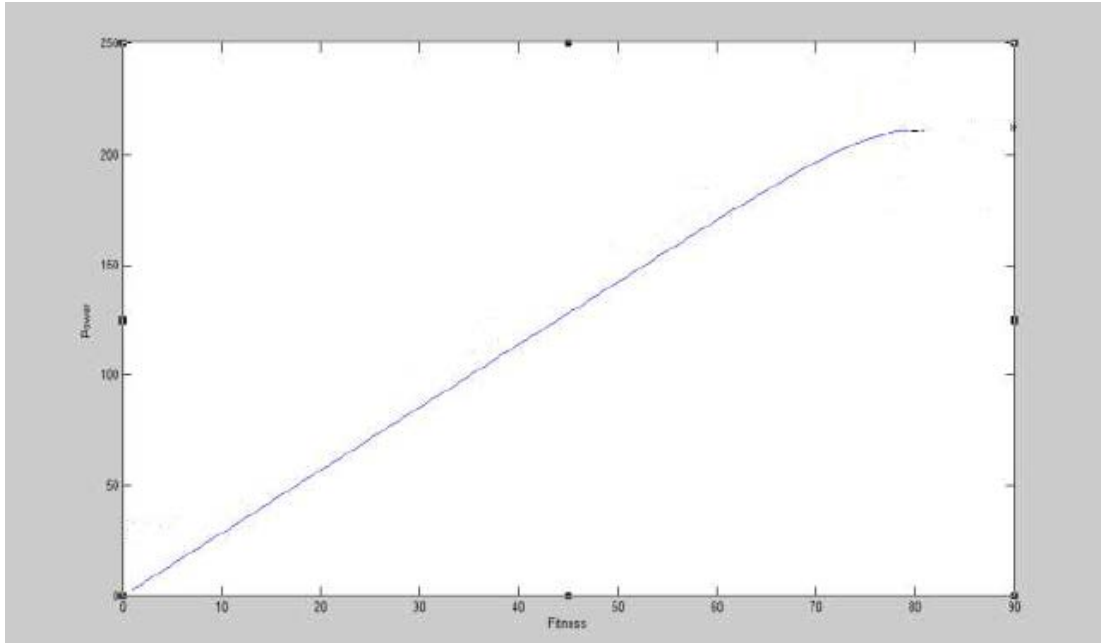
Figure 30: Fitness function vs. Ppv

Figure 28, 29 and 30 are similar to the ones obtained in Section 4.1.1.

However, Figure 30 is smoother than Figure 23.

4.2.2. Case study 1-Saudi Arabia Results:

The results for KSA data set are shown in Figures 31, 32 and 33
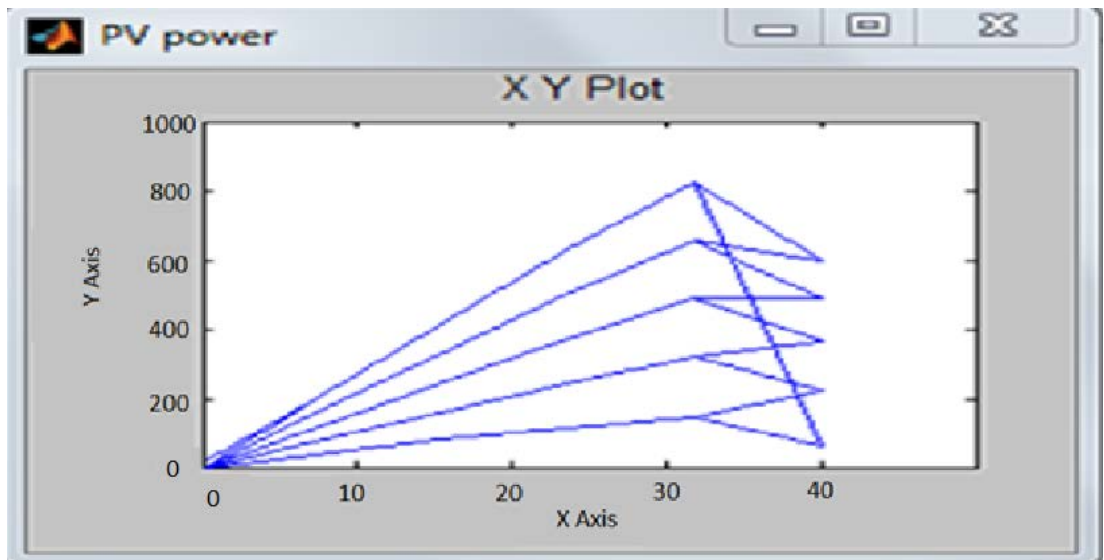
Figure 31: Power vs. Voltage at different irradiance
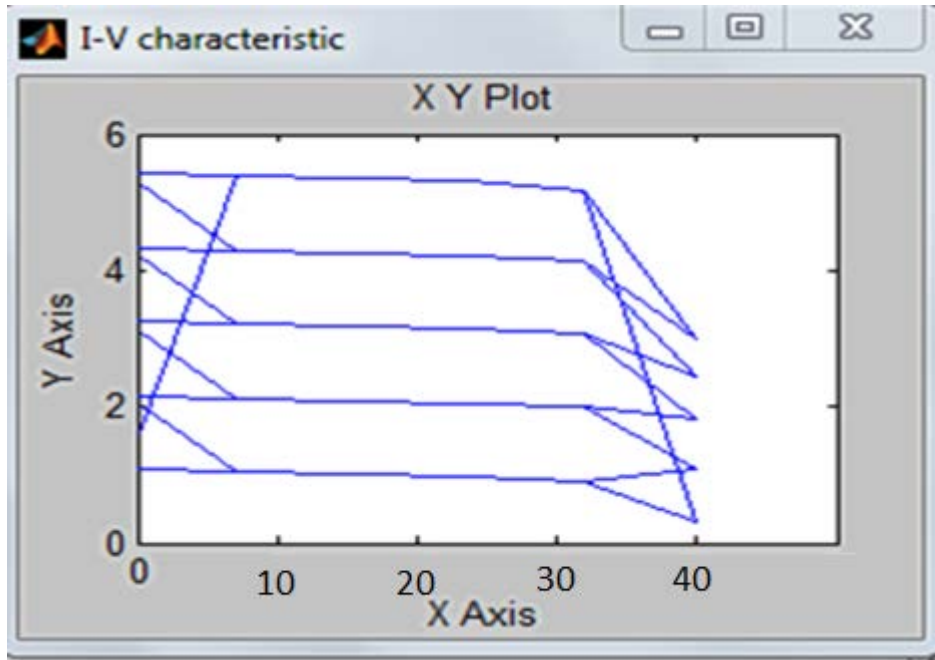
Figure 32: I-V Characteristic at different irradiance
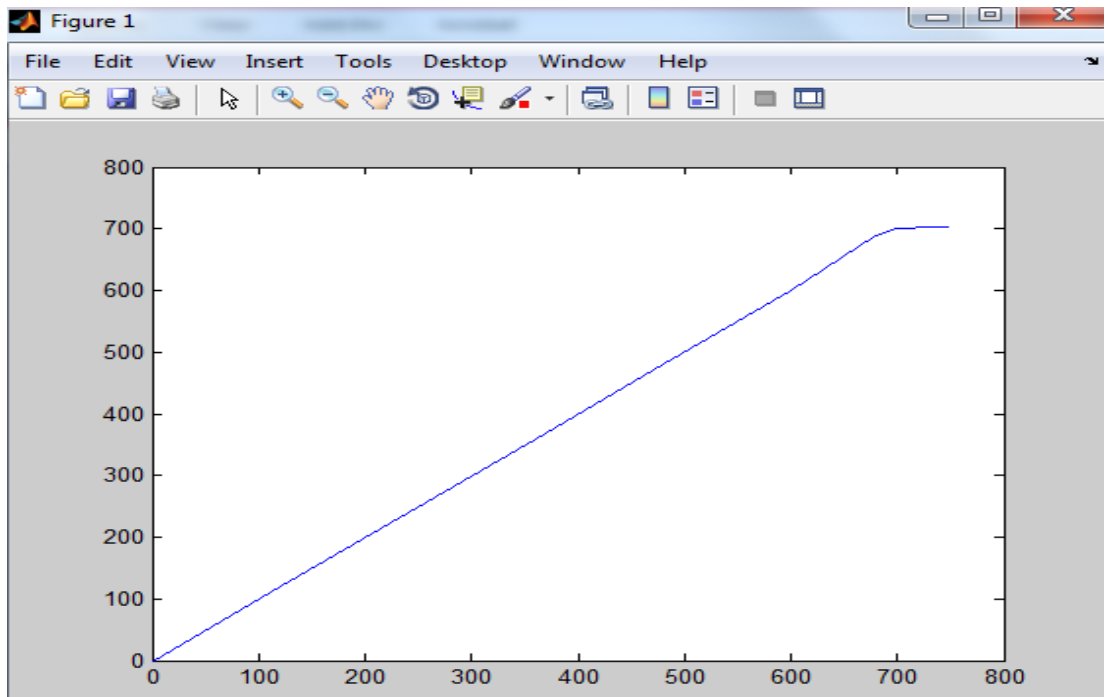
Figure 33: Fitness function vs. Ppv

MPPT system using PSO-INC calculates the voltage at which the module is able to produce maximum power and input to the PV module. In addition to increased efficiency and correct sense of tracking direction, the PSO–INC reaches steady state rapidly with no oscillations.

The simulated results using PSO and PSO-INC techniques are successfully able to track the maximum power point for a PV panel at any given Irradiation.

4.3. Validation:

The theoretical power, voltage and current output of the PV module (Kuala Lumpur Data set) are calculated for different irradiance and compared with the values obtained using Method 1 (PSO) and Method 2 (PSO-INC)

Table 8 : Comaprison between Calculated and obtained results

G W/m 2	Theoretical Output of PV panel [1]			Output of PV panel using PSO (Proposed Method 1)			Output of PV using PSO-INC (Proposed Method 2)		
	Voltage V(volts)	Current I (Amps)	Power P (watts)	Voltage V(volts)	Current I (Amps)	Power P (watts)	Voltage V(volts)	Current I (Amps)	Power P (watts)
200	13.9	1	13.9	15.42	0.9	14.08	14.17	0.98	13.89
400	14.14	2.27	32.1	13.91	2.3	32	14.32	2.24	32.09
600	14.83	3.08	45.8	15.14	3.02	45.2	15.1	3.03	45.34
800	16.8	4.3	68.09	17	4	67.93	16.585	4.1	68
1000	14.9	5.3	79	15.2	5	76	14.6	5.44	79.9
200	13.9	1	13.9	15.43	0.89	14.09	14.18	0.98	13.91
400	14.14	2.27	32.1	13.91	2.3	32	14.32	2.24	32.11
600	14.83	3.08	45.8	15.14	3.02	45.68	15.1	3.06	45.7
800	16.8	4.3	68.09	17	4	67.94	16.58	4.1	68
1000	14.9	5.3	79	15.2	5	76	14.59	5.44	79.98

To validate the developed methods, the efficiency of PSO and PSO-INC techniques are compared to previously developed methods using conventional algorithms (INC, P&O...) as well as earlier developed PSO algorithms.

Table 9: Efficiency of suggested Methods for MPPT compared to previously developed methods

No	Efficiency	Improvement

Conventional MPPT algorithm	97.8 (mean)[1]	-
Previously developed PSO algorithm	98.3% [1]	0.5%
Proposed Method 1	98.6%	0.82%
Proposed Method 2	99%	1.23%

It is seen that the algorithms are able to track Maximum power point without being stuck in local minima and can track the direction of maximum power point at changing conditions (irradiance).

4.4. Case Study: Pulau Perhentian renewable energy farm

Applications of the above algorithms are various.

The fact that the efficiency was increased even though it is not very large, can contribute to the boost of the output of solar power farms in addition to the improvement of the overall performance.

For instance, the RE hybrid Site at Pulau Perhentian has a Solar farm housed for 100kW Solar PV.

According to the March 2008 system analysis, the Solar radiation at the location is presented in Figure 34 [21].
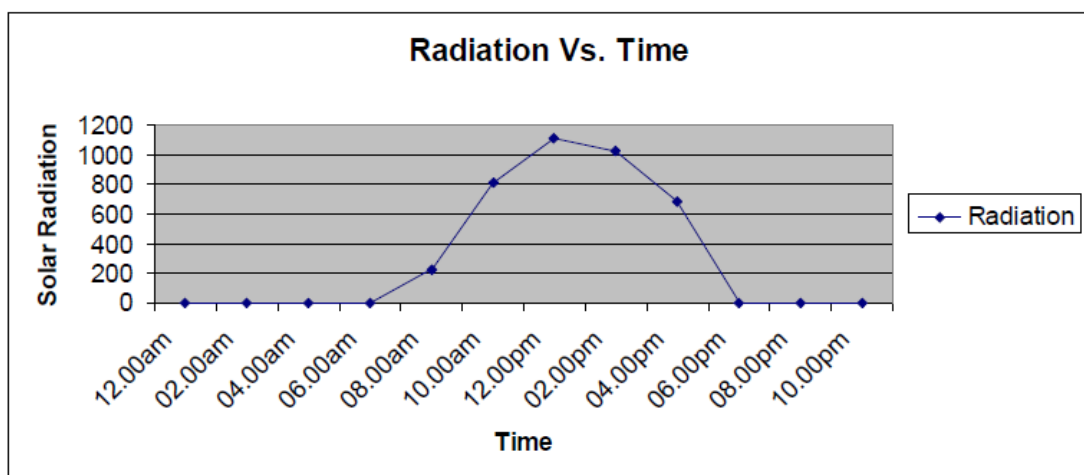
Figure 34: radiation Vs. Time in Pulau Perhentian

Also, Figure 35 shows that the maximum reached power is around 60Kw.
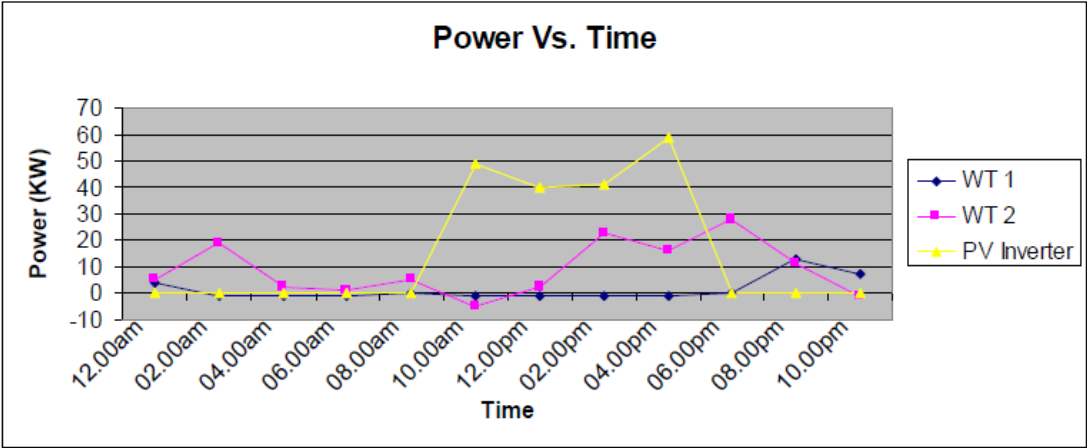
Figure 35: PV power vs time

The PSO-INC method can be used in this plant, especially that no mechanical tracker is installed. There are 585 single crystalline photovoltaic cells packed into modules (12modules) in the farm, each providing 171 W and the module efficiency in 13.7%.

If the algorithm is to be used a 1.25% increase in the efficiency of the module is to be achieved. The new efficiency becomes 43.65%. Therefore, The maximum power output can reach up to 80 KW.

CHAPTER 5: Conclusion and Recommendations

5.1. Conclusion

Solar energy is an abundant source of renewable energy. However, the efficiency of solar panel is limited. Efforts are made to improve it.

The development of Maximum Power Point Tracking algorithm of a Solar PV panel using Particle Swarm Optimization and Incremental conductance techniques is presented.

Two methods are proposed and two different set of irradiance are used to generate, verify and validate the results.

Comparison of Solar Photovoltaic panel output with and without optimization is presented. The results show that particle swarm optimization technique given better results. The efficiency of MPPT increases using PSO (reaches 98.6%) and PSO-INC Algorithm (reaches99.3%). Compared to the theoretical values, the Maximum Power output increases with increased irradiance using AI techniques. At higher irradiance value, the output value can surpass the theoretical power value.

In addition to this, some drawbacks present in previously developed MPPT algorithms were overcome such as getting stuck in maxima or minima and oscillation at maximum power point. Also, the algorithm was able to track the power in the correct direction.

5.2.Recommendations for Future Work

Further work can be done by implementing the suggested method.
One way of realizing the hardware prototype is using Microcontrollers.

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[4]   H. Cha and S. Lee, "Design and Implementation of photovoltaic power conditioning system using a current based Maximum Power Point tracking," in *43rd IEEE IAS*, 2008.

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Appendices:

Appendix A:

No.	Description /weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of Project topic	▓	▓													B															
2	Literture Review			▓	▓	▓	▓									R															
3	Extended Proposal						★									E															
4	Algorithm Development								▓	▓	▓	▓	▓	▓	▓	A															
5	Proposal defense presentation									★						K															
6	Interim report draft													★																	
7	Interim report final draft														★																
8	Coding/Implementation																▓	▓	▓	▓	▓	▓	▓	▓	▓	▓					
9	Progress report																										★				
9	Analysis																							▓	▓	▓	▓				
10	Algorithm enhancement																										▓	▓	▓		
11	Pre-EDX																											★			
12	Documentation / Final report draft																												★		
13	Final report																													★	
14	Viva																														★

(pink)	to be competed
(blue)	completed
★	suggested milestone

Appendix B:

Sample data from NASA climatology Resource for Agro climatology Daily averaged

Data (Evaluation Version) extracted for Kuala lumpur in 2012 .

```
INSI   WTHLAT   WTHLONG  WELEV   TAV   AMP   REFHT   WNDHT
  NASA     3.133    101.000    151                         10

@ WEYR WEDAY   SRAD    TMAX    TMIN    RAIN   WIND    TDEW     T2M    RH2M
  2012    1    16.5    28.3    26.3    -99    2.2    24.1    27.2    82.7
  2012    2    20.6    30.2    25.1    -99    1.4    23.6    27.7    78.0
  2012    3    17.5    29.4    25.6    -99    1.8    23.9    27.5    80.3
  2012    4    21.0    29.5    25.1    -99    2.8    23.4    27.2    79.1
  2012    5    21.1    29.9    24.3    -99    2.1    22.6    27.3    75.3
  2012    6    20.4    29.3    25.1    -99    2.2    23.3    27.3    78.4
  2012    7    22.1    29.9    24.3    -99    2.7    22.5    27.1    75.8
  2012    8    15.5    29.3    25.6    -99    2.0    23.2    27.2    78.6
  2012    9    13.1    28.1    24.5    -99    1.9    23.0    26.4    81.3
  2012   10    14.8    28.9    25.5    -99    2.0    23.7    27.3    80.6
  2012   11    13.3    28.5    25.4    -99    2.1    23.8    27.1    81.8
  2012   12     7.6    28.0    25.6    -99    2.4    23.8    26.9    82.9
  2012   13    12.3    28.9    26.5    -99    1.9    24.1    27.5    81.5
  2012   14    -99     28.3    26.4    -99    1.7    24.0    27.4    81.5
  2012   15    15.9    28.6    25.9    -99    2.6    23.8    27.2    81.5
  2012   16    20.6    29.6    27.1    -99    2.0    23.9    28.3    76.7
  2012   17    20.8    28.5    26.1    -99    2.9    24.2    27.3    82.9
  2012   18    15.3    28.2    26.1    -99    2.4    24.3    27.2    84.1
  2012   19    18.6    29.2    26.3    -99    1.3    23.8    27.7    79.0
  2012   20    18.1    28.2    26.5    -99    2.5    23.9    27.3    81.5
  2012   21    18.5    28.4    26.2    -99    3.4    23.9    27.1    82.8
  2012   22    18.6    27.9    26.2    -99    2.8    24.1    26.9    84.4
  2012   23    18.4    28.6    26.2    -99    2.5    23.8    27.1    82.2
  2012   24    22.6    29.3    26.0    -99    2.2    23.9    27.7    79.7
  2012   25    20.9    30.6    26.2    -99    2.1    23.5    28.3    74.7
  2012   26    20.7    29.7    24.6    -99    2.6    22.7    27.5    74.7
  2012   27    18.5    30.4    24.5    -99    2.4    23.2    27.5    77.2
  2012   28    13.4    28.4    25.5    -99    1.6    23.8    26.9    82.5
  2012   29    16.7    28.7    26.0    -99    1.4    23.6    27.5    79.1
  2012   30    -99     29.1    26.2    -99    1.8    24.1    27.7    80.4
  2012   31    13.9    29.1    27.0    -99    1.3    24.3    27.8    81.0
  2012   32    19.7    29.3    25.6    -99    2.5    23.8    27.2    81.8
  2012   33    19.5    28.4    24.8    -99    2.5    23.6    26.6    83.6
  2012   34    15.4    27.4    25.4    -99    2.2    23.5    26.4    83.8
  2012   35    17.2    28.6    24.7    -99    2.2    23.4    26.5    82.8
  2012   36    22.4    30.1    25.1    -99    2.0    23.4    27.6    77.7
  2012   37    21.4    28.8    26.8    -99    2.5    24.3    27.7    81.7
  2012   38    19.1    28.6    26.7    -99    2.6    24.7    27.6    84.2
  2012   39    23.5    29.1    26.6    -99    2.4    24.8    27.9    83.0
  2012   40    24.2    30.3    24.6    -99    2.3    23.0    27.7    75.1
  2012   41    23.6    30.3    24.4    -99    2.4    22.8    27.4    75.6
  2012   42    22.2    30.0    24.8    -99    2.6    23.5    27.4    79.0
  2012   43    20.9    29.4    25.4    -99    2.0    24.1    27.4    81.7
  2012   44    19.1    29.3    25.1    -99    2.2    24.1    27.3    82.4
  2012   45    20.9    29.3    25.9    -99    1.7    24.3    27.7    81.6
  2012   46    -99     28.4    26.9    -99    2.1    24.7    27.5    84.6
  2012   47    14.1    29.5    27.1    -99    2.2    24.2    28.1    79.3
  2012   48    19.3    29.3    26.9    -99    1.3    23.9    28.0    77.7
  2012   49    14.4    28.8    26.3    -99    2.1    24.1    27.3    82.2
  2012   50    16.8    28.2    26.0    -99    2.1    24.1    27.1    83.2
  2012   51    18.5    28.6    26.6    -99    2.0    24.4    27.5    83.0
```

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2012    52   16.2   29.1   27.3   -99   1.4   24.1   28.2   78.3
2012    53   22.4   29.9   26.3   -99   1.6   24.3   28.3   78.5
2012    54   19.5   29.3   26.3   -99   1.5   24.6   28.2   80.6
2012    55   19.7   29.4   26.6   -99   1.8   24.9   28.0   82.7
2012    56   21.4   30.2   25.9   -99   1.4   24.4   28.0   80.2
2012    57   17.7   30.0   27.4   -99   1.1   24.4   28.5   78.2
2012    58   18.9   28.9   27.0   -99   1.7   24.6   28.0   81.7
2012    59    -99   28.7   27.0   -99   1.2   24.8   27.9   83.1
2012    60   16.3   28.1   26.6   -99   2.8   24.8   27.1   86.9
2012    61   19.9   29.1   26.3   -99   2.4   24.4   27.4   83.5
2012    62    -99   28.2   26.6   -99   1.6   24.8   27.4   85.4
2012    63   16.9   29.1   26.6   -99   1.2   24.0   27.7   79.8
2012    64   22.7   28.8   27.0   -99   1.7   24.0   27.8   79.4
2012    65   13.8   29.3   26.8   -99   2.1   24.2   27.9   80.2
2012    66   17.4   29.7   26.9   -99   2.7   24.2   28.0   79.3
2012    67   20.8   28.3   26.4   -99   2.4   24.3   27.1   84.3
2012    68   12.0   27.5   25.8   -99   2.3   23.7   26.6   83.8
2012    69   21.2   28.6   26.1   -99   3.1   24.1   27.1   83.6
2012    70   17.2   29.4   26.2   -99   2.2   24.1   27.8   79.8
2012    71   18.3   29.3   27.4   -99   1.6   24.4   28.3   78.9
2012    72    5.8   28.4   26.4   -99   2.0   24.4   27.3   84.0
2012    73   16.1   29.6   27.1   -99   1.4   24.4   28.0   80.7
2012    74    9.3   30.5   26.9   -99   1.4   24.0   28.4   76.6
2012    75   20.1   29.3   27.5   -99   2.1   24.4   28.3   79.3
2012    76   23.8   30.4   26.3   -99   2.1   24.6   28.4   79.4
2012    77   19.2   29.1   27.7   -99   2.2   25.2   28.3   82.7
2012    78    -99   29.1   27.0   -99   2.4   25.2   28.1   84.2
2012    79   17.5   29.5   27.9   -99   2.5   25.0   28.5   81.0
2012    80   20.2   29.2   27.6   -99   2.4   24.8   28.3   81.2
2012    81   21.2   29.3   27.2   -99   2.8   24.7   28.1   81.7
2012    82   22.3   29.9   27.4   -99   2.8   24.6   28.6   78.9
2012    83   19.5   30.2   26.9   -99   3.0   24.2   28.4   77.6
2012    84   21.1   30.3   27.0   -99   1.6   24.4   28.7   77.0
2012    85   18.9   29.5   27.5   -99   1.6   24.8   28.5   80.4
2012    86   15.0   29.1   26.7   -99   1.6   24.8   28.2   81.4
2012    87   18.8   29.3   27.8   -99   1.5   24.8   28.3   81.0
2012    88   11.1   30.1   27.7   -99   1.2   24.4   28.6   77.7
2012    89   20.5   29.2   27.7   -99   2.0   24.5   28.3   79.2
2012    90   18.9   28.5   26.9   -99   3.5   24.2   27.7   81.0
2012    91   12.6   28.2   26.7   -99   3.1   24.2   27.4   82.7
2012    92   21.9   28.6   27.1   -99   2.5   24.7   27.8   83.0
2012    93   17.7   29.7   27.4   -99   1.8   24.4   28.4   78.6
2012    94    -99   30.3   27.8   -99   1.8   24.3   29.0   75.5
2012    95   21.1   30.2   27.5   -99   2.4   24.0   28.5   76.3
2012    96   21.8   29.6   28.0   -99   2.0   24.5   28.7   77.7
2012    97   18.8   29.2   27.8   -99   1.6   24.9   28.5   80.9
2012    98   20.8   29.2   27.9   -99   1.4   25.1   28.6   81.0
2012    99   16.5   29.0   27.7   -99   1.5   24.9   28.4   81.0
2012   100   21.8   29.3   27.2   -99   1.7   24.6   28.1   81.2
2012   101   20.4   29.1   27.3   -99   1.6   24.9   28.1   82.9
2012   102   19.3   30.1   28.2   -99   1.5   24.6   28.9   77.6
2012   103   19.1   29.8   28.3   -99   1.4   24.8   28.9   78.4
2012   104   21.3   29.8   29.0   -99   1.4   24.8   29.3   76.3
2012   105   11.9   30.3   28.0   -99   1.1   25.2   28.9   80.1
2012   106   18.8   29.3   27.9   -99   1.3   24.9   28.5   80.7
2012   107   18.3   29.9   27.9   -99   1.6   25.2   28.7   80.9
2012   108   19.7   29.5   27.1   -99   1.9   24.7   28.0   81.9
2012   109   16.1   29.4   27.6   -99   1.9   25.0   28.5   81.1
2012   110    -99   29.0   27.7   -99   1.7   25.1   28.2   82.9
2012   111   20.8   29.4   27.9   -99   1.9   25.0   28.5   81.1
2012   112   18.3   29.8   27.2   -99   3.1   24.4   28.4   78.9
```

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2012  113   22.0   30.2   28.0   -99   1.4   24.7   28.9   77.5
2012  114   21.9   30.3   28.5   -99   1.3   25.1   29.2   78.0
2012  115   16.7   29.4   27.7   -99   2.4   25.0   28.4   81.6
2012  116   19.3   29.9   27.9   -99   2.2   24.8   28.8   78.5
2012  117   22.2   29.6   27.7   -99   2.6   24.9   28.4   81.1
2012  118   22.5   30.0   27.8   -99   2.1   24.7   28.8   78.3
2012  119   19.4   29.7   28.0   -99   1.7   24.9   28.7   79.6
2012  120   21.3   29.0   27.6   -99   2.5   25.1   28.1   83.8
2012  121   20.7   30.5   26.8   -99   2.2   24.7   28.4   80.4
2012  122   19.7   29.8   28.2   -99   1.3   25.3   28.9   80.5
2012  123   16.7   29.0   27.5   -99   2.1   25.3   28.1   84.6
2012  124   21.5   29.4   27.7   -99   2.0   24.8   28.4   81.0
2012  125   21.7   29.8   27.2   -99   2.1   24.8   28.4   80.4
2012  126   -99    29.7   27.4   -99   1.7   25.1   28.4   81.9
2012  127    9.5   29.3   27.4   -99   1.3   25.0   28.3   81.8
2012  128   16.8   30.3   27.9   -99   1.3   24.3   28.7   76.8
2012  129   21.4   30.1   28.4   -99   1.1   24.9   29.2   77.0
2012  130   21.3   31.1   28.4   -99   1.1   24.6   29.7   73.6
2012  131   17.1   30.2   28.4   -99   1.5   25.0   29.3   77.6
2012  132   10.0   29.0   27.6   -99   2.2   25.2   28.3   83.4
2012  133   21.3   29.4   27.7   -99   2.5   25.1   28.3   82.5
2012  134   21.1   29.5   27.1   -99   2.9   24.8   28.2   81.6
2012  135   17.7   29.7   27.5   -99   1.9   25.3   28.6   82.0
2012  136   15.6   29.7   27.7   -99   2.5   25.2   28.4   82.4
2012  137   20.8   29.6   27.3   -99   2.4   25.1   28.4   82.1
2012  138   14.3   29.8   27.3   -99   2.2   25.1   28.4   81.8
2012  139   20.5   29.8   28.0   -99   1.9   25.5   28.9   81.6
2012  140   20.9   30.3   27.1   -99   2.6   25.2   28.9   80.5
2012  141   11.1   29.4   27.2   -99   1.9   25.5   28.5   83.5
2012  142   -99    29.9   27.9   -99   1.9   25.2   28.7   81.3
2012  143   15.6   29.2   28.2   -99   1.6   25.4   28.6   82.2
2012  144   17.8   28.7   27.5   -99   1.9   25.1   28.0   84.3
2012  145   18.7   30.0   27.2   -99   1.7   24.9   28.6   79.9
2012  146   14.7   29.2   27.9   -99   1.4   25.0   28.6   80.6
2012  147   20.6   30.2   27.9   -99   2.3   25.1   28.8   80.1
2012  148   18.3   30.1   27.8   -99   1.9   25.0   28.7   80.2
2012  149   21.0   29.7   27.5   -99   2.0   25.0   28.5   81.1
2012  150   16.4   29.3   27.8   -99   1.7   25.2   28.4   82.2
2012  151   17.4   29.0   27.5   -99   1.9   25.5   28.1   85.6
2012  152   19.3   31.1   28.1   -99   1.4   25.3   28.9   80.4
2012  153   18.5   30.0   28.1   -99   1.4   24.8   28.9   78.2
2012  154   21.3   30.0   27.7   -99   1.8   25.1   28.9   79.7
2012  155   20.3   30.1   27.8   -99   1.6   25.3   29.0   80.1
2012  156   20.6   29.7   28.4   -99   1.6   25.6   29.1   80.9
2012  157   20.8   29.6   28.3   -99   1.9   25.4   28.8   81.5
2012  158   -99    29.2   27.7   -99   2.4   24.7   28.4   80.0
2012  159   15.3   29.4   27.6   -99   2.4   24.4   28.6   77.7
2012  160   13.5   28.9   27.5   -99   2.5   25.1   28.1   83.6
2012  161   14.0   29.1   26.7   -99   3.5   24.3   27.8   81.1
2012  162   18.6   30.0   26.8   -99   2.9   24.2   28.4   77.9
2012  163   19.7   30.1   27.5   -99   2.5   24.5   28.8   77.3
2012  164   21.0   29.9   27.1   -99   3.1   25.0   28.5   80.9
2012  165   21.9   30.1   27.3   -99   2.8   24.9   28.8   79.3
2012  166   18.8   30.1   28.5   -99   1.7   24.9   29.3   76.8
2012  167   19.9   30.6   28.7   -99   1.5   24.9   29.4   76.2
2012  168   18.9   29.8   28.2   -99   2.1   25.0   29.0   78.8
2012  169   18.3   29.2   27.7   -99   3.0   24.9   28.5   80.5
2012  170   19.2   29.9   26.6   -99   2.7   25.1   28.5   81.5
2012  171   18.3   30.0   27.5   -99   2.1   25.1   28.6   81.1
2012  172   19.4   29.5   27.0   -99   3.0   25.0   28.2   82.2
2012  173   14.1   29.4   27.0   -99   3.4   24.9   28.0   83.4
```

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2012  174   -99   30.9   26.2   -99   2.1   24.6   28.3   79.9
2012  175  16.3   29.7   27.5   -99   2.1   25.1   28.6   81.2
2012  176  21.1   30.1   27.4   -99   2.0   24.8   28.8   78.7
2012  177  18.4   29.5   28.0   -99   1.9   24.8   28.7   79.0
2012  178  11.4   29.6   27.2   -99   1.4   24.8   28.5   79.8
2012  179  15.6   29.2   27.8   -99   1.4   24.4   28.5   78.0
2012  180  20.8   28.9   27.3   -99   1.7   24.5   27.9   81.5
2012  181  19.2   29.5   27.2   -99   2.2   24.9   28.3   81.6
2012  182  15.6   28.9   27.2   -99   2.5   25.0   27.9   83.7
2012  183  19.7   28.7   26.6   -99   3.0   24.8   27.5   85.1
2012  184  19.8   29.0   26.7   -99   2.6   24.6   27.8   82.5
2012  185  20.6   29.6   27.0   -99   1.8   24.3   28.1   79.5
2012  186  15.0   29.2   27.1   -99   1.7   24.3   27.9   80.6
2012  187  20.6   29.3   26.6   -99   1.7   24.3   27.8   81.0
2012  188  17.9   28.8   26.9   -99   2.2   24.1   27.9   79.4
2012  189  19.2   28.2   26.6   -99   2.0   24.4   27.4   83.7
2012  190   -99   28.6   26.5   -99   2.5   24.1   27.4   81.6
2012  191  15.8   28.6   26.8   -99   1.8   24.3   27.7   81.5
2012  192  22.4   29.0   26.2   -99   1.9   24.3   27.6   81.7
2012  193  11.8   28.4   26.5   -99   2.1   24.4   27.5   82.8
2012  194  22.1   28.7   27.1   -99   3.0   24.4   27.7   82.2
2012  195  22.4   28.6   26.6   -99   3.5   24.5   27.5   83.5
2012  196  17.6   29.2   26.6   -99   3.0   24.2   27.8   80.4
2012  197  15.7   29.7   26.0   -99   2.9   24.0   27.8   79.5
2012  198  15.7   28.8   26.4   -99   2.1   24.5   27.6   83.1
2012  199  11.6   27.9   26.6   -99   2.2   24.4   27.1   84.7
2012  200  16.9   28.6   26.7   -99   1.3   24.5   27.6   83.3
2012  201  15.2   28.4   26.9   -99   1.3   24.3   27.8   81.0
2012  202  21.2   28.9   27.2   -99   1.9   24.4   27.8   81.4
2012  203  16.7   29.0   26.8   -99   2.5   24.7   27.9   82.9
2012  204  17.8   28.6   27.2   -99   2.3   24.9   27.9   83.6
2012  205  12.6   28.6   26.9   -99   2.1   24.6   27.8   82.5
2012  206   -99   29.0   26.7   -99   2.9   24.1   27.9   79.7
2012  207  21.2   30.3   26.3   -99   3.8   23.7   28.0   77.0
2012  208  22.1   29.5   26.5   -99   3.5   24.5   28.0   81.2
2012  209  22.6   29.6   26.5   -99   3.6   24.9   28.1   82.8
2012  210  22.8   29.6   26.5   -99   3.1   24.4   28.0   80.2
2012  211  19.9   29.4   27.0   -99   2.5   24.2   28.2   78.8
2012  212  18.1   29.4   27.1   -99   2.2   24.4   28.3   79.1
2012  213  17.3   28.9   27.3   -99   2.0   24.8   28.1   82.2
2012  214  22.8   29.4   27.2   -99   2.2   24.3   28.3   78.3
2012  215  15.3   29.0   27.2   -99   2.6   24.6   28.2   80.3
2012  216  19.8   28.6   27.4   -99   2.2   24.7   28.0   81.7
2012  217  17.5   28.7   26.7   -99   2.1   24.8   27.6   84.4
2012  218  12.1   28.5   27.2   -99   2.0   24.9   27.7   84.5
2012  219  11.4   28.4   27.1   -99   2.2   24.5   27.8   82.1
2012  220  22.5   29.4   26.9   -99   1.8   24.5   28.4   79.2
2012  221  22.2   29.9   28.2   -99   1.9   24.4   28.9   76.0
2012  222   -99   30.5   26.5   -99   3.8   23.9   28.3   76.8
2012  223  24.4   30.8   26.4   -99   3.3   23.9   28.5   75.8
2012  224  23.7   30.1   26.5   -99   2.8   24.3   28.3   78.4
2012  225  19.9   29.7   26.4   -99   3.2   24.6   28.0   81.7
2012  226  23.3   29.7   26.4   -99   2.3   24.8   28.2   81.4
2012  227  24.1   30.0   28.2   -99   1.7   24.7   29.0   77.1
2012  228  17.6   29.5   28.4   -99   1.4   25.0   28.9   79.4
2012  229  17.4   28.9   27.9   -99   1.4   25.0   28.4   81.5
2012  230  23.4   30.4   27.9   -99   1.4   24.1   28.9   74.9
2012  231  20.9   29.4   27.2   -99   2.6   24.3   28.3   78.8
2012  232  21.7   29.3   27.2   -99   2.8   25.1   28.1   83.2
2012  233  13.3   29.4   26.9   -99   2.3   24.6   28.1   81.2
2012  234  15.8   28.5   27.4   -99   1.9   24.5   27.9   81.6
```

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2012   235   18.6   28.7   27.1   -99   2.0   24.5   27.9   81.3
2012   236   21.2   28.2   26.3   -99   3.6   24.2   27.2   83.5
2012   237   22.4   30.0   27.8   -99   1.4   24.3   28.8   76.5
2012   238    -99   29.4   27.4   -99   1.4   24.3   28.4   78.4
2012   239   21.0   29.4   28.3   -99   1.4   24.6   28.8   78.1
2012   240   20.3   28.9   27.5   -99   1.7   24.5   28.0   80.7
2012   241   17.3   28.1   26.9   -99   1.9   24.3   27.4   83.1
2012   242   20.3   28.5   27.3   -99   2.0   24.7   27.8   83.3
2012   243   23.1   28.9   26.6   -99   2.7   24.6   27.6   83.5
2012   244   15.0   29.6   26.4   -99   2.7   24.3   27.9   80.9
2012   245   19.8   29.5   26.9   -99   2.7   24.8   28.2   81.4
2012   246   20.3   29.6   26.7   -99   2.4   25.0   28.3   82.2
2012   247   15.3   29.9   28.3   -99   1.3   25.2   29.0   79.6
2012   248   12.3   29.9   27.8   -99   1.9   25.3   28.5   82.3
2012   249   16.3   28.3   26.5   -99   2.8   24.4   27.4   84.0
2012   250   17.3   29.8   26.7   -99   1.5   24.2   28.2   78.6
2012   251   19.8   30.1   27.8   -99   2.3   24.4   28.8   76.9
2012   252   12.5   29.0   26.5   -99   2.3   24.6   27.7   83.0
2012   253   19.9   29.0   27.0   -99   1.6   24.5   28.1   80.4
2012   254    -99   29.4   28.1   -99   1.7   24.4   28.5   77.8
2012   255   17.2   29.0   27.6   -99   2.1   24.6   28.2   80.5
2012   256   17.9   28.1   27.0   -99   2.2   24.4   27.5   83.3
2012   257   20.8   29.0   27.1   -99   2.4   24.0   27.9   79.0
2012   258   18.0   29.1   27.2   -99   1.5   24.0   28.2   77.7
2012   259   20.4   29.8   28.2   -99   1.7   24.0   28.8   74.9
2012   260   15.0   28.7   26.8   -99   2.2   24.6   27.8   82.8
2012   261   20.6   29.3   27.1   -99   2.4   24.7   28.2   81.1
2012   262   20.3   29.1   26.8   -99   2.1   24.8   28.1   82.0
2012   263   18.9   29.0   27.8   -99   1.7   24.7   28.4   80.4
2012   264   17.0   30.1   27.2   -99   1.9   24.2   28.3   78.2
2012   265   20.4   29.2   26.6   -99   1.9   24.2   27.9   80.3
2012   266   19.4   30.0   26.7   -99   1.7   23.9   28.1   77.5
2012   267   18.6   29.7   27.2   -99   2.2   24.2   28.2   79.0
2012   268   21.8   28.9   26.7   -99   2.9   24.4   27.6   82.1
2012   269   20.3   29.0   26.2   -99   2.5   24.2   27.7   81.0
2012   270    -99   28.1   26.9   -99   2.0   24.2   27.4   82.2
2012   271   18.5   29.2   26.7   -99   1.7   24.2   28.0   79.6
2012   272   13.1   28.9   26.8   -99   1.4   24.5   27.7   82.3
2012   273   15.8   29.6   27.8   -99   1.4   24.2   28.6   76.7
2012   274   18.6   31.0   28.5   -99   1.1   23.8   29.5   70.8
2012   275   14.5   29.5   27.8   -99   1.6   24.4   28.6   78.0
2012   276   19.9   31.2   27.4   -99   1.9   24.1   28.8   75.3
2012   277   21.5   30.5   27.8   -99   2.4   24.4   28.7   77.0
2012   278   16.6   29.6   26.7   -99   3.4   24.2   27.9   79.8
2012   279   16.5   29.2   26.1   -99   3.4   23.6   27.4   79.5
2012   280   22.5   29.1   26.9   -99   2.8   24.3   27.8   80.9
2012   281   18.8   28.8   26.9   -99   3.0   24.0   27.8   79.9
2012   282   16.1   29.5   26.2   -99   2.3   23.8   27.9   78.1
2012   283   20.0   29.7   27.3   -99   1.6   24.3   28.4   78.4
2012   284   18.1   29.5   28.1   -99   1.6   24.4   28.6   77.6
2012   285   17.5   29.0   27.7   -99   1.6   24.4   28.3   79.1
2012   286    -99   28.6   27.1   -99   2.0   24.8   27.8   83.4
2012   287    5.9   28.9   26.9   -99   1.7   24.3   27.8   81.0
2012   288   19.0   29.0   27.4   -99   1.5   24.4   28.0   80.5
2012   289   18.7   29.6   27.5   -99   1.3   24.2   28.4   77.7
2012   290   17.8   29.2   27.5   -99   1.6   24.4   28.2   79.1
2012   291   20.1   28.6   27.1   -99   1.7   24.3   27.7   81.6
2012   292   16.8   28.3   27.2   -99   1.6   24.5   27.7   82.7
2012   293   14.3   28.9   27.4   -99   1.3   24.3   28.1   80.0
2012   294   19.1   29.4   26.4   -99   1.2   24.2   27.9   80.2
2012   295   14.9   28.8   27.1   -99   1.4   24.4   27.8   81.6
```

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2012   296   10.7   28.6   27.4   -99   1.0   24.2   28.0   79.8
2012   297   19.5   29.3   27.6   -99   1.7   24.3   28.3   78.5
2012   298   21.3   30.6   27.3   -99   1.3   24.3   28.8   76.2
2012   299   18.1   30.1   28.1   -99   1.3   24.2   29.1   74.7
2012   300   19.5   29.6   27.1   -99   1.4   24.6   28.3   79.9
2012   301   20.3   30.6   27.6   -99   1.2   24.5   28.8   77.5
2012   302    -99   31.6   26.8   -99   1.4   24.1   29.2   73.6
2012   303   19.2   30.4   27.4   -99   1.4   24.5   29.1   75.7
2012   304   17.3   29.3   27.7   -99   1.4   24.7   28.6   78.9
2012   305   15.1   28.7   27.5   -99   1.1   24.6   28.1   81.1
2012   306   11.5   28.4   27.0   -99   1.4   24.7   27.5   84.2
2012   307   18.2   28.6   27.2   -99   1.3   24.7   27.7   83.1
2012   308   15.9   27.9   26.5   -99   2.8   24.5   27.1   85.5
2012   309   10.2   27.5   26.3   -99   2.9   24.1   26.7   85.5
2012   310   13.5   27.8   26.1   -99   3.0   23.8   26.8   83.5
2012   311   20.1   29.6   27.2   -99   1.3   24.0   28.2   77.6
2012   312   19.6   30.2   27.1   -99   1.4   24.3   28.5   77.8
2012   313   17.8   28.8   27.5   -99   1.4   24.7   28.1   81.6
2012   314   16.8   28.6   27.3   -99   1.5   24.8   27.9   83.0
2012   315   17.1   28.2   26.9   -99   2.1   24.6   27.4   84.2
2012   316   12.0   28.4   27.0   -99   1.6   24.6   27.5   83.7
2012   317   16.1   28.5   27.0   -99   1.9   24.5   27.6   83.2
2012   318    -99   28.7   27.3   -99   1.7   24.6   27.9   82.1
2012   319   19.0   29.2   27.2   -99   1.6   24.6   28.1   81.0
2012   320   19.6   29.4   27.4   -99   2.3   24.7   28.4   80.2
2012   321   20.4   30.4   27.8   -99   2.2   24.8   28.9   78.1
2012   322   10.9   28.8   27.4   -99   3.0   25.3   28.0   85.2
2012   323   17.0   29.2   27.0   -99   2.1   24.7   28.1   81.8
2012   324   12.7   28.4   27.5   -99   1.9   24.5   27.9   81.8
2012   325   19.7   28.6   27.1   -99   1.7   24.2   27.9   79.7
2012   326   18.9   28.6   26.7   -99   3.0   24.4   27.6   82.3
2012   327   14.7   28.8   26.9   -99   2.6   24.7   27.8   83.0
2012   328   12.6   29.1   26.7   -99   2.7   24.5   27.6   83.2
2012   329   19.8   27.5   26.2   -99   3.3   24.4   26.8   86.8
2012   330   18.6   28.6   26.3   -99   3.1   24.3   27.2   83.8
2012   331   14.7   27.9   26.6   -99   2.8   24.5   27.2   85.5
2012   332   19.3   28.0   26.6   -99   1.8   24.6   27.2   85.3
2012   333   16.8   28.5   27.1   -99   1.2   24.5   27.9   81.8
2012   334    -99   28.5   26.7   -99   2.4   24.6   27.5   83.7
2012   335   17.0   28.5   26.8   -99   2.6   24.9   27.5   85.3
2012   336   16.6   28.3   26.7   -99   2.8   24.6   27.3   85.1
2012   337   17.5   29.3   27.2   -99   1.6   24.4   28.1   79.9
2012   338   16.6   28.5   26.6   -99   1.5   24.5   27.5   83.8
2012   339   19.3   29.3   26.9   -99   1.7   24.3   27.9   80.4
2012   340   14.1   28.9   25.6   -99   2.6   23.8   27.2   81.8
2012   341   19.9   29.2   26.3   -99   1.4   24.2   28.0   79.3
2012   342   19.1   29.4   26.8   -99   1.4   24.5   28.2   79.7
2012   343   20.7   29.6   27.7   -99   1.3   24.4   28.5   78.3
2012   344   17.6   28.5   26.9   -99   1.7   24.8   27.6   84.6
2012   345   15.4   28.7   26.7   -99   1.5   24.3   27.6   81.8
2012   346   14.8   28.7   27.0   -99   1.1   23.8   27.8   78.9
2012   347   17.8   28.0   26.2   -99   2.6   24.1   27.1   83.4
2012   348   18.2   28.6   26.7   -99   1.2   24.2   27.7   81.0
2012   349    -99   29.0   26.9   -99   1.2   24.4   28.1   80.1
2012   350    -99   29.0   27.5   -99   1.3   24.3   28.2   79.2
2012   351    -99   28.3   27.0   -99   1.3   24.2   27.7   81.0
2012   352    -99   28.9   26.5   -99   1.5   24.6   27.7   82.9
2012   353    -99    -99    -99   -99   -99    -99    -99    -99
2012   354    -99    -99    -99   -99   -99    -99    -99    -99
2012   355    -99    -99    -99   -99   -99    -99    -99    -99
2012   356    -99    -99    -99   -99   -99    -99    -99    -99
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50

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2012   357   -99   -99   -99   -99   -99   -99   -99   -99
2012   358   -99   -99   -99   -99   -99   -99   -99   -99
2012   359   -99   -99   -99   -99   -99   -99   -99   -99
2012   360   -99   -99   -99   -99   -99   -99   -99   -99
2012   361   -99   -99   -99   -99   -99   -99   -99   -99
2012   362   -99   -99   -99   -99   -99   -99   -99   -99
2012   363   -99   -99   -99   -99   -99   -99   -99   -99
2012   364   -99   -99   -99   -99   -99   -99   -99   -99
2012   365   -99   -99   -99   -99   -99   -99   -99   -99
2012   366   -99   -99   -99   -99   -99   -99   -99   -99
```

Appendix C:

PSO algorithm codes:

```matlab
function [y1,y2] = fcn(Ipv,Ppv)
%% Initialization

n = 3;            % Size of the swarm " no of birds "
bird_setp  = 50; % Maximum number of "birds steps"
dim = 2;          % Dimension of the problem

c2 =1.2;          % PSO parameter C1
c1 = 0.12;        % PSO parameter C2
w =0.9;           % pso momentum or inertia


%    initialize the parameter %


R1 = rand(dim, n);
R2 = rand(dim, n);
current_fitness =0*ones(n,1);

% Initializing swarm and velocities and position %

current_position = 0*(rand(dim, n)-.5);
velocity = 0*randn(dim, n) ;
local_best_position  = current_position ;
globl_best_position = local_best_position;




%    Evaluate initial population          %



for i = 1:n
    current_fitness(i) = max (Ppv);
end


local_best_fitness  = current_fitness ;
[global_best_fitness,g] = max(local_best_fitness) ;

for i=1:n
    globl_best_position(:,i) = local_best_position(:,g) ;
end

%  VELOCITY UPDATE  %


velocity = w *velocity + c1*(R1.*(local_best_position-
current_position)) + c2*(R2.*(globl_best_position-
current_position));


%   SWARMUPDATE    %
```

```matlab
current_position = current_position + velocity ;

%  evaluate new swarm    %


%% Main Loop
iter = 0 ;          % Iterationscounter
while  ( iter < bird_setp )
iter = iter + 1;

for i = 1:n,
current_fitness(i) = Ppv ;

end


for i = 1 : n
if current_fitness(i) > local_best_fitness(i)
            local_best_fitness(i)  = current_fitness(i);
            local_best_position(:,i) = current_position(:,i)    ;
end
end


 [current_global_best_fitness,g] = max(local_best_fitness);


if current_global_best_fitness > global_best_fitness
   global_best_fitness = current_global_best_fitness;

for i=1:n
        globl_best_position(:,i) = local_best_position(:,g);
end

end


 velocity = w *velocity + c1*(R1.*(local_best_position-
current_position)) + c2*(R2.*(globl_best_position-
current_position));
 current_position = current_position + velocity;



end% end of while loop


 [PVmppt,I] = max(current_fitness) % minimum fitness
 [PV,I] = min(current_fitness)
 current_position(:,I)

  y1 = PVmppt;
  y2= PV;
```