# PV Module based water pumping system

Final Report

*Submitted by*


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**Abstract**

This report deals with the simulation and design of a simple and efficient photovoltaic water pumping system. It gives theoretical studies of photovoltaics and designing techniques using equivalent electric circuits. The system also has a maximum power point tracker (MPPT). The report includes discussion of various MPPT algorithms and control methods. MATLAB simulations verifies the DC-DC converter design and it performs tests on two popular MPPT algorithms using various irradiance data. The report works on the output sensing direct control method because fewer sensors are required. This allows a lower cost system. Each subsystem is designed in order to simulate the whole system in MATLAB. MATLAB simulations verifies the system and and design of MPPT. Simulations also make comparisons with the system with MPPT Incremental Conductance algorithm and P and O algorithm. The results tells us that MPPT can significantly increase the efficiency and the performance of PV water pumping system relative to the system without MPPT.

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# Chapter 1

# INTRODUCTION

In this project, a simple but efficient photovoltaic water pumping system is presented. It gives the theoretical studies of photovoltaics (PV) and its modeling techniques. It also investigates in detail the maximum power point tracker (MPPT), a power electronic device that significantly increases the system efficiency. At last, it presents MATLAB simulations of the system and makes comparisons with a system without MPPT.

## 1.1 Background and Motivation

Water assets are basic for fulfilling human needs, securing wellbeing, and guaranteeing sustenance creation, vitality and the rebuilding of biological systems, just as for social and monetary improvement and for practical advancement . In any case, as indicated by UN World Water Development Report in 2003, it has been assessed that two billion individuals are influenced by water deficiencies in more than forty nations, and 1.1 billion don't have adequate drinking water. There is an incredible and pressing need to supply naturally stable innovation for the arrangement of drinking water. Remote water siphoning frameworks are a key part in gathering this need. It will likewise be the principal phase of the refinement and desalination plants to create consumable water.

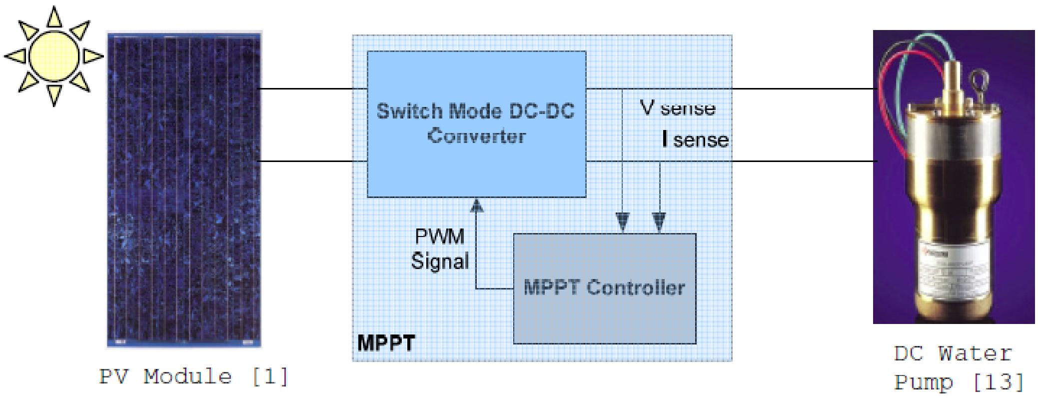
## 1.2 Literature Review

This report deals with the design and simulation of a simple but efficient photovoltaic water pumping system. It provides theoretical studies of photovoltaics and modeling techniques using equivalent electric circuits. The system has the maximum power point tracker (MPPT). The topic includes discussion on various MPPT algorithms and control methods. Matlab Simulink verifies the various designs. The report decides on the output sensing direct control method because it requires fewer sensors. This allows a lower cost system. Each system is modeled in order to simulate the whole system in MATLAB.

## 1.3 Objectives

To reduce the wastage of water resource and rely mainly on renewable resources as non renewable resources are limited in nature.

We have tried to make the system more efficient and tried to use less power. The main components are PV Panel, MPPT, Cuk converter, RL(motor) load. The assumption made is there are no losses in voltage or current from PV module to dc-dc converter.



# Chapter 2

# BACKGROUND THEORY

- This chapter deals with the 4 main parts of our system:
  1.PV module
  2.MPPT
  3.DC-DC converter design
  4.Water Pump as RL load

  The PV module consists of solar cells of rating 150W which is the input to the DC-DC converter, the DC-DC converter manipulates the voltage so that the water pump can work at its designated voltage level. The MPPT which is the Maximum Power Point Tracker work tracks the Voltage vs Current curve of the module and brings out the point where the power is maximum and hence improves the efficiency of the system.

## 2.1 Introduction

Our project deals with a PV module being a source to the DC-DC converter which provides the requisite amount of energy to pump the water out of the ground.

### 2.1.1 PV Module

Photons of light with vitality higher than the band-hole vitality of PV material can make electrons in the material break free from atoms that hold them and create hole electron pairs. These electrons, in any case, will before long fall again into holes causing charge transporters to vanish. On the off chance that an adjacent electric field is given, those in the conduction band can be consistently cleared far from openings toward a metallic contact where they will develop as an electric flow. The electric field inside the semiconductor itself at the intersection between two regions of crystals of different type called a p-n intersection. The

PV cell has electrical contacts on its top and base to catch the electrons. At the point when the PV cell conveys power to the load, the electrons stream out of the n-side into the interfacing wire, through the load, and back to the p-side where they recombine with holes. Note that regular current flows the other way from electrons.

We can accomplish a progressively pragmatic PV model by considering

i)Series resistance

In a practical PV cell, there is a series of resistance in a current path through the semiconductor material,contacts, metal grid, and current collecting node. These resistive losses are added together as a series resister (Rs).Its impact turns out to be very significant in a PV module that comprises of numerous arrangement associated cells, and the estimation of obstruction is increased by the quantity of cells.

ii)Parallel resistance

This is also known as shunt resistance. It is a misfortune related with a little leakage of current through a resistive path in parallel with the intrinsic device. This can be shown as a parallel resister (Rp). Its impact is considerably less significant in a PV module contrasted with the arrangement opposition, and it will possibly wind up valuable when various PV modules are associated in parallel are exceptionally huge.

iii)Recombination diode

Recombination in the depletion area of PV cells gives non-ohmic current paths in parallel with the intrinsic PV cell.

A solitary PV cell creates a yield voltage of 0.6 V for crystalline silicon (Si) cells, in this manner various PV cells are associated in arrangement to get an ideal yield voltage. At the point when arrangement associated cells are put together, it is known as a module. The greater part of market accessible PV modules with crystalline Si cells have either 36 or 72 arrangement associated cells. A 36 cell module gives a voltage reasonable to charging a 12 V battery, and comparably a 72 cell module is useful for a 24 V battery. This is on the grounds that most of PV frameworks used to have reinforcement batteries, anyway today numerous PV frameworks don't utilize batteries. Model, matrix tied frameworks and the coming of high effectiveness Cuk converters has expanded the requirement for modules with explicit voltages. At the point when the PV cells are included in arrangement, the present yield is equivalent to the single cell, however the voltage yield is the aggregate of every single cell voltage. PV cells are associated in arrangement to make up a PV module Likewise, numerous modules can be included in arrangement or parallel to convey the voltage and current dimension required. The gathering of modules is called an array.

We are utilizing BP Solar BP SX 150S PV module and is likewise picked for a MATLAB simulink. The module is made of 72 multi crystalline silicon sun oriented cells in arrangement and gives 150W of ostensible greatest power.

Electrical Characteristics

Maximum Power (Pmax) 150W

Voltage at Pmax (Vmp) 34.5V

Current at Pmax (Imp) 4.35A

Open-circuit voltage (Voc) 43.5V

Short-circuit current (Isc) 4.75A

Temperature coefficient of Isc 0.065

Temperature coefficient of Voc -160 mV/ oC

Temperature coefficient of power -0.5

The PV module which we have made using Matlab has three inputs:

1.Va = Module operating voltage (V)

2.G = irradiance (1G = 1000 W/$m^2$)

3.$TaC = inC$

and Ia = Module operating current (A) as the output.

A Matlab code with these inputs and outputs are in Appendix section.

The PV module is connected to a controlled current source.The use of controlled currect source block is it converts the Simulink input signal into an equivalent current source. The generated current is driven by the input signal of the block.

The array is used because array operations execute element by element operations on corresponding elements of vectors, matrices, and multidimensional arrays. If the operands have the same size, then each element in the first operand gets matched up with the element in the same location in the second operand. If the operands have compatible sizes, then each input is implicitly expanded as needed to match the size of the other.

A diode is added to the circuit in reverse bias for the recombination.

The output graph of the PV Panel is shown in results.

### 2.1.2 DC-DC Converter

The main part of MPPT is a switch mode DC-DC converter. It is mainly used in DC power supplies and DC motor drives for the purpose of converting unregulated DC input in a very much controlled DC output at a desired voltage level. MPPT uses the same converter for a different purpose: regulating the input voltage at the PV MPP and providing loadmatching for the maximum power transfer.

1.DC-DC converter topologies-

There are a number of different topologies for DC-DC converters. They are divided into isolated and non isolated topologies. The isolated topologies use a small-sized high-frequency electrical isolation transformer that provides the benefits of DC isolation between its input and output, and step up or down of output voltage by changing the transformer turns ratio. They are very often used in switch mode DC power supplies. Popular topologies for a majority of the applications are flyback, half-bridge, and full-bridge. In PV applications, the grid-tied systems commonly use these types of topologies when electrical isolation is adviced for safety purposes.

Non-isolated topologies don't have isolation transformers. They are always used in DC motor drives. These topologies are later categorized in three types: step down (buck), step up (boost), and step up and down (buck boost). The buck topology is used for voltage step down. In application of PV the buck type converter is usually used for charging batteries. The boost topology is used for stepping up the voltage. The given systems use a boost like converter to step up the output voltage to the particular level before the inverter stage. Then, there are topologies that are able to step up and down the input voltage such as Cuk, buck boost and SEPIC (stands for Single Ended Primary Inductor Converter). For PV system with batteries the MPP of commercial PV module is adjusted little above the charging voltage of batteries for many combinations of irradiance and temperature. A buck converter can work at the MPP under most situations but it can't do so when the MPP goes below the battery charging voltage under a low irradiance and high temperature condition. Thus, the boost capability can slightly increase the overall efficiency .

2.CUK Converter-

For water pumping system the output voltage needs to be stepped down to provide a high starting current for a motor. The buck converter is the simple topology and easy to understand and design, however it has the most severe destructive failure mode of all configurations . Another loss is that the input current is not continuous because of the switch situated at the input so good input filter design is essential. Another topology capable of voltage step-down is Cuk converter. Even though its voltage step up function is optional, it has many advantages over the buck converter. It provide capacitive isolation which protects from switch failure (unlike the buck topology) . The input current of the Cuk topology is continuous and it can draw a ripple free current from a PV module which is important for efficient MPPT.

The specifications of the cuk converter are-

Input Voltage (Vs) 20-48V

Input Current (Is) 0-5A

Output Voltage (Vo) 12-30V

Output Current (Io) 0-5A
Maximum Output Power (Pmax) 150W
Switching Frequency (f) 50KHz
Duty Cycle (D) 0.1 to D to 0.6

### 2.1.3 MPPT

When a PV module is coupled to a load, the PV modules operating point will be at the point of intersection of its IV curve and the load line which is the I-V relationship of load. Example- resistive load has a straight line with a slope of 1/R. Simply, the impedance of load guides the operating condition of the PV module. Generally, this operating point is rarely at the PV modules MPP, so it is not producing the maximum power. A experiment shows that a direct coupled system consumes around 31 percent of the PV capacity . A PV array is normally oversized to compensate for a low power output during winter days. The mismatching between a PV module and a load requires further over sizing of the PV array and thus it increases the overall cost of the system. To solve this issue, a maximum power point tracker (MPPT) can be used to maintain the PV modules operating point at the MPP. MPPTs can extract more than 97 percent of the PV power when properly used.
There are two types of alogorithm used by us for maximum power point tracking-
1.Perturb Observe Algorithm-The perturb observe (PO) algorithm, aka hill climbing method,is popular and is commonly used in practice because of its simplicity in algorithm and the ease of implementation.In this algorithm the operating voltage of the PV module is perturbed by a very small increment, and the resulting change of power, Delta P, is observed. If the Delta P is positive, then it has moved the operating point nearer to the MPP. And if Delta P is negative then it has moved the operating point further from MPP and the direction of perturbation should be reversed to move back toward the MPP. The PO algorithm Matlab code is in Appendix section.
2.Incremental Conductance Algorithm-The idea of this algorithm is that the slope of P-V curve becomes zero at the MPP. It is possible to get a relative location of the operating point to the MPP by just looking at the slopes. The slope is a derivative of the PV module power with respect to its voltage and has following relations with the MPP.
dV/dP is equal to 0 at MPP
dV/dP is greater than 0 at the left of MPP
dV/dP is less than 0 at the right of MPP
same direction should move the operating point toward the MPP if the delta P is

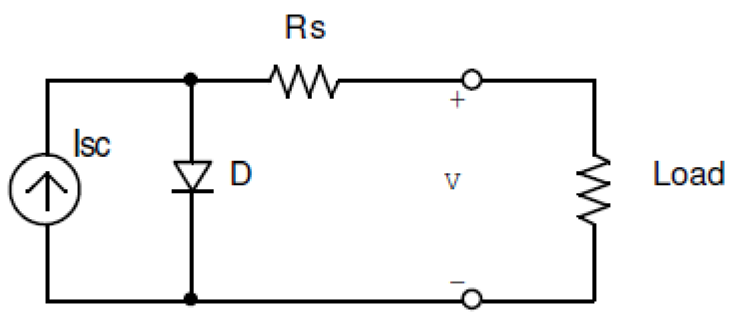
negative.
MATLAB simulations perform tests of the PO and incCond algorithm. Simulations also verifies the workinh of MPPT with a resistive load and then with the DC pump motor load(RL)

### 2.1.4 DC Motor

The stream rate of water in positive relocation siphons is legitimately corresponding to the velocity of the pump motor, which is represented by the accessible driving voltage. They have steady burden torque to pump motos, and it is communicated by the all out powerful head as far as its comparable vertical segment of water; for instance, vertical lift and rubbing changed over to vertical lift .It has the ordinary working voltage of 12 to 30V and the most extreme intensity of 150W. In this project we have replaced the DC motor as an RL load as the equivalent circuit diagram can be represented as the same.

## 2.2 General circuit analysis

Equivalent circuit used in the MATLAB simulations

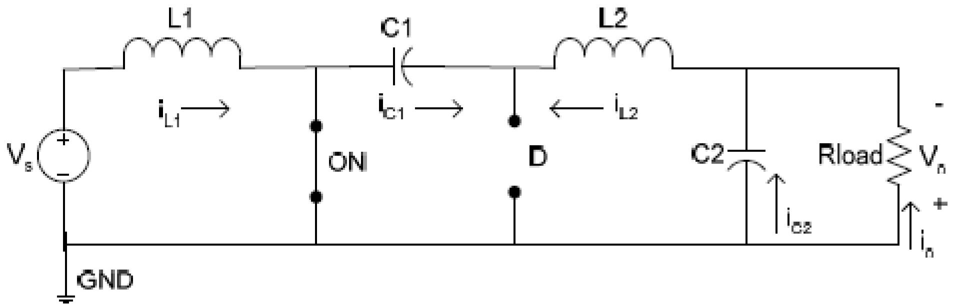



The tactic of designing a PV module is not different from designing a PV cell. It uses the same PV cell model. The parameters are the all same, but only the voltage parameter (or open circuit voltage) is different and must be divided by the number of cells. The design consists of a current source (Isc), a series resistance (Rs) and a diode (D). The effect of parallel resistance (Rp) is negligible in a single module thus the design doesn't include it. To make it a better model it also includes temperature effects on the short circuit current (Isc) and the current of reverse saturation of diode (Io). It uses a single diode with the diode ideality factor (n) set to get the best I-V curve match.

CUK CONVERTER DESIGN

The fundamental task of Ck converter in constant conduction mode is clarified here. In unfaltering state, the normal inductor voltages are zero, in this manner by applying Kirchoff's voltage law (KVL) around furthest circle of the circuit appeared in the given figure. C s o V = V +V1 Accept the capacitor (C1) is huge enough and its voltage is sans swell despite the fact that it stores furthermore, move enormous measure of vitality from contribution to yield (this requires a decent low ESR capacitor ). The underlying condition is the point at which the info voltage is turned on and switch (SW) is off. The diode (D) is forward one-sided, and the capacitor (C1) is being charged. The task of circuit can be isolated into two modes.

MODE 1-SWITCH is ON

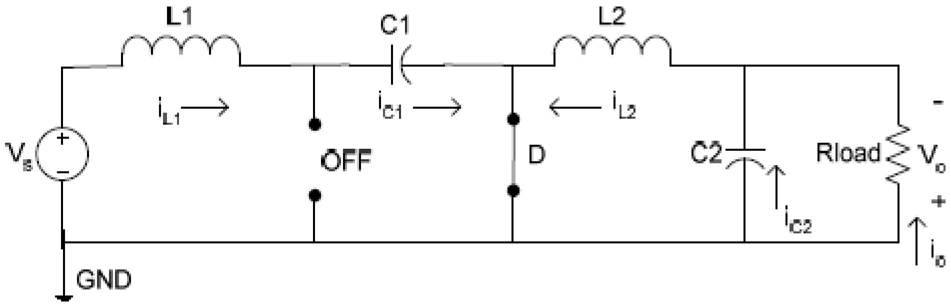



The voltage of the capacitor (C1) makes the diode (D) invert one-sided and killed.

The capacitor (C1) release its vitality to the heap through the circle framed with SW, C2, Rload,

what's more, L2. The inductors are enormous enough, so accept that their flows are without ripples. Along these lines, the accompanying relationship is set up.
Ic1=Ic2

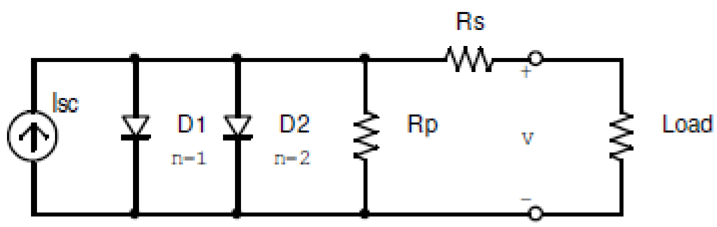
MODE 2-SWITCH IS OFF




The capacitor (C1) is getting charged by the voltage input (Vs) through the inductor (L1). The amount of energy that is stored in the inductor (L2) is move to the load through the circuit framed by D, C2 and resistance R. In this way, the accompanying relationship is set up
Ic1=Ic2

Its relationship to the duty cycle (D) is: If 0 ¡ D ¡ 0.5 the output is smaller than the input.
If D = 0.5 the output is the same as the input.
If 0.5 ¡ D ¡ 1 the output is larger than the input.

- Fundamental mathematical derivations
  Accurate and practical PV module circuit is designed as




Adding these effects, the current and voltage relationship of PV module is written as:

$$I = Isc - Io1[e^q(V + I.Rs/(kT)] - Io2[e^q(v + I.Rs/(2kT)) - 1] - (V + I.Rs)/Rp(2.1)$$

If we combine the first diode (D1) and the second diode (D2) and rewrite the equation in the given form.

$$I = Isc - Io[e^q(V + I.Rs/(nkT)] - (V + I.Rs)/Rp \tag{2.2}$$

Derivatons related to cuk converter are:

Assuming that this is an ideal converter, the average power supplied by the source must be the same as the average power absorbed by the load

$$Pin = Pout \tag{2.3}$$

$$VsI1 = VoI2 \tag{2.4}$$

$$Il1/Il2 = Vo/Vs \tag{2.5}$$

Calculation of inductances and capacitances in Cuk Converter:

For periodic operations the average capacitor current is zero
Il1/Il2=D/(1-D)
L=Vs.D/(Change in iL.f)
C1=Vo.D/(R.f.Change in voltage across the capacitor C1)
C2=1-.D/(8.L2.F$^2$.$(Rate of Change in output voltage)$

# Chapter 3

# METHODOLOGY

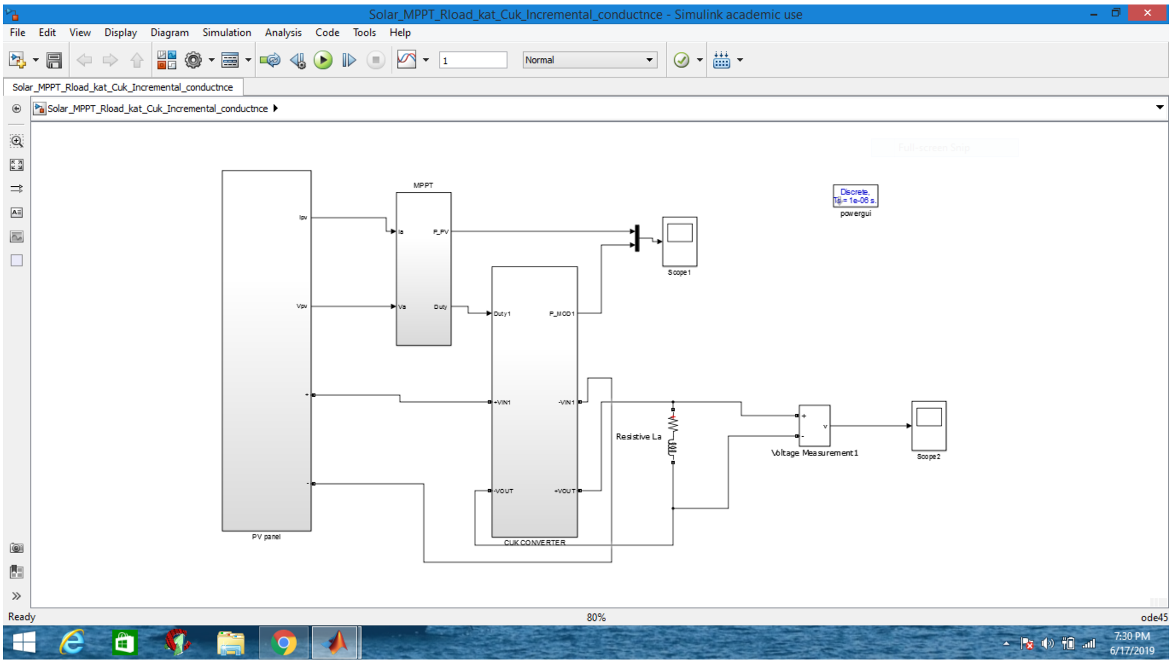
## 3.1 Introduction

This section deals with the tools and software we have used to simulate the I-V characteristics.The softwares used is MATLAB .This section also deals with our approach towards the topic and segregating the entire PV based water pumping system into sub systems and working individually on the the different sub systems which includes the PV based module,DC-DC converter,MPPT and the pump.

## 3.2 Proposed Solution

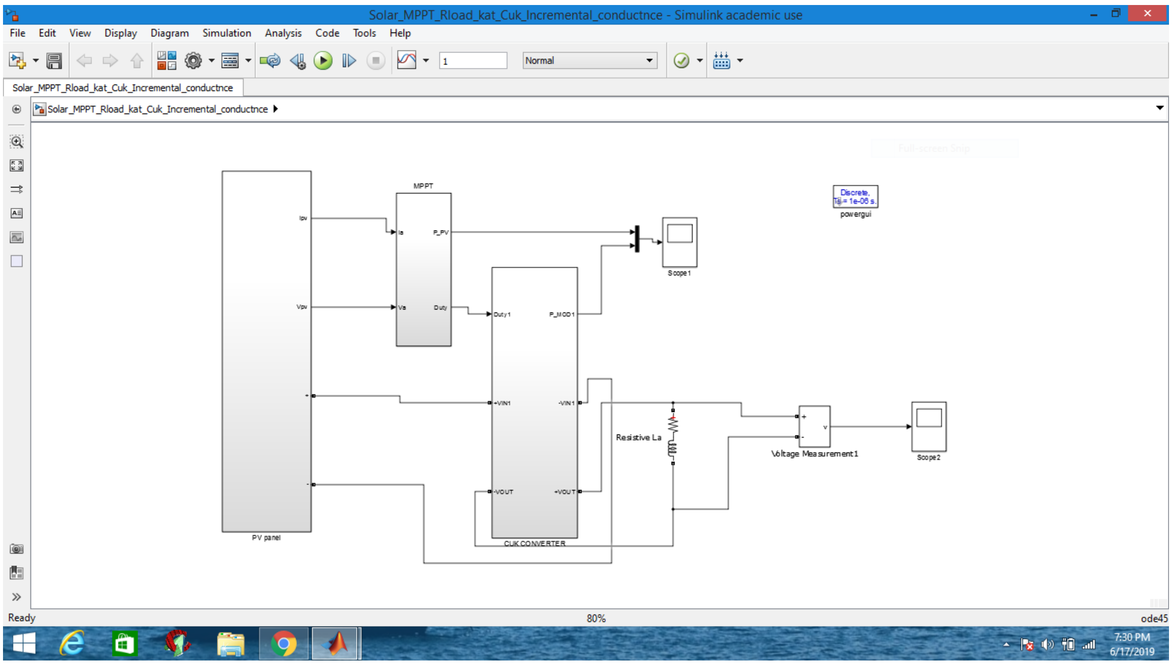
The Matlab Simulink model of our project is-

1.Whole PV system (with incremental conductance)(RL)-
The figure shows the different simulink blocks to make the project.It shows the connections of the PV module, MPPT and Cuk converter and the RL load.The MPPT algorithm used is Incremental Conductance.



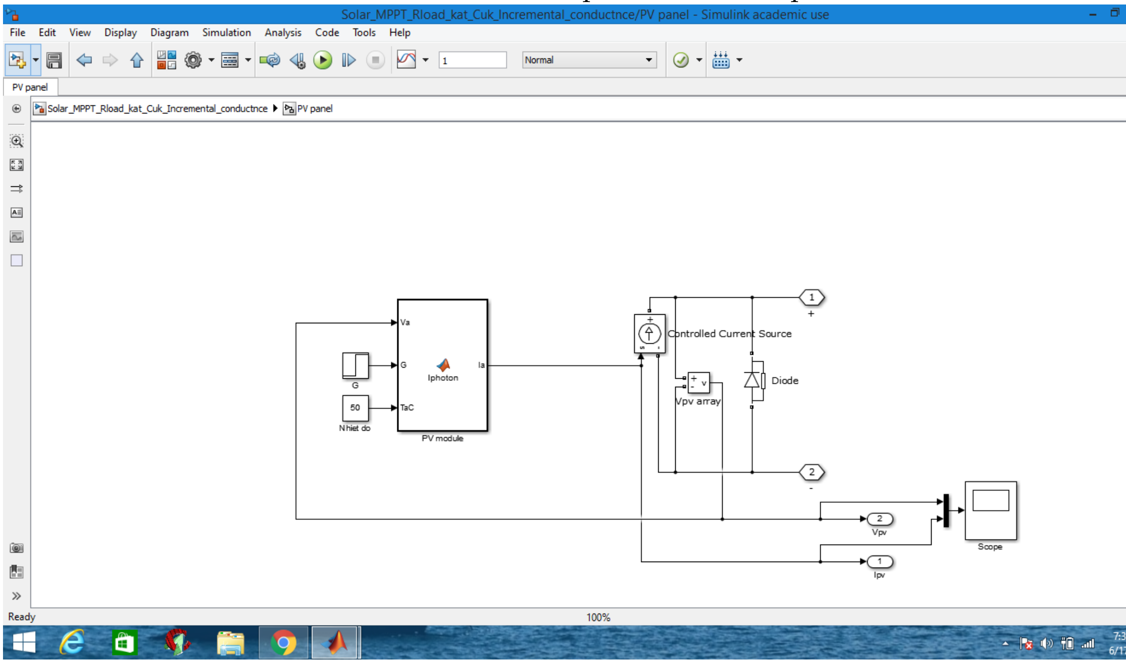

2.Whole PV system (with PO algorithm)(RL)-

The figure shows the different simulink blocks to make the project.It shows the connections of the PV module, MPPT and Cuk converter and the RL load.The MPPT algorithm used is Perturb and Observe.




3.PV panel-

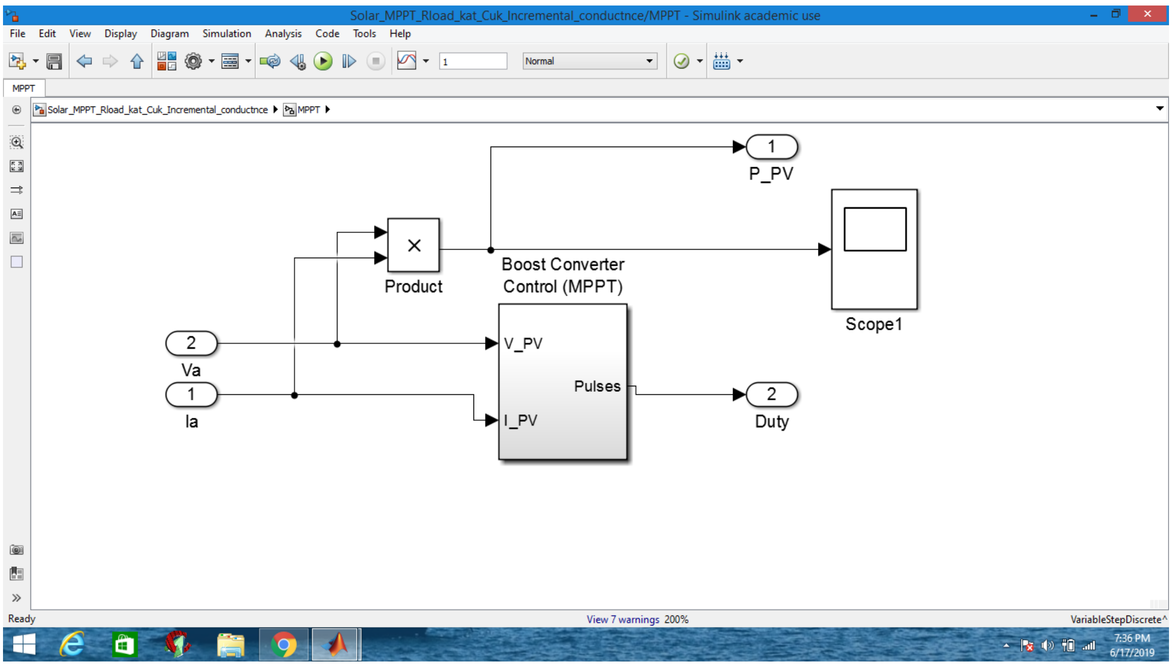
The Iphoton block contains a series of code which generates the module current.The inputs to the bpsx150s are operating voltage,irradiance and module temperature.The pv module consists of a series of 72 cells and the current source provides the requisite cur-




rent. panel.PNG

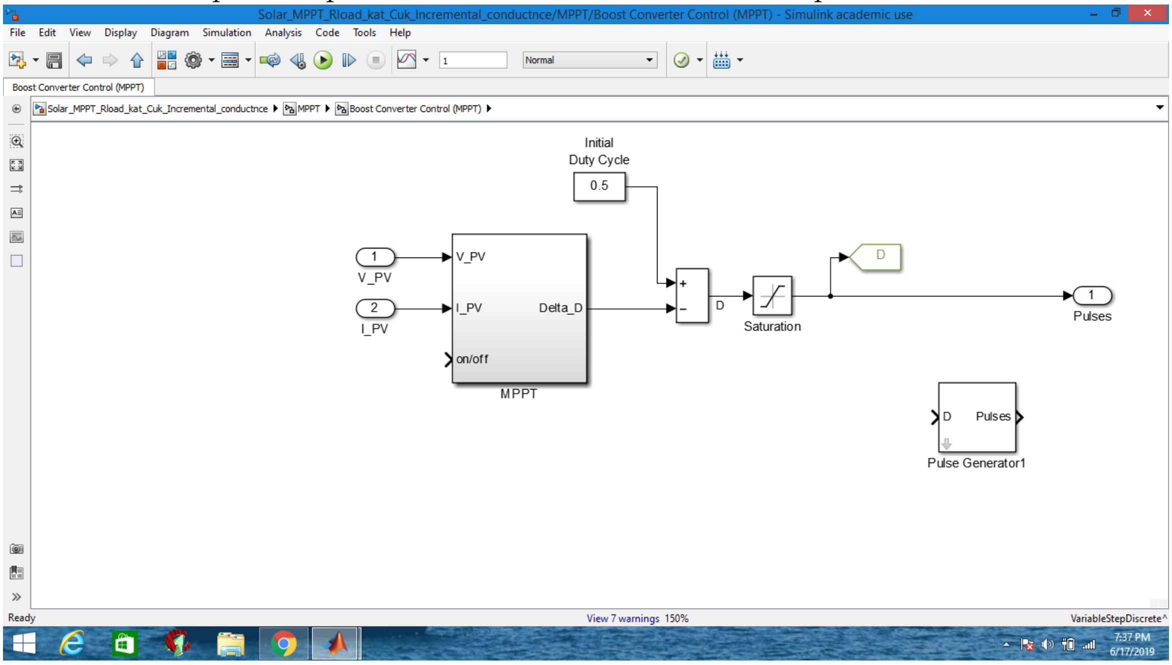
4.MPPT (with incremental conductance)-

The inputs to the heart of the incremental conductance MPPT are Va and Ia which are taken as VPV and IPV.The circuit inside the block helps in calculating the duty cycle which is shown as an output terminal.The product of current and voltage gives us the power output of the mppt.




5.Inside MPPT-

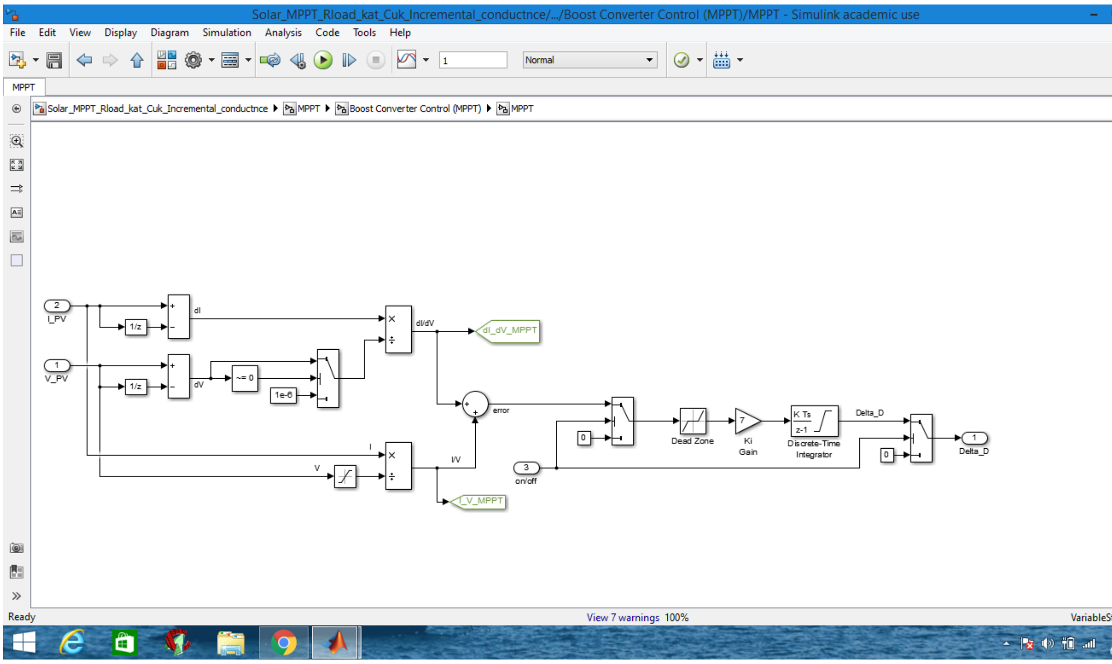
Here the vpv and ipv enter the mppt block the output which we get is the change in duty cycle delta D which forms the negative part of the saturation block and the initial duty cycle of 0.5 forms the positive part of the saturation block.The output is the final




duty cycle.

6.Mathematical Calculation inside MPPT-

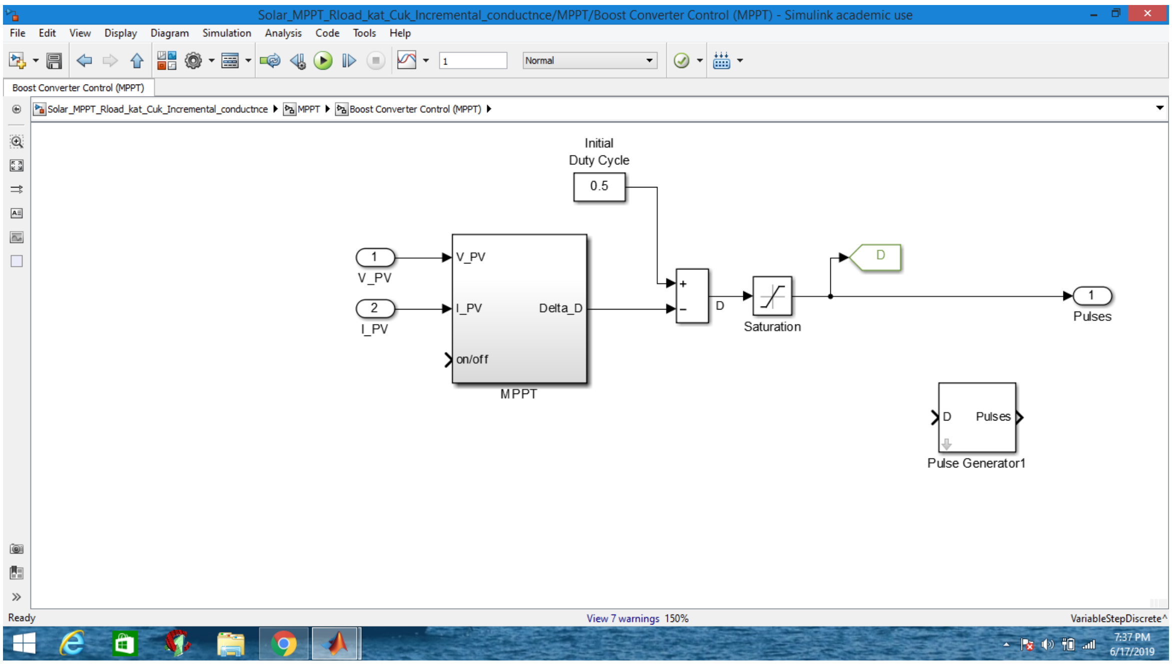
This figure shows what all components were required to make the core of the incremental conductance the inputs being the same the current and voltage is fed to respective blocks which calculates the change in voltage and current.The three way switches make or break the current and voltage components.At the end of the figure we are also adding some error and creating a feedback with a PI controller.The output in this figure is the change in duty cycle which along with the initial duty cycle gives us the entire duty cycle. mppt11.PNG




## 7.MPPT (with PandO algorithm)-

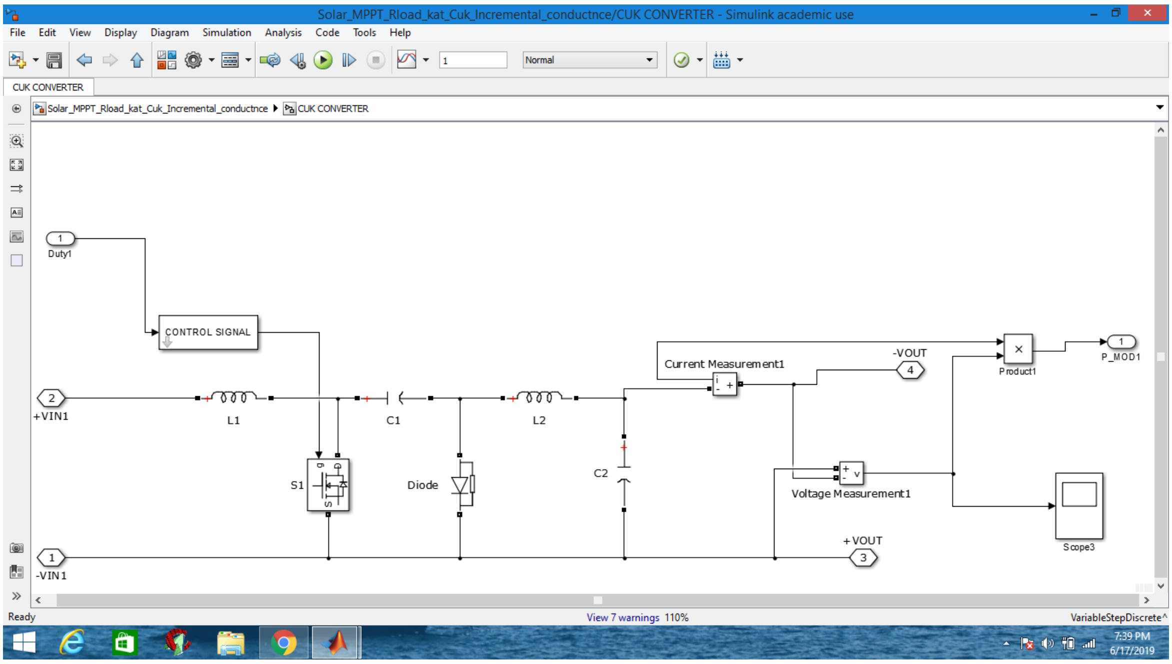
Here the inputs are current,voltage and a clock.Th product block gives the output power which can be seen in the scope.The other output which we can see is the duty cycle.The series of code inside the matlab function gives us the duty cycle.

MPPT.PNG




## 8.Cuk converter-

The cuk converter shows a combination of inductors and capacitors. Thhe control signal works on the duty cycle calculated from the MPPT algorithm.The positive and negative terminals have also been marked.The switch used here is a mosfet which is favourable for small range power application.The freewheeling diode helps in calculation of currents and voltages which are in turn measured by the componets. The current and the voltage measured gives the power and the current which flows through the RL load and the voltage across the load.




Th experimental water pumping system proposed here is a stand-alone type without backup batteries. The system is very simple and consists of a single PV module, a maximum power point tracker (MPPT), and a DC water pump. The size of the system is intended to be small. The system including the subsystems will be simulated to verify the functionalities.

The inputs and outputs of our system and sub systems are:

The inputs to the PV module is solar energy which senses the solar energy and produces voltage. The input to the cuk converter is current at a particular voltage and the output is elevated volatge. The input and output of the system as a whole is light energy and mechanical energy respectively.

Our project fits into situations where there is acute shortage of water and rural areas. Water resources are essential for satisfying human needs, protecting health, and ensuring food production, energy and the restoration of ecosystems, as well as for social and economic development and for sustainable development. However, according to UN World Water Development Report in 2003, it has been estimated that two billion people are affected by water shortages in over forty countries, and 1.1 billion do not

have sufficient drinking water. There is a great and urgent need to supply environmentally sound technology for the provision of drinking water. Remote water pumping systems are a key component in meeting this need. It will also be the first stage of the purification and desalination plants to produce potable water.
The software components used are Matlab and Simulink.

The main constraints include cost and the size of the model.Availability of the solar energy is also dicey.The output voltage at the end of the cuk converter fluctuates in harware form.

## 3.3 Implementation

We are using different simulation softwares to simulate the model through which we can track the current and voltage variation in the pv module and also track the power using MATLAB,which will be used in the MPPT.

### 3.3.1 Software Implementation

The software simulations done using Simulink are:
1.I vs t and V vs t characterstics of whole system.
2.P-V characterstics of whole system.
3.P-V characterstics of PV panel.
4.P-V characterstics of MPPT( Inc conductance algorithm).
5.P-V characterstics of MPPT( PO algorithm).
6.I-V characterstics of cuk converter.
7.I-V characterstics of whole system.(RL)
8.P-V characterstics of whole system.(RL)

# Chapter 4

# RESULT ANALYSIS

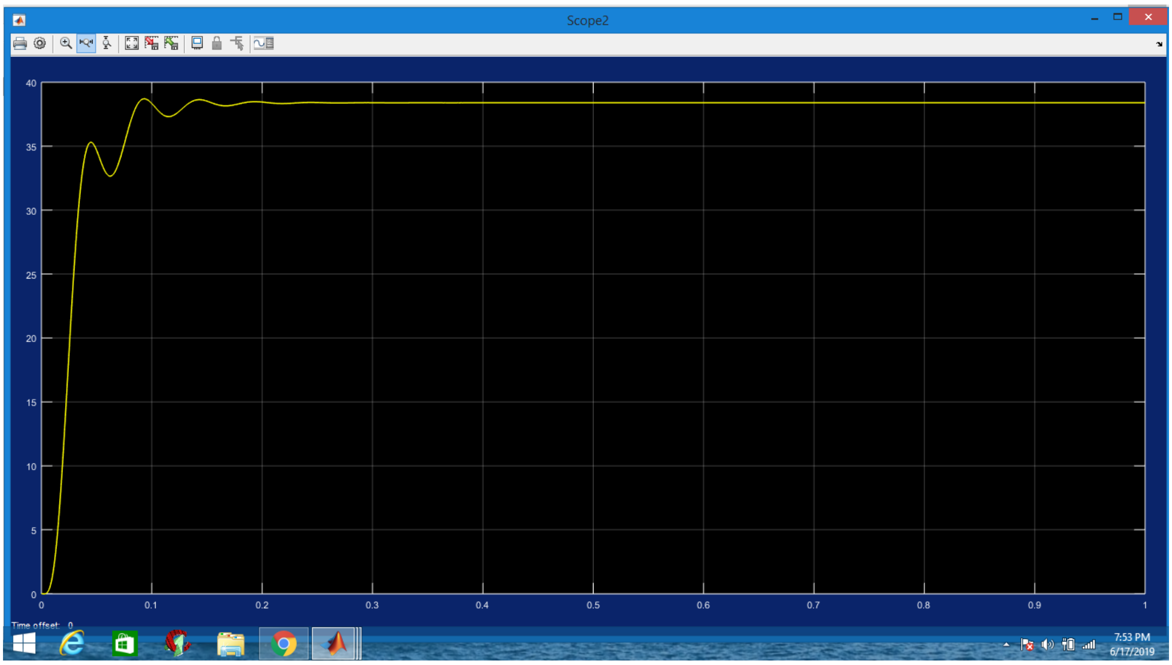
## 4.1 Introduction

This chapter deals with the different simulations we have done and their respective outputs.

## 4.2 Result Analysis

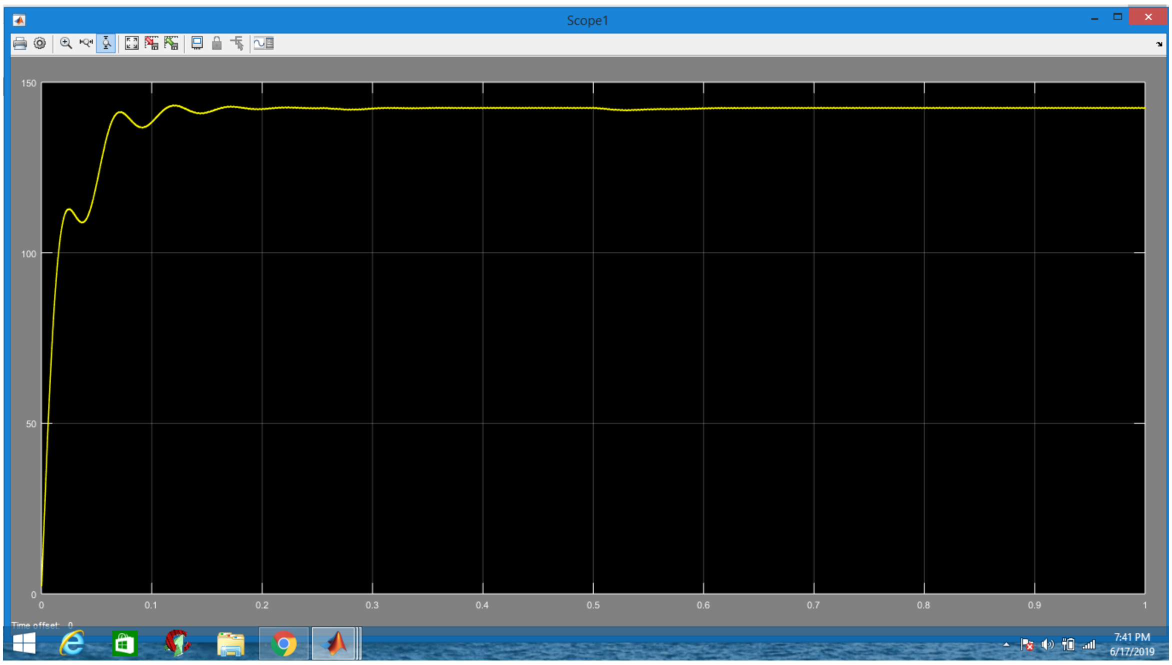
1.I vs t and V vs t plot of PV Panel-

It shows the variance in power and voltage with respect to time when the load is purely resistive the output being taken at the terminals of the pv module.



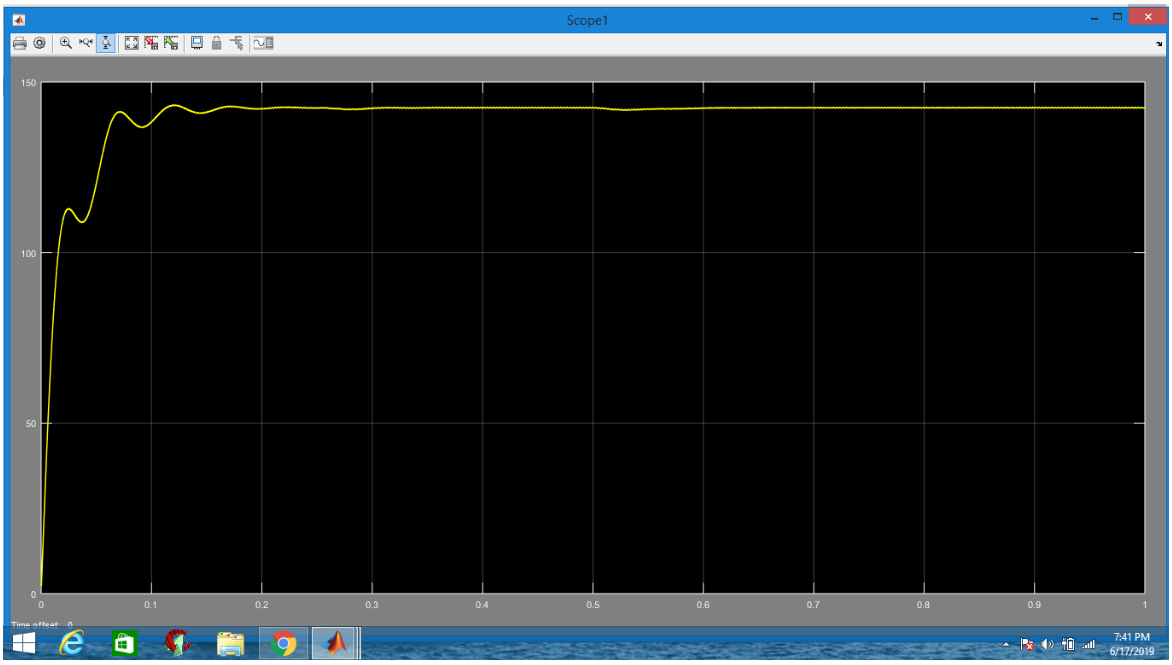
2.P-V vs t characterstics of MPPT (Inc. Conductance algorithm)

We have used Inc algorithm here to see the power and voltage variance with time and the output is taken at the end of the MPPT.



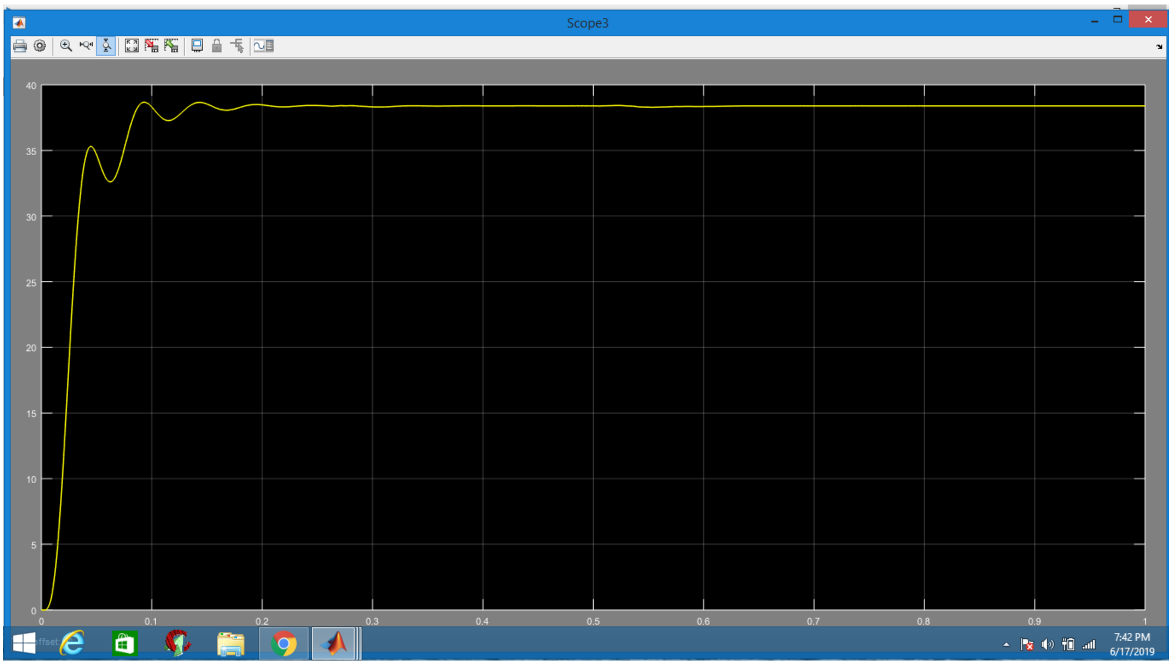

3.P vs t characterstics of MPPT (PO algorithm)

This graphs clearly brings out the difference between po and Incd algorithm with showing the nature of the curve and the output here also is taken at the end of the MPPT.



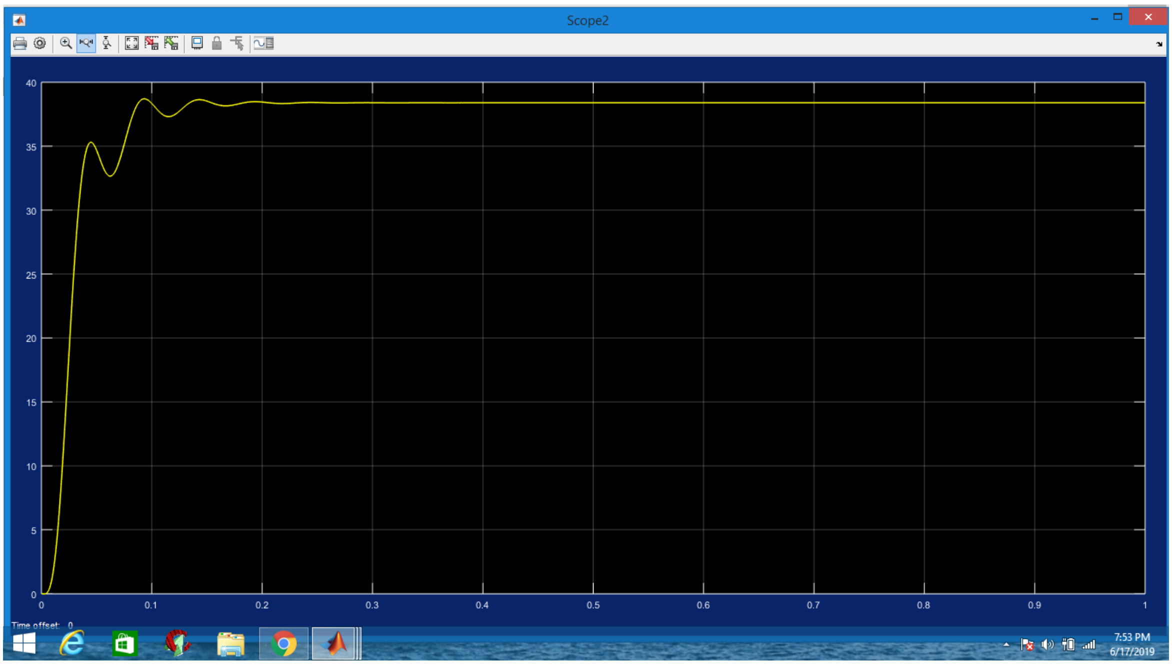
4.P vs t characterstics of Cuk Converter(Only R)-

This gives the nature of the graph seen the end of the Cuk converter but with pure resistive load.



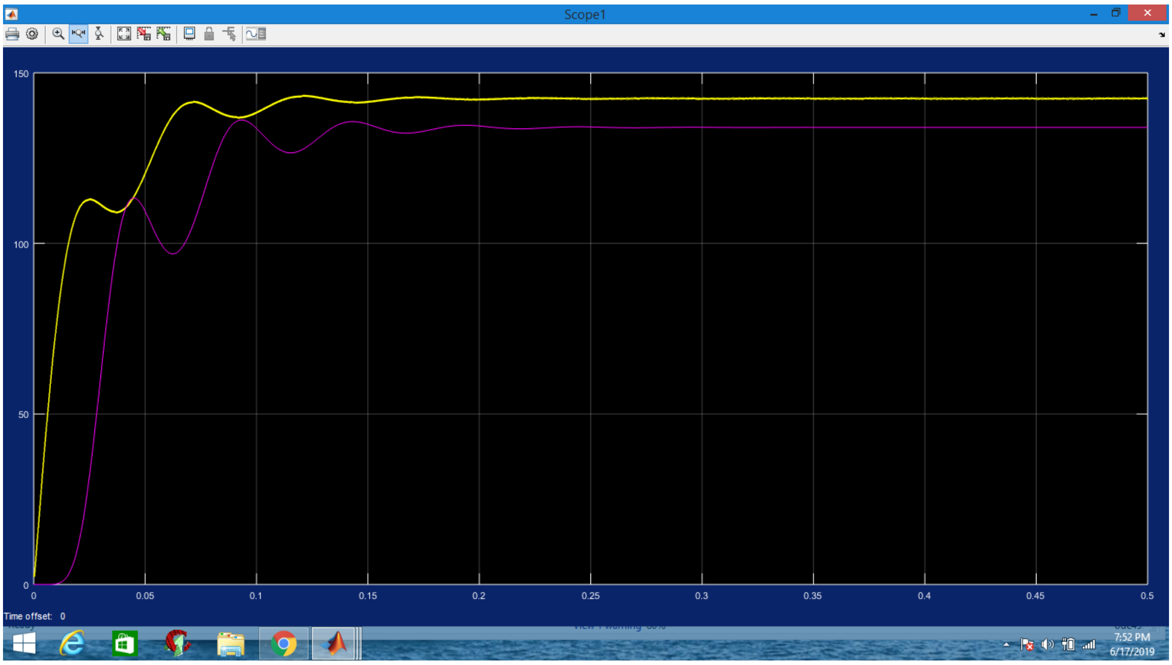

5.P vs t an V vs t characterstics of whole system (only R)-

It shows the variance in power and voltage with respect to time when the load is purely resistive and the output measured when PV module,MPPT and cuk converter is taken into consideration.



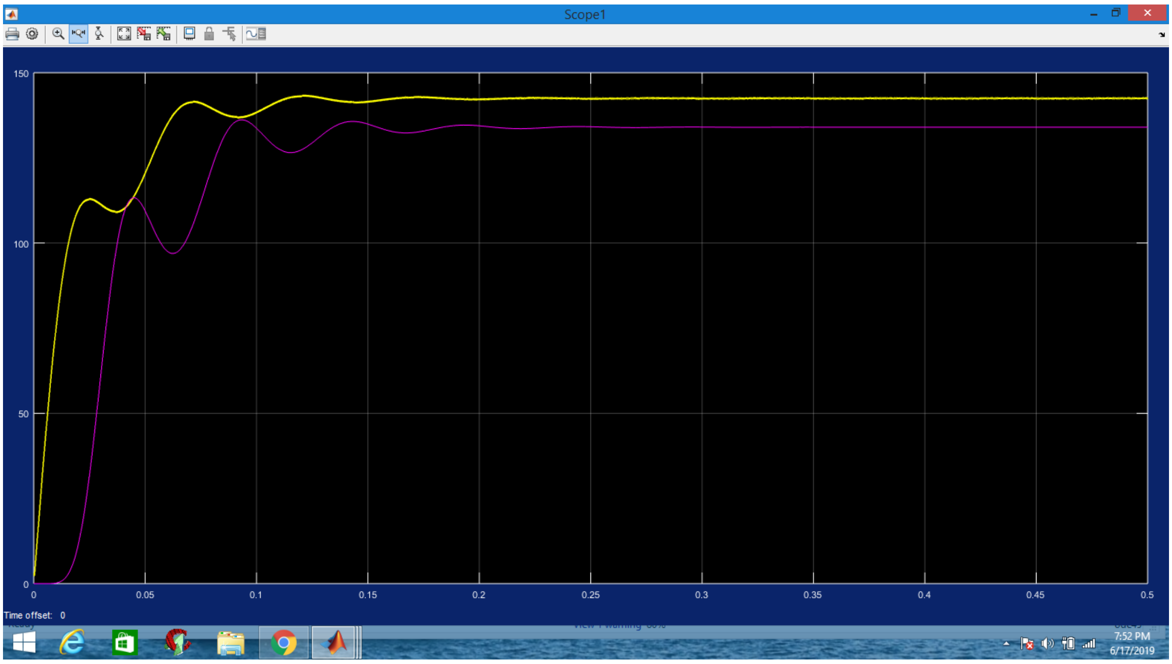

6. I vs t and V vs t characterstics of whole system (only R)-

It shows the variance in current and voltage with respect to time when the load is purely resistive.



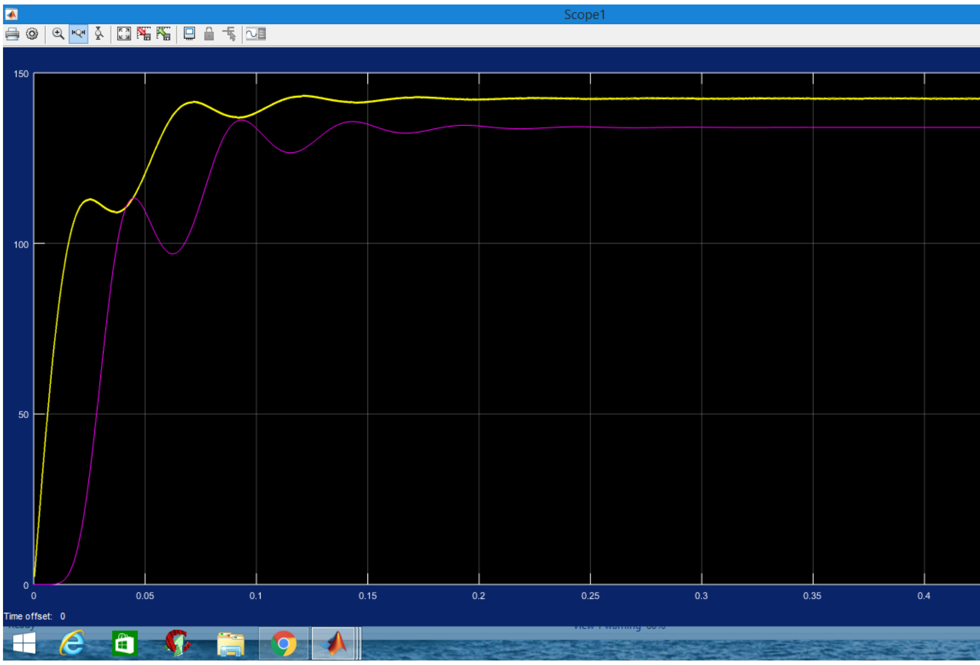

7. P vs t and V vs t characterstics of whole system (RL)-

From this graph we can clearly see that the value of the maximum power is close to 150W which is close to the rated value.The deviation might result from the use of resistor in series with an inductor rather than the exact model of the DC pump.

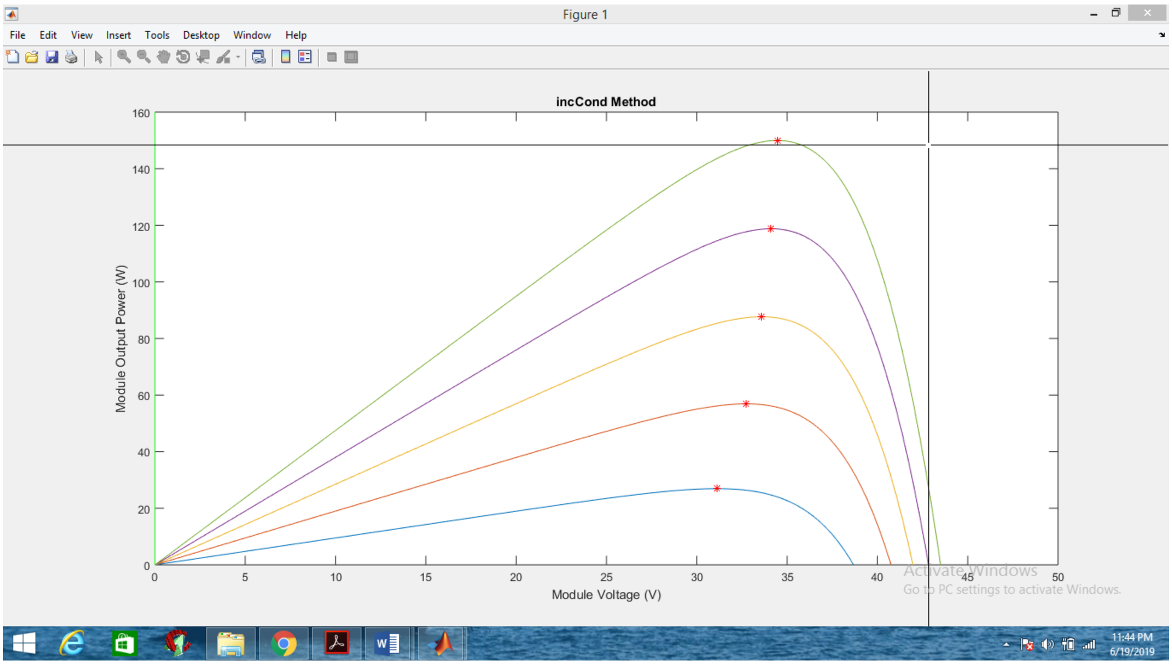


8. I vs t and V vs t characterstics of whole system (RL)-

In these graphs we are getting a value of 38V as maximum voltage and the value of the maximum current is 4.35 which is close to the rated values.

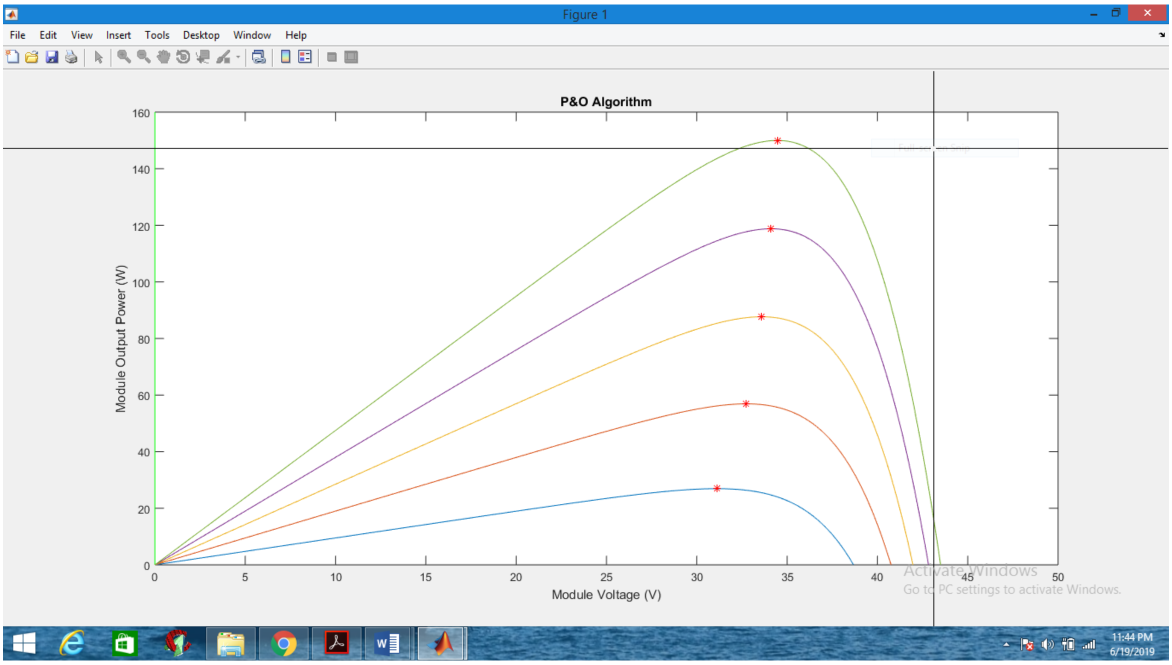
system scope 1 output.PNG 


9.P vs t and V vs t characterstics at various irradiance (inc conductance)-
The instaneous value of power is greater at a greater irradiance,the latter which actually measures the amount of solar energy incident on the panel.



10.P-V characterstics at various irradiance (PO algorithnm)-

It clearly shows that the effect of irradiance on power remains unaffected with change in MPPT algorithm.



# Chapter 5

# CONCLUSION

The thesis presents a simple and efficient photovoltaic water pumping system. WE designed each component and simulates the system using MATLAB and Simulink. The results shown in the PV model using the equivalent circuit in moderate complication provides us with good matching with the real PV module. Simulations perform relative tests for the two MPPT algorithms using irradiance data different weather conditions.The incCond algorithm shows better performance in terms of efficiency as compared to the PandO algorithm under the given weather condition. A small improvement in efficiency can bring large savings if the system is large. Since, it could be hard to justify the use of incremental Cond algorithm for small and low cost systems since it requires four sensors. In order to develop a simple and low cost system, we can adopt the direct control method which employs the PO algorithm and requires only two sensors for output. This control method offers another advantage of allowing steady state analysis of the DC to DC converter, as opposed to the more composite state space averaging method, because it performs sampling of voltage and current at the periodic steady state. Simulations use MATLAB SIMULINK to model the whole system. It performs simulations of the whole system and verifies the working and benefits of MPPT. The PandO and Inremental conductance MPPT algorithms are simulated and compared using the same weather conditions. When atmospheric conditions are constant or change slowly, the PandO MPPT oscillates close to MPP but Incremental conductance finds the MPP accurately at changing atmospheric conditions also and thus it increases the overall efficiency of the system.

# Bibliography

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2.$https : //ieeexplore.ieee.org/document/$8077302

# Chapter 6

# Appendix

# Project Details

| | | | |
|---|---|---|---|
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| **Project Title:** | PV module based water pumping system | | |
| Project Duration | 4months | 3rd January,2019 | 27th April,2019 |
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