MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

Photovoltaic Water Pumping System Using Maximum Power Point Tracking

by

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DEDICATION

This thesis is dedicated to my beloved parents, my loving brothers and all well-wishers helping me to accomplish this work.

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Abstract

Water resources are essential for satisfying daily human needs varying, from agriculture to energy production. As a tropical country Bangladesh receives a substantial amount of solar insolation suitable for PV application. Being an agricultural economy, the irrigation need is increasing day by day. Use of diesel run pumping system is neither cost effective nor environment friendly. Among the various form of renewable energy technologies Solar photovoltaic technology is perhaps the most used one to generate electricity especially in the rural area of all over the world. The purpose of this research is to analyze the potentiality and cost effectiveness of using solar irrigation system in Bangladesh and also to harness maximum power from the solar panel. The work presented in this thesis present the design and the simulation of a centrifugal pump coupled to a photovoltaic PV generation via a maximum power point tracker MPPT controller. Maximum power point trackers (MPPTs) play a vital role in photovoltaic (PV) systems because they increase the efficiency of the solar photovoltaic system by increasing the power output. The paper presents an Open voltage (OV) scheme for extracting the maximum power from a PV system for use in a water pumping system. A new topology of buck converter is used with feedback PI controller which adjusts the duty cycle of buck converter to match the load impedance to the PV panel, consequently maximizes the motor speed and water discharge rate of the centrifugal pump. The performance of the OV method is evaluated and modeled in SIMULINK environment of MATLAB to confirm the significance of its power improvement and efficient technique for water pumping system.

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List of Abbreviation and symbols

PV	Photovoltaic
Vmpp	Maximum power point voltage
Impp	Maximum power point current
SHS	Solar home system
SPVWP	Solar photovoltaic water pumping system
MPPT	Maximum power point tracking
CCM	Continuous conduction mode
P&O	Perturb & Observe
VOC	Open circuit voltage
ISC	Short circuit current
D	Duty Cycle
k	Fractional ratio
η_{pump}	Pump efficiency
τ	Torque

Chapter 1

Introduction

1.1 Introduction

Application of solar photovoltaic (PV) energy for water pumping gained popularity recent years because of drastic decrease of PV panel's price. Also direct coupling of PV panels with the pump system has shown great potential with low cost for water pumping applications. Direct coupling of mechanical load with PV array requires a systematic study of load which might be cumbersome but eventually leads to a very simple and reliable design [1]. Usually, the output of the PV array is time-dependent and also non-linear in nature which directly varies with solar insolation level and cell temperature [2]. The proper matching of components is greatly essential in a direct coupling Pump-motor system. Bangladesh is a predominantly an agricultural country with a capability of producing three crops a year if proper irrigation facilities can be provided. The main crop is rice which requires extremely high amount of water in the paddy fields. Different studies show varying water requirement for the crop, but an acceptable figure ranges from 1000-3000kg of water per kg of rice (1.5kg of paddy produces approximately 1kg of rice) [1,2].During the rainy season, natural rain water is sufficient for most of the places, but irrigational requirement is quite high all over Bangladesh for crop production during the dry months. It is particularly high during the summer months (March to May) as the rate of evaporation and percolation is high due to dry climatic condition and high ambient temperatures. Although Bangladesh is a riverine country with numerous rivers and canals crisscrossing the country, irrigation during the peak dry months are mainly done from the subsoil water as the canals and the rivers dry up.

Being a tropical country, Bangladesh endowers with abandon supply of solar energy. The range of solar radiation is between 4 and 6.5 kWh/m2/day and the bright sunshine hours vary from 6 to 9 hours/day [1]. Being an agrarian economy, the agricultural sector alone accounts for 20% of GDP and provides employment for more than half of the labour force. Furthermore in Bangladesh, about 59% land is under irrigation system, based on diesel and grid electricity. However there remains vast area of cultivable land which is needed to be irrigated where grid connection is not available. Solar PV pump may be used for irrigating these lands for better crop production. This study presents the scenario of solar pump irrigation system in Bangladesh along with its economic feasibility for different crops [7]. The government of Bangladesh is planning to install close to 19,000 solar-powered irrigation pumps by 2016 [17], in a bid to expand the country's irrigated land area and boost food production, while limiting its reliance on fossil fuels. Once installed, the planned 18,750 solar-powered pumps will irrigate an additional 590,000 hectares (1.5 million acres) of land for cultivating rice and vegetables, without requiring any grid electricity or diesel fuel [3]. The government estimates that, once all the pumps are in place, their solar panels will save 675 MW hours of electricity per day, cut imports of diesel fuel by 47,000 tons per year, saving $45 million annually, and reduce carbon dioxide emissions by an annual 126,000 tons [19].

Fig 1.1 Solar panel in Gaibandha

Fig 1.2 Pump Installation in rural area

Among the various form of renewable energy technologies Solar photovoltaic technology is perhaps the most used one to generate electricity especially in the rural area of all over the world.[40-42] The purpose of this thesis is to analyze the potentiality and cost effectiveness of using solar irrigation system in Bangladesh. In Bangladesh, the introduction of solar water pumps, which are manufactured using locally available technologies, will not only shorten the gap between demand and production of electricity immensely and help poor and marginal farmers increase their yield but also bring down their agricultural production costs substantially in the next 20 years.

1.2 Related work

Water pumping system technique using solar power is studied by researchers for many years. The most of the existing systems are manual system. The manual system needs labor for monitoring the productivity and health crop. Considering labor salary, the system will cost much more than the automatic system, in which there is no assistance to the system. M. A. Hossain, M. S. Hassan, and M. A. Mottalib have done a feasibility study on solar irrigation in Bangladesh in which they have shown solar irrigation as profitable and environment friendly. S. I. Khan, M. M. R. Sarkar, and M. Q. Islam of Bangladesh University of Engineering & Technology have done a design and analysis of a low cost solar water pump for irrigation in rural Bangladesh. The prospect of hybrid solar irrigation system in Bangladesh was also studied by M. A. Hasnat, M. N. Hasan, and N. Hoque. In 2009, the first ever solar irrigation pump was set up in Northern Naogaon district by Grameen Shakti [10]. From 2013, Bangladesh Rural Electrification Board (BREB) set up the pumps at Mohadevpur in Naogaon and Mirjapur and Modanhati in Rajshahi on experimental basis by spending around Taka 1.20 crore with joint initiative of South Korea and the Government of Bangladesh [10-12]. The government of Bangladesh is planning to install close to 10,000 solar powered irrigation pumps by 2016, in a bid to expand the country's irrigated land area and boost food production, while limiting its reliance on fossil fuels [5-9]. The government estimates that, once all the pumps are in place, their solar panels will save 675 MW hours of electricity per day, cut imports of diesel fuel by 47,000 tons per year, saving the government nearly $100 million in fuel-subsidy costs over 20 years and reduce carbon dioxide emissions by an annual 126,000 tons [10-14]. The freely and abundantly available solar energy can be easily converted into electrical energy using Photo-Voltaic (PV) cells. PV source has the advantage of low maintenance cost, pollution-free energy conversion process and low operating cost. In the conventional method,. MPPT is employed to track maximum voltage from the solar panel. Hill climbing or Perturb and Observe (P&O) MPPT algorithm which is used in the conventional method. The main drawback of P&O is at steady state condition the operating point oscillates around the Maximum Power Point (MPP), which increase the wastage of some amount of available energy and also the algorithm can be confused during those time intervals characterized by rapidly changing atmospheric conditions.[16-17] Solar PV based irrigation is not a new concept and there are already a number of such irrigation schemes running in Bangladesh. Technologically, it is not a big challenge, as it does not require any highly sophisticated component.[47-48] However, the main challenge comes from the actual cost of irrigation which is heavily dependent on the irrigation model in the context of the socio-economic condition of rural Bangladesh. As irrigation requirements are quite severe only during the dry months (3-4 months), the over head cost becomes too high for dedicated irrigation projects. So, it is essential to integrate the Solar PV panels with other energy usage of rural areas to reduce the overhead cost and to make it competitive with diesel based irrigation system. During last 5-6 years, Solar Home Systems (SHS) has seen a tremendous growth in rural Bangladesh and it reflects the attitude of the rural people towards a viable energy alternative.[24-26] Unfortunately, energy output in a SHS is very low and is barely enough to meet the basic household need like lighting. A SHS is not designed to provide energy support even to small scale cottage industry. Hence, we must look at other possible alternative models for powering the irrigation pumps. [28-30]

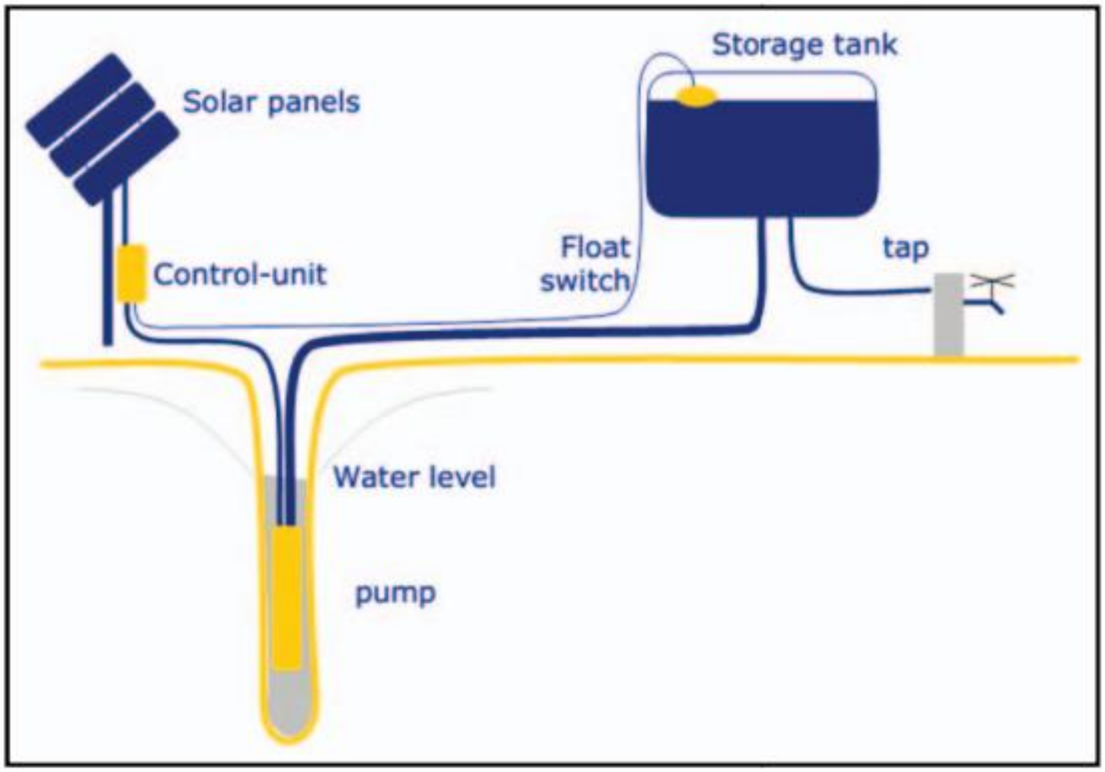


Fig 1.3 general set up for solar pump system.

Furthermore, In some research the Fuzzy logic MPPT algorithm is used, which is a very complex algorithm of tracking maximum power from the solar panel. Also the dc-dc converters used are the conventional ones. [7-8]. It is very important to make sure that maximum power from the solar panel is transferred to the motor for its smooth running. The battery is an important part in this matter, since the radiation of the sun will vary during the day also in different weather conditions.

Some statistical studies are done in the recent research papers, how to store the power in the battery bank also the radiation changes in different locations of the country[11-12]. The two problems in solar cell technology is low efficiency (i.e. 10 % to 20%) & non linear I-V characteristics. In order to meet this draw back many MPPT algorithm has been developed in recent studies which extract maximum power from P-V cell in any environmental conditions. In recent research studies regarding this topic the fuzzy logic controller are very famous in applying the MPPT algorithm. Amongst the dc-dc converters used for impedance matching, boost converters are used to boost up the panel voltage. However, the current from the solar panel is also very important. The use of buck converter is appropriate in this case. Some research papers discussed the use of brushless d.c motor and induction motor to control the pump.[49-50]. Many software were used to design the system amongst which, the MATLAB simulink design was a very new and improved design of them all. Some of the works created a great scope to design an efficient and new form of MPPT based solar water pumping system.

1.3 Motivation

The demand of water for irrigation purpose is still an issue to be solved in many developing countries, mainly in rural areas. With energy crisis and environmental pollution created mostly by the use of fossil fuel, this problem has unfolded a solution using solar photovoltaic water pumping (SPVWP) system. Now solar powered pumps represent a growing market as it offers a better and viable solution for off grid areas. The water pumping system driven by electrical motors is a popular application of the photovoltaic energy utilization . Two main constraints for using solar energy are the high initial installation cost and low photovoltaic cell conversion efficiency . Solar photovoltaic pumping systems have become so popular not only in the agricultural sector but also for drinking water and micro-irrigation applications in developing countries of Africa & Asia. Photovoltaic System consists of a PV array, Dc-Dc converter, PMDC motor coupled to centrifugal pump. The PV output varies with the changes in amount of solar radiation reach in to solar PV. The converter maintains the power output constant from a PV module with varying operating conditions. In the recent studies it is seen that there is a huge scope to improve the water pumping performance with a better MPPT algorithm. In our research, the primary goal was to develop an efficient cost effective water pumping system run by solar power, which will be optimized specially for the rural areas of Bangladesh. In doing so firstly we tried to use minimum number of components to minimize cost and losses. Then investigated if the MPPT that are said to be highly efficient and do track the true maximum power point under the various conditions in a country like Bangladesh .

1.4 Research objectives

The proposed design will be mathematically modeled and simulated via MATLAB and finally the results will be presented to confirm the effectiveness of the proposed system. The major objective of this research is to design a SVPWP system which will be suitable for the applications

i) First, a PV panel design in MATLAB with different radiations will be simulated.

ii) A DC-DC converter of new topology will be modeled in the Simulink.

iii) A DC motor design will be proposed along with the switching states for the smooth operation of the motor, and to ensure a continuous supply of power to the motor.

iv) A Centrifugal pump design with simulation and graphical analysis.

1.5 Thesis Outline

Chapter 1 describes general introduction of Solar pumping system, explained previous works done on the topic. Later. explained the motivation of doing the work. Chapter 2 includes basic ideas of solar pumping system . It describes the DC-DC converter proposed in the thesis and the approached MPPT algorithm. Chapter 3 presents the dc motor characteristics and centrifugal pump and its performance analysis. Chapter 4 shows the result and simulation of pv output under different radiations and other output of pump and d.c motor. Chapter 5, shows and explains the practical implementation and hardware testing of the thesis. Chapter 6 describes the possible future works of the proposed design.

CHAPTER 2
THEORY & SYSTEM ANALYSIS

2.1 Introduction

PV array is a highly nonlinear DC source of electricity and its operation has to be carefully matched to that of its equivalent electrical load in order to extract maximum available energy. The simplest model of a PV cell is shown as an equivalent circuit in fig. 2.1 that consists of an ideal current source in parallel with an ideal diode and a series resistance Rs. The current source represents the current generated by photons (denoted as Iph), and its output is constant under constant temperature and constant incident radiation of light. Series resistance Rs is neglected here [6]. The intensity of the current is directly proportional to the light received by the cell from the sun.

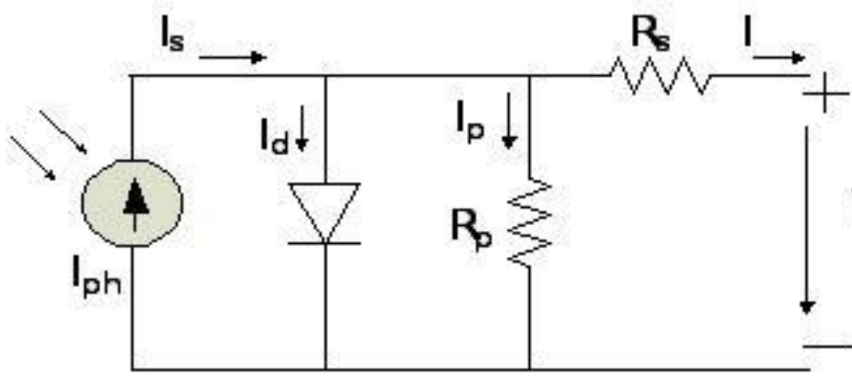


Fig 2.1 Equivalent solar cell circuit

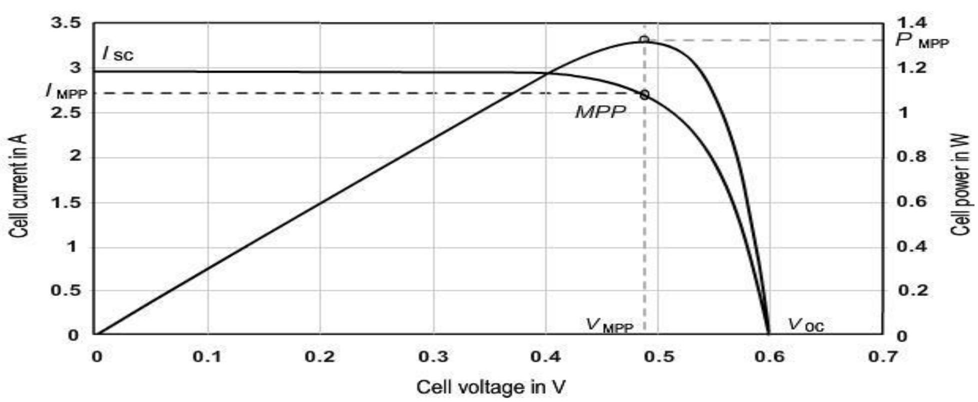


Fig 2.2 I-V characteristic curve of a solar cell

The current–voltage characteristic of the PV cell is shown in fig. 2.2 . It depends on both temperature and radiation. As the module temperature increases, it can deliver lesser power [7]. A single solar cell with a resistance Rs that is connected in series with a parallel combination of the following elements:

- Current source
- Two exponential diodes
- Parallel resistor R_p

2.1.1 Equation of Solar cell

The output current I is:

$I = I_{ph}-I_s*(e^{((v+i*Rs)/(N*Vt))}-1) – I_{s2}*(e^{((v+i*Rs)/(N_2*Vt))}-1) – (V+I*R_s)/R_p$ (2.1)

$I_{ph}=I_{ph0}\times\frac{I_r}{I_{r0}}$

Where:

I_{ph} is the solar-induced current:

$$I_{ph}=I_{ph0}\times\frac{I_r}{I_{r0}} \quad (2.2)$$

Summarizing these effects of Parallel and Series Resistance, the current-voltage relationship of PV cell is written as:

$$I=I_s - I_{o1}[e^{\frac{q(V+R_SI)}{KT}} - 1]-I_{o2}[e^{\frac{q(V+R_SI)}{2KT}} - 1]- \left(\frac{V+I.R_S}{R_P}\right) \quad (2.3)$$

It is possible to combine the first diode (D1) and the second diode (D2) and rewrite the equation (3) in the following form.

$$I=I_s - I_o[e^{\frac{q(V+R_SI)}{mKT}} - 1]-\left(\frac{V+I.R_S}{R_P}\right) \quad (2.4)$$

2.1.2 Details about SIMSCAPE Solar Cell Model

In simulation of the solar panel the 5 – parameter model is used

- A 5-parameter model that applies to the preceding equation (2.4)
- The saturation current of the second diode is zero.
- The impedance of the parallel resistor is infinite.

If you choose the 5-parameter model chosen, anyone can parameterize solar cell block in terms of the preceding equivalent circuit model parameters or in terms of short-circuit current and open-circuit voltage the block uses to derive these parameters.

2.1.3 Photovoltaic Module

A single PV cell produces an output voltage less than 1V, about 0.6V for crystalline silicon(Si) cells, thus a number of PV cells are connected in series to achieve a desired output voltage. When series-connected cells are placed in a frame, it is called as a module. Most of commercially available PV modules with crystalline-Si cells have either 36 or 72series-connected cells. A 36-cell module provides a voltage suitable for charging a 12Vbattery, and similarly a 72-cell module is appropriate for a 24V battery. This is required since most of PV systems use backup batteries, however today many PV systems do not use batteries; for example, grid-tied systems. Furthermore, the advent of high efficiency DC-DC converters has alleviated the need for modules with specific voltages. When the PV cells are wired together in series, the current output is the same as the single cell, but the voltage output is the sum of each cell voltage.

2.2 DC-DC Converter

Use of DC-DC converter is more favorable when it comes to implementing MPPT algorithms. This is a cheap power electronic device arrangement which absorbs the power of the PV array at a fixed voltage & current (for maximum output), and acts as a current generator for feeding the DC motor of the pump (for greater output). At the input side, the voltage is chosen close to the maximum power point. A schematic diagram of a buck converter is shown in fig. 2.3. In this DC-DC device, the input voltage is adjusted by hardware. At the output side, the power is supposed to be transmitted to the motor at the optimum voltage point corresponding to the available power the motor needs [8]. In this research work DC-DC buck converter has been used. Simplest most transfer function among the DC-DC converters make Buck converter attractive for implementing open voltage algorithm. Buck converter is similar to step down operation, which means output current is higher than input current. So it is suitable for loads with high current demand. Buck converter uses only a single switch, usually one controlled (eg. MOSFET, IGBT etc.) other one is uncontrolled (i.e. Diode) is used to achieve unidirectional power flow from input to output. The Buck converters also uses an inductor and a capacitor to store and transfer energy from input to output. They also smoothen or filter voltage and current. The DC-DC converters can have two distinct modes of operation: Continuous conduction mode (CCM) and Discontinuous conduction mode (DCM) [9]. A converter may operate in both modes, which have significantly different characteristics. Therefore, a converter and its control should be designed based on both modes of operation. However, for this research work Continuous conduction mode operated DC-DC converters have been considered.

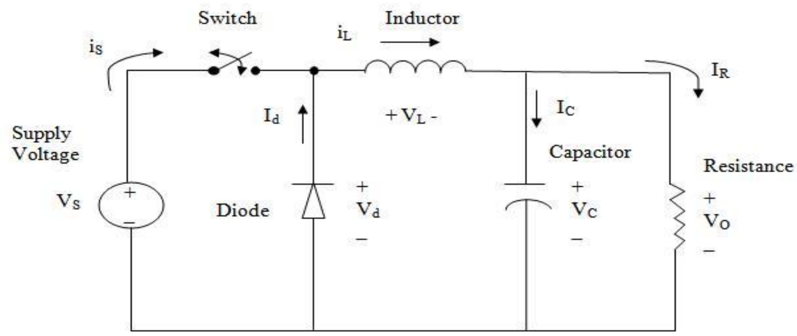


Fig. 2.3 Schematic diagram of DC-DC Buck Converter.

Ripple load current ΔI_L to be 40% of output current,

ΔI_L = 40% of I_{out},

Then the value of inductance, L can be calculated using the following equation:

$$L = \frac{(V_{in} - V_{out}).V_{out}}{V_{in}.f_{sw}.\Delta I_L} \quad (2.5)$$

If choosing to allow a maximum output voltage ripple ΔV_{out}, Ripple of 100mV (1% V_{out}),

Then the maximum effective series resistance (ESR) can be calculated using the following equation:

$$ESR = \frac{\Delta V_{out,ripple}}{\Delta I_L} \quad (2.6)$$

The output capacitance (C_{out}) can be calculated using the following equation :

$$C_{out} = \frac{L(I_{L,max})^2}{(V_{out} + \Delta V_{out})^2 - V_{out}^{\ 2}} \quad (2.7)$$

2.3 Maximum power point tracking

As was previously explained, MPPT algorithms are necessary in PV applications Because the MPP of a solar panel varies with the irradiation and temperature, so the Use of MPPT algorithms is required in order to obtain the maximum power from a solar Array. Over the past decades many methods to find the MPP have been developed and published. These techniques differ in many aspects such as required sensors, Complexity, cost, range of effectiveness, convergence speed, correct tracking when Irradiation and/or temperature change, hardware needed for the implementation or Popularity, among others. There are different types of techniques used for maximum power point tracking. Among these techniques, the P&O and the Incremental Conductance algorithms are the most common. These techniques have the advantage of an easy implementation but they also have drawbacks, as will be shown later. Other techniques based on different principles are fuzzy logic control, neural network, fractional open circuit voltage or short circuit Current, current sweep, etc. Both P&O and In.Cond algorithms are based on the “hill-climbing” principle, which Consists of moving the operation point of the PV array in the direction in which power increases and Hill-climbing techniques are the most popular MPPT methods Due to their ease of implementation and good performance when the irradiation is constant. The advantages of both methods are the simplicity and low computational Power they need. The shortcomings are also well-known: oscillations around the MPP and they can get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions.

2.3.1 Advantages of MPPT

MPPT solar controller is necessary for any solar power systems need to extract maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power. MPPT solar controller allows users to use PV module with a higher voltage output than operating voltage of battery system. MPPT solar controller reduces complexity of system while output of system has high efficiency. Additionally, it can be applied to use with more energy sources. Since PV output power is used to control DC-DC converter directly. MPPT solar controller can be applied to other renewable energy sources such as small water turbines, wind-power turbines, etc.

2.4 Types of Algorithm

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

1) Perturb and observe (hill climbing method)
2) Incremental Conductance method
3) Fractional short circuit current
4) Neural networks
5) Fuzzy logic

2.5 Approached MPPT Algorithm

Fractional open circuit method uses the approximate linear relationship between the Maximum Power Point voltage (VMPP) and the open circuit voltage (VOC), which varies with the irradiance and temperature:

$$V_{MPP}=V_{OC}*k \quad (2.8)$$

Where k is a constant depending on the characteristics of the PV array and it has to be determined beforehand by determining the VMPP and VOC for different levels of irradiation and different temperatures. The value for k has been reported to be between 0.71 and 0.78. Once the constant of proportionality k is known the MPP voltage VMPP can be determined periodically by measuring VOC. To measure VOC the PV module has to be disconnected or unloaded momentarily so in each measurement a loss of power occurs [11].

According to the fractional open circuit voltage algorithm, the value of k is determined by,

$$k = \frac{V_{mpp}}{V_{oc}} \qquad (2.9)$$

The duty cycle (D) was calculated using the following formula [23]

$$D = \frac{V_o}{(k * V_{mpp})} \qquad (2.10)$$

A number of MPPT algorithms have been developed for PV systems, and for all conventional MPPT algorithms the main problem is how to obtain optimal operating points (voltage and current) automatically at maximum PV output power under variable atmospheric conditions. Here is a comparison of different MPPT algorithms given below.

2.5.1 Advantages of using Fractional Open circuit voltage algorithm

This algorithm is very cheap and easy to track the maximum power point by varying the duty cycle within a certain range. Normally, it does not require any microcontroller or any other digital signal processor. However, if a microcontroller is used to generate the PWM signal, the disadvantages associated with this method can be easily eliminated. Table-1 shows comparison of different MPPT algorithms.

Table -I Comparison of different MPPT Algorithm.

MPPT Technique	PV Array Dependent ?	True MPPT ?	Analog or Digital?	Periodic Tuning?	Convergence Speed	Implementation Complexity	Sensed Parameters
Hill Climbing P & O	No	Yes	Both	No	Varies	Low	V/Current
Lac Cond	No	Yes	Digital	No	Varies	Medium	V/Current
Fuzzy Logic Control	Yes	Yes	Digital	Yes	Fast	High	Varies
Neural Network	Yes	Yes	Digital	Yes	Fast	High	Varies
RCC	No	Yes	Analog	No	Fast	Low	V/Current
Current Sweep	Yes	Yes	Digital	Yes	Slow	High	V/Current
DC Link Capacitor Droop Control	No	No	Both	No	Medium	Low	Voltage
Load/V Maximization	No	No	Analog	No	Fast	Low	V/Current
Array Reconfiguration	Yes	No	Digital	Yes	Slow	High	V/Current
Linier Current Control	Yes	No	Digital	Yes	Fast	Medium	Irradiance
State-Base MPPT	Yes	Yes	Both	Yes	Fast	High	V/Current
OCC MPPT	Yes	No	Both	Yes	Fast	Medium	Current
BFV	Yes	No	Both	Yes	N/A	Low	None
LRCM	Yes	No	Digital	No	N/A	High	V/Current
Slide Control	No	Yes	Digital	No	Fast	Medium	V/Current

2.5.2 System Configuration

A PV pumping system consists of a PV module and a pumping subsystem [4]. The pumping subsystem is composed of a motor-pump set and a power conditioning equipment [5]. The designing and simulation of the system have been carried out in software within Simscape library environment. Depending on the design, a system may use storage batteries and a charge regulator. Batteries confer the advantage of working when the intensity of solar radiation is low (on cloudy days or at dawn or dusk).Battery-less system is, however, cheaper and simpler.

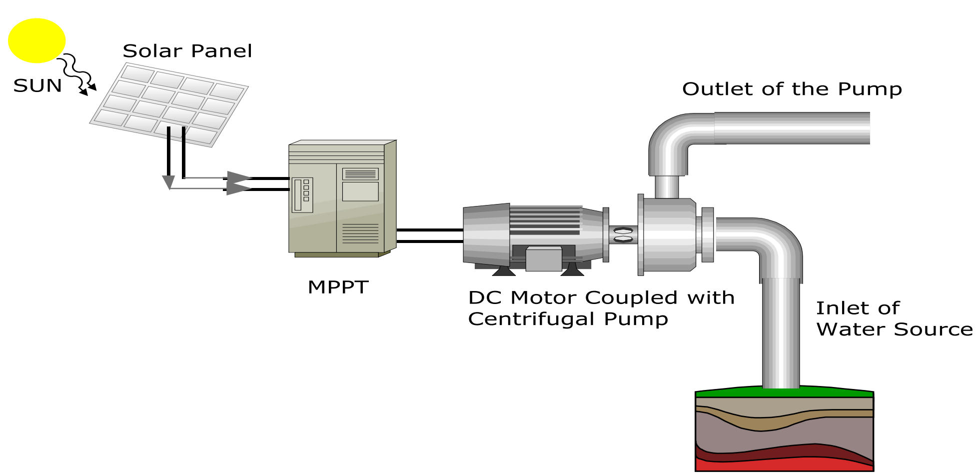


Fig 2.4 Solar pumping system

2.6 Summary

This chapter covers the basic working principle of a pv system. The parameters are also defined and stated elaborately. Solar cells are one kind of energy transducer which converts solar energy to electrical energy via photovoltaic effect. The combination of using MPPT technology with modern photovoltaic panels enables panel manufacturers to offer considerable performance improvements of the PV energy generation facility. The chapter discuses about DC-DC Converters and also the type of mppt algorithms that are being already used in recent years. There are many types of DC-DC converter available for coupling the photovoltaic panel with the motor. The buck converter is used in the research and the chapter explains why this is the better choice. Then it explains the approached algorithm of the research and how the algorithm works.

Chapter 3

MOTOR & PUMP CHARACTERISTICS

3.1 Dc Motor

DC motors are classified according to the connection of the field circuit with respect to the armature circuit. Permanent-magnet DC (PMDC) motors have only one circuit of armature winding and the flux which is generated by natural magnets is constant [12]. On the other hand, in DC shunt motors field circuit is connected in parallel with the armature circuit while DC series motors have their field circuit in series with the armature where both field and armature currents are identical. Compared with conventional electrical machines, PMDC motors exhibit higher efficiency and simpler construction. PMDC Motor is used because of its simplistic characteristics, although currently brushless DC (BLDC) motor can serve these purposes. Controlling BLDC is rather complex, so simpler motor has been chosen for this work. The DC Motor block represents the electrical and torque characteristics of a DC motor using the following equivalent circuit model show in the figure:

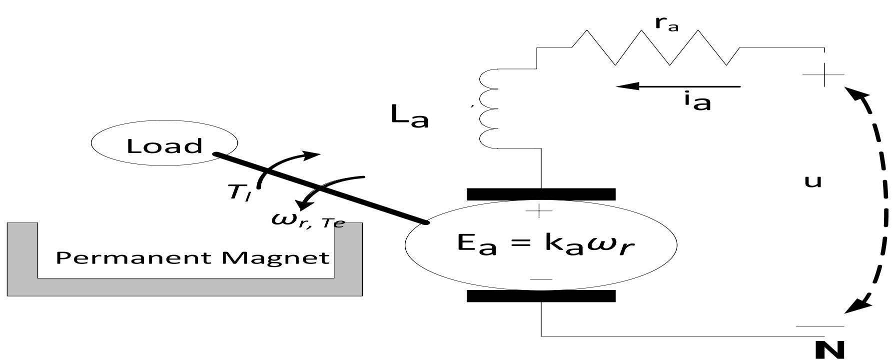


Fig 3.1 Equivalent circuit model of DC motor.

3.2 Design Methodology

In this research work, PMDC motor is used to actuate the pump. In a PMDC motor its field is provided by permanent magnets. The less cost, more efficiency and produces less noise are the advantages of PMDC motor. The ratings of PMDC motor is used as follows:

Table -II Dc motor Configuration

Parameter	**Value**
Power	50 W
Voltage	10V
No load speed	215(rad/sec)
Rated speed	190(rad/sec)

3.3 Centrifugal Pumps

Centrifugal pumps are relatively inexpensive in comparison with other available pump in the market. They have few moving parts and tend to have greater on-stream availability and need lower maintenance costs and also PV energy utilized by centrifugal pump is much higher [2]. There are no close clearances in the fluid stream and also they can handle liquids containing (sludge) dirt, solids etc. Because there is very little pressure drop and no small clearances between the suction flange and the impeller, so they can operate at low suction pressure. Centrifugal pumps can automatically adjust to changes in head. Therefore capacity can be controlled over a wide range at constant speed. In the developing countries like Bangladesh most of the people here using centrifugal pump for irrigation purpose as it is available and easy to operate. In this work centrifugal pumps efficiency is calculated by the equations given below [13].

Pump Efficiency , $\eta_{pump} = \frac{QgHm}{Po} \times 1000$ (3.1)

$$H_m = H + \frac{fHV^2}{2gd} + \frac{V^2}{2g} \quad (3.2)$$

$$V = \frac{4Q}{\pi d^2} \quad (3.3)$$

Centrifugal pumps are relatively inexpensive in comparison with other available pump in the market. They have few moving parts and tend to have greater on-stream availability and need lower maintenance costs and also PV energy utilized by centrifugal pump is much higher [2].There are no close clearances in the fluid stream and also they can handle liquids containing (sludge) dirt, solids etc.Fig. 3.2 shows performance curve of a centrifugal pump.

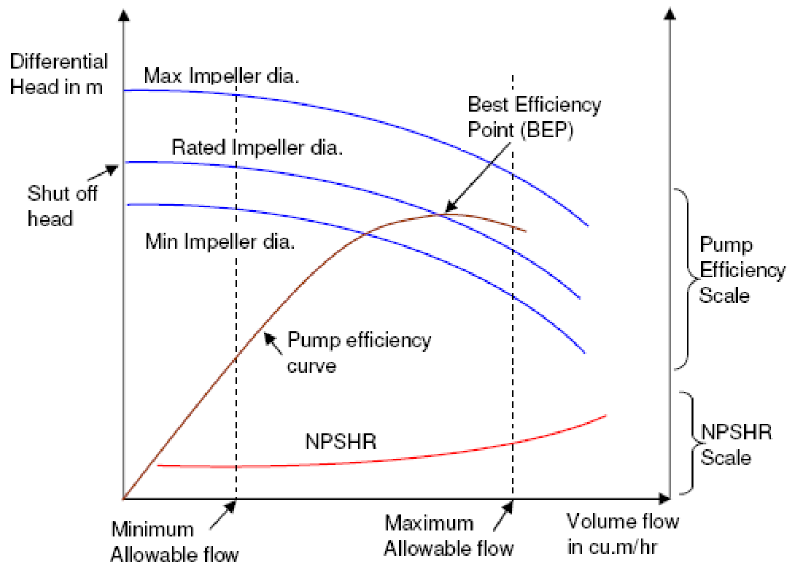


Fig 3.2 Centrifugal pump performance curves

3.4 Summary

The chapter discuses about Dc motor and its characteristics also the centrifugal pump and its performances. Then it explains the Dc motor configuration used in the research. Dc motor has the simplest of construction also its working is much easier than other motors. However, induction motors are more preferable in the case of water pumping system but, in this research we have used d.c motor. The centrifugal pump has many advantages over other pumps. Also in design and simulation chapter the pump characteristics are further discussed.

Chapter 4

DESIGN & SIMULATION

4.1 Introduction:

The whole thesis design & simulation is performed with matlab2012 **simulink** .Here the components from **SIMSCAPE** library for simulation were used . Hence this thesis work basically based on the use of solar panel which generates power under certain condition such as radiation , temperature and inclination of the panel etc. all this parameters are very fragile and limit the success of this project to a certain extent.

4.2 Circuit design and simulation:

The design for the simulation were done on the characteristics of the component used in the thesis and also the calculations were done in such way that an approximate model can be constructed for the simulation purpose. Here we have 4 section of design:

- Solar Module
- Buck Converter
- DC Motor & Centrifugal Pump
- Pumping Section

4.2.1 Simulation of I-V and P-V Curve Different Radiations For Module

The following circuit of the panel is generated in SIMULINK. The 2012 MATLAB version has been used to design this circuit.

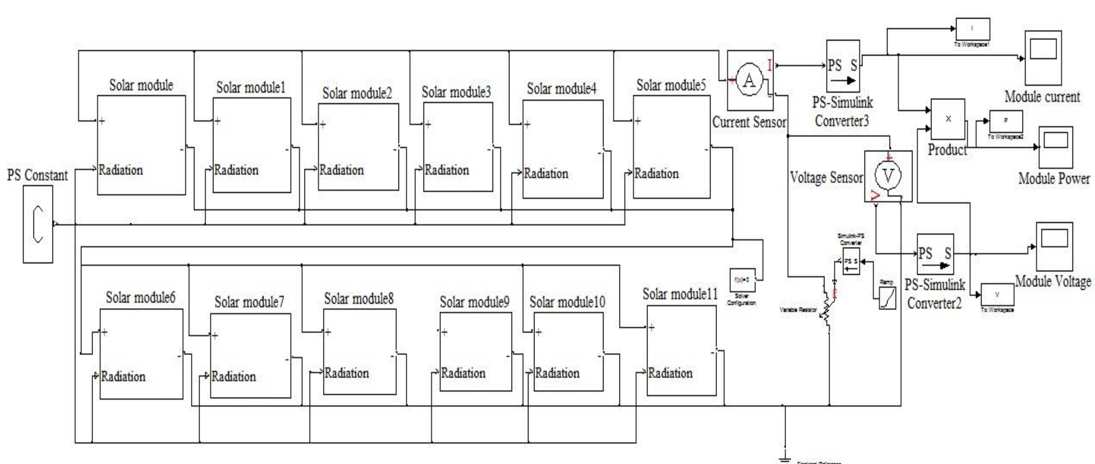


Fig 4.1 Solar module design

4.3 The circuit to obtain characteristics Curve in SIMULINK.

In the previous circuit a parallel combination of 6 module panel are in a series connection with another parallel combination of 6 module panel. So in this case current will increase for a certain voltage level. This design is done according to our output requirement for thesis purpose .Each module consists of 21 solar cells.

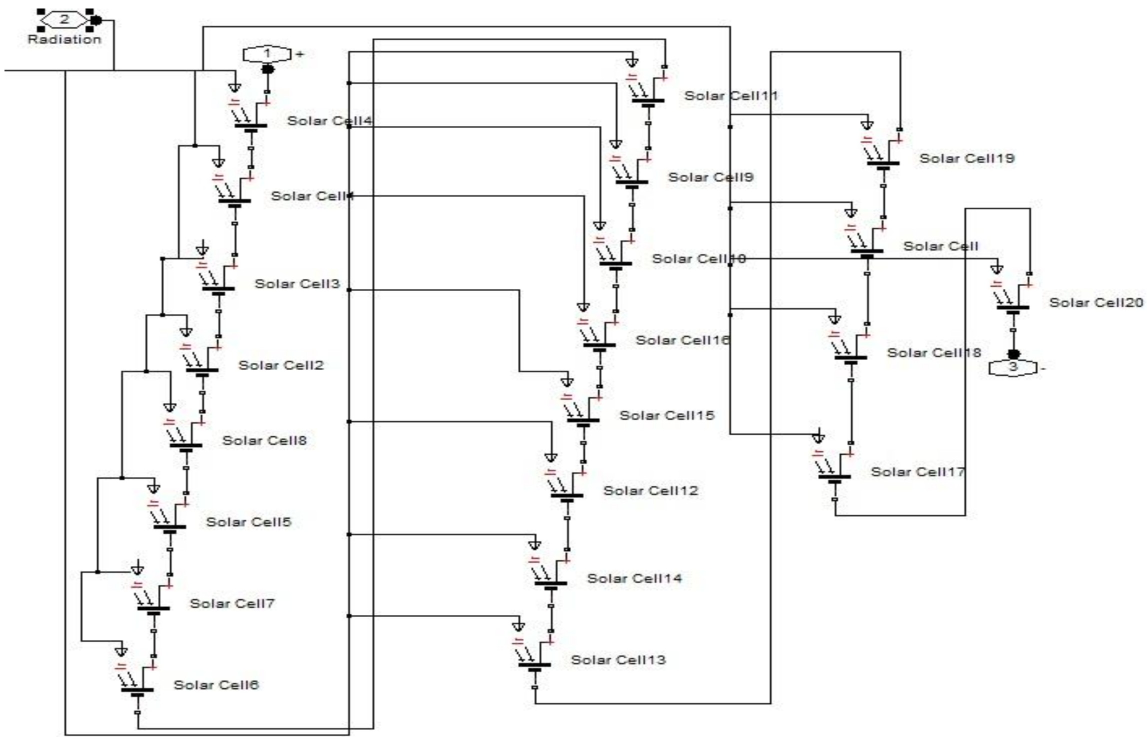


Fig 4.2: Construction for a Single module panel .

The solar cell in the SIMULINK consists of a current source and a diode connected parallel to it . By connecting a the cells in series an equivalent model of the panel. The radiation was varied from 1000 Wm^{-2} to 200 Wm^{-2} to obtain the following I-V and P-V characteristics curves.

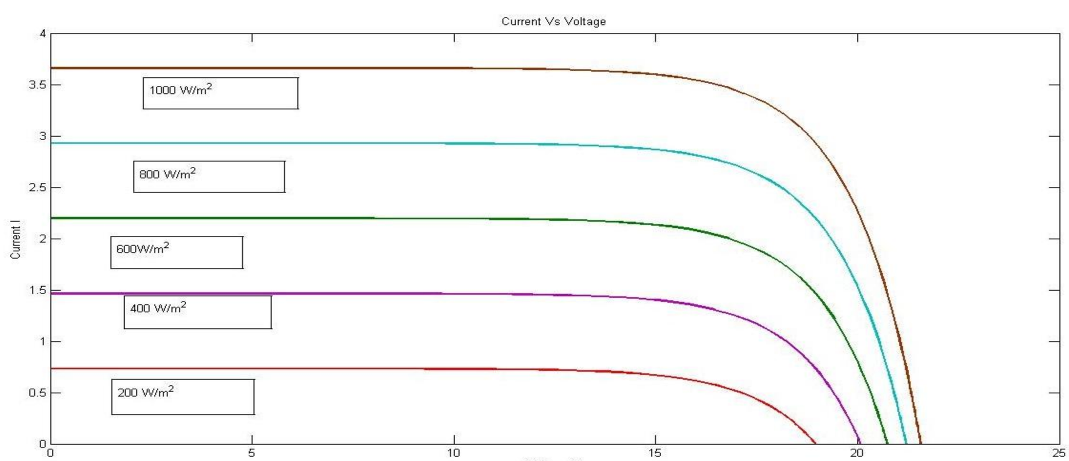


Fig 4.3: I-V characteristics Curve of 12 module panel in MATLAB.

As previously discussed in chapter 2, the change in radiation causes the short circuit current to change significantly but the change in open circuit voltage is not significant.

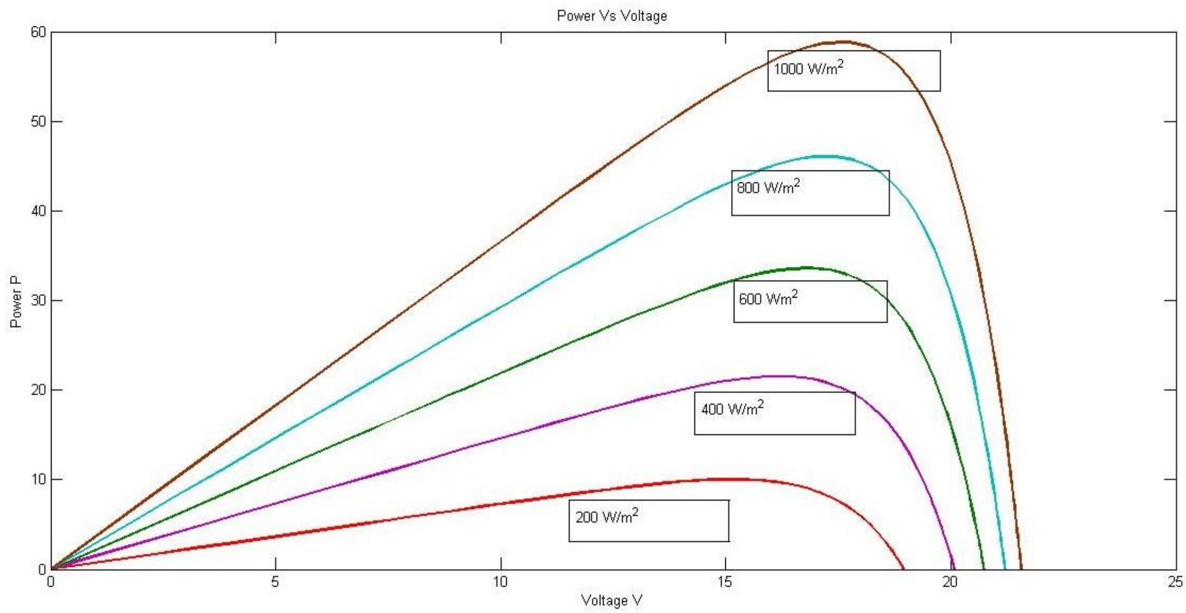


Fig 4.4: P-V characteristics Curve of 12 module panel in MATLAB.

From the P-V curve it is seen that the locus of the maximum power point shifts to the right. This is due to the change in radiation, the short circuit current changes and so does the maximum power point.

4.3.1 Simulation of the Buck Converter

The following circuit in fig. 4.5 is conventional Buck converter generated in SIMULINK. The 2012 MATLAB version has been used to design this circuit.

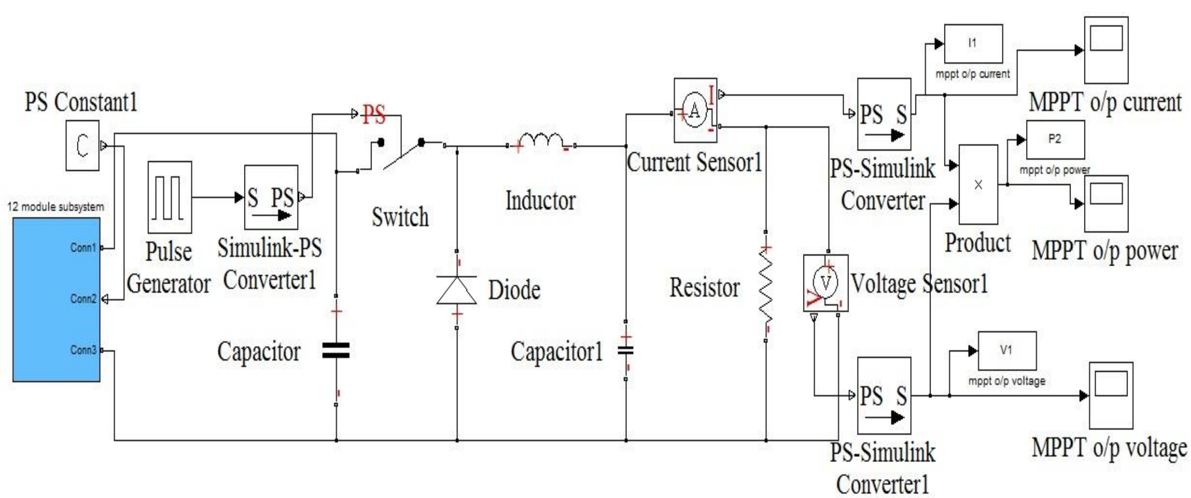


Fig 4.5: Buck Converter in SIMULINK.

The PWM signal was generated using pulse generator. The value of the inductor , resistor and capacitor were calculated based on the object of the Thesis requirement.

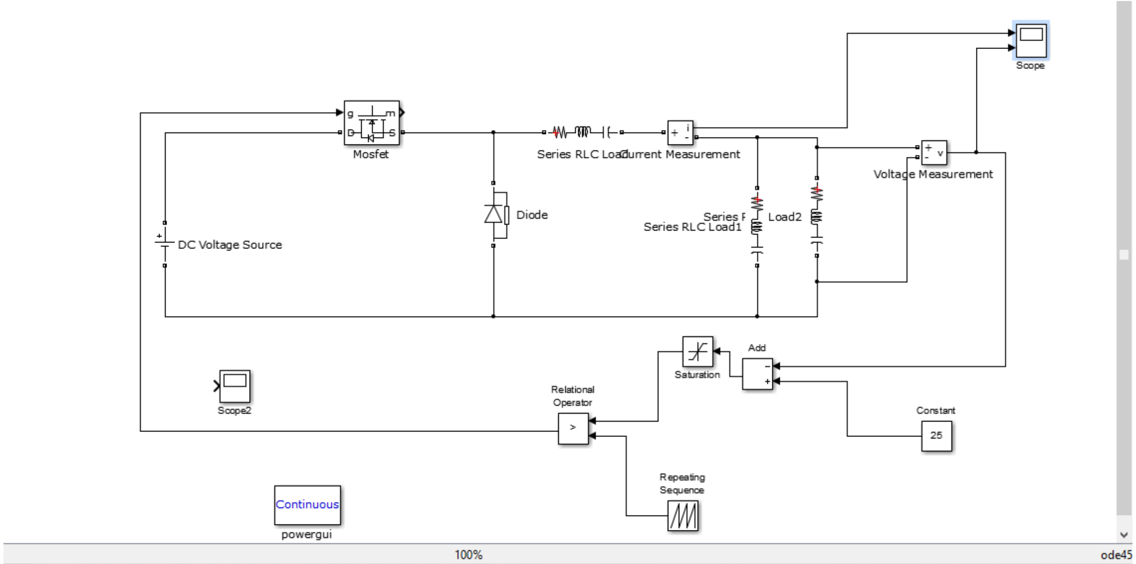


Fig 4.6: Synchronized Buck converter.

Fig 4.6 shows a synchronized buck converter for closed-loop system. as the radiation of the sun changes the duty cycle will automatically adjust. The Fractional factor K of the algorithm adjusts the duty cycle as the radiation varies during 24-hr day.

Application conditions:

- V_{in} : 19.0992 V to 21.56V
- V_{out} : 9.31 V to 10 V
- I_{out} : 5.392 A to 6 A
- f_{sw} (Switching frequency) = 100 KHz.

Based on the application conditions above L, $C_{out}C_{in}$ are calculated.

Output Inductor L:

If choosing to have ΔI_L

ΔI_L = 240 mA (40% of I_{out}), the value of L can be calculated using the following equation :

$$L = \frac{(V_{in} - V_{out}).V_{out}}{V_{in}.f_{sw}.\Delta I_L} \text{[1](5.1)} \qquad (4.1)$$

Using equation (4.1) the value of L is,

L = 110.786 µH

Output Capacitor C_{out}:

If choosing to allow a maximum output voltage ripple ΔV_{out} , Ripple of 100mV (1% V_{out}),

Then the maximum ESR can be calculated using the following equation:

$$ESR = \frac{\Delta V_{out,ripple}}{\Delta I_L} \qquad (4.2)$$

Using the equation (4.2) the value of ESR is ,

ESR= 417mΩ

The output capacitance(C_{out}) can be calculated using the following equation :

$$C_{out} = \frac{L(I_{L,max})^2}{(V_{out} + \Delta V_{out})^2 - V_{out}^2} \qquad (4.3)$$

Using equation (4.3),

C_{out}= 270 µF

The input Capacitance(C_{in}) :

The input capacitor needs to have a low ESR to keep power dissipation at low levels. A capacitance value of 100µF is likely to be adequate.

The following is output of the Buck converter for calculated values of the parameters. The parameters are calculated for standard radiation of 1000 Wm^{-2}.

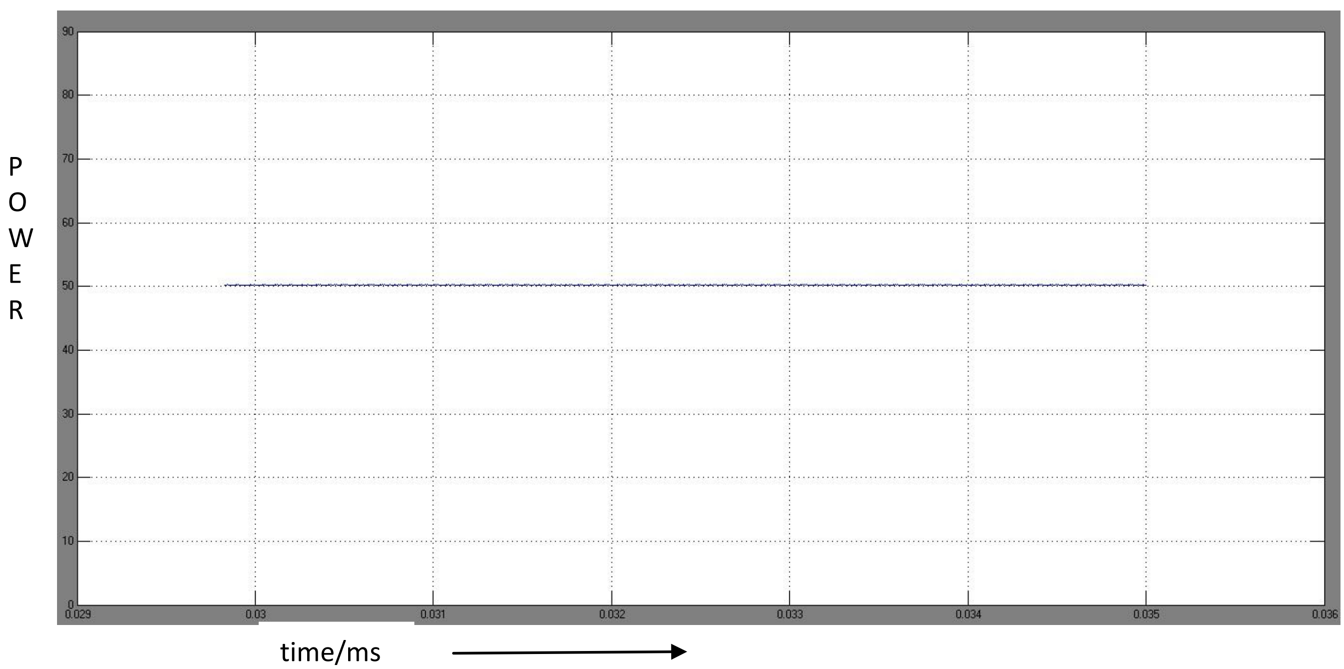


Fig 4.7 : Waveform of Output power of the Buck converter for 1000 Wm^{-2}at transient period.

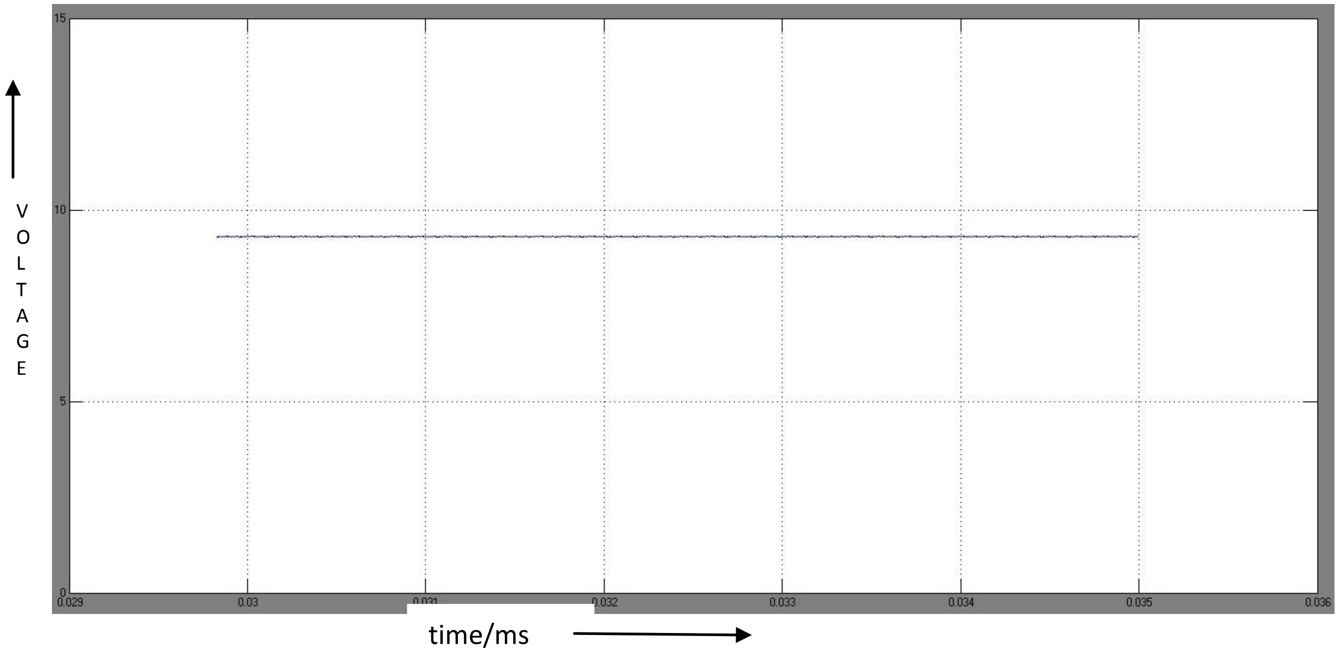


Fig 4.8 : Waveform of Output Voltage of Buck converter 1000 Wm^{-2}transient period.

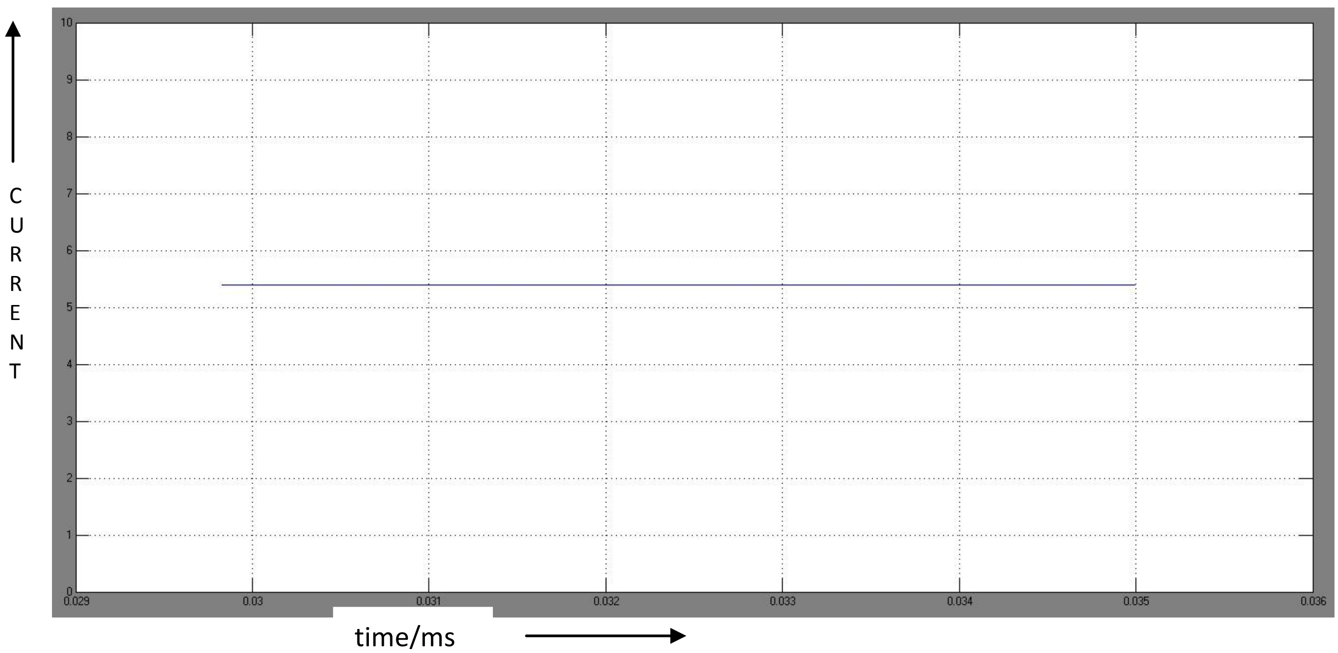


Figure 4.9 : Waveform of Output Current of Buck Converter 1000 Wm^{-2}.

4.4 Simulation of MPPT I-V and P-V Curve Different Radiations

The radiation of solar module was varied from 1000 Wm^{-2} to 200 Wm^{-2} to obtain the following I-V and P-V characteristics curves for MPPT.

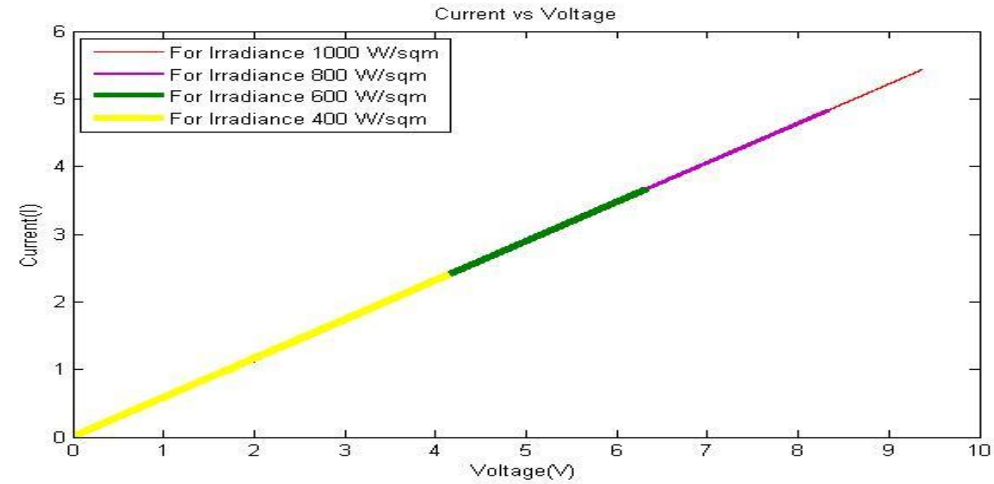


Fig 4.10: I-V characteristics of MPPT in MATLAB.

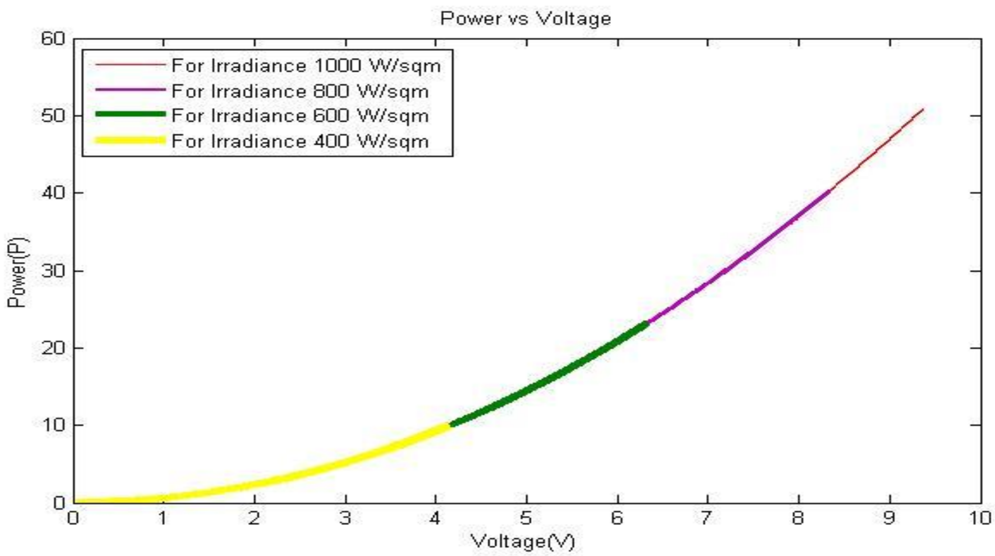


Fig 4.11 : P-V characteristics of MPPT in MATLAB.

By changing the radiation (G), theoretical values of the open circuit voltage (V_{oc}),Maximum power point voltage(V_{mpp}) , Current(I_{mpp}), constant of proportionality of the fractional open circuit method(k), duty cycle(D), power input(P_{in}), Power output(P_{out}) and efficiency of the Buck converter(η) are as follows:

Table -III Data obtain from Simulation

G (Wm^{-2})	**V_{oc} (V)**	**V_{mpp} (V)**	**I_{mpp} (A)**	**K**	**D (%)**	**P_{in} (W)**	**P_{out} (W)**	**η (%)**
1000	21.5612	17.7294	3.66	0.8223	56.4	58.8111	50.2737	85.48
800	21.1998	17.9983	2.928	0.823	57.31	46.0602	40.2605	87.41
600	20.7338	16.8053	2.196	0.8105	59.51	33.849	23.18	69.21
400	20.0768	16.4592	1.464	0.8198	60.76	21.5217	9.9719	48.64

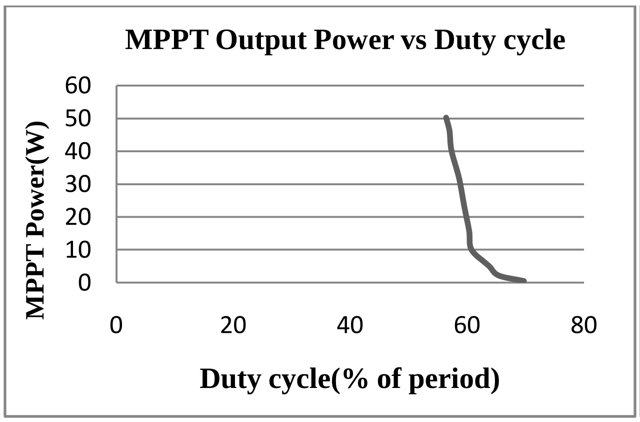
We know according to the fractional open circuit voltage algorithm, the value of k is determined by,

$$k=\frac{V_{mpp}}{V_{oc}} \qquad (4.4)$$

The duty cycle (D) was calculated using the following formula

$$D= \frac{V_o}{(k*V_{mpp})} \qquad (4.5)$$

From the simulations, it is observed that the constant proportionality of fractional open circuit voltage is around 0.8 and the efficiency of the Buck converter is approximately 85%. Under practical conditions, the value of k varies to inconsistent radiation and temperature.



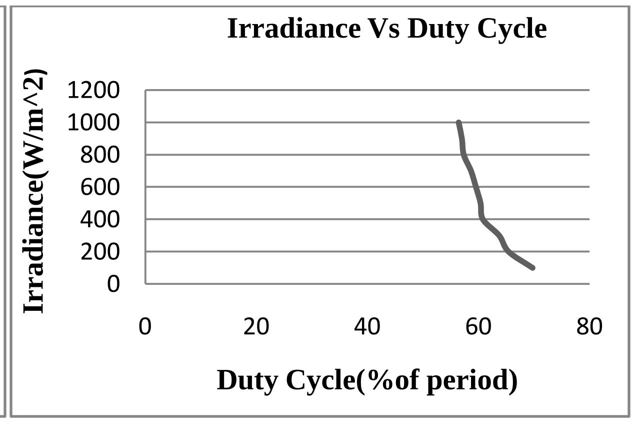


Fig 4.12(a): MPPT Output Power vs Duty cycle.

Fig 4.12(b):Irradiance Vs Duty Cycle(D)

From the figure 4.12(a) and Figure 4.12(b) it shows that as MPPT power varies with irradiance within a very short range of duty cycle value around 56%-69%.

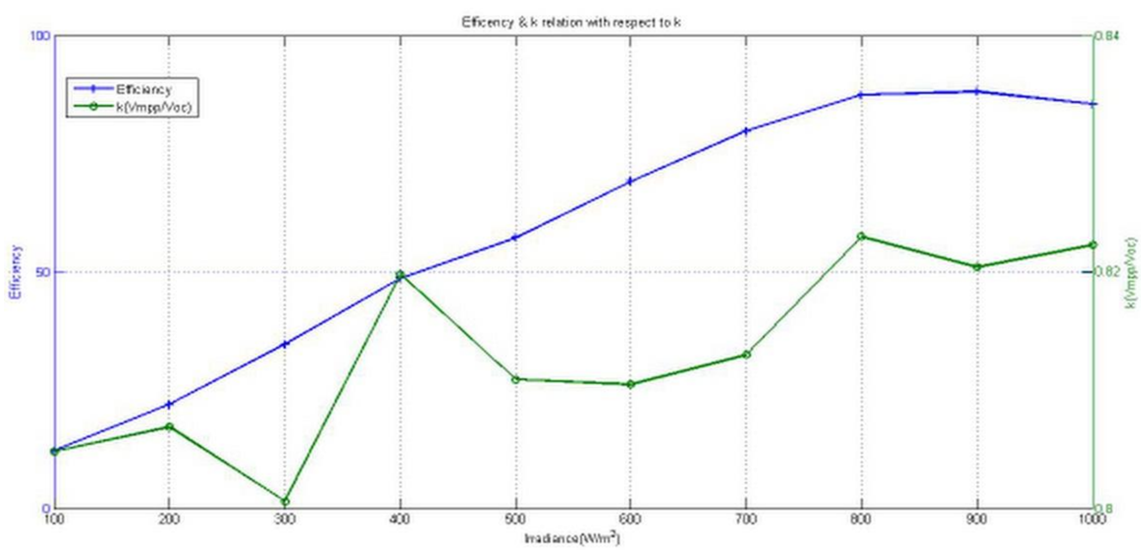


Fig 4.13 : Efficiency and k relation with respect to Irradiance.

From the figure 4.13 shows that MPPT efficiency is more or less become stable within the range between 800-1000 Wm^{-2} whereas the value of constant of proportionality of the fractional open circuit method(k) is round 0.8. This figure also verify that under practical conditions, the value of k varies to inconsistent radiation and temperature and thus the efficiency varies.

Table -IV Irradiance at different day time.

Day hours(24hrs)	Irradiance (Wm^{-2})
6	300
7	500
8	600
9	700
10	800
11	900
12	1000
13	900
14	700
15	600
16	500
17	400
18	300

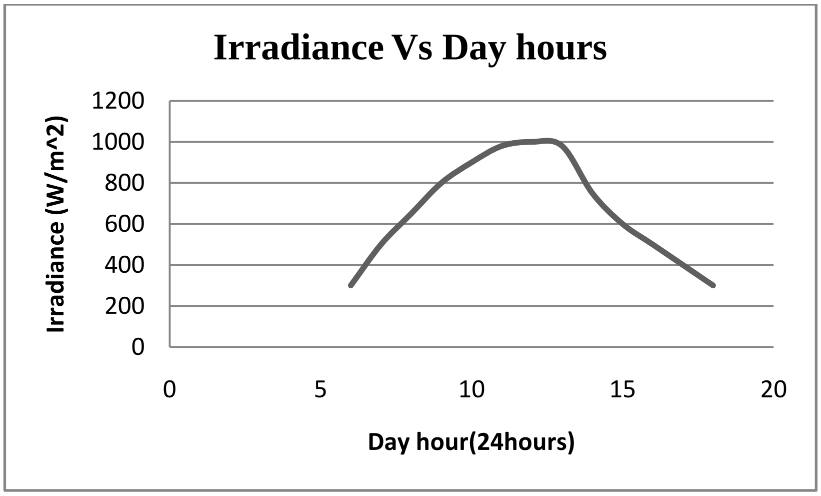


Fig 4.14: Irradiance at different day time.

Here the values are assuming depending upon the properties of solar irradiance intensity. From the Table IV & Figure 4.14 it shows that irradiance varies for different day hours, at morning the intensity of of the sunlight intensity is powerful. After the rising of the sun solar intensity is increasing gradually, t the middle of a day the sun radiate to its maximum irradiance which is around 1000 Wm^{-2}. The intensity of the sun gradually decreasing towards the end of the day. Generally a sun insolation is from 0 Wm^{-2} to maximum 1000 Wm^{-2} in a day.

4.5 DC Motor & Centrifugal Pump

The following setup shown in fig 4.15 of the DC motor & Pump is generated in SIMULINK. The 2012 MATLAB version that has been used to design this combination.

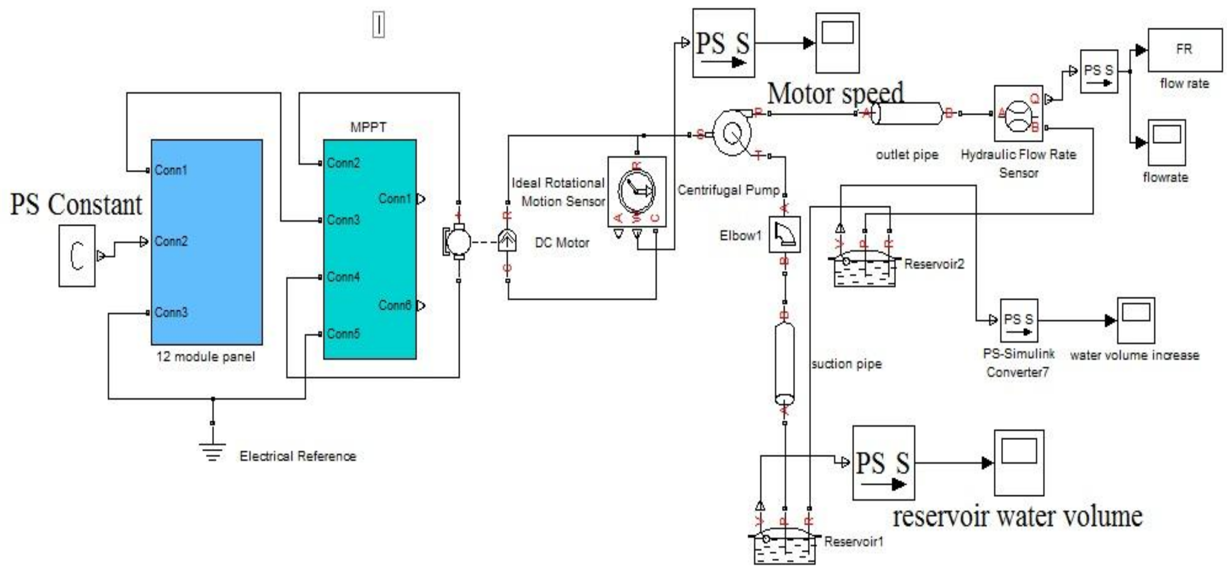


Figure 4.15:Total system with Dc motor & Centrifugal Pump in SIMULINK.

4.5.1 DC Motor characteristics

Torque Calculation:

$P_{rot} = \tau * \omega$ (4.6)

Where

P_{rot}= Rotational mechanical power

τ= Torque of motor

N = Motor speed (rpm)

ω = Angular velocity(rad/sec)

$\omega = \frac{2\pi N}{60}$ (4.7)

$\eta_{motor} = \frac{Pout}{P_{in}}$ (4.8)

η_{motor} is the efficiency of the motor but for the thesis it is considered to be ideal.

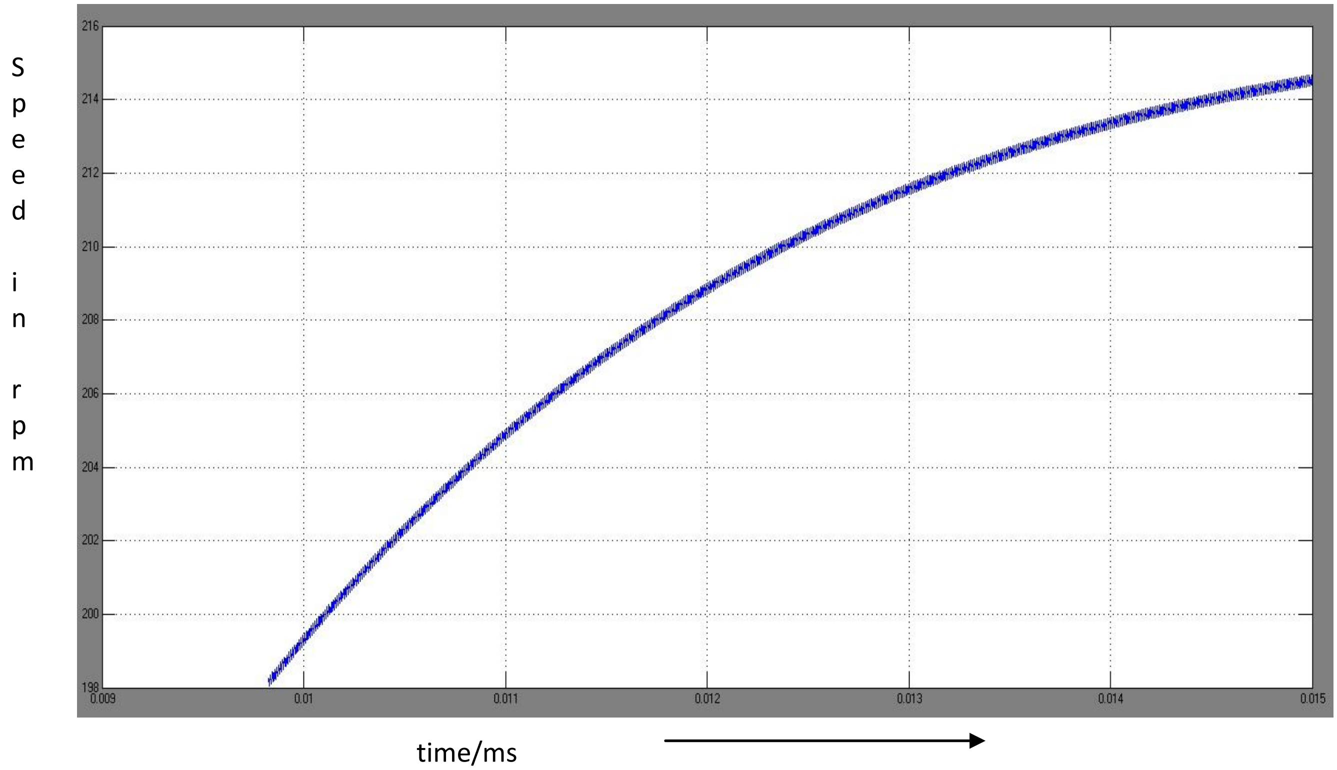


Fig 4.16(a): Motor Speed (rpm) at $1000Wm^{-2}$at transient state.

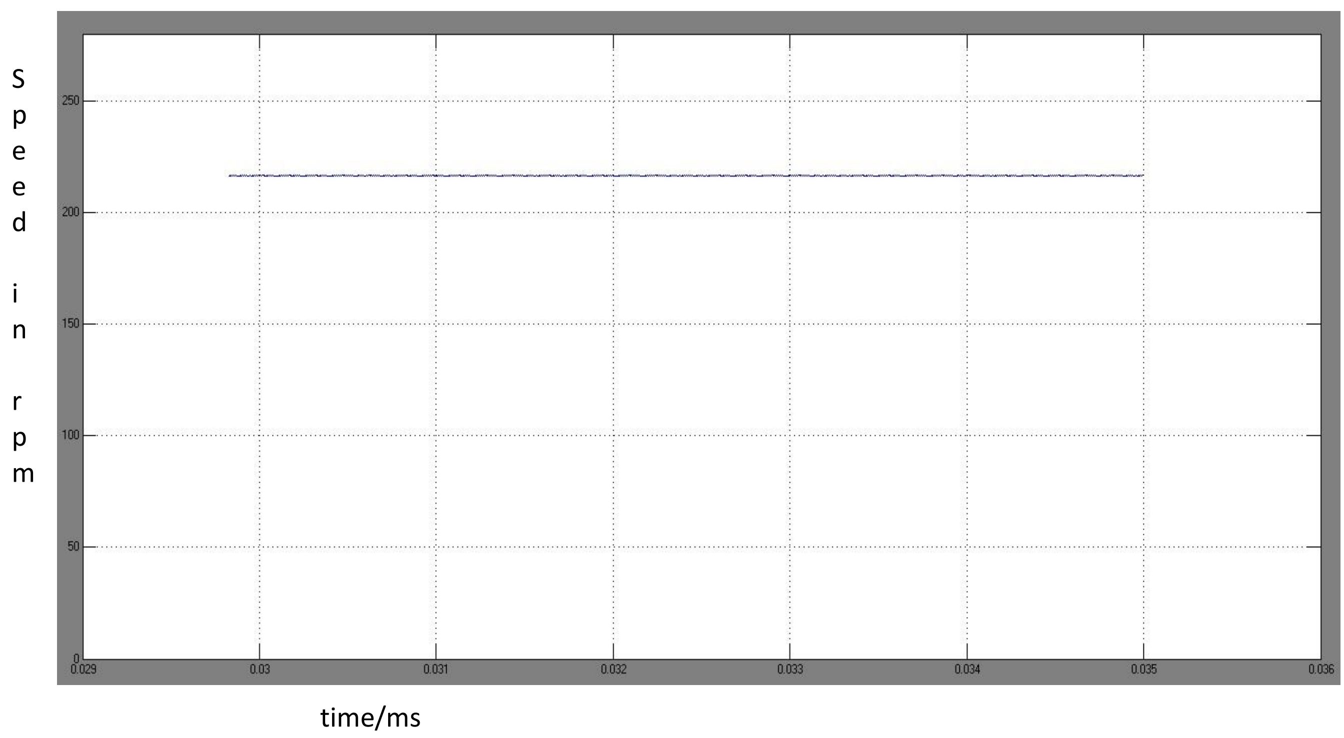


Fig 4.16(b): Motor Speed (rpm) at $1000Wm^{-2}$at steady state.

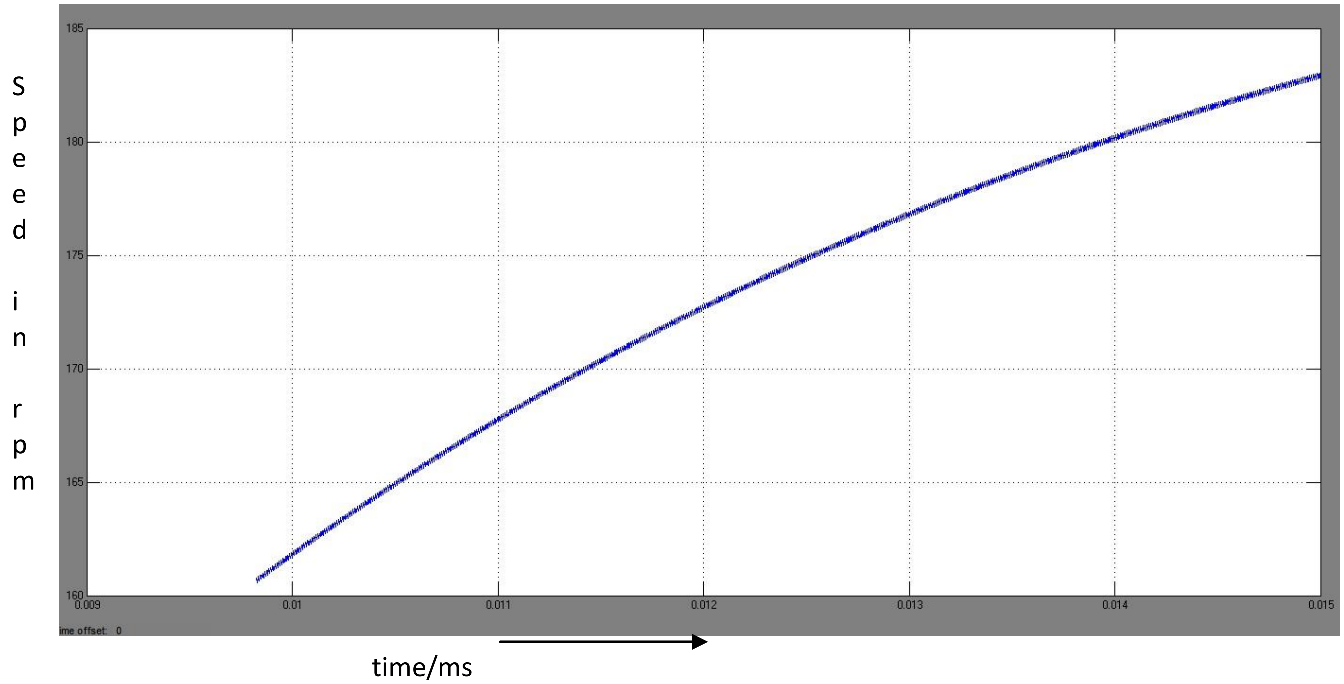


Fig 4.17(a) : Motor Speed at 800 Wm^{-2} irradiance at transient state.

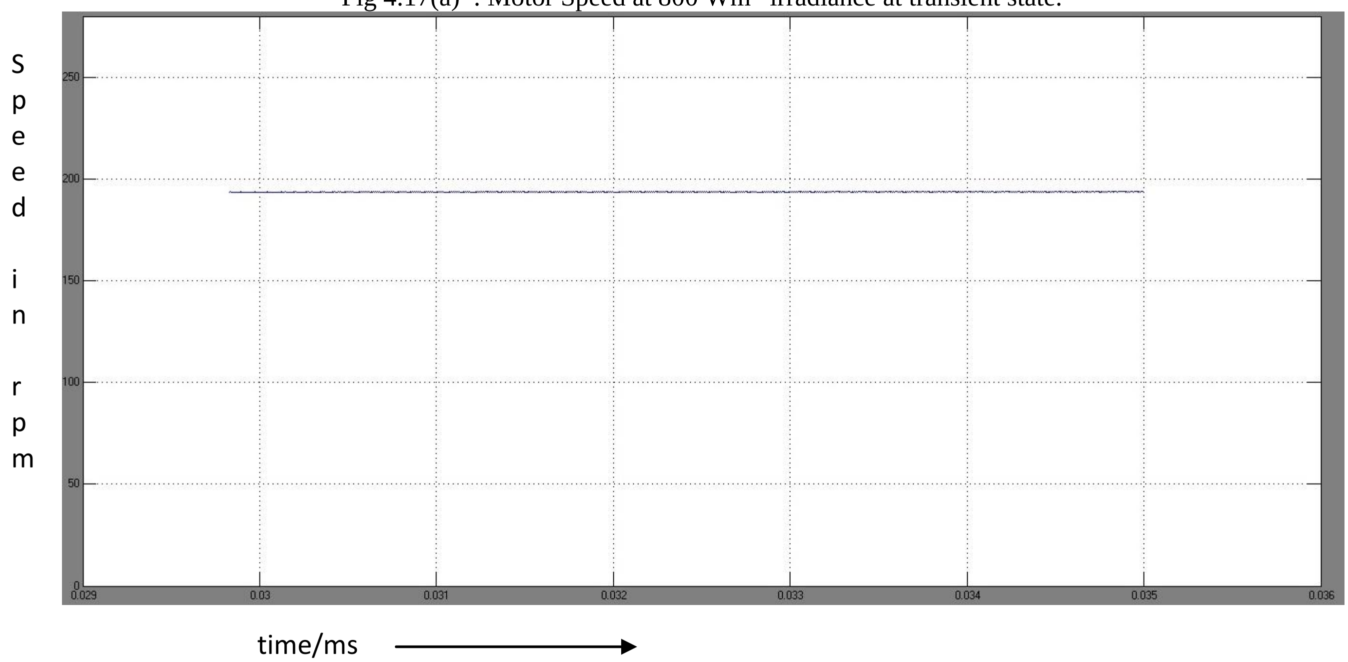
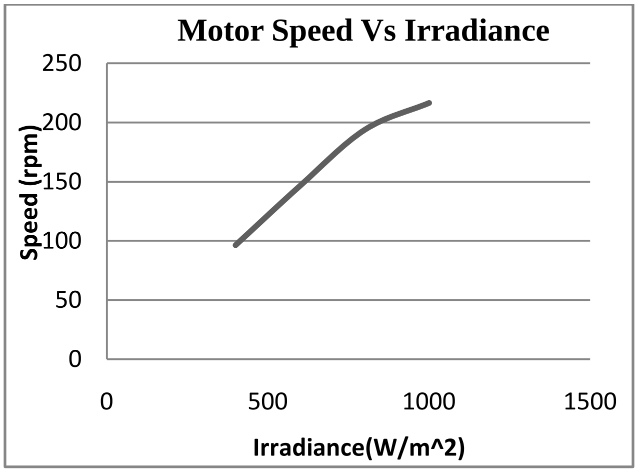


Fig 4.17(b) : Motor Speed at 800 Wm^{-2} irradiance at steady state.

Earlier we have seen that MPPT output power is varies with the different irradiance value, so as the MPPT output varies thus the dc motor speed is also varies. Motor is connected with the MPPT in parallel a rated load and a rated voltage is given in the DC motor parameter.



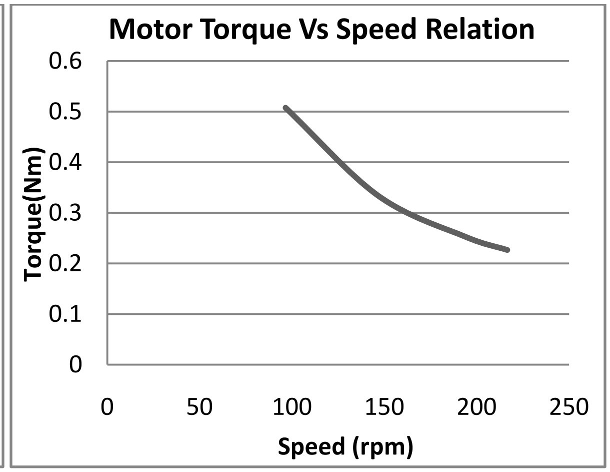


Fig 4.18(a): DC motor Speed vs Irradiance.

Fig 4.18(b): Dc Motor Torque vs Speed.

As in the Figure 4.18(a) above irradiance increases, so output mppt power also increases so that MPPT dissipated more power to the DC motor while increasing the irraadiance .

From the theoretical knowledge DC motor torque is inversely proportional to the speed of the output shaft of the DC motor. So here in the figure 4.18(b) it proves the DC motor Torque-Speed inverse relationship.

Pump characteristics :

Pump Efficiency ,η_{pump} :

$$\eta_{pump} = \frac{QgHm}{Po} \times 1000 \qquad (4.9)$$

$$H_m = H + \frac{fHV^2}{2gd} + \frac{V^2}{2g} \qquad (4.10)$$

$$V = \frac{4Q}{\pi d^2} \qquad (4.11)$$

Q = flow rate in m³/sec
H = height of pipe
H_m =manometric height of pipe
V = velocity of water
f=friction factor=0.05
d=diameter of pipe

Here,

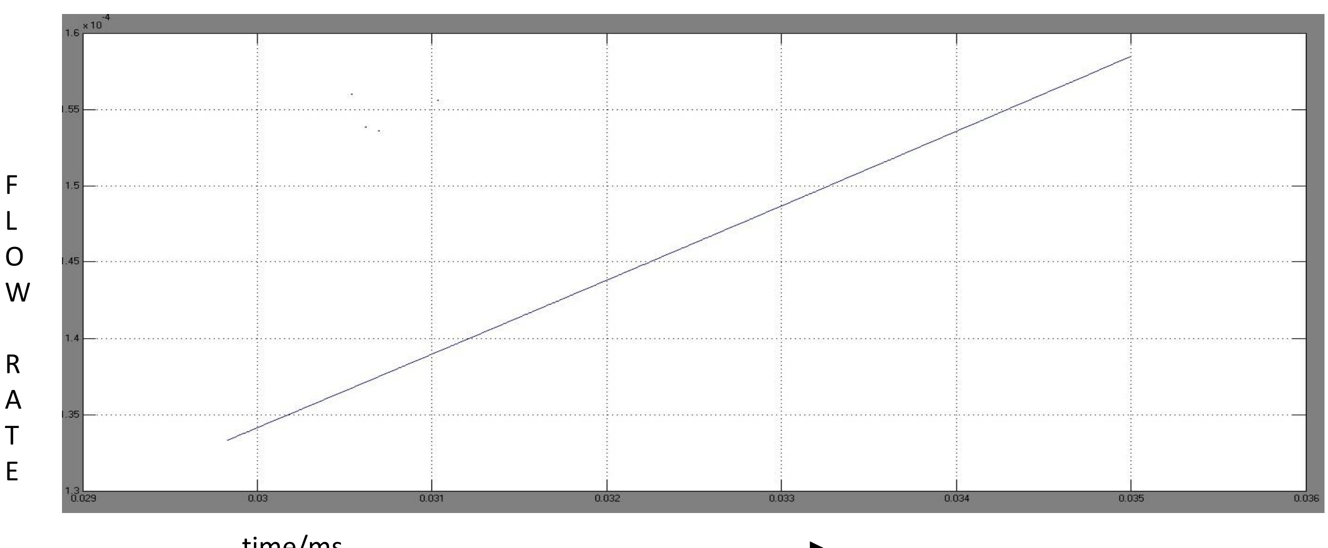


Fig 4.19 : Flow rate for 1000Wm^{-2}.

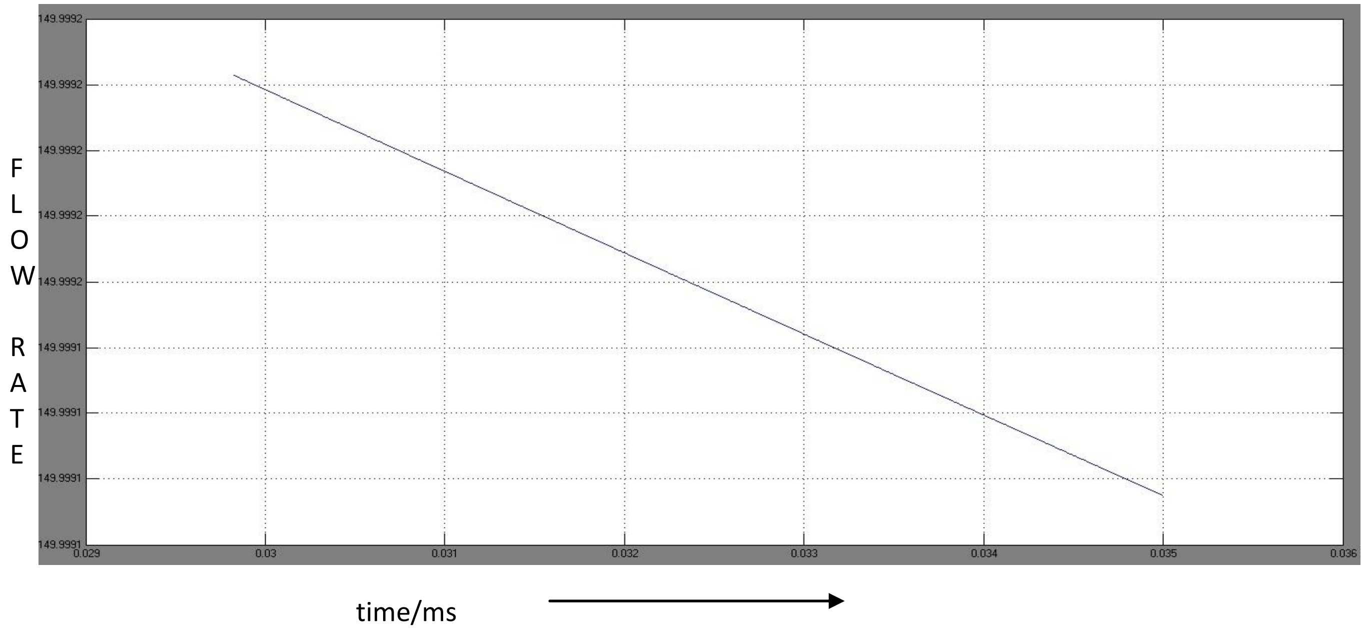


Fig 4.20 : Inlet reservoir Volume decrease at 1000Wm^{-2}.

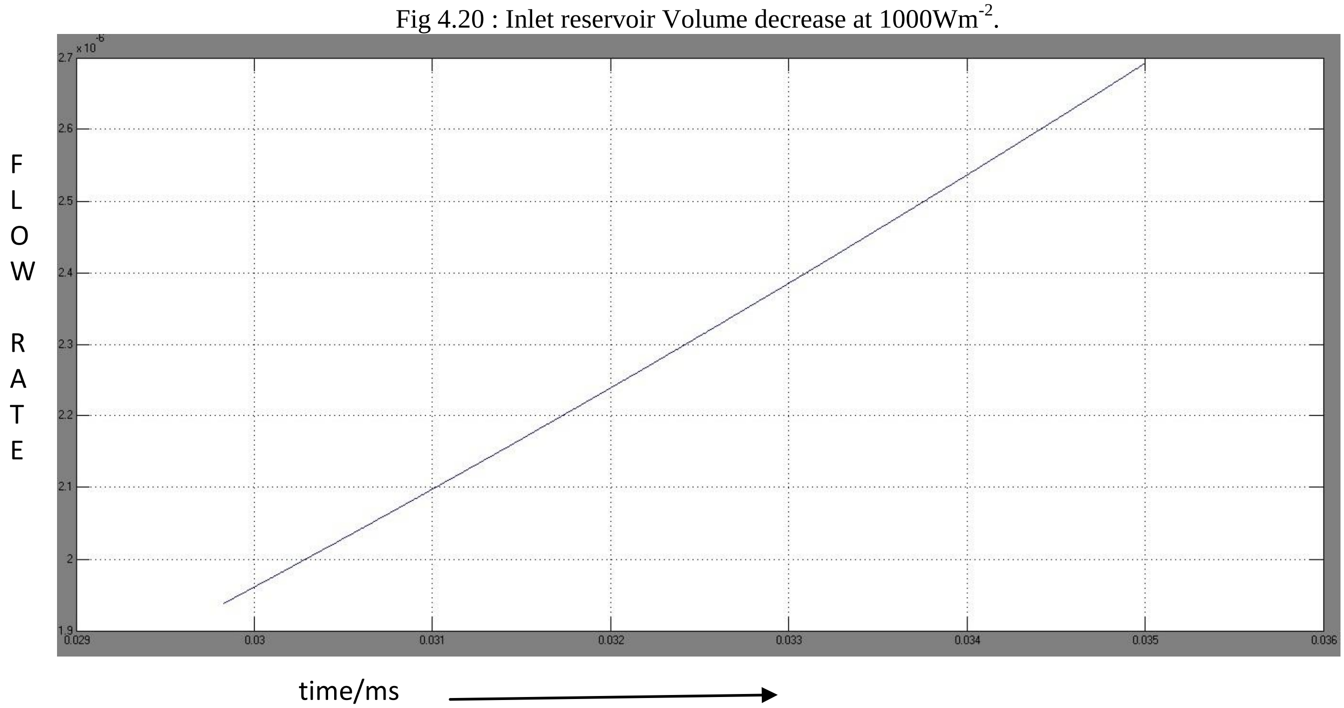
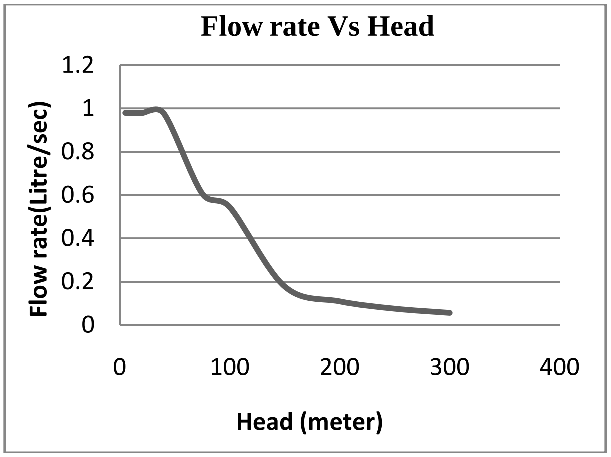


Fig 4.21: Outlet reservoir volume increase for 1000 Wm^{-2}.

In the above Figure 4.20 & 4.21 it is seen that inlet reservoir volume is decreasing while the outlet reservoir volume is decrease because of flow rate of the water. Here are some characteristics of pump with the pipe length



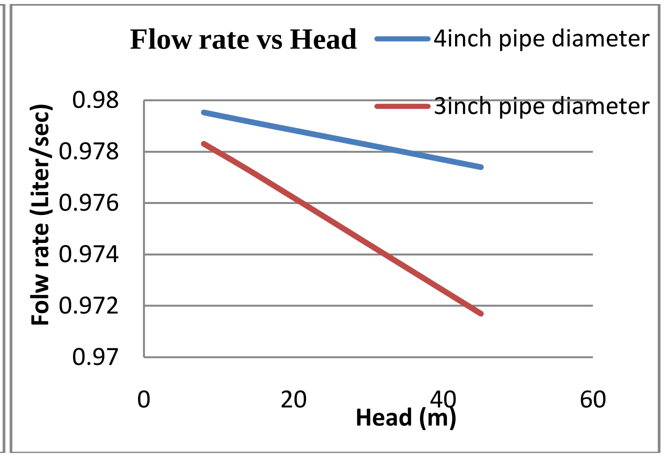


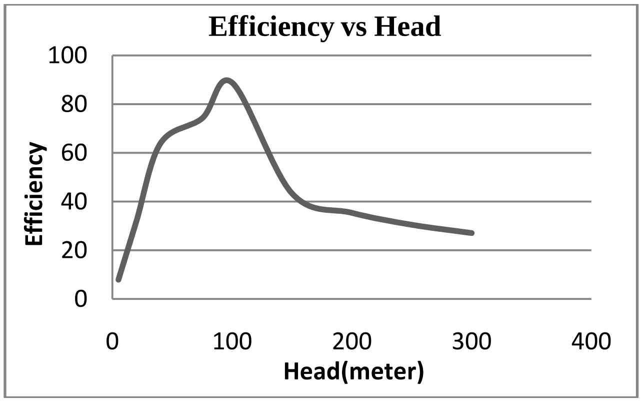
Fig 4.22: (a) Flow rate vs Head 4.22 (b)Flow rate vs. Head for different diameter

Figure 4.22(a) reveals that when the Head is creasing then the flow rate of the pump is decreasing gradually, for larger Head, flow rate will be close to zero(but not approximately zero). In the figure 4.22(b) it shows if the diameter of the head increases or decreases then the flow rate is also linearly decreases or increases respectively. Here the simulation has done for a head diameter of 4inch & 3inch. Here is some statistical data in the Table-V which are found by doing simulation in the SIMULINK.

Table -V Centrifugal pump performance at different head

Head(m)	Flow rate(Liter/sec)	η_{pump}
5	0.9797	8.1
20	0.9789	32
40	0.9777	63.88
75	0.6065	74.29
100	0.54401	88.86
150	0.17709	43.4
200	0.1085	35.45
250	0.0748	30.54
300	0.0554	27.16

The characteristic curves of this values are plotted below here in fig, 4.23a & 4.23b



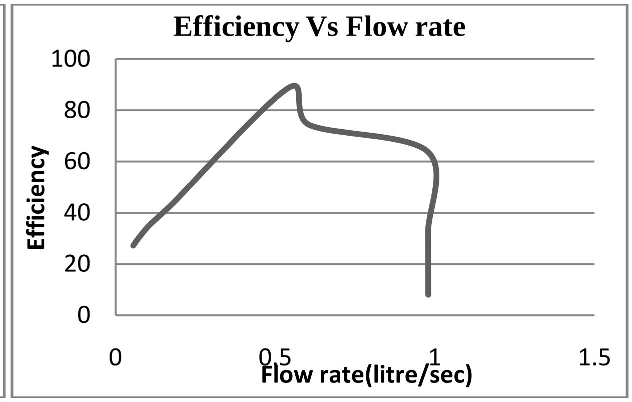


Fig 4.23 (a): Pump Efficiency vs Head.

Fig 4.23(b): Pump Efficiency vs Flow rate.

4.6 Pump operating point

When a pump is installed in a system the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect. The rate of flow at a certain head is called the duty point. The pump performance curve is made up of many duty points.

If the actual system curve is different in reality to that calculated, the pump will operate at a flow and head different to that expected. For a centrifugal pump, an increasing system resistance will reduce the flow, eventually to zero, but the maximum head is limited as shown. Even so, this condition is only acceptable for a short period without causing problems. An error in the system curve calculation is also likely to lead to a centrifugal pump selection, which is less than optimal for the actual system head losses.

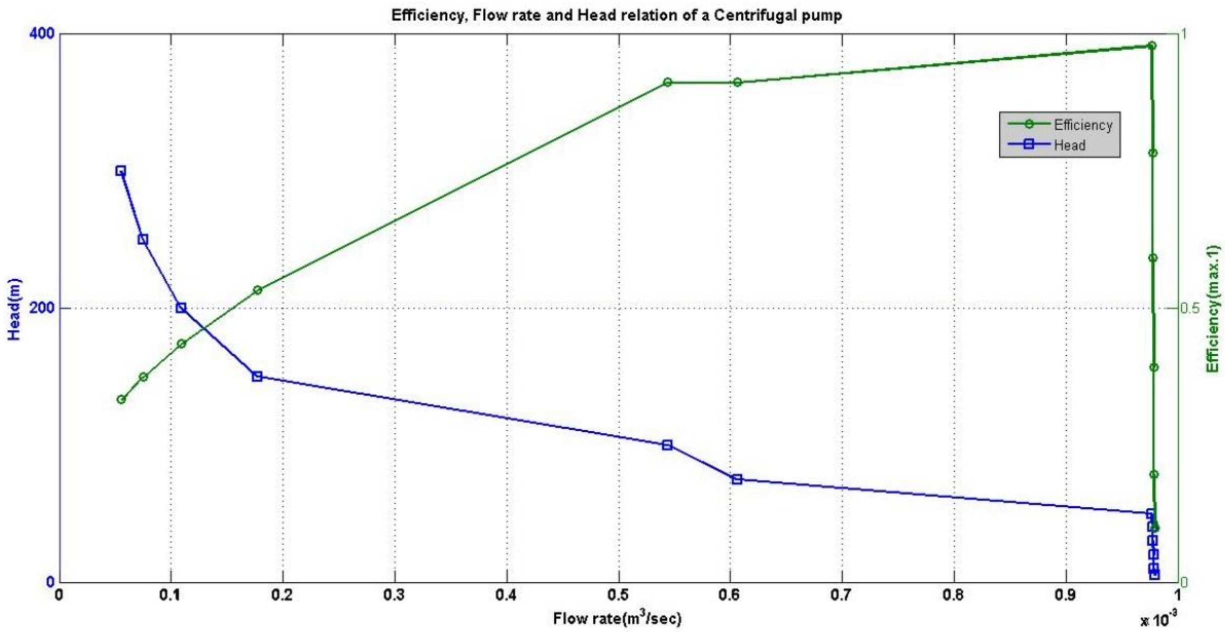


Fig 4.24 : Pump performance with Pump Operating point.

Here is a performance curve of centrifugal pump :

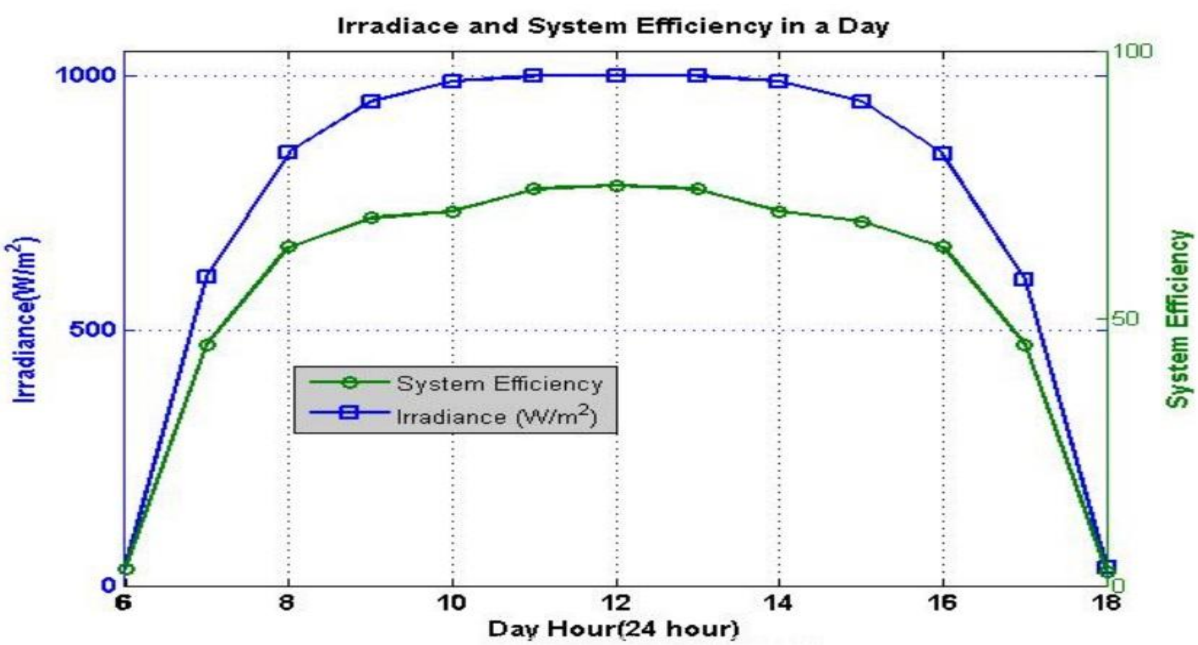


Fig 4.25 : Irradiance &System Efficeibncy relationship of a centrifugal pump with respect to Day time(24hrs).

Here the figure 4.24 & 4.25 shows the variation of centrifugal pump for different irradiance at different day time. From the above figure it shows that for maximum Output from the system the system operation will be efficient from 10am to 2pm in a day. Here the Schematic diagram of the total system generated in **MATLAB Simulink** with the **Simscape** library:

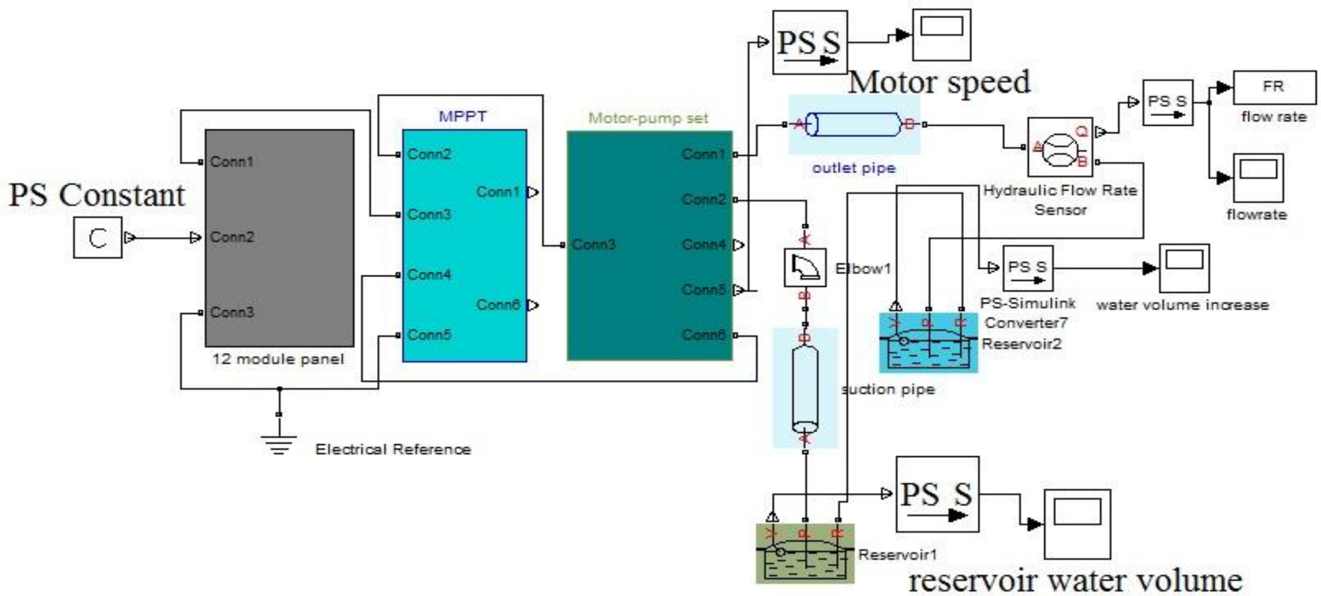


Fig 4.26 : DESIGN AND SIMULATION OF DC POWERED SOLAR PUMP USING MATLAB SIMSCAPE.

4.7 Overall efficiency of the system

The overall efficiency of the system was taken under condition. The whole system has a efficiency around : 74.70%. This gives a big scope for the implementation of the idea for practical design and practice.

Here we consider, Some other efficiencies of the system.

Avg. MPPT efficiency=85%

Motor efficiency=99%(considering ideal case)

Pump maximum efficiency=88.78%

4.8 Summary:

The chapter is based on simulation results and the data obtained from simulation. The simulated data and results gives a good view of the research that has been done also it approves the design's feasibility for practical implementation. As discussed in the chapter the MATLAB software is used for design of the system.

Chapter 5

PRACTICAL DATA & IMPLEMENTATION

5.1 Solar Panel

A 20 watt solar panel shown in fig 5.1 was taken for practical implementation. The $V_{mpp,}$ maximum power point voltage is around 19.5 v and $I_{mpp,}$ maximum power point current is 1A. The data were given in the solar panel specifications. The solar panel worked well at the presence of good sunlight at noon time. However, the current value reading in the multi meter was showing very small value because of the improper inclination of the solar panel. There were few occasions where, the ammeter was showing some current reading.

Fig 5.1 Solar Panel 20 W

5.2 Data obtained

The data taken from the solar panel output are shown in the table VI. These data were taken at different time period of a day in a particular location. The data may vary on a different day in a different location. In some remote areas the solar panel may give better values for the proper irradiance. In order to obtain the solar data radiation in a day in remote areas of Bangladesh, the solar data statistics can be found from research centre in Bangladesh and website. Fig 5.2 shows the buck converter circuit connected to the solar panel under normal conditions.

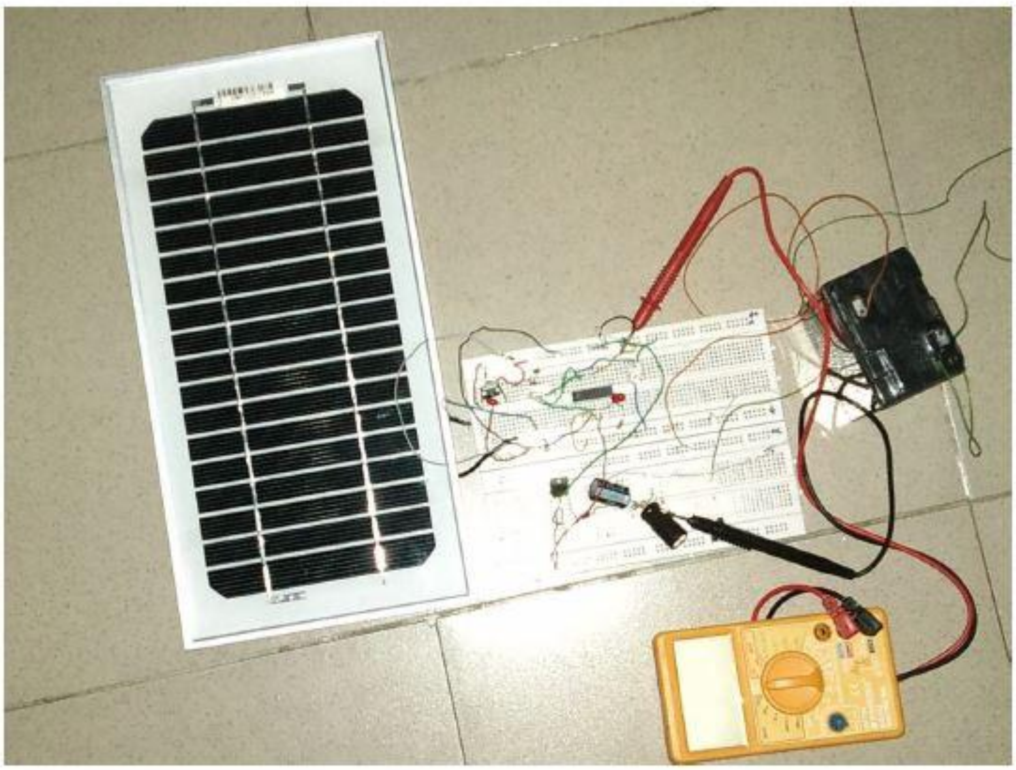


Fig 5.2 Solar panel with buck converter circuit in bread board.

5.3 List of equipment & Costing

The list of the equipment required for the practical implementation are given with market price in Table VI. A small model of the research was implemented with Dc motor. The pump is not used due to its size and high price. The centrifugal pump is very much available in the market. For the buck converter design, the inductor & capacitor values were carefully chosen according to the values obtained from the simulation data. It was difficult to obtain the exact value component, but the components with close values were used. For the switching of the DC-DC converter, Mosfet was used because of its low switching power loss. The duty cycle of the converter was controlled using a microcontroller with simple code. The close loop buck converter circuit was design to give a better output. The total cost of the project was around Tk.3000.

Table- VI Equipment List

Equipment Name	Quantity	Price(Tk)
Solar Panel	1	450
Resistor	10	20
Schottkey Barrier Diode	1	15
Diode	2	20
Capacitor	3	40
Inductor	2	20
12v Battery	1	550
Transistor	2	30
Lcd Display	1	150
Bread Board	1	200
Plastic Board	1	100
Switch	1	25
Push Button	2	30
Dc motor	1	200
Wire		150
Others		700
	TOTAL	= 2680

5.4 Practical Implementation

The buck converter was designed first in the bread board for proper working of the circuit. The whole circuit was then implemented in the pcb board shown in fig 5.3. The LCD display was used to see the measured value of the output voltage. The microcontroller used is to provide the duty cycle . The microcontroller eases the project with automatic duty cycle that changes under different radiations. The synchronizing buck converter works according to the duty cycle with mppt algorithm. As the data measured in table shown. The values are consistent with the algorithm and very close to the simulation values obtained for output voltage.

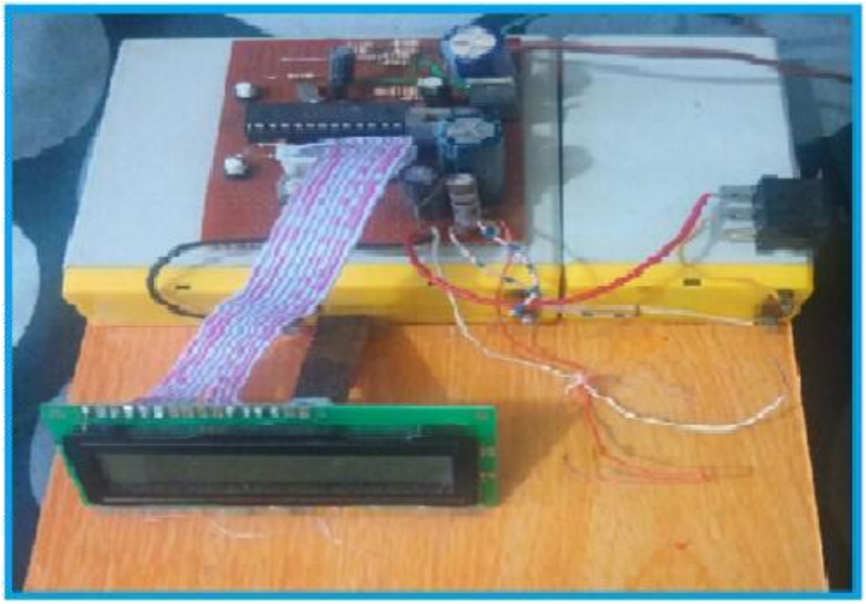


Fig 5.3 Hardware design of the project

Table-VII Data obtained during different time interval

Time	Source Voltage(V)	Battery Voltage(V)	Output Voltage(V)
6am-8am	13	12	12.3
8am-10am	15	12	14.5
10am-12pm	18.5	12	17.9
12pm-2pm	19	12	18.4
2pm-3.30pm	17	12	15.5

From the table-VII data obtained, it is seen that the voltage value is almost the same as V_{mpp} during 10am-2pm. At this time of a day, the radiation from the sun is high and the solar panel gives a better value. A 12-v battery is used for charging and to store the power because of the change in weather conditions. The battery will supply power to the Dc motor and the motor will run the centrifugal pump.

Chapter 6

CONCLUSION

6.1 Conclusion

PV powered water pumping system is now a growing interest which can be a simple and efficient option for the irrigation purposes. In chapter 1 the background of the thesis was discussed along with the related work done in the past by many researchers over the years. Later the motivation of the work was mentioned with few important points and the research objectives were stated. The chapter 2 explains the related theory of the system analysis that is being proposed in the thesis. The Pv system design and DC-DC converter with the Approached MPPT algorithm were discussed in that chapter. The comparison of different existing algorithm was shown in chapter 2. Also the advantages of the proposed algorithm was explained. In chapter three the motor and the pump performance and design methodology were taken under account for the desired system. Since there are many types of motors and pumps available for irrigation, chapter three discuses the type motor & pump used in the proposed system along with their characteristics. In Chapter 4 all the simulated data are shown with results. The total system design and other circuit design were represented with detailed components in chapter 4. Finally in chapter 5, the practical implementation of the proposed system was explained with the practical data obtained. A model system was implemented for the proposed system for the testing and validity. In the proposed system , the main idea was to increase the efficiency of the MPPT and the converter system for better operation at very low cost and maintenance. The idea was to design a new converter topology, which will accustom to change in duty cycle due to variation of sun radiation also a closed-loop system that could give better outcome.

Especially, PV has a powerful attraction because it produces electric energy from the sun, consuming no fossil fuels, and creating no pollution or greenhouse gases during the power generation. Together with decreasing PV module costs and increasing efficiency, PV is getting more pervasive than ever. As in this thesis Simscape library in MATLAB is used where many components related to this type of work are available and easily can be changed to design and simulate as they need. The MATLAB environment gives a real time design system for the thesis. The model used for simulations of DC water pump gives results within a reasonable range. The accuracy of model was tested by practical implementation. some parameters are only estimated in simulation.

6.2 Future work & Scopes

Physical implementation of the system remains for future research. It may involve implementation of a DSP or a microcontroller, a method of supplying power to the controller, signal conditioning circuits for A/D converters, an improved MPPT algorithm and a water level sensor that detects when the water reservoir reaches full. It may also involve performance analysis on the actual system and comparisons with simulations. This research will be more effective for those who want to work on it in future. For induction motor run some additional circuits can be added. For a three phase inductor, Three phase inverter can be connected to the circuit along with T-LCL Filter to obtain 3-phase output.

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APPENDIX A

A.1 MATLAB coding for generating I-V curve and P-V curve and finding the maximum power point (mpp).

```
x=input('voltage');
y=input('current');
z=input('power');
figure(1)
plot(x,y);
hold on
figure(2)
plot(x,z);
ylabel('Power/W');
xlabel('Voltage/v');
hold on
M=max(power);//to find maximum power
Isc=max(current);// short-circuit current
Voc=max(voltage);// open-circuit voltage
Vmpp=0;
Impp=0;
j=length(z);
for i=1:j
if power(i)==M
Vmpp=voltage(i);
Impp=current(i);
end
end
k=Vmpp/Voc;
```

A.2 Microcontroller coding in MiKroC pro for PIC for generating PWM signal

```
#include<stdio.h>
unsigned short j;
unsigned int adc_0, temp;
void InitMain()
{
ADCON1 = 0x80; // Configure analog inputs and Vref
TRISA = 0b00000001; // PORTA is input
TRISB = 0b11111110; // Pins RB7 is output
Pwm_Init(5000); // Initialize PWM module
}
void main()
{
InitMain();
j = 1; // Initial value for j
Pwm_Start(); // Start PWM
while (1) // Endless loop
{
adc_0=Adc_Read(0)/4;
temp=adc_0*j;
Pwm_Change_Duty(temp);
}
}.
```