بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

Sudan University of Sciences and Technology

College of Engineering

Electrical Engineering

Smart Agriculture System Powered by Solar Energy

منظومة الزراعة الذكية باستخدام الطاقة الشمسية

A Project Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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الآيـــــة

قال تعالى:

" وَهُوَ الَّذِي أَنزَلَ مِنَ السَّمَآءِ مَآءً فَأَخْرَجْنَا بِهِ نَبَاتَ كُلِّ شَيْءٍ فَأَخْرَجْنَا مِنْهُ خَضِراً نُّخْرِجُ مِنْهُ حَبّاً مُّتَرَاكِباً وَمِنَ النَّخْلِ مِن طَلْعِهَا قِنْوانٌ دَانِيَةٌ وَجَنَّاتٍ مِّنْ أَعْنَابٍ وَالزَّيْتُونَ وَالرُّمَّانَ مُشْتَبِهاً وَغَيْرَ مُتَشَابِهٍ انظُرُواْ إِلِى ثَمَرِهِ إِذَآ أَثْمَرَ وَيَنْعِهِ إِنَّ فِي ذَلِكُمْ لآيَاتٍ لِّقَوْمٍ يُؤْمِنُونَ "

(سورة الأنعام : الاية 99)

صَدَقَ اللهُ العَظِيم

DEDICATION

Affectionate mom, your little one has grown up and snow on the verge of becoming an engineer as you dream. Thanks in your right is not enough... nor is your debt on me repaid, because I was born because of you and grew up with your kindness and care, this work is a dedicate to you.

My great dad, you have spent whole your life for our sake, you work night and day striving for the sake of our breeding and education, my tongue is unable to thank you, and my letters are incapable of carrying these feelings. So accept this dedication from us.

To family, friends and batch 31, Takaful and our loyal teachers we dedicate this work to you all.

ACKNOWLEDGEMENT

First and above all, we praise God, the almighty for providing us this opportunity, and granting us the capability to proceed successfully. Grateful for this opportunity, we would like to give our sincere thanks to our supervisor**, Dr. Salah Eldeen Gasim Mohamed** for his continuous support in this project. His sharp mind, intuitive understanding, powerful observation and immense knowledge were great help to us. Without his assistant and dedicated involvement in every step throughout the process, this project would have never been accomplished. Lastly thanks to our teachers in electrical engineering school for their effort, without them we wouldn't be able to reach this far.

ABSTRACT

Smart agriculture system powered by solar energy is a system designed to control the irrigation operation automatically, and use the solar energy as a source of power to feed the pump. The main aim of the project is to design a system that irrigate plants without human contribution, and to ensure a minimum water losses, also to provide the system with power that needed by solar panel. PVsyst software and hand calculations have been used to developed a successfully design. The project automation is developed by using Arduino Uno, soil moisture sensor, water tank float switches and relay. The proposed automation design simulated on the simulation software Proteus to test its functionality. An economic comparison was made between solar energy system, diesel generators and the national grid to determine the most appropriate system for operating the irrigations system in the area under study.

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المستخلص

منظومة الزراعة الذكية باستخدام الطاقة الشمسية هي منظومة تتم فيها عملية التحكم في ري المزروعات آليا وتستخدم الطاقة الشمسية لتغذية المضخة. الهدف الرئيسي للمشروع هو تصميم نظام آلي لري المزروعات؛ لضمان الإستغلال الأمثل لموارد المياه الجوفية بدون فقد ويستخدم هذا النظام الواح الطاقة الشمسية؛ لتوفير الطاقة اللازمة لتشغيل المضخة. تم استخدام طريقة الحسابات اليدوية بالإضافة لبرنامج "PVsyst" لتصميم النظام الملائم. لعملية الأتمتة تم استخدام "Arduino Uno"، محساس رطوبة التربة، عوامة كهربائية، و مرحل؛ لبناء النظام الآلي. لإختبار النظام وأدائه تمت محاكاة منظومة الري الآلي باستخدام برنامج "Proteus". تم اجراء المقارنة الإقتصادية بين تكلفة نظام يعمل بالطاقة الشمسية مرة مع نظام يعمل بمولدات الديزل، ومرة اخرى مع نظام يتم تغذيته من الشبكة القومية للكهرباء لتحديد النظام الملائم لتشغيل منظومة الري للمنطقة موضوع الدراسة.

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LIST OF ABREVIATIONS

PV	Photovoltaic
PSH	Peak Sun Hour
Si	Silicon
DC	Direct Current
AC	Alternating Current
Voc	Open Circuit Voltage
Isc	Short Circuit Current
Vmp	Voltage at Maximum Power
Imp	Current at Maximum Power
Pm	Maximum Power
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
TDH	Total Dynamic Head
ICSP	In Circuit Serial Programing
USB	Universal Serial Bus
PWM	Pulse Width Modulation
Wp	Watt Peak
HP	Horse Power
LCD	Liquid Crystal Display
GlobEff	Effective Global, corr. for IAM and shadings
EArrMPP	Array Virtual Energy at MPP
E_PmpOp	Pump Operating Energy
ETkFull	Unused Energy (tank full)
H_Pump	Average total Head at Pump
WPumped	Water Pumped
W_Used	Water drawn by the user
W_Miss	Missing Water
IAM	Incidence Angle Modifier
STC	Slandered Test Condition
USD	United State Dollar
SDG	Sudanese pound

CHAPTER ONE

INTRODUCTION

1.1 Overview

In most of the developing countries, the national economy mainly depends on the agriculture. But all these countries are not able to make proper use of agricultural resources due to the high dependency on rain. In the Sudan the rain farming contributes 80% of whole agriculture area [1].

Nowadays more than 23 million acre compose the rain farming area implants only in the rain season, and for all the remaining months remain without plants, so there are need to irrigation systems ensuring a good exploit this lands for whole year's seasons. Sudan has solar shining about $5.8 - 7.2 kWh/m^2/day$, and solar brightness hours about 9-10hours/day, and the underground water was estimated by 16 billion m^3. This resources must be exploit [1].

The proposed solution is to use underground water which pumping by solar pumping system. In addition it provides automatic control system depended on soil moistures sensors to ensuring maximum water usage efficiency by monitoring the water flow. In this proposed system, smart indicates that there are no human intervention in irrigation process and all the operations controlled automatically by using the soil moistures sensor float switches and control board.

The world today suffers from a severe shortage in the amount of fresh water suitable for drinking. However, the process of irrigation of agricultural crops consumes large quantities of this water. Therefore automatic irrigation using drip irrigation technology helps to reduce the amount used in irrigation, as it reduces employment, which reduces the cost of the agricultural process makes it more profitable.

The proposed solution provides a good base for future study for more improvement such as adding different control system. IOT can be used in the system for continuous monitoring by the farmer.

1.2 Problem Statement

The developing African countries are totally dependent on agriculture as the main engine of their economy, but all these countries lack modern technologies and innovative agricultural methods that can increase their efficiency and productivity to turn into economically stable countries.

In the State of Sudan, rain-fed agriculture represents 80% of the total cultivated land, which is equivalent to 23 million acres, and more than 80% of the total workers in the agricultural sector work in rain-fed agriculture. The main problem here is that vast lands are used only in the rainy season and remain unexploited for the rest of the year.

Large percentages of farmers are still below the poverty line, because of the financial income from the seasonal agricultural process, so the percentage of the poor and unemployment increased. As a result of poverty and unemployment, many economic and social problems and security disturbances resulted in a clear impact on the stability of the country.

Because rain-fed agricultural is only in the rainy season, the farmer cannot grow much of the crops that can be grown in other seasons of the year, thereby losing the ability to diversify the cultivated crops and thus not achieve any good yields.

In the absence of rain, these societies suffer from severe food shortages, which may result in famines and may cause many diseases. Drought can also cause large numbers of livestock to die.

1.3 Objectives

The main objectives of this study are to:

- Design a solar powered irrigation system for small and medium areas.
- Make an economic comparison between the irrigation system fed by diesel, the irrigation system fed by the national grid, and the irrigation system which be fed through solar energy.
- Design smart irrigation system to automatically irrigate crops without human intervention, based on the plant needs for water.

1.4 The Scope

The research intends to answer the following questions:

1 - Which is better economically to irrigate small areas in the rural Bara region of the Kordofan region, is it a diesel system, solar energy, or using the national electricity grid?

2- How to design a solar powered irrigation system?

3- How to design a smart irrigation system that works automatically to irrigate crops?

1.5 Research Limits

Most of the agricultural lands in Sudan depend on rain water for the irrigation process, except for the adjacent areas to the Nile, as they depend on surface irrigation from the Nile and small rivers. In areas far from the Nile and water valleys, and for agriculture outside of the rainy season, we will need to use groundwater.

In this project, the Umm Jnah village in the countryside of Bara 350km west of Khartoum was chosen as a case for study, where the predominant activity in this area and its similarities is rain-fed agriculture with the presence of small projects using groundwater by submersible pumps.

An area of one acre of land was chosen equal to 4200 m^2 of agricultural land as an area that is supposed to be cultivated and based on it, the irrigation system is calculated and designed, knowing that the tomato crop has been identified as a crop to be cultivated in this area.

1.6 Methodology

The methodology followed in this project includes:

1- Collecting geographical and environmental data about the case study area.
2- Using calculations and equations to design solar pumping system.
3- Using PVsyst to design the solar pumping system.
4- Using mathematical calculations and statistical methods to make an economic comparison between the three systems, solar energy versus diesel, and solar energy versus national grid.
5- Using Proteus software to simulate the smart irrigation system.

1.7 Project Layout

The project consists of five chapters: Chapter One presents an overview, problem statement, objectives, methodology, scope, research limit and project layout. Chapter Two reviews solar resources in Sudan, solar pumping techniques, components of solar pumping system. Chapter Three presents system description, solar system design, solar system components, economic comparison, smart irrigation system design. Chapter Four presents Solar system design results, approachment between calculation method and PVsyst software, economic comparison, Smart system simulation. Chapter Five presents a conclusions and recommendations for future works.

CHAPTER TWO

THEORETICAL BACKGROUNG AND LITERATURE REVIEW

2.1 Introduction

Solar Energy is the most important source across the agricultural sector in developing countries, access to irrigation is important step in improving farmer livelihoods and productivity as it increases productive yields. Through providing water for portable use, irrigation, and livestock, solar water pumping brings obvious benefits, especially to rural areas and remote communities.

2.2 Solar Resources in Sudan

Sudan is blessed with good solar radiation levels varying from a yearly average of $2{,}000$ kWh $/m^2$ (or 5.5 PSH) in the least irradiated regions to $2{,}500$ kWh $/m^2$ (or 6.9 PSH) in those regions with best solar irradiance. PSH indicates the average equivalent hours of full sun energy received per day, this varies based on the location and the angle of module relative to the sun (Tilt angle) [2]. Figure 2.1 shows the global horizontal irradiation in Sudan

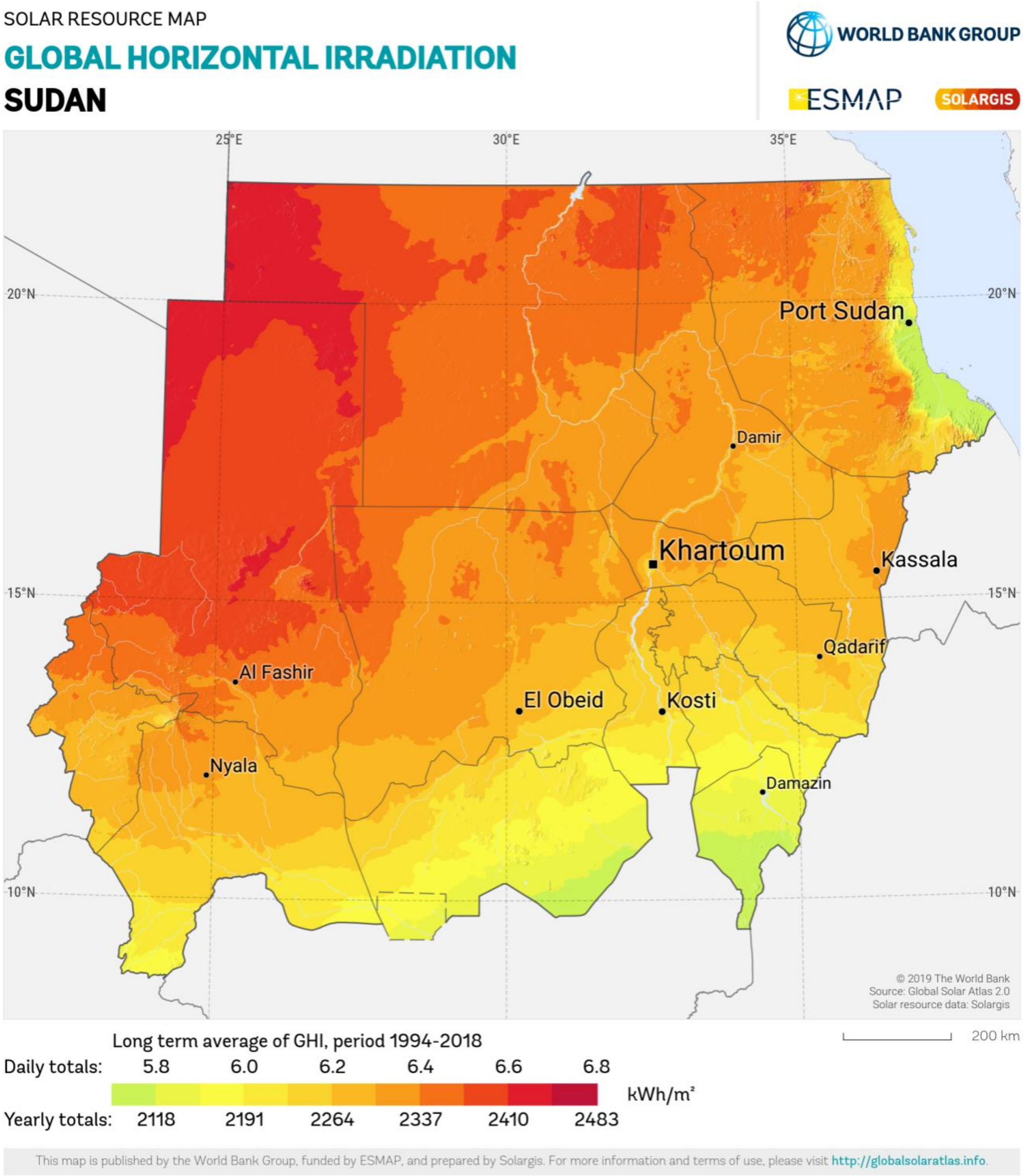

Figure 2.1 The global horizontal irradiation in Sudan

2.3 Solar Pumping Techniques

When the solar energy drops sun rays on the PV panels then the solar panel converts the rays into electrical energy with the help of Si wafers fixed within the PV panels. Then the solar energy supplies to the electrical motor to operate the pumping system using cables. By the revolution of the shaft which is fixed to the pump, then the pump begins to pick up the soil water and supplies to the fields.

2.4 Components of Solar Pumping System

A solar pumping system mainly consists of a solar PV array, a pump, a voltage controller (inverter or converter) and a water storage tank. For pumping purposes, the water source can be a well, a pond, a stream or a river [3]. Figure 2.2 illustrates the main components of solar pumping system.

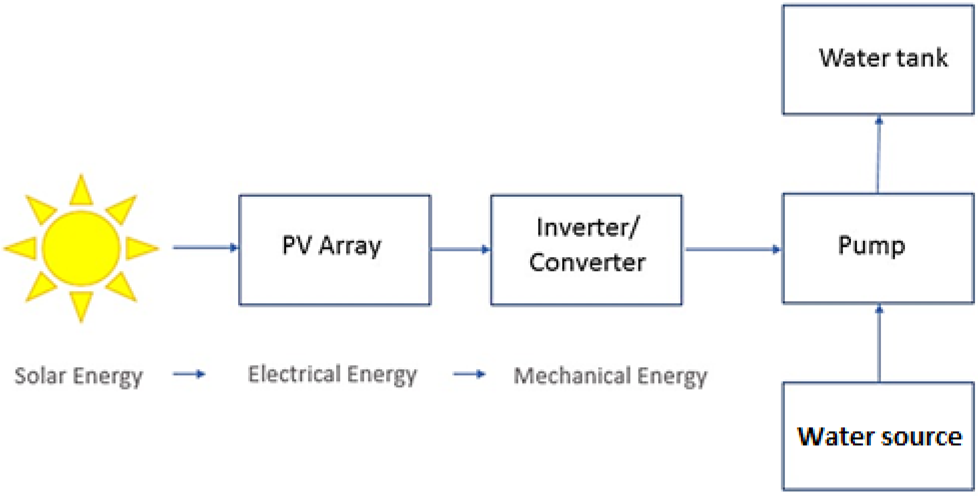

Figure 2.2. The main components of solar pumping system

2.4.1 Solar PV Module

Solar PV is short for solar photovoltaic and is the same as solar cells. When solar cells are coupled together, they are called solar panels. Groups of solar panels coupled together are called arrays. Figure 2.3 shows PV cell, module and array. When the sun is shining on a solar electric device, the solar energy received is converted to electric energy in the form of DC electricity. The most common cell materials are poly crystalline and mono crystalline silicon. Poly crystalline is a module where the cells are made of many crystals and mono crystalline modules are made of single crystals [4]. According to

[5], these operating principles of solar modules are important when sizing PV system.

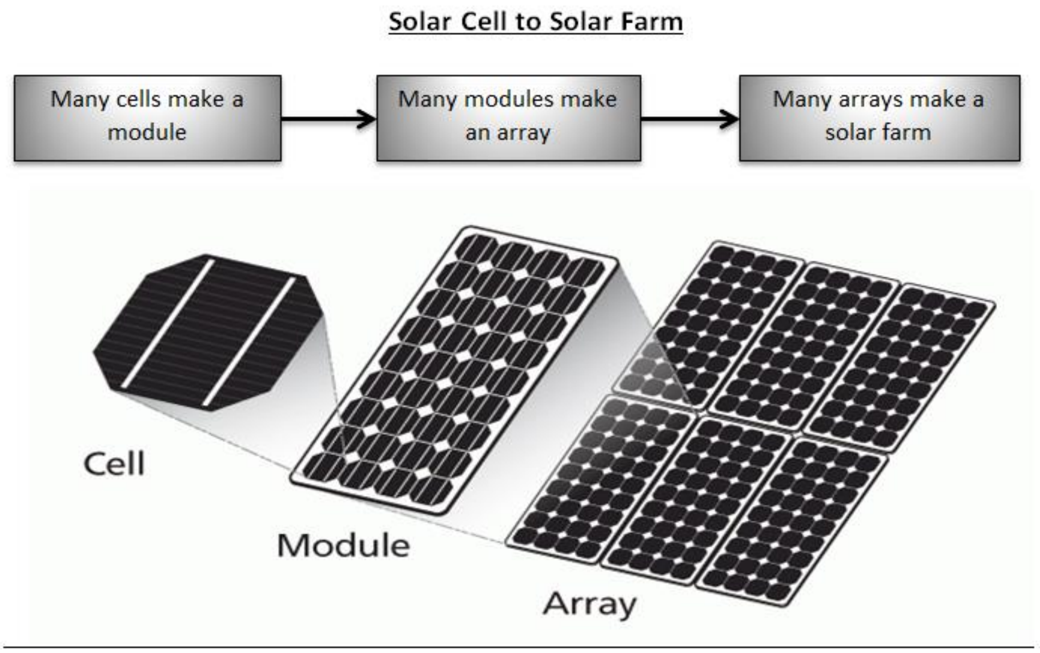

Figure 2.3 PV cell, module and array

2.4.1.1 Solar insolation

When talking about solar irradiance, one factor mentioned is the solar constant, which is a measure of solar irradiance per unit area. The constant measured above earth's atmosphere is approximately 1,350 W/m^2. Though, due to the absorption and reflection that occurs when the sun's rays travel through the atmosphere, the maximum power that can reach a solar PV device is 1,000W/m^2. This is called the peak sun condition and occurs only when it is clear weather and full sun. When it is cloudy the power can drop down to a tenth of peak sun. Furthermore, humidity, atmospheric clarity and the position of the solar device on earth (latitude) are other factors that can affect the irradiance [5].

The solar energy received on a specific site over a set time period is called insolation. Insolation is measured in $kWh/m^2/day$, which describes the quantity of incoming solar energy on a square meter in a day. In the calculations, peak sun hours, are used. This is how many hours 1,000W/m^2 hits the ground, thus the maximum power that can reach a solar PV device. In fact, the insolation will not reach full power all sun hours. Some hours the solar insolation will be less than 1,000 W/m^2 [5].

2.4.1.2 Angle of module

When placing a solar module, the angle towards the sun affects the electricity outcome. Solar PV receives maximum power when the angle towards the sun is 90°. Therefore, this is the optimal position of the solar panels. Depending on the location on earth, the seasonally and the hourly variation of the insolation angle will affect the optimal position of the solar panels. However, this variation is smaller on locations close to the equator [4]. Solar panels installed south of the equator will be placed against north and the other way for solar panels installed on the north side of the equator. A general rule that can be used to know in what angle the module shall be placed in, is the site's latitude + 10° [5].

2.4.1.3 Current and voltage characteristics

Current-voltage characteristics are important for the performance of the solar modules. When the voltage is measured in an open circuit, the maximum operating voltage Voc is showing. Further, in short-circuit condition, the voltage is zero and the operating current I, is at its maximum, Isc. To show how these parameters vary due to various temperatures and levels of insolation, an IV-curve is commonly used. At a specific combination of voltage and current the maximum power is generated. This voltage is defined as Vmp and the current as Imp. Multiplication of the voltage, Vmp, and the current, Imp, is denominated as Pm, the maximum power point as shown in

Figure 2.4. This value shows the greatest power a certain system can produce [4].

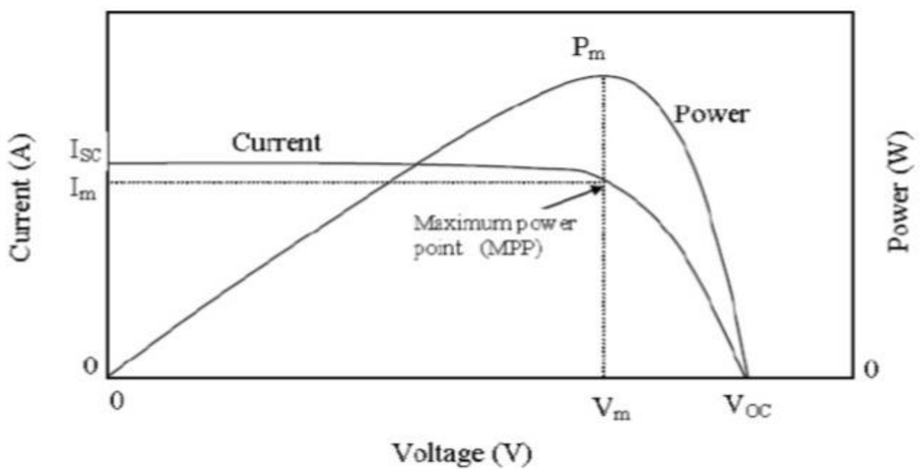

Figure 2.4 V-I curve of a solar panel

2.4.2 Solar pumps

When choosing pump, water requirements, total head and water quality must be measured. An optimal pump is one that can meet the daily water flow and the height to lift the water. Pumps can be driven both by DC and AC motors. DC pumps are difficult to maintain in remote areas as it needs specialized service centers, also its price is higher than AC pumps [2]. There are two main categories of pumps, positive displacement pumps and centrifugal pumps. Both can be either DC or AC driven and function for water pumping purposes. Further, both types exist as surface or submersible pumps [6].

A submersible pump is a pump placed under the surface of the liquid to be pumped. Therefore, the pump is designed to resist water and is customized for under-water conditions. It operates by pushing the water, rather than pulling, which allows a greater head. Submersible pumps can be used in both wells and free streams, which enable a wide variety of applications, both commercial and industrial [3].

A surface pump is, unlike a submersible pump, placed over the surface of the liquid to be pumped. It can pump water from both wells and free streams. It operates by pulling the liquid into the pump and afterwards pushing the water to the output. The shell of a surface pumps is water sensitive and it needs to be protected from rain [3].

When choosing pump for a system a pump curve is often used. A pump curve is a x-y graph where the performance characteristics of the pump is shown. Pump curves can be presented in different ways. In one type on pump curve, the y-axis shows the total dynamic head, which is the vertical head added with pressure losses and the x-axis represents the flow rate m^3/h. Several lines then graphically show the pump power. A pump curve of a specific pump is used to see if it suits the requirements. It also shows the required power needed for the pump to operate. This is for the worst-case scenario, on the highest possible head for the pump [7].

2.4.3 Controller

To match the voltage demand from the pump, a controller is used to protect the system from overloading and to improve the system performance. There are different types of controllers depending on if the system includes an AC or DC-driven pump. For a DC system, a DC-DC converter is used and for an AC system a DC-AC inverter is used. The controller sends a signal to the converter/inverter which adjusts to the correct voltage [8].

2.4.4 Water storage tank

Solar energy is only available during the day, and can sometimes be absent during heavy winter days, which would require storage for some applications. In principle, batteries could be used storage method for electricity, but it is a major burden due to its high cost and maintenance and replacement requirements. For this reason, a lot of solar pumping applications favor the use of water storage instead, here water is pumped whenever sufficient solar power is available and stored in an elevated tank, form which water can be withdrawn whenever required[9].

Water storage is very practical when the system is properly sized. During sunny days, the system provides enough water more than the daily requirements, since pumping is free, this water can be stored in water tanks that should be sized to ensure sufficient storage volume depending on climatic conditions and water consumption patterns. Figure 2.5 shows a water storage tank.

Figure 2.5 Water storage tank

CHAPTER THREE

METHOD AND SYSTEM COMPONENTS

3.1 System Description

This system provides a solution for unexploited resources in agricultural sector, this project uses the sun radiation and underground water to achieve a good using for this resource. The proposed solution is using the underground water by electrical power pump powered with solar energy. In addition it provides full automatic system depended on soil moisture sensor to ensuring maximum water usage efficiency by managing water flow.

The system is operates in this following procedure:

The PV panel cell Receives the solar radiation and convert it in to electrical power energy goes directly to convertor to ensuring steady output used to operate the AC pump. The AC pump takes water outside the well, the water goes into storage tank, in this tank there are limit sensors that controls the tank feeding process. The irrigation system was controlled by using soil moisture sensors positioned in the planted land. The soil moisture sensor senses the soil moisture and sends a signal to Arduino Uno to open or close the valve.

This system helps to optimize the use of groundwater reserves and to use clean energy to extract water for irrigation purposes. The use of smart irrigation system helps to achieve rational use of water, increase the productivity of crops and reduce the cost of labor. Figure 3.1 illustrate the smart irrigation system powered by solar energy.

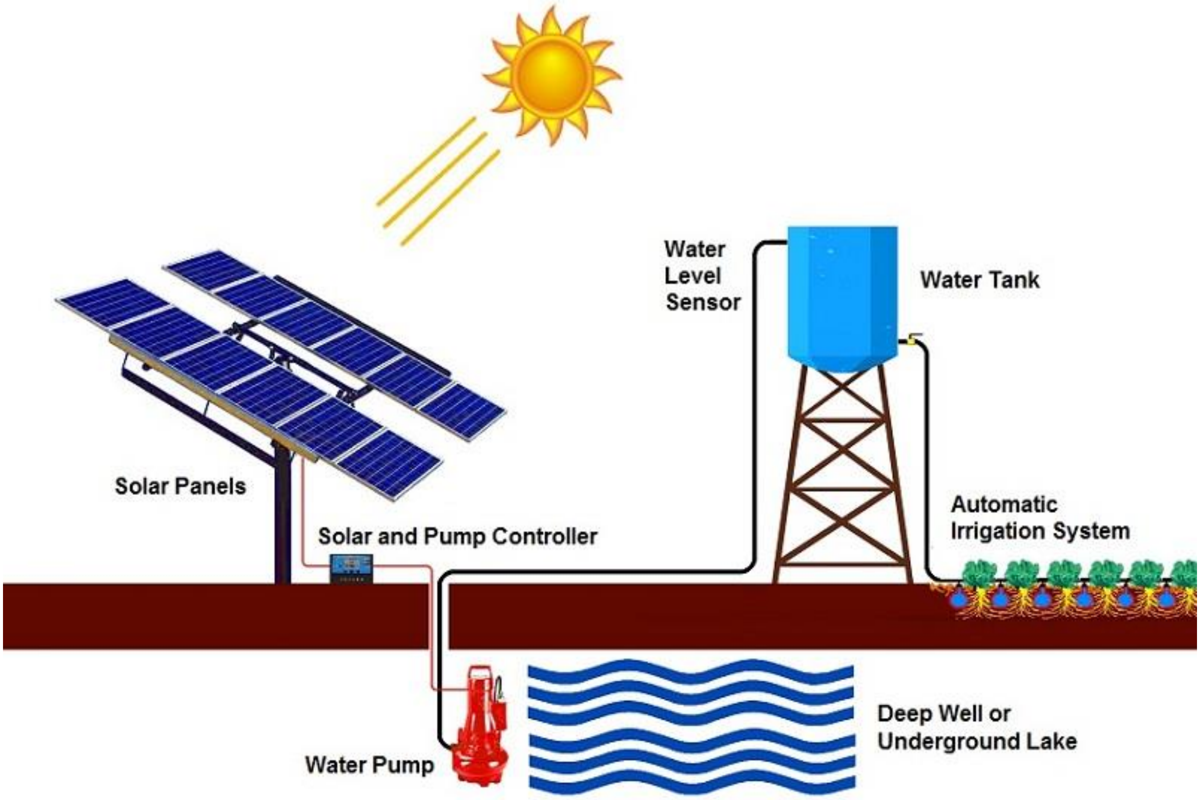

Figure 3.1 Smart irrigation system powered by solar energy

3.2 Solar System Design

To design a solar energy system that performs the purposes of irrigation of agricultural projects, must first be familiar with all the details related to the well, such as the depth in which the water is located, and the geographical and environmental conditions of the well area, and before designing the system it is necessary to determine whether the system is off grid or on grid and whether it is The system will operate with batteries or without batteries, and determine the type of pump is it AC or DC and whether to use a DC to AC inverter or using a DC to DC converter. Proper selection from all these considerations will lead to building and designing an appropriate system that provides the energy needed to operate the system at an appropriate economic cost.

3.2.1 Design of solar system using calculation method

To find the size and specifications of the system such as determining the size of the pump, the appropriate size of the inverter, determining the size of the solar panel array and how to connect them with each other. The steps that need to be followed in the manual sizing process of a new water pumping system powered by solar are presented in the Table 3.1

Table 3.1 Sizing solar system parameters

Assessment	Variables	Output
-Water Source	water depth- water level- Delivery capacity-	-Pump size -Capacity of water available
Water demand	Consumption profile Storage capacity	Storage size
Total head	Static head Dynamic head	Pump size
Solar resources	Solar radiation Sun peak hour	PV size
Flow rate		Pump size
Sizing	Input	
Pump	Flow rate Total head	
Solar array	Pump size	

3.2.1.1 Water resource

The distance between the well hole and the water depth is about 44 meter, while the pump is lowered to depth of 50 meter.

3.2.1.2 Water demand

Its amount of water required to be provided daily by the system, in this project a water tank with a volume of $50m^3$ must be filled and it represents the daily water demand for irrigation of crops.

3.2.1.3 Total dynamic head

The total dynamic head is the distance between the storage delivery points to the submerged depth of the pump in addition head losses through the piping system.in this project the TDH equal to 62 m.

3.2.1.4 Peak sun hour

Indicates the average equivalent hours of full sun energy received per day, the well is located in an excellent location, as the number of beak sun hour per day is 6.3 hour/day.

Required Flow rate:

The flow rate is the result of the demand in cubic meter divided by the peak sun hours in hour

$$\text{Flow rate} = \text{Demand} \div \text{PSH} \tag{3.1}$$

$$=50/6.3 \quad = 7.936\, m^3/h$$

3.2.1.5 Pump size

The pump power required can be calculated as usual by using the pump sizing chart provided by the pump manufacturer and requiring two variables only that are the total dynamic head and the flow rate, pump sizing chart are shown in Figure 3.2.

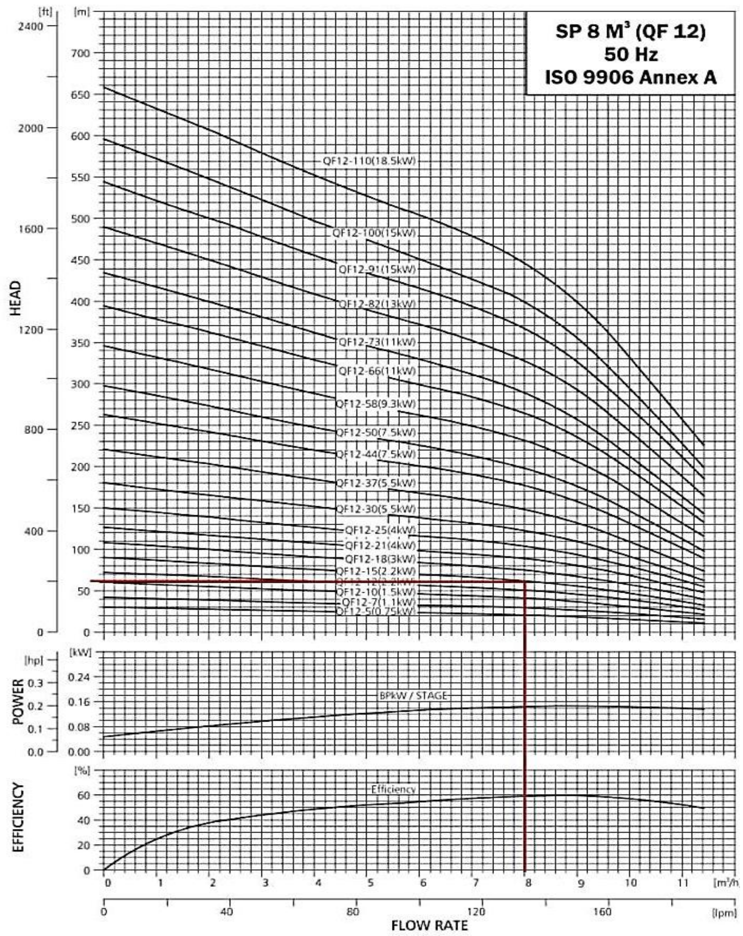

Figure 3.2 Pump sizing chart

3.2.1.6 Inverter size

The inverter performs the function of converting DC voltage into a three phase AC voltage to operate the pump, the size of inverter is chosen based on size of the pump and value of DC input voltage

3.2.1.7 Solar array size

After determining the size of pump and the inverter size, the size of solar array will be determined based on the following equation:

The hydraulic energy required (kWh/day)

= volume required (m^3 /day) x head (m) x water density x gravity / (3.6×10^6) … (3.2)

= 0.002725 x volume (m^3 /day) x head (m)

$$dialy\ energy\ demand\ = \frac{hydraulic\ energy\ requierd}{pump\ efficency} \quad (3.3)$$

$$solar\ array\ power\ = \frac{dialy\ energy\ demand}{PSH} \quad (3.4)$$

Power of array is at least 1.3 times of the pump power required

$$required\ power\ of\ solar\ array = solar\ array\ power \times 1.35 \quad (3.5)$$

3.2.2 Design of solar system using PVsyst software

One of the oldest photovoltaic software, developed by the University of Geneva. PVsyst is designed to be used by architects, engineer and researchers and it is also a very useful pedagogical tool. In this project, the software was used to design a solar energy system for irrigation purposes by finding the appropriate capacity to operate the pump and the energy needed to be saved from solar energy panels and compare it with the results obtained through mathematical equations and calculations, and the software was also used to assist in choosing the appropriate pump, inverter and panels for the system. The main design and simulation input parameters are listed in the Table 3.2

Table 3.2 PVsyst input parameters

Parameter	Simulation input value
Water required per day	$50.00\ m^3/day\ , two\ days\ autonomy$
Total dynamic head	62m
Water storage tank volume	50.00 m^3
Pump depth	50m
Borehole diameter	30 cm
Array tilt angle	18°
Power conditioning	MPPT – AC Inverter
Solar panels type	Model:SPR-E19-310-COM,si-poly-Manuf.sunPower.310w

3.3 Solar System Components

3.3.1 PV panel

There are different solar panels made with different materials Silicon mono and poly-crystalline are most popular and used one. The Mono crystalline solar PV panel is more efficient than polycrystalline panel. In this project, 10 solar modules mono-crystalline were used, manufactured by SunPower with high efficiency rate of 19.3%, in addiction because it has long life time of 25 years. The capacity of one module is 310W. Two rows of modules are connected in parallel, each row contains 5 modules connected in series, all of solar array produce 3100W sufficient to operate the system. Figure 3.3 shows the PV panel used in this project.

Figure 3.3 PV panel

3.3.2 AC pump

There are two types of pumps, a surface pump and a submersible pump that depend on the depth of the water level. The pump that was selected to work on this project is Submersible QF 12A-15 2.2 kW manufactured by Shakti. The pump pumps water from the well to the tank, then irrigates the plants .Figure 3.4 shows submersible pump.

Figure 3.4 Submersible pump.

3.3.3 Inverter

Inverter ACS355 Tri 3.0 kW 440VAC manufactured by ABB is used to convert DC voltage into 3 phase 440V. The Inverter supplies the pump with an AC voltage of 440V. The following Figure 3.4 shows the inverter that was used in this project.

Figure 3.5 Inverter

3.3.4 Storage tank

It is a large container for storing water and comes in different sizes, and it is placed in different heights according to the level of pressure to be obtained, in this project the size of the water tank was determined based on the maximum amount of water required for irrigation per day, the storage tank positioned at height of 8 meters with top feeding system and it was designed to store 50 cubic meters of water.

3.4 Economic Comparison

An economic comparison is made between the cost of using the solar energy system compared to the cost of using a diesel generator system, and the cost of using the solar energy system compared to the cost of using the national grid, in order to obtain the amount of water needed for irrigation in the area under study. The comparison process aims to identify and choose the most appropriate system for operating the irrigation system in the area under study, according to the nature and geography of the area.

3.4.1 Comparison considerations

1- All prices for components are fixed and unchanged.

2- All systems are the same in size, type of pump and amount of water required.

3- The components that are used in the three systems are not counted, such as tanks pipes, and operating switches.

4- The period of time in which the comparison is made is 10 years.

5- Fuel and electricity bill from the national grid are fixed throughout the comparison period.

3.4.2 Methodology used for comparison

To make a comparison between the cost of the solar energy system and the generator system, and compare the solar energy system with the system that operates on the public electricity network, based on the size of the pump and the amount of water required, the number of kWh required to be provided by each of the three systems during 10 years each year separately was determined and Then, the details of the construction cost of each of the three systems were obtained by private companies and government institutions, then the operational cost of each system was calculated, and using forecasting technique, the cost of each of the three systems was calculated for 10 years each year separately. Then by dividing the cost by the number of the kWh produced in each year we will get the cost of one kWh in each year of the comparison period.

3.5 Smart Irrigation System Design

The smart irrigation system aims to convert the irrigation crops into automatic techniques in which the irrigation is controlled by controller and based on the reading of soil moisture sensor and the water level sensor positioned in the tank, the water valve will be opened and closed.

3.5.1 Smart irrigation system components

The following component will be required for project`s objectives to be successfully accomplished

- soil moisture
- Arduino Uno
- Relay
- Float switches
- Solenoid Valve

3.5.1.1 Arduino uno

Arduino Uno has been selected as controller in this project due to its low cost, compact size, compatibility, easy interfacing over several other type of controller such. Arduino Uno is microcontroller board based on ATmega 328P microcontroller. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button as shown in Figure 3.6.

Figure 3.6 Aduino Uno

The Arduino gets parameters from the soil moisture sensor in order to trigger the valve. The Arduino also gets parameter from float switches which are inserted into the tank.

3.5.1.2 Soil moisture sensor

Soil moisture sensor as shown in Figure is used in this project to measure soil moisture, the soil moisture sensor is buried in the ground at required depth. The working of the soil moisture is pretty straightforward, the fork shaped probe with two exposed conductors, acts as a variable resistor just like potentiometer whose resistance varies according to the water content in the soil. This resistance is inversely proportional to the soil moisture, the more water in the soil means better conductivity and will results in a lower resistance. The less water in the soil means poor conductivity and will results in a higher resistance. The sensor produces an output voltage according to the resistance, which can determine the moisture level. Figure 3.7 illustrate the soil moisture sensor.

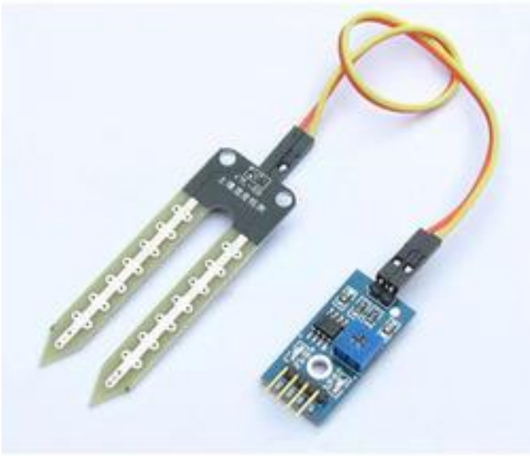

Figure 3.7 Soil moisture sensor

3.5.1.3 Relay

In this project, two Relays are used. The first one is used to open or close the pump circuit, and the other to operate or stop the solenoid valve. Relay Gn325DlZ 4-32 VDC is used in this project, the relay receive the control signal from the Arduino through transistor pin. Figure 3.8 shows Relay Gn325DlZ 4-32 VDC.

Figure 3.8 Gn325DLZ 4-32 Relay

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3.5.2 System flow chart

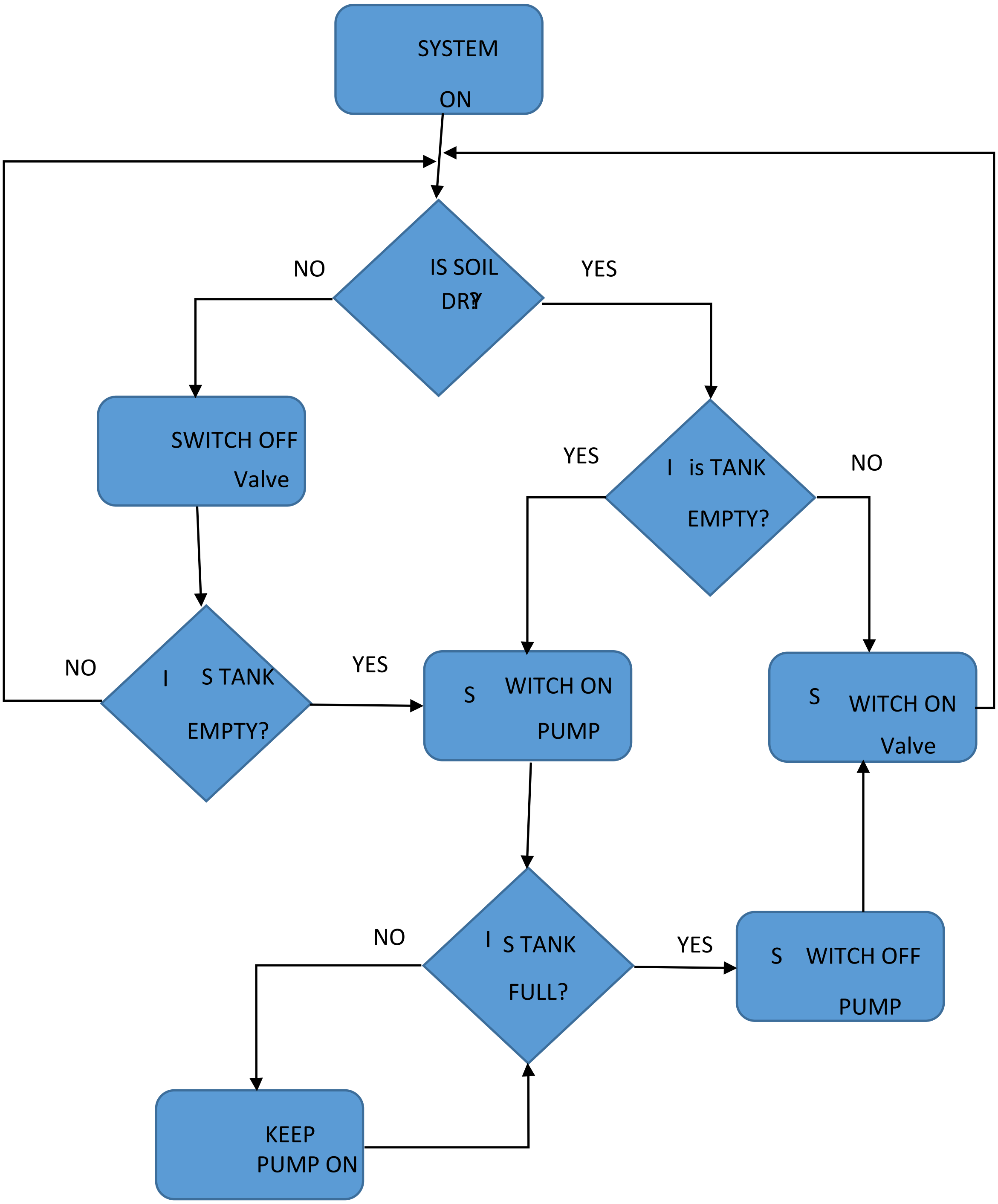

Figure 3.9 System flow chart

3.5.3 How the system works

When the soil moisture sensor is injected into the ground, the control system has to be initiated so as to act on the irrigation system. The Arduino reads the sensor output through the analog input pin A0 using analog read function which convert the voltage (in the range 0 to 5 V) at the A0 pin into a number (in range of 0 to 1023). In this way the voltage at A0 is compared to a fixed number (threshold) for identifying the current status of the soil .When the soil is dry, the system turns ON the irrigation system (open valve). When the soil is now wet enough, the system turns OFF the irrigation system (close valve). The irrigation system is only turned on provided the tank providing the irrigation water is not empty. When the tank is empty, the system turns ON the pump to fill up the tank. Once the tank is filled up the pump is turns OFF. Two float switches were inserted into the tank. One at the half level, and a second one to represent the full level. The statuses of the float switches are compared to identify the current water level and according to these both sensor statuses the controller will switch the pump to ON or OFF condition.

3.5.4 Proteus software

Proteus is a virtual system modeling and circuit simulation application. Proteus was used to come up with the circuit diagram and simulation. Due to the difficulty or inability to represent some devices in the software design, it has been improvised. Water tank levels had to be improvised using switches. Soil moisture sensor had to be improvised by using variable resistance. Solenoid valve had to be improvised by using lamp and the solar array with MPPT converter by using DC supply.

The software parameters are:

- Arduino Uno
- Transistor
- Potentiometer
- Lamp
- LCD display
- Resistances
- Motor
- Switches
- Wires
- Power supply
- Relays

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 Introduction

In this project, PVsyst software has been used to simulate the solar photo-voltaic water pumping system. The simulation are performed based on the maximum possible annul water demand. The pump and solar panels are selected from the PVsyst software database to meet the maximum possible annual demand.

Proteus software has been used to design smart irrigation system which automatically irrigates crops without human intervention, based on the plant's need for water.

4.2 Solar System Design Results

The solar system was designed in two ways, which are the method of equations and mathematical calculations and the second method using PVsyst software.

4.2.1 Design of solar system using calculation method

PSH=6.3 h/day.

Demand= 50 m^3/day.

TDH=62m.

Flow rate = Demand ÷ PSH (4.1)

$= 50/6.3 = 7.936\ m^3/h$

The hydraulic energy required (kwh/day)

= volume required (m³/day) x TDH (m) x water density x gravity / (3.6×10^6) … (4.2)

= 0.002725 x volume (m³/day) x head (m)

$= 0.002725 \times 50 \times 62 = 8.175$ kWh/day

$$dialy\ energy\ demand = \frac{hydraulic\ energy\ requierd}{pump\ efficency} \qquad (4.3)$$

$$\frac{8.175}{0.6} = 13.625\ kWh/day$$

$$solar\ array\ power = \frac{dialy\ energy\ demand}{PSH} \qquad (4.4)$$

$$\frac{13.625}{6.3} = 2.16 \cong 2.2kW$$

Power of array is at least 1.3 times of the pump power required

$solar\ array\ power = 2.2 \times 1.35 = 2.97kW$

4.2.2 Design of solar system using PVsyst software

PVsyst helps to get more accurate results because it takes a lot of considerations and gives detailed results regarding system performance and efficiency.

4.2.2.1 PVsyst main results

The inputs of this software are monthly average solar irradiation, average daily water demand, well depth characteristics, selection of PV modules and pump. The main simulation results are shown in Table 4.1.

Table 4.1 PVsyst Main results

Parameters	Simulation results
PV size	310 Wp, 5 modules in series and 2 strings in parallel
Total area	16.3 m²
Pump power	3HP, 2.2 kW
Pump type	Submersible QF12A-15, manufactured by Shakti
Energy at pump	4942 kWh
Pump efficiency	60%
Water needs	18250 m³
Water pumped annually	17303 m³
Missing water	5.2%
Unused PV energy (Tank full)	411 kWh
System efficiency	81.0%

4.2.2.2 Energy balance (per installed kWp)

Figure 4.1 shows the energy balance of the proposed solar Photo-voltaic water pumping system, as can be observed from the figure, the unused energy, system and collection losses are low. This is because, the system is designed based on the maximum possible water production volume within the year.

(Nominal power 3100 WP).

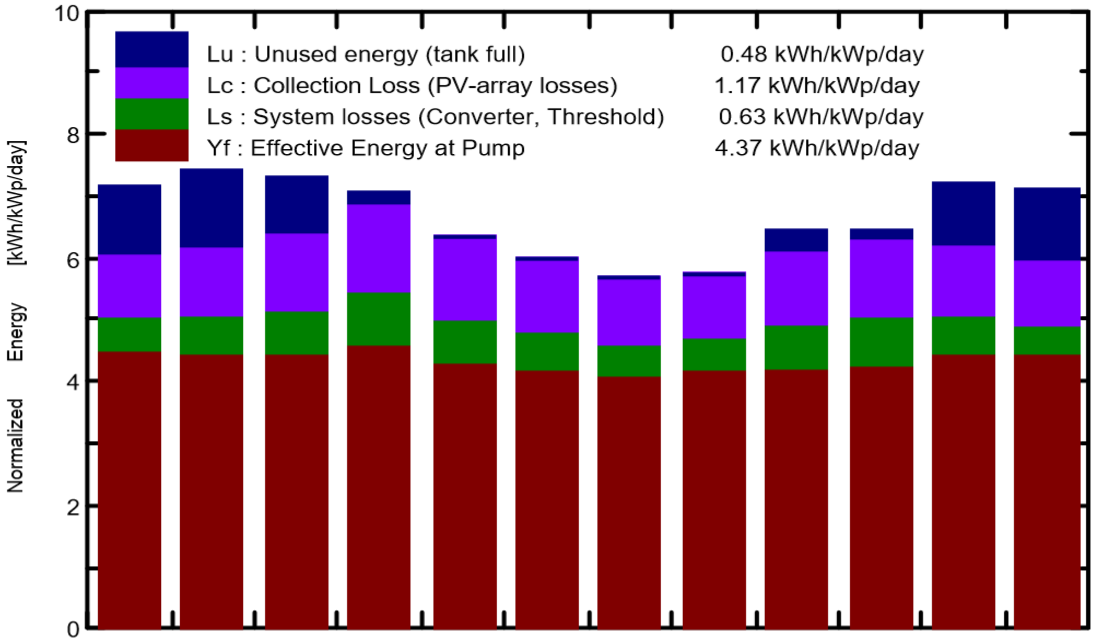

Figure 4.1 Energy balance of the PV water pumping system

4.2.2.3 Performance ratio

The performance ratio of the designed system is shown in Figure 4.2

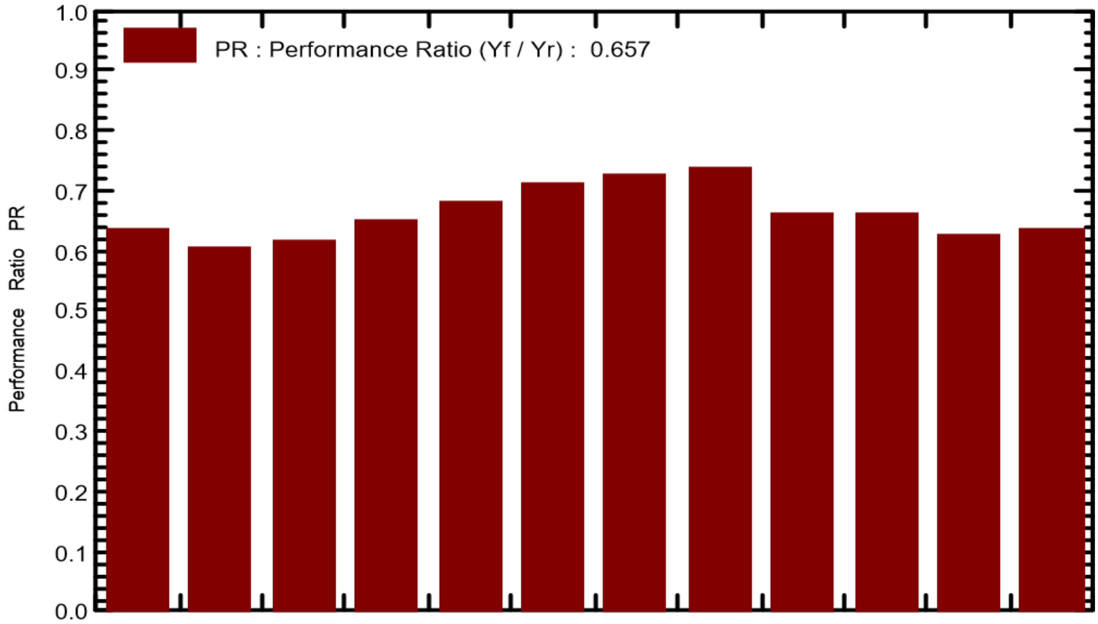

Figure 4.2 Performance ratio

4.2.2.4 Balances and main results:

The main results of the designed system are detailed in Table 4.2.

Table 4.2 Balances and main results

	GlobEff kWh/m²	EArrMPP kWh	E_PmpOp kWh	ETkFull kWh	H_Pump meterW	WPumped m³	W_Used m³	W_Miss m³
January	219.3	570.1	433.2	78.03	56.89	1560	1550	0.0
February	205.7	525.5	388.2	79.74	56.88	1400	1400	0.0
March	224.0	564.8	431.3	62.46	56.79	1550	1550	0.0
April	209.5	522.7	427.9	12.17	56.65	1499	1500	0.0
May	193.4	484.8	414.1	0.09	56.54	1400	1426	124.4
June	176.7	447.5	393.1	0.00	56.53	1321	1329	171.5
July	173.3	444.5	396.1	0.00	56.53	1328	1311	238.6
August	176.0	452.9	406.3	0.00	56.58	1383	1401	149.0
September	190.6	480.2	393.1	19.79	56.65	1373	1370	129.9
October	198.3	496.8	410.8	7.66	56.63	1431	1434	115.5
November	215.0	545.2	417.9	67.63	56.84	1506	1472	28.0
December	218.1	563.4	430.2	83.44	56.88	1550	1550	0.0
Year	2399.9	6098.4	4941.9	411.01	56.69	17303	17293	956.9

4.2.2.5 Loss diagram:

Loss diagram over the whole year is shown in Figure 4.3.

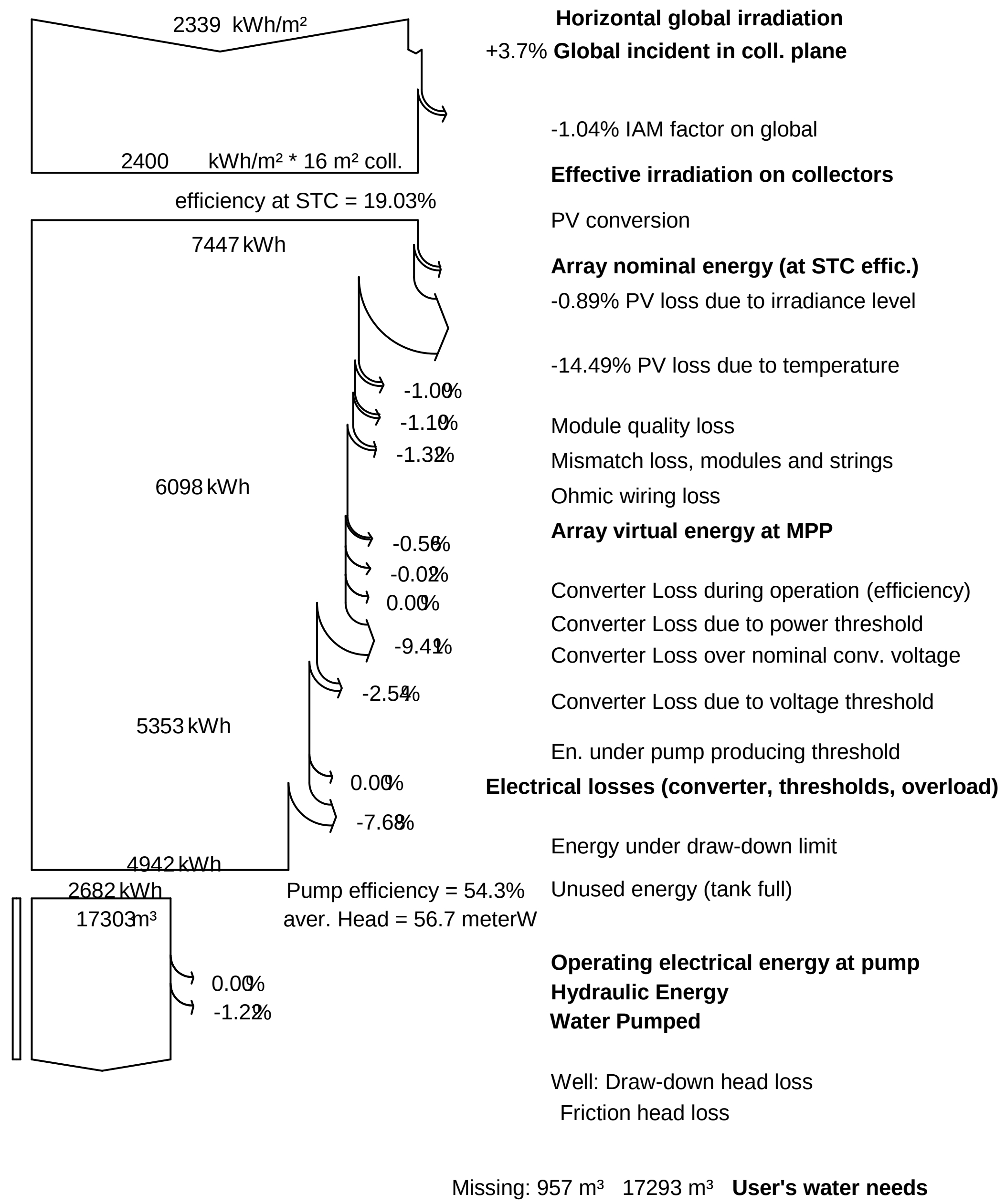

Figure 4.3 Loss diagram over the whole year

From the Figure 4.3 the amount of water missing and energy losses are low (the system is designed based on the maximum possible water production volume within the year).

4.3 Approachment between Calculation Method and PVsyst Software

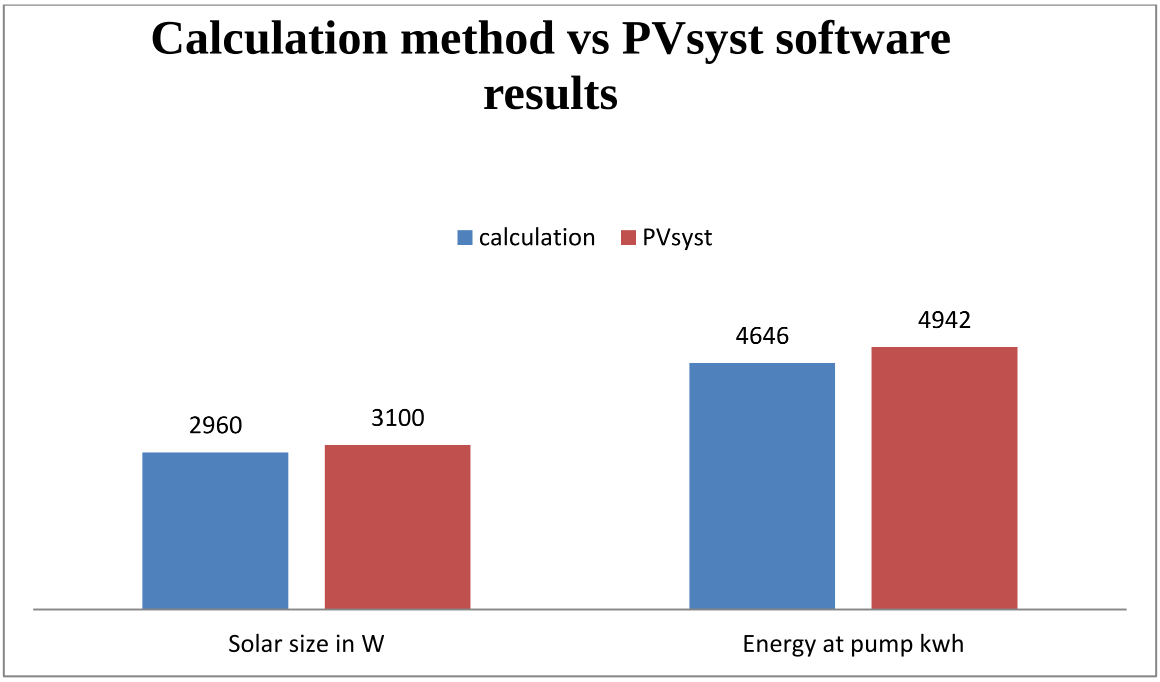

Figure 4.4 Calculation method VS PVsyst software results

It is noticed that there is slight discrepancy between the mathematical results and the results of PVsyst software, because PVsyst software takes many considerations, so its results are more accurate.

4.4 Economic Comparison

The cost of establishing and operating a solar energy system has been studied and compared with cost of system, which is powered by diesel generator. Also, the cost of establishing and operating a solar energy system has been compared with cost of energized from national electricity grid. The comparison was made over a period of 10 years.

The economic study of the system has two main aspects:

-The construction cost

-Operational cost

4.4.1 Cost of solar energy system

The economic study for establishing a solar energy system is as follows:

4.4.1.1 Construction (initial) cost

The cost of construction a solar energy system shown in Table 4.3.

Table 4.3 Solar energy initial cost

Description	Quantity	Unit price $	Total
Solar power plant 310 w	10	150	1500
Pump converter	1	390	390
Water submersibl pump 3HP	1	270	270
Solar panel support structure	1	280	280
Cables	1	130	130
Electrical Box	1	150	150
Civil work + Accessories	1	60	60
Installation	1	150	150
Total			2930 $

4.4.1.2 Operating cost

No operating cost, but it needs regular cleaning at a cost of 100$ per year (1000$ per 10 years).

4.4.1.3 Solar system cost per year

(For a period of 10 years)

System cost/year=initial cost/10 + operating cost

Average System cost/year =2930/10 + 100 = 393$

4.4.2 Cost for energized from the national grid

The economic study for connecting to the electricity network is as follows:

4.4.2.1 Initial cost

The initial cost of connecting to the electricity network shown in Table 4.4.

Table 4.4 National grid initial cost

Transformer conduit	127 $
Fuses	110 $
Fuse holder	12.7 $
30m Copper wire 70mm (700sdg/m)	177.9 $
3 Shoes (150 SDG/shoes)	3.8 $
12 Shoes 70mm (80 SDG/shoes)	8.1 $
Ground nail	10.1 $
Material cost	210643.3 $
Checking cost	4212.8 $
Labor cost	52660.8 $
Total	267967.07 $

*1 USD = 118 SDG

Cost/year = 26796.7$

4.4.2.2 Operating cost over 10 years

*Supervising the construction process has a cost of 12638.59$ to be paid if contracting with a private company.

OP cost= supervising +the cost of electric meter bill

Cost of electric meter bill per year = energy consumed per year * kWh cost

The cost of 1 kWh = 1SDG

(1SDG/kWh=0.00847$/kWh)

- For load of 3HP pump (2.23kW) operating for 6 hours per day and 365 day per year
- Cost of electric meter bill per year= 2.23*6*365*0.00847=41.38$

Cost of electric meter bill per 10 years=413.8$

OP cost =12638.59+413.8=13052.39$

OP cost per year = 13052.39/10=1305.239$

4.4.2.3 System cost per year

Average System cost per year=initial cost/10year +op cost per year

Average System cost per year =2679.67+1305.239=28101.939$

4.4.3 Diesel generator

The economic study for establishing a diesel generator system is as follows:

4.4.3.1 Initial cost

The cost of construction a diesel generator system is 1800$

4.4.3.2 Operating cost over 10 years

Operating requirement over 10 year

Fuel	7095.6$
Oil	2100$
Labor	6000$
Major service	1000$

*In the first year the machine consumes one liter of fuel per hour, and in every next year this amount increases by 0.1 liter due to machine wear.

The machine operate 6 hour/day and 365 day/year

amount of fuel required each year =6h*365day*fuel consumed/day

*Fuel cost/liter = 0.2$/liter

Fuel cost/year= amount of fuel required each year*fuel liter cost

OP cost per year = (2100+6000+1000)/10+fuel cost per year

OP cost per year=910+fuel cost/year

4.4.3.3 System cost per year

Diesel generator system cost per year is shown it Table 4.5

System cost per year=initial cost/10year + op cost/year =1800/10 + op cost =180 + op cost

Table 4.5 Diesel generator system cost per year

Year	Liter consumed	Fuel require	Fuel cost (0.2$/liter)	Operation cost	System cost	Cumulative cost
1	1	2190	438 $	1348 $	1528 $	3148 $
2	1.1	2409	481.8 $	1391.8 $	1571.8$	4539.8 $
3	1.2	2628	525.6 $	1435.6 $	1615.6$	5975.4 $
4	1.3	2847	569.4 $	1479.4 $	1659.4$	7455.3 $
5	1.4	3066	613.2 $	1523.2 $	1703.2$	8978.5 $
6	1.5	3285	657 $	1567 $	1747$	10545.5 $
7	1.6	3504	700.8 $	1610.8 $	1790.8$	12156.3 $
8	1.7	3723	744.6 $	1654.6 $	1834.6$	13810.9 $
9	1.8	3942	788.4 $	1698.4 $	1878.4$	15509.3 $
10	1.9	4161	832.2 $	1742.2 $	1922.2$	17251.5 $

4.4.4 KWH cost per year

*For 3 HP pump

*When using solar system, the maximum energy that can be produced in the first year = 3.1 x 6 x 365= 6789 kwh

*The system efficiency decrees by 1% every year

*When using diesel generator, the rating of the generator used = 5.5 kw, then the maximum energy that can be produced in the first year= 5.5 x 6 x 365=12045 kwh

*The system efficiency decrees by 5% every year

*When using national grid the demand is 4883.7kWh

4.4.4.1 Solar energy system

The kWh cost per year is shown in Table 4.6

Table 4.6 KWH cost of solar energy system per year

Year	Solar KWH /year	Cost/year	KWH cost
1	6789	393 $	0.0578 $
2	672.11	393 $	0.0584 $
3	6653.22	393 $	0.0590 $
4	6585.33	393 $	0.0596 $
5	6517.44	393 $	0.0602 $
6	6449.55	393 $	0.0609 $
7	6381.66	393 $	0.0615 $
8	6313.77	393 $	0.0622 $
9	6245.88	393 $	0.0629 $
10	6177.99	393 $	0.0636 $

4.4.4.2 Diesel generator

The kWh cost per year is shown in Table 4.7

Table 4.7 KWH cost of diesel generator system

Year	Diesel KWH/year	Cost/year	KWH cost
1	12045	1528 $	0.126 $
2	11442.75	1571.8 $	0.137 $
3	10840.5	1615.6 $	0.149 $
4	10238.25	1659.4 $	0.162 $
5	9636	1703.2 $	0.176 $
6	9033.75	1747 $	0.193 $
7	8431.5	1790.8 $	0.212 $
8	7829.25	1834.6 $	0.234 $
9	7227	1878.4 $	0.259 $
10	6624.75	1922.2 $	0.290 $

4.4.4.3 National grid

The kWh cost per year is shown in Table 4.8

Table 4.8 KWH cost of national grid system

Year	Grid KWH/year	Cost/year	KWH cost
1	4883.7	28101.9 $	5.754 $
2	4883.7	28101.9 $	5.754 $
3	4883.7	28101.9 $	5.754 $
4	4883.7	28101.9 $	5.754 $
5	4883.7	28101.9 $	5.754 $

6	4883.7	28101.9 $	5.754 $
7	4883.7	28101.9 $	5.754 $
8	4883.7	28101.9 $	5.754 $
9	4883.7	28101.9 $	5.754 $
10	4883.7	28101.9 $	5.754 $

4.5 Economic Comparison between Solar System and Diesel System

When comparing the solar energy system with the diesel system, the construction cost of the solar energy system is greater, but with the passage of years the cumulative cost of the diesel system will become higher due to the increase in the operational cost of the diesel system as shown in Figure 4.4.

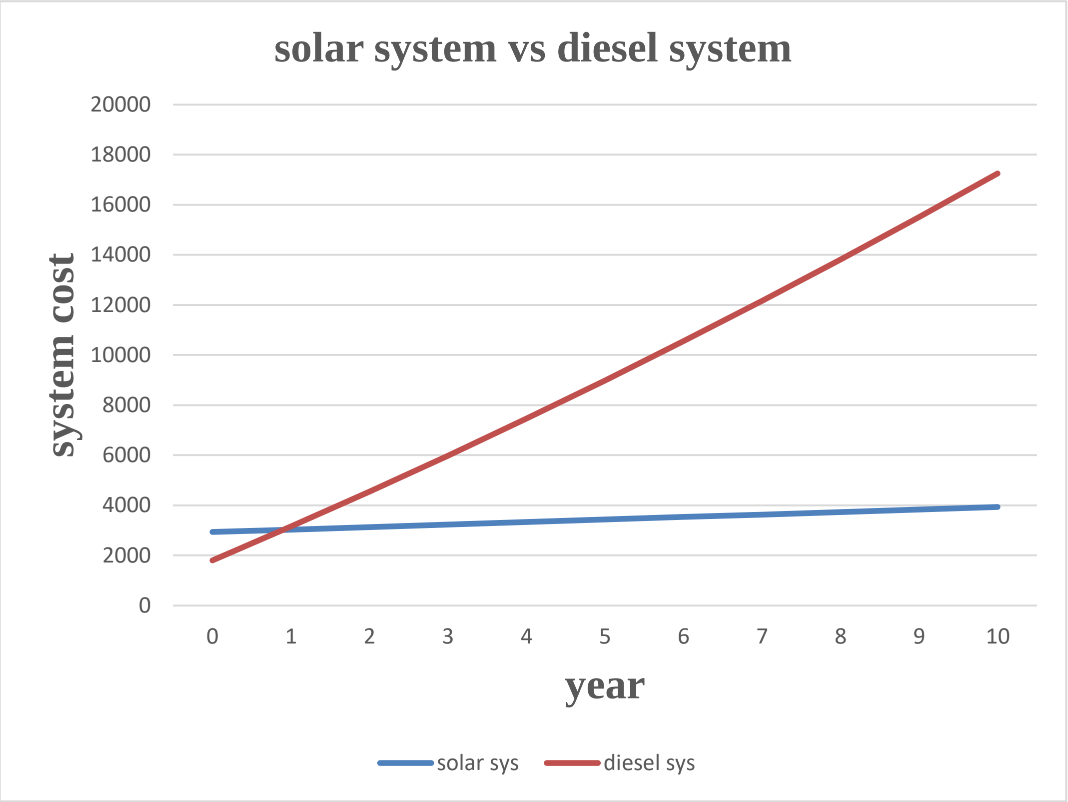

Figure 4.5 Economic comparison between solar and diesel system

4.6 Economic Comparison between Solar System and Grid System

When comparing the solar energy system with a system fed from electric grid it was found that the cost of solar energy system is much better. The Figure 4.5 shows the economic comparison between the two systems where the logarithmic method was used to approximate the results.

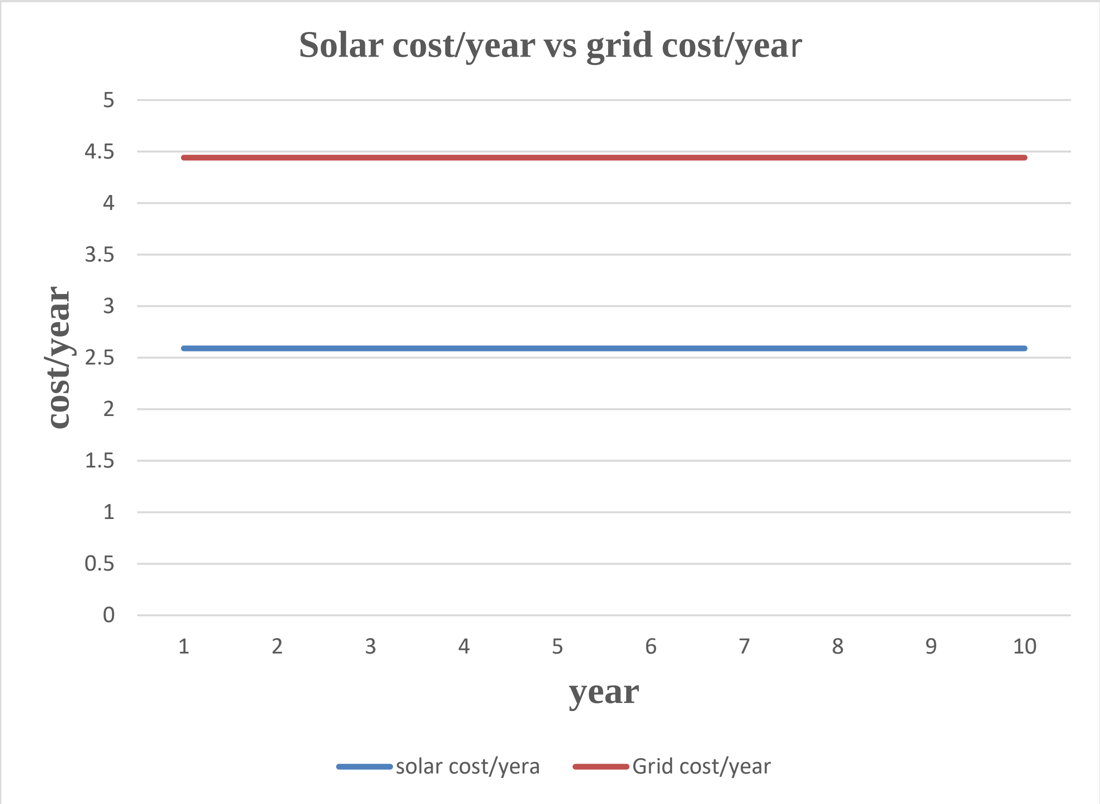

Figure 4.6 Economic comparison between solar and grid system

4.7 Smart System Design

The system simulation starts by screen definition, which carried out by sending the message " AUTO IRRIGATION SYS", from the Arduino to the LCD screen as shown in Figure 4.7. The programming is designed using Arduino C language and proteus simulation.

The system performed as expected. When the system startup, Arduino was started to receive the field status signals from the sensors. The soil moisture sensor manager to report when the soil was dry and when it was wet. The water tank float switches also managed to indicate status of the water levels. From low, good and full.

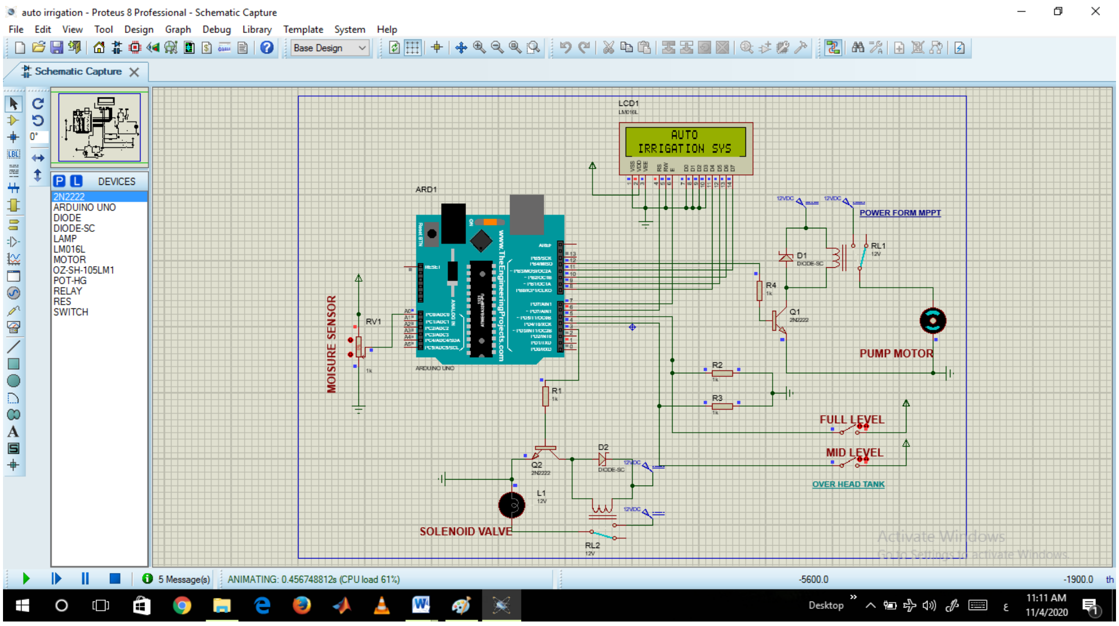

Figure 4.7 System starting up

When tank was empty, and soil was dry as shown in Figure 4.8, the system turned water pump on. When the middle tank's float switch was switched on, the solenoid valve was opened to irrigate the filed, as shown in Figure 4.9.

Finally when the full tank's float switch was switched on, the system turned water pump off as shown in Figure 4.10. Once the soil reached the wet point, system was turned the solenoid valve off, as can be shown in Figure 4.11.

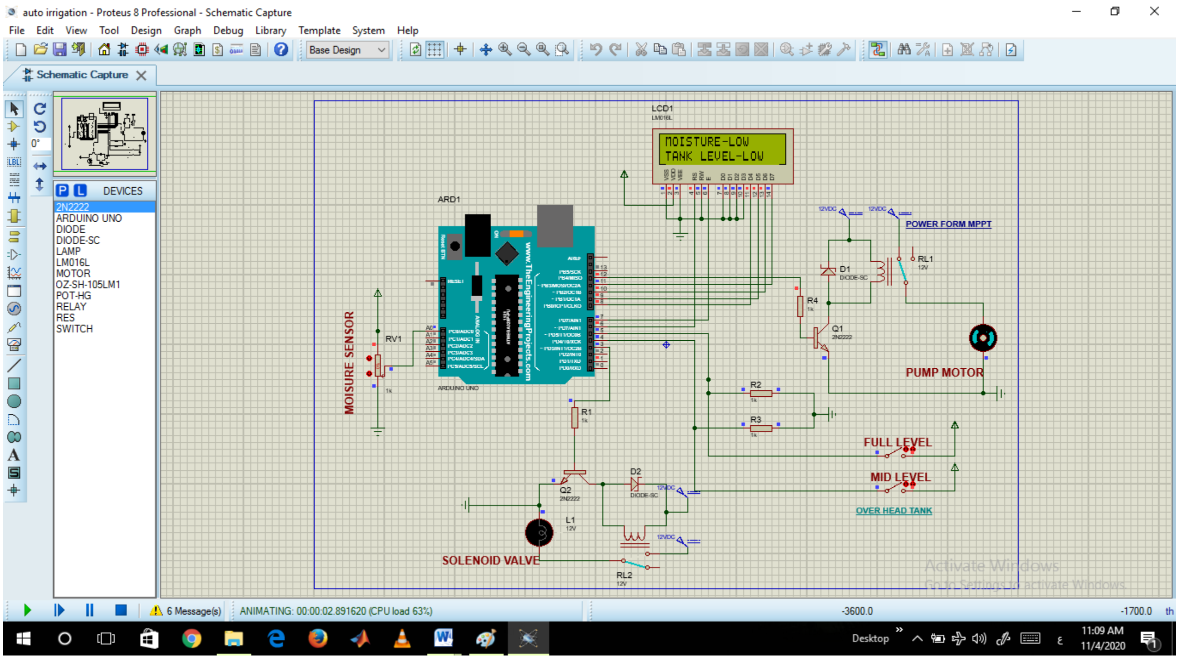

Figure 4.8 Pumping starting up

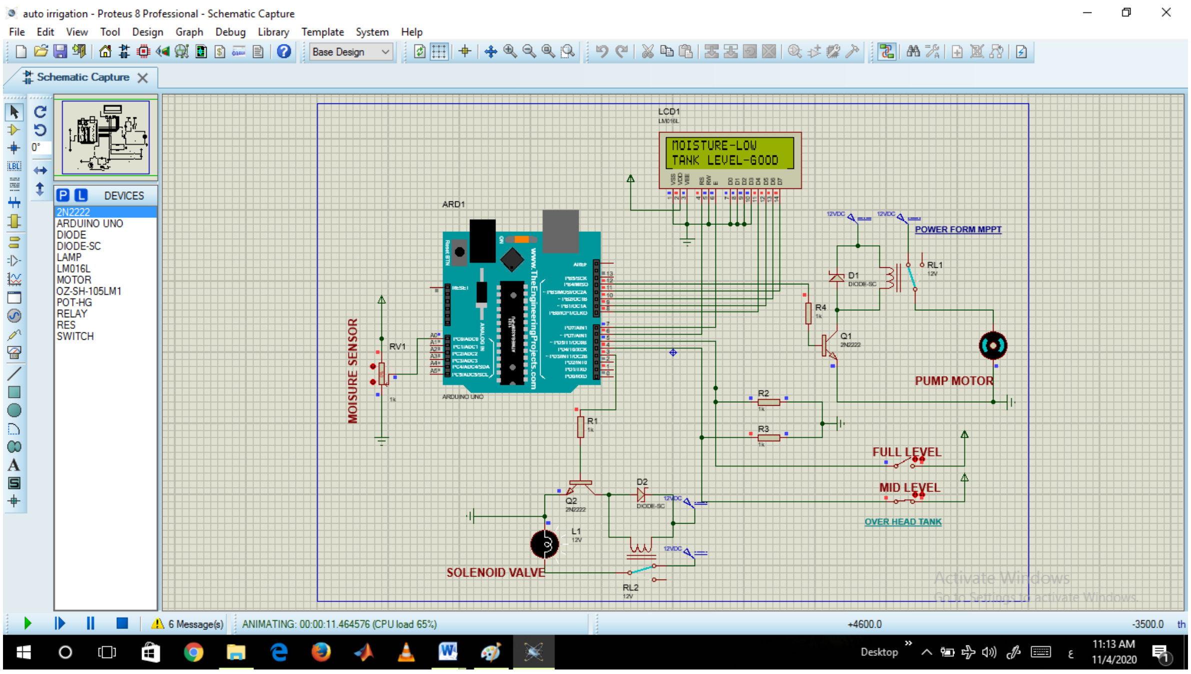

Figure 4.9 Irrigation starting up

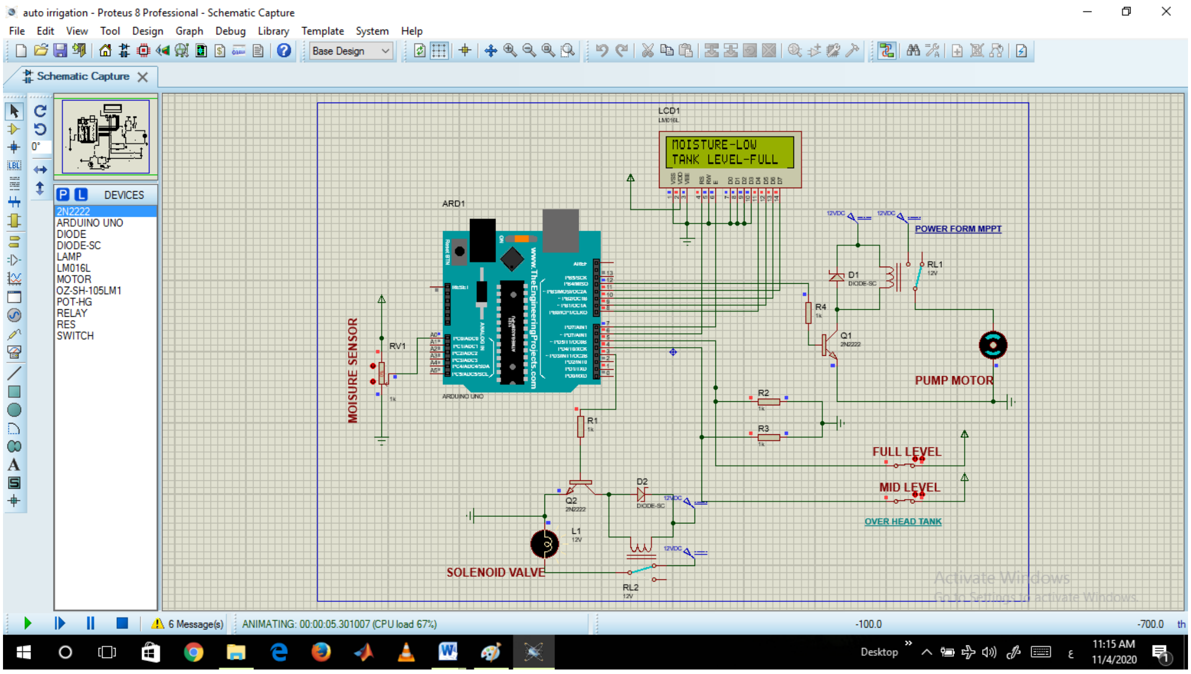

Figure 4.10 Pumping shutdown

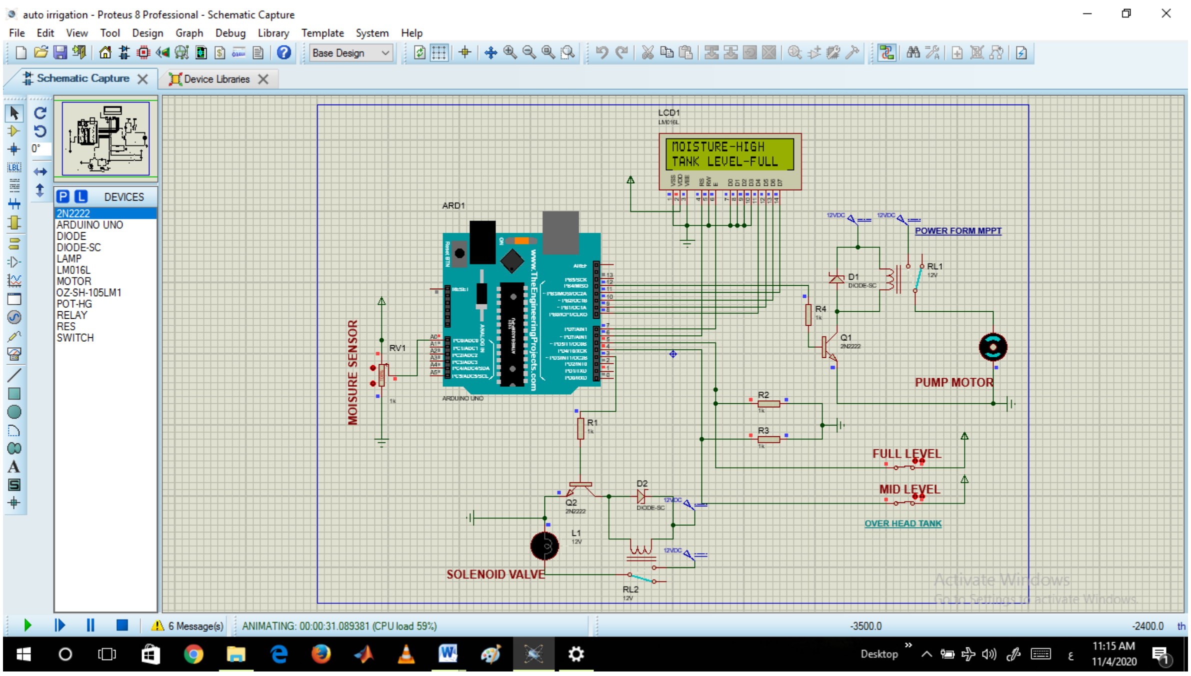

Figure 4.11 Irrigation shutdown

CHAPTER FIVE

CONCLUSTION AND RECOMMENDATIONS

5.1 Conclusion

The project mainly aims to design a smart irrigation system powered by solar energy, in addition to make an economic comparison between the solar energy system with diesel generators, and then with the national grid electricity to determine the ideal system for operating the pump and providing the amount of water needed for the irrigation process.

The irrigation system using solar energy has been designed in two ways, the first is the manual calculation method and the second is using PVsyst software. The system is designed to drive a 2.2kW pump and 3.1kW solar array to make the system run at an efficiency of 81%. As for the comparison process, the construction and operational costs of each system were calculated separately, and then the economic comparison between the costs of three systems was made. After making the calculations and comparison, it was found that the cost per unit kWh produced from the solar energy system starts from 0.076 $ for the first year, which is less expensive than the cost of the other two systems.

As a result of the project, a smart irrigation system was designed to irrigate small and medium farms powered by solar energy in order to achieve optimum utilization of solar energy and water resources in the area under study. It has also been proven that the use of solar energy is the most appropriate option to provide irrigation water in the area under study.

5.2 Recommendations

Recommendations and proposed ideas for improve the project:

1- Adding temperature, humidity, amongst other sensors.

2- The system can be further improved by adding IOT system.

3- The system can also be further improved by adding a tracker system.

4-Build an experimental setup of smart agriculture system.

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APPENDIX

Arduino code written in Arduino C language

```
#include <LiquidCrystal.h>

LiquidCrystal lcd(6, 7, 8, 9, 10, 11);

//Defining Pins on arduino

#define pumpPin 12

#define tleveF 5

#define tleveM 4

#define moisture A0

#define valvePin 3

const int thrsh = 800;

int F;

int M;

float moist ;

void setup() {

  Serial.begin(9600);

  lcd.begin(16, 2);

  pinMode(pumpPin, OUTPUT);

  pinMode(valvePin, OUTPUT);

  pinMode(tleveF, INPUT);

  pinMode(tleveM, INPUT);
```

```
  pinMode(moisture, INPUT);
  digitalWrite(pumpPin, LOW);
  digitalWrite(valvePin, LOW);
  //LCD Startup display
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("      AUTO      ");
  lcd.setCursor(0, 1);
  lcd.print(" IRRIGATION SYS ");
  delay(2000);}
void loop() {
  lcd.begin(16, 2);
  lcd.setCursor(0, 0);
  lcd.print("MOISTURE-");
  moist = analogRead(moisture);
  if ( moist < thrsh) {
    lcd.print("LOW");
    }
  lcd.setCursor(0, 1);
  lcd.print("TANK LEVEL-");
  F = digitalRead(tleveF);
```

```
M = digitalRead(tleveM);
if (F == HIGH) {
  lcd.print("FULL");
  digitalWrite(pumpPin, LOW);
  }
else if (F == LOW && M == LOW) {
  digitalWrite(pumpPin, HIGH);
  lcd.print("LOW");
  }
else if (F == LOW && M == HIGH) {
  lcd.print("GOOD");
  }
delay(3000);
while (moist < thrsh && M == HIGH){
  lcd.setCursor(0, 0);
  lcd.print("MOISTURE-LOW");
  digitalWrite(valvePin, HIGH);
  F = digitalRead(tleveF);
  if (F == HIGH) {
    digitalWrite(pumpPin, LOW);
  }
```

```
}
if (moist > thrsh) {
  lcd.setCursor(0, 0);
  lcd.print("MOISTURE-HIGH");
  lcd.setCursor(0, 1);
  digitalWrite(valvePin, LOW);
  delay(3000);
  }
if (M == LOW) {
  lcd.setCursor(0, 0);
  lcd.print("TANK LEVEL-LOW");
  lcd.setCursor(0, 1);
  digitalWrite(pumpPin, HIGH);
  delay(3000);
  }
}
```