A PROJECT REPORT MAJOR -II

ON

"SOLAR POWERED INTELLIGENT IRRIGATION MONITORING AND CONTROLLING SYSTEM"

Submitted in Partial fulfillment for the award of the Degree of

MASTER OF TECHNOLOGY

IN

RENEWABLE ENERGY TECHNOLOGY

By

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STUDENTS DECLARATION

I **Sandeep Sudheer**, hereby certify that the work which is being presented in the major project-II entitled "**Solar powered intelligent irrigation monitoring and controlling system"** is submitted in the partial fulfillment of the requirements for the degree of **M.Tech** at **Delhi Technological University** is an authentic record of my own work carried under the supervision of **Dr K .Manjunath,** Assistant Professor**,** Department of Mechanical Engineering. I have not submitted the matter embodied in this major project-2 for the award of any other degree. Also it has not been directly copied from any source without giving its proper reference.

Sandeep Sudheer

M.tech (Renewable Energy Technology)

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CERTIFICATE

This is to certify that the project entitled "**Solar powered intelligent irrigation monitoring and controlling system**" is submitted by **Sandeep Sudheer (Roll no. 2K13/RET/07)** to Delhi Technological University, Delhi for the evaluation of M.Tech Major Project- II as per academic curriculum. It is a record of bona fide research work carried out by the student under my supervision and guidance, towards the partial fulfillment of requirement for the award of the Master of Technology degree in Renewable Energy Technology.

The work is original as it has not been submitted earlier in part or full for any purpose before.

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This project could not have been reached to this stage without the support of my mentor. I take this opportunity to express my gratitude to **Dr.K Manjunath** (Assistant Professor, Department of Mechanical Engineering, Delhi Technological University). His commitments, interest and positive attitude for the project has always been undiminished. The numerous discussions in which ideas and opinions were heard and decisions taken accordingly helped me to do my work regarding the project.

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ABSTRACT

To meet the growing demand of irrigation in India due to the uncertain climatic conditions, it is necessary to focus on sustainable irrigation approaches and improving the efficiency of the existing irrigation systems. Irrigation requirement varies from a couple of life saving watering during the monsoon season to assured year-round water supply. Due to rapid urbanization in India demand for water from urban sector is increasing. The scarcity of water will shoot up with time due to increasing population and growing demands. Study conducted by National Commission for Integrated Water Resources Development (NCIWRD) reveals that the irrigation water demand in India will shoot up to 1180 Billion cubic meters (BCM) by 2050 from the demand value of 710 BCM in 2010[1]. Agriculture sector in India which consumes around 79 per cent of the total available water resources should introduce reforms in efficient water management and thus minimizing water wastage. Estimation of water requirement, proper scheduling of irrigation and implementation of efficient irrigation system are the key solutions of the above problem. India has huge untapped solar energy potential. One of the most promising sectors for solar utilization is solar water pumping. It is necessary to dimension photovoltaic installation accurately so as to reduce the cost and improve efficiency. The aim of the project work is to incorporate proper solar pumping sizing method with a properly scheduled intelligent irrigation system to make it highly efficient model. The objective is to tackle concerns on water wastage and over watering by accurately estimating water requirement of any crop, schedule the irrigation process properly and to design an optimum solar photovoltaic powered pumping system along with development of a prototype intelligent irrigation control facility.

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NOMENCLATURE USED

ET_0	Reference evapotranspiration [mm day^{-1}]
ET_c	Crop evapotranspiration
R_n	Net radiation at the crop surface [MJ m^{-1} day^{-1}]
G	Soil heat flux density [MJ m^{-2} day^{-1}]
T	Mean daily air temperature at 2 m height [°C]
u_2	Wind speed at 2 m height [m s^{-1}]
e_s	Saturation vapour pressure [kPa]
e_a	Actual vapour pressure [kPa]
$e_s - e_a$	Saturation vapour pressure deficit [kPa]
Δ	Slope vapour pressure curve [kPa $°C^{-1}$]
g	Psychometric constant [kPa $°C^{-1}$]
I_t	Average daily total radiation on the plane of the array (KWh/m^2day).
P_{peak}	Peak power rating of solar array [Kilowatts]
E_h	Daily hydraulic energy requirement [KWh/day]
P_{eff}	Monthly mean effective rainfall [mm]
P_{mon}	Monthly mean rainfall [mm]
η_s	Overall efficiency of the Photovoltaic water pumping system.
η_{PC}	Power conditioning unit efficiency
η_P	Motor-pump unit efficiency
η_{PV}	PV module efficiency
η_W	Wiring efficiency.
ρ	Density of water [999.97 Kg/m^3].
g	Acceleration due to gravity [$9.81m/s^2$]

W_g Water demand expressed in m^3/ha day .

TDH Total Dynamic Head [metres].

Q Water flow [m^3/second].

K_c Crop coefficient.

SPCU Solar power Conditioning Unit

MPPT Maximum Power Point Tracking

DC Direct current

AC Alternating Current

HP Horse Power

GSM Global System for Mobile communication.

PV Photovoltaic.

CWR Crop Water Requirement.

LCD Liquid crystal display.

ROM Read Only memory

RAM Random Access memory.

ADC Analog to digital converter.

MHz Mega Hertz.

SPDT Single pole Double Throw.

Vdc DC voltage.

Mn Million .

CHAPTER 1

INTRODUCTION

1.1 Background

Over the last decades, water and energy shortage has been a great concern. Proper management of both is of at most importance for a sustainable development. Water scarcity is a cause of concern around the globe. United Nations study on the global population which are living in areas of physical water scarcity, economic water shortage (lacking infrastructure to utilise available water) and population approaching physical water scarcity is shown in figure 1.1.

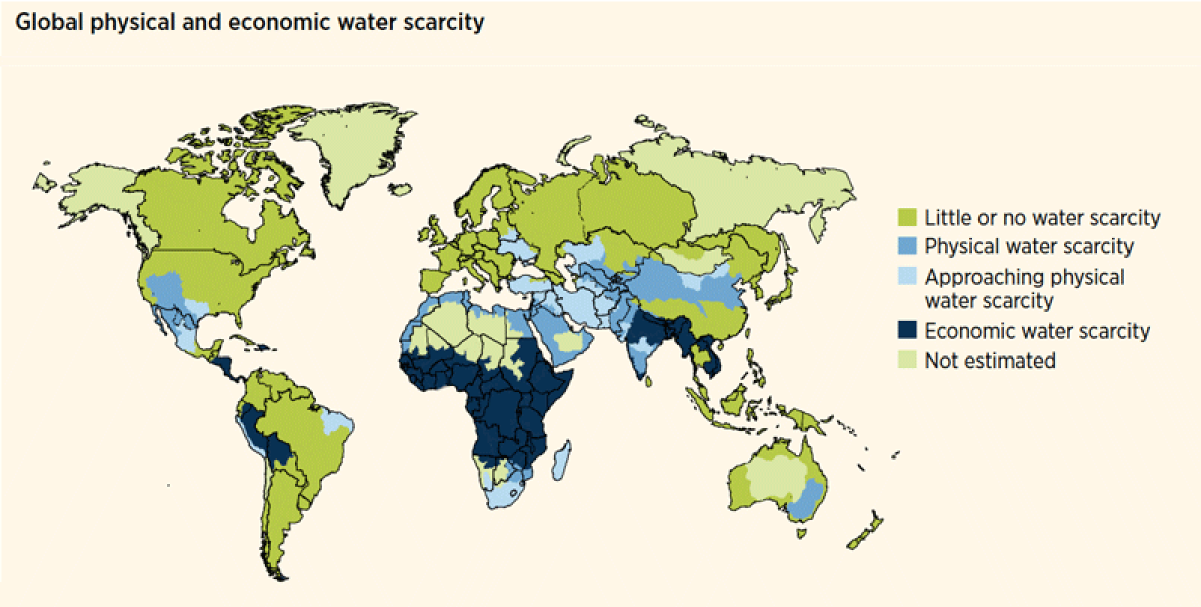

Figure 1.1: World water scarcity distribution

Source: United Nation's World water development Report 2012.

The study reveals that almost 1.2 billion faces physical scarcity of water, around 1.6 billion have economic water scarcity and another half a billion are approaching physical water scarcity. Figure 1.1 shows that major part of northern and central India comes under economic water scarcity regions whereas most part of southern India already faces water shortages. Studies all over the world on climate change also reveals that Indian subcontinent is going to face severe water crisis due to climatic variations, increasing population as well as rapid urbanisation. It is also likely to affect agricultural production and land use patterns because of the more frequent droughts and floods, soil erosion, decreased organic matter in soil, energy scarcity etc. All these studies come to a same conclusion that water crisis is going to affect our country severely in the near future. The fresh water on the planet is unevenly distributed making it inaccessible to a large amount of population. Huge amount of water is wasted, polluted and managed unsustainably making the crisis worse. Thus a water scarcity can be summarised as both natural as well as human made phenomenon.

In India the total gross cropped area is 194 million hectares out of which only 88 million hectares are irrigated leaving behind 106 million hectares to depend on rainfall. This makes rain fed area 55% of the gross cultivated land. Unpredictable rainfall is a major concern for rain fed lands. Out of the 641 meteorological district data's available, 52% of the sites received normal/excess rainfall and remaining 48% with scanty rainfall during 2014.

Ground water sources play a crucial role in delivering required amount of water for irrigation as well as house hold applications. Out of the estimated 140 million hectares irrigation potential of India, 64 million hectare is from ground water, 17.4 million hectare from surface water and rest 58 million hectare from major as well as minor irrigation facilities. Huge number of ground water pumping facilities will be needed in near future to sustain the agricultural production.

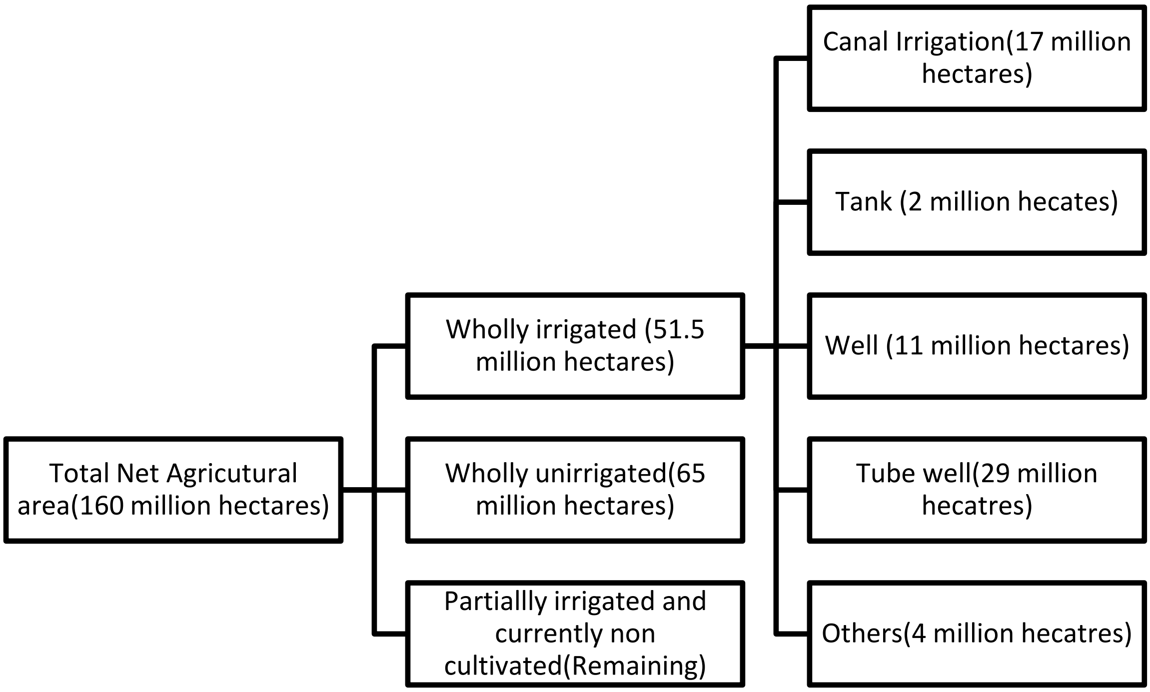

Figure 1.2: Indian scenario of irrigated land and Irrigation sources.

Source: Agricultural survey report 2010-11, Government of India.

As per study conducted by Ministry of New and Renewable Energy [2], around 7 million of diesel pumps are used all over India for irrigation and 18 million pumps connected with grid power. The power consumed by agriculture sector is nearly 20% of installed capacity of power generation in the country. Annual consumption of coal and diesel for water pumping are estimated as 85 million tonnes and 4 billion litres respectively. Thus agricultural sector is also considerably contributing to the carbon footprint of India.

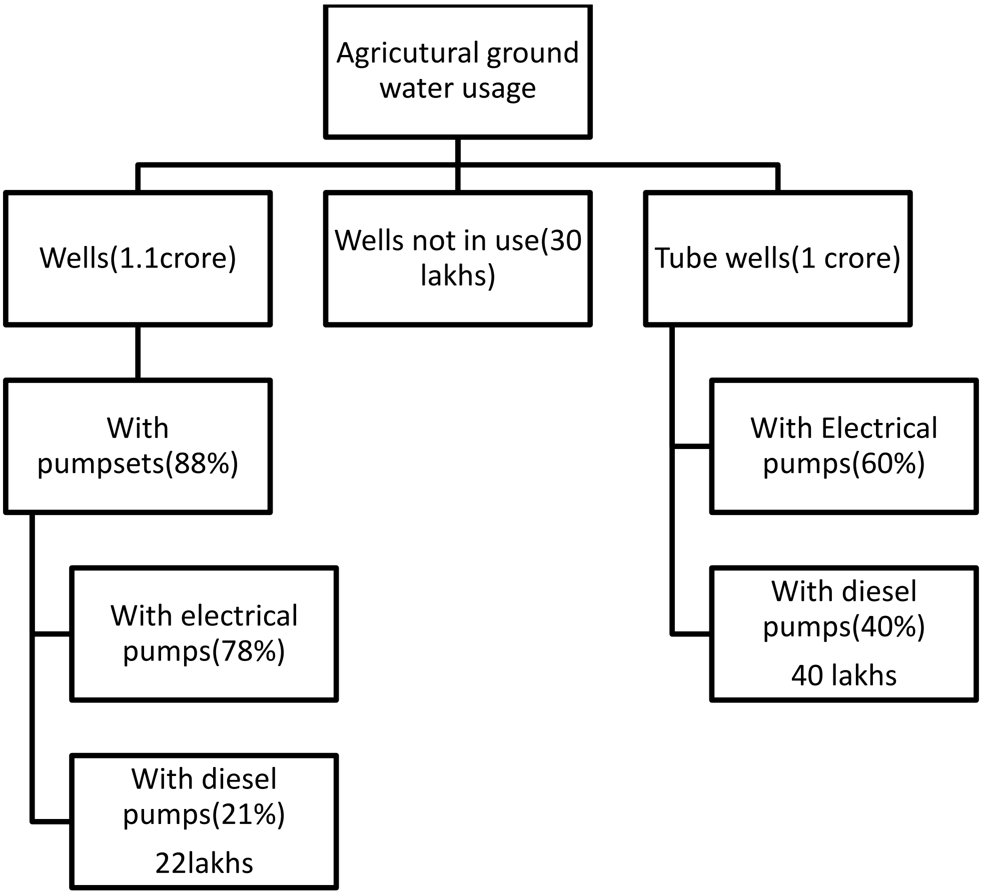

Figure 1.3: Ground water sources for agriculture.

Source: Agricultural survey report 2010-11, Government of India.

Water saving in irrigation sector can be achieved by promoting micro irrigation methods like drip irrigation, trickle irrigation, micro sprinklers, micro-jets etc. But only a miniscule area is applying these modern technologies despite its wide promotions. Other modern techniques like rainwater harvesting, water shed management and ground recharging will also improve utilisation efficiency of the existing facilities. Irrigation sector also demand advanced methods to apply water as precisely and effectively as possible depending on the climatic conditions of the particular site. Thus for enhancing the efficiency of water usage major investments in research and development and awareness and knowledge development programmes in this field are required.

1.2 Solar pumping in India

Ministry of New and Renewable Energy (MNRE) started Solar Pumping Programme in India in the year 1992. A total number of only 13964 pumps were installed during the period of 1992 to 2014. The main factor which had contributed to the low penetration of solar pumps is obviously the high cost of solar modules. But the costs are plummeted considerably in recent times making it a more viable solution to tackle the energy crisis in agricultural sector. MNRE targets to achieve deployment of 1 lakh pumps in 2014-15 and at least 10 lakh by the year 2020 [2].

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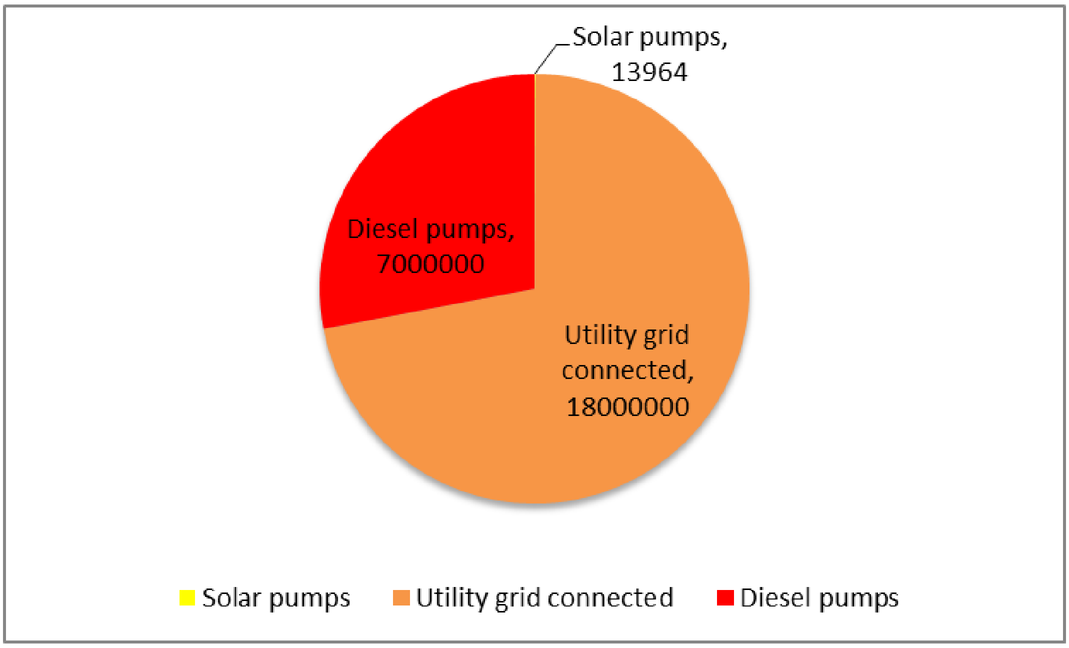


Figure 1.4: Distribution of number of water pump used in irrigation sector

Source: MNRE survey for solar pumping programme 2015.

1.3 Sugar cane agriculture in India

Sugarcane crop is one of the most important industrial crops cultivated in India. It occupies around 5 million hectares in area which accounts for around 3% of the gross cultivated area in the country [3]. India is the second largest producer, lagging behind Brazil, producing nearly 15 and 20% of global sugar and sugarcane respectively. Water management is identified as a common problem faced by sugarcane cultivation [4]. Many research works [5],[6] were carried out analysing the impact of drip irrigation for sugarcane and have concluded that drip irrigation is an advisable solution for the water management. The benefits of the micro irrigation includes higher yields by avoiding excess irrigation thus avoiding weed formation and huge amount of water saving.

Sugar cane is one of the world's thirstiest crops; approximately 25000 kg of water is required to produce 100 kg of sugarcane [7]. According to Directorate of Economics & Statistics, Department of Agriculture & Cooperation 92.5 per cent of total sugar cane cultivated area in India is irrigated. A survey conducted by ASSOCHAM, an industry body in 2014 reveals that Uttar Pradesh suffers from lowest yield per hectare despite having highest area under cultivation among other states (39.78% share). One of the reasons identified for the low yield was inadequate irrigation facilities coupled with improper water management.

Thus water management in irrigation process is a serious issue which has to be addressed soon. In this project work the sizing of the solar photovoltaic pumping system is done according to the crop water requirement of the sugar cane crop in Uttar Pradesh state. Farmers are interested not only in saving irrigation water but also in using solar pumping as it provide them greater flexibility and reduced running cost . Thus solar photovoltaic pumping system along with an automated drip irrigation facility, which was found reliable in many studies [8] can be a solution for the water management crisis.

CHAPTER 2

LITERATURE REVIEW

This chapter deals with theoretical background and the published research work that is related to the project work.

2.1 Theoretical background

S. Solomon [3] conducted detailed study on sugarcane agriculture and sugar Industry in India. The sugar requirement of the country is growing consistently with the population growth. Sugar consumption in the next 5 years is expected to touch 30 MT mark due to improved domestic supplies and strong demand, fuelled by a growing population and continued growth in economy. Many bulk consumers of sugar such as bakeries, candy, local sweets, and soft-drink manufacturers account for about 60–65 % of mill sugar demand. The population in the country is set to reach 1.50 billion by 2030 at the present compound growth rate of 1.6 % per annum. The projected requirement of sugar for domestic consumption in 2030 is 36 million tons, which is about 50 % higher than the present production. To achieve this target, the sugarcane production should be about 500 MT from the current 350 MT for which the production has to be increased by 7–8 MT annually. The increased production has to be achieved from the existing cane area through improved productivity (greater than 100 tons/ha) and sugar recovery (greater than 11 %) since further expansion in cane area is not feasible. This study clearly shows the need of improving the existing methods of sugarcane farming.

D. Esther Shekinah et al. [7] have conducted studies which deals with the various irrigation methods practiced in India and the various technologies that have been adopted by sugarcane farmers for improved irrigation and water use efficiency. They found different methods which are used to apply irrigation water to sugar cane crop. They studied on sugar cane because it is one of the world's thirstiest crops; approximately 25,000 kg of water is needed to produce 100 kg of sugarcane. With a projected area of 4.5 million ha and yield of about 90 t/ha and a recovery of 11%, it is necessary that sugarcane cultivation is carried out without resource crunch, especially water. They concluded their study with a number of suggestions or improvements which will tackle the issues of water crisis. Some of the suggestions are assessment of water availability before planting and restricting crop area, avoiding flood irrigation and reduction of water losses through conveyance if still needed, sprinkler irrigation is advantageous in heavy soils during germination phase to give light irrigation and obtain better germination, drip irrigation for saving water and possible increase in cane yield, guidance to farmers from research institutes and industries, Training to farmers on the maintenance of drip irrigation, review of the sustainability of the low cost micro irrigation technologies for successful use, cost reduction strategies for the conventional micro irrigation technology, availability of support base technical and knowledge for farmers for adopting micro irrigation technology.

C. Papanikolaou.et al. [8] experimentally analysed the effect of an intelligent surface drip irrigation method on sorghum biomass thereby calculating energy and water savings. The study was conducted at the farm of the University of Thessaly in Velestino, Volos, Central Greece. According to the results of this two-year study, the biomass production was only 2.7 % higher in the conventional treatment than in the automated one, which means that the automations were used properly and they had at least the same impact on biomass production. The highest mean Irrigation water-use efficiency (IWUE) was recorded in the automated treatment. Better water management between irrigations, due to the soil moisture values taken from the soil moisture sensor, was the reason not only for the higher IWUE in the automated treatment but also for a 12.5 % mean water saving with the same treatment. Furthermore, the mean energy saving was 12.4 % in favour of the automated treatment. As a general conclusion, based on the study, the cultivation of energy plant sorghum seems to be profitable under full irrigation conditions in the Greek region. The use of new technology (irrigation scheduling with soil moisture sensor) is profitable for the farmer while the system proved quite reliable in the open-field conditions under consistent full use. A combination of new technology and certain cultivation techniques could increase the gross margin for the farmer even more. So, under the Greek conditions, it can be suggested that farmers cultivate the energy plant sorghum and schedule their irrigations using soil moisture sensors.

Ricardo Carvajal et al. [9] describes the analysis of a virtual prototype of an automated greenhouse irrigation system. The simulations used reduced the uncertainty that exists when a design concept, developed with computer aided tools, is taken to the real world. Thus, a virtual prototype of the greenhouse irrigation system was designed, modelled and simulated using the RFLP (Requirements Functional Logical Physical) approach. Then, a physical prototype was built and implemented into a real greenhouse environment in order to compare both models. The total opening time and water consumption percentage error was about 2 %, showing that the virtual model is accurate and is able to predict values for those outputs. On the other hand the number of activation signals was different on both models. Such difference can be explained by noise signals in the the physical model sensors. Besides, as the virtual model has a smaller sample time, small variations on the input signals may activate the valve, those changes might not be detectable using the real controller. However, the total time that the valve remains open and the water consumption are reliable indicators of the system behaviour as are directly related to the main output that finally is the water that goes to the crops. According to this, for future implementations the number of valve activations is not recommended as an indicator for the model reliability. They proposes that system can be enriched by adding more complex weather forecasting models to test system behaviour and foresee possible scenarios that may affect the crops beforehand. However, by having a virtual model that represents the real system, it is possible to test new improvements to the system before change the real implementation. Additionally, important alerts can be sent to the stakeholders of the greenhouse by using email, SMS, etc. Adding more functions to the system and reducing the time and frequency of visits to the greenhouse.

Francisco Cuadros et al. [10] provided a practically reliable procedure to size solar-powered irrigation (Photo irrigation) schemes. The method consists of three main stages: (1) One determines the irrigation requirements of the specific estate according to the characteristics of its soil-type and climate. (2) A hydraulic analysis of the pumping system is made according to the depth of the aquifer and the height needed to stabilize the pressure in the water distribution network. (3) Finally, one determines the peak photovoltaic power required to irrigate a 10 ha sub-plot of the estate taking into account the overall yield of the photovoltaic-pump-irrigation system. They call this arrangement ‘‘photo irrigation’’, and believe that it may be of great utility to improve the output of such socially significant crops as olives and wine grapes, optimizing the use of water and solar energy resources at the same time as preserving the environment.

P.C. Pande et al. [11] A Solar Photovoltaic (PV) pump operated drip irrigation system has been designed and developed for growing orchards in arid region considering different design parameters like pumps size, water requirements, the diurnal variation in the pressure of the pump due to change in irradiance and pressure compensation in the drippers. The system comprising a PV pump with 900 Wp PV array and 800 W dc motor-pump mono-block, micro filter, main and sub mains and three openable low-pressure compensating drippers on each plant was field tested. The emission uniformity was observed to be 92–94% with discharge of 3.8 l/h in the pressure range of 70–100 kPa provided by the pump and thus the system could irrigate some 1 ha area within 2 h. Based on the performance of the PV pump and the drip system, it was inferred that about 5 ha area of orchard could be covered. The projected benefit–cost ratio for growing pomegranate orchards with such a system was evaluated to be above 2 even with the costly PV pump and therefore the system was considered to be an appropriate technology for the development of arid region. It is suggested that such systems need to be extensively tested particularly along IGNP canal and around water harvesting tanks having lower suction head for growing orchards in arid region.

R. López-Luque et al.[12] An optimal standalone direct pumping photovoltaic irrigation system is proposed for the deficit irrigation of olive orchards in Mediterranean basin. The irrigation distribution system is composed of a pumping system that boosts water directly into the irrigation distribution network. The aim is to vary the discharge of water as a function of the power generated by the PV system. To achieve this objective two elements are used. First of all, a variable speed pump powered by an asynchronous electric motor, secondly non-compensating emitters that vary their discharge as a function of their working pressure. It is obtained that for 40m head peak power required is 300 watts/hectare. It has been proved that standalone direct pumping irrigation systems are a technically and economically feasible alternative to transform rain fed olive orchards into irrigated ones, especially when the costs of the electricity or the electrification of the farm are high. Increasing interest will be focused on these systems in the near future as PV equipment and water pump costs will eventually decrease.

P.E. Campana et al, [13] identified that photovoltaic water pumping technology as a sustainable and economical solution to provide water for irrigation, which can halt grassland degradation and promote farmland conservation in China. A simulation model, which combines the dynamics of photovoltaic water pumping system, groundwater level, water supply, crop water demand and crop yield, is employed during the optimization. To prove the effectiveness of the new optimization approach, it has been applied to an existing photovoltaic water pumping system. Results show that the optimal configuration can guarantee continuous operations and lead to a substantial reduction of photovoltaic array size and consequently of the investment capital cost and the payback period. Sensitivity studies have been conducted to investigate the impacts of the prices of photovoltaic modules and forage on the optimization. Results show that the water resource is a determinant factor.

Pietro Elia Campana et al, [14] have carried out Dynamic modelling of a PV pumping system with special consideration on water demand. The aim of this paper was to develop a dynamic modelling tool for the design of a of photovoltaic water pumping system by combining the models of the water demand, the solar PV power and the pumping system, which can be used to validate the design procedure in terms of matching between water demand and water supply. Both alternate current (AC) and direct current (DC) pumps and both fixed and two-axis tracking PV array were analysed. They concluded that the sizing of photovoltaic water pumping systems for irrigation is extremely affected by the dynamic character of the water demand and collectable solar energy. In order to define the worst condition on the basis of which the system is sized, the lowest ratio between required hydraulic energy and available solar radiation has to be considered. Preliminary economic analysis based on the initial investment costs showed that AC pump powered by fixed PV array represent the most cost-effective solution for water pumping.

Chandan kumar sahu et al,[15] designed a low cost smart irrigation control system. The objectives of the paper were to control the water motor automatically and select the direction of the flow of water in pipe with the help of soil moisture sensor. Finally send the information(operation of the motor and direction of water) of the farm field to the mobile message and g-mail account of the user. Prototype includes number of sensor node placed in different directions of farm field. Each sensor are integrated with a wireless networking device and the data received by the “ATMEGA-328” microcontroller which is on a “ARDUINO-UNO” development board. The RASPBERRY-Pi is for send messages through internet correspondence to the microcontroller process. The experimental results show that the prototype is capable for automatic controlling of irrigation and providing feedback of soil moisture sensor.It saves energy also as it automatic controlling the system. It is implemented in all type of irrigation system (channel, sprinkler, drip). They also concluded that the power consumption of the wireless network devices are also less and the system perform a long time function.

Dipesh Patel et al, [16] This paper provides the use of solar energy to produce electricity to run the water pump for fetching water from well in Rajasthan state. The paper is based on the theoretical prospect of designing a solar pumping system considering the aspects of Dynamic head, economic feasibility, water requirement and solar irradiance. The theoretical study shows that the proposed system's cost recovery time is half of the life time of system. Cost recovery time of the system is much smaller than its lifetime. Calculation shows that the system is capable of providing 30% (on average) more water than required which accounts for a bad weather condition. Even if the inverter and pump are changed, the system provides 6 years of cost free operation which is very important for Bharunda village from economic point of view. They calculated that, for 26852 litres/day a 3kW submersible motor-pump set is required. The overall cost was obtained as Rs.509370 in the year 2012.

Aravind Anil et al. [17] proposes the design and implementation of a highly energy efficient, multimode control for an automated irrigation system. The system uses an in-situ soil moisture potential measurement and the programmed data to irrigate a desired area.

The major components of the intelligent irrigation control system are microcontroller, GSM module, LCD panel, keypad, solar panel, battery, pump, rain water harvesting system and moisture sensors. Atmega328, an 8-bit microcontroller is used in the system. The microcontroller is the main functional unit, which is programmed to send commands to different components of the system. It handles real time data and takes timely decisions.

SIM 300DZ model is the GSM module used, which is a triband GSM/GPRS engine operating at frequencies 900 MHz, 1800 MHz and 1900 MHz. The GSM module provides a two-way communication between system and the user through SMS. An LCD panel and a keypad provides user interface along with the GSM module. A 40W solar panel is used to harvest solar energy which is stored in a 12V 5AH battery and is used to power the complete unit. Soil moisture sensors placed near the plants accurately detect the soil moisture content. The data from the soil moisture sensors decides the time and duration of irrigation. The system does not take into account of the various crops but exclusively considered the garden irrigation. The system lacks link with the climate condition of the region, coordination between weather and irrigation initiation as well as soil retention properties.

Jia Uddin et al. [18] propose an automated irrigation system using solar power for paddy fields. With this system Farmers can remotely turn on or turnoff the motor by using cell phone through SMS. They used microcontroller PIC16F628 along with other interfacing integrated circuits to obtain the proposed model. As the proposed model is automatically controlled it will help the farmers to properly irrigate their fields. The model always ensures the sufficient level of water in the paddy field avoiding the under-irrigation and over-irrigation. The proposed system does not take into account of the fact that some crop yields will be affected adversely when the soil is always moisturized, for some crops certain level of water stress conditions increases the yields.

2.2 Summary of literature review

After going through the literature review it can be summarised that more of the work has been done in developing suitable pumping system, automated circuitry for irrigation controlling purpose separately. Many research works on bringing the wireless technologies in automation circuits are carried out. These technologies surely are reliable and reduce regular field monitoring. A number of research works are available on methods of calculating crop water requirement and scheduling the irrigation process. But studies which combine the crop water requirement with pumping system design and the automated irrigation controlling method to reduce the water usage are rare to find. There for the work on combining the crop water requirement based pumping design as well as designing automated irrigation controlling circuitry has been carried out in this project.

2.3 Problem Statement

The main aim of this project is to combine the crop water requirement based solar pumping system design as well as an automated irrigation controlling prototype circuit design. The intelligent irrigation circuitry will incorporate all the important features of a typical irrigation control device, which include soil moisture testing, water level monitoring of overhead tank, timely irrigation procedure and SMS based feedback facility. The prototype design also utilises solar power, for the working of system as well as for pumping facility. The crop water requirement can be accurately obtained by using Cropwat8.0 simulation platform developed by Water Resources Development and Management Service of Food and Agricultural Organisation of United Nations (FAO) [19]. The simulated results can be used for efficiently scheduling the irrigation for any crop by making use of designed automated circuit.

2.4 Organization of report

The report has been organized in the following sequence. The report is divided into 6 chapters. Introduction of the project topic is given in Chapter 1. An overview of the related literature is given in Chapter 2. Description of methods used and design details has been described in Chapter 3. Results followed by discussions are presented in Chapter 4. Conclusions are presented in chapter-5. Future scope of the present work is presented in Chapter 6, References are presented after chapter 6 followed by the appendix section.

CHAPTER 3

METHODOLOGY

The entire project work can be broadly classified into two major sections. First section deals with systematic designing of Solar Photovoltaic water pumping system (PVWPS) which includes water demand estimation, solar power availability study and required photovoltaic pumping capacity sizing for a particular site and selected crop. Second section consists of designing of solar powered intelligent system prototype model which automates the irrigation process.

3.1 Solar Photovoltaic Water Pumping System

A solar photovoltaic water pumping system essentially consists of the following components

1. Photovoltaic modules.
2. Motor pump set.
3. Solar power conditioning unit (SPCU).
4. Battery back-up if necessary.
5. Suction and delivery pipe fittings.

Solar photovoltaic panels convert sunlight into DC electrical energy. Solar power conditioning Unit can be a DC-DC converter or a DC-AC inverter depending on the motor used for pumping. If DC motors are used SPCU will be DC-DC converter otherwise an inverter when AC motors are used. In both cases the unit is incorporated with Maximum Power point Tracking (MPPT) facility maximise power output from the solar panels. The overall system cost is mainly decided by the cost of the solar panels. So the sizing of the panel strictly according to the needs of the customer is a crucial step in solar pumping calculations.

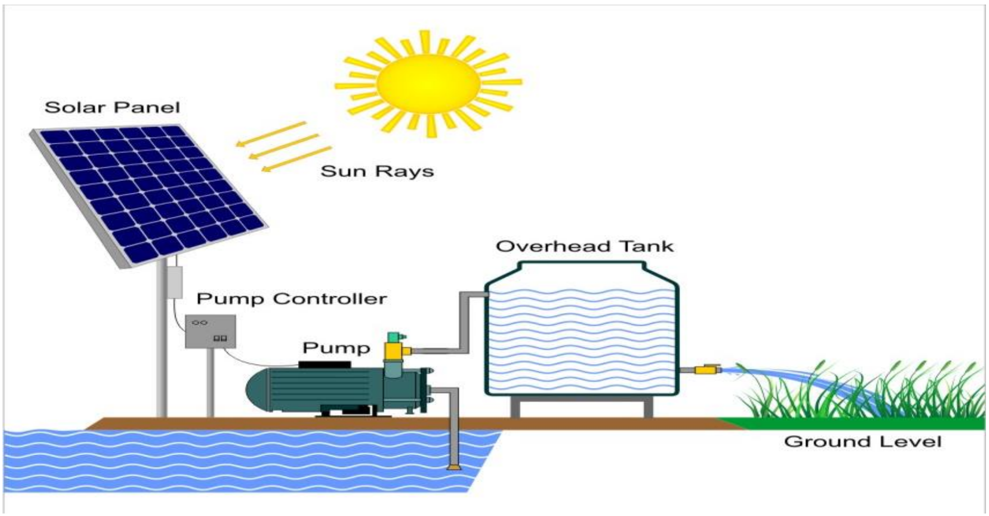


Figure 3.1: Components of a typical solar pumping system

Source: http://taiyosolar.in/solarpump.html

A grid tied/diesel pump set usually operates with constant power input from the grid or diesel engine and thus gives constant water output at a particular head. In case of solar water pump the water output at the same head depends on varying power inputs from the solar panels through out the day, with higher inputs in the after noons and lower inputs during mornings and evenings. E.g. a standard 3HP pump which works on grid /diesel power for, say 3 hours a day, may able to pump the same amount of water in a day as a solar pump of 2HP working for 7 hours using the sunlight avilable. This fact is important in for designing and selection of an appropriate solar pump for irrigation as well as domestic purposes. The parameters to be considered for the selection of a suitable solar pump are : the amount of water needed for a day, total dynamic head at the site and the location, they are important as solar energy availbale varies from region to region .

3.1.1 Photovoltaic modules.

Traditional photovoltaic panels consist of a number of solar cells usually made of silicon. Crystalline Silicon based flat plate solar cells are efficient (11-19%) and are widely used (around 90% used). Thin film solar cells are second generation with very thin and flexible silicon wafers with lower efficiencies ranging from 7-14% but are cheaper . Third generation technologies tries to tackle the Shockley Queisser efficiency limit, which is the theoretical maximum efficiency limits around (40-45%) depending on solar spectrum and band gap of material used. Third generation cells uses alternatives like cadmium, gallium, indium, organic solar cells and various multi junction models which are most successful. A record efficiency of 44% is obtained with metamorphic triple junction cells. These researches clearly indicates that the price of the solar panels will continue to drop without compromising the efficiency in years to come, will make them widely acceptable.

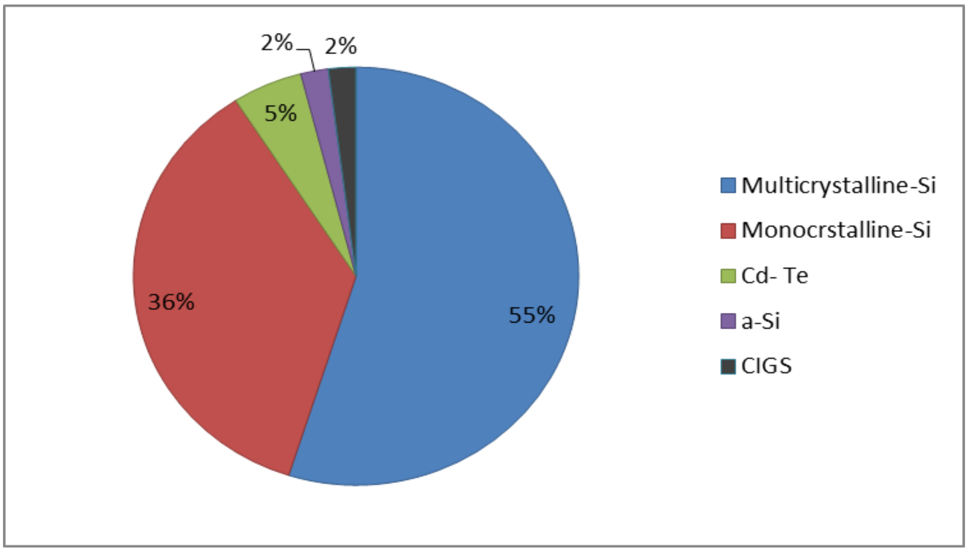


Figure 3.2: Solor cell technologies market share.
Source: Solar Photovoltaics Report, Fraunhofer ISE, 2014.

Solar photovoltaic array (PV array) comprises of a number of solar photovoltaic modules essentially sized to satisfy the energy requirement of the customer. A number of solar photovoltaic modules, connected in series as well as parallel depending on the voltage and load requirements makes solar array. Solar arrays installed in a field can be a fixed type or tracking one. Tracking system will considerably improve the efficiency although it adds additional cost of tracking equipment. Photovoltaic panels makes up to 40 to 60% of the overall system costs, thus proper sizing of the panel as per requirement is a crucial as well as difficult process as power output of the PV array varies according to differences in location, solar radiation, temperature and other atmospheric factors.

The sizing of the PV array is to be done by considering the daily hydraulic energy requirement for lifting the required amount of water E_h, the daily average radiation on the photovoltaic array I_t and the overall system efficiency η_s . This approach makes the system more precise and reliable. The stepwise approach is expressed in equations 3.1, 3.2 and equation 3.3.

$$P_{peak} = E_h / (I_t \eta_s) \quad (3.1)$$

The overall efficiency of the system comprises of efficiencies of power conditioning unit, motor- pump unit and other unavoidable system losses like power losses of PV modules due to temperature variation as well as electric losses in the wires. All these losses are taken care of by considering the overall system efficiency η_s

$$\eta_s = \eta_{PC}\, \eta_P\, \eta_{PV}\, \eta_W \quad (3.2)$$

where η_{PC} is the efficiency of the power conditioning unit, η_P is the pumping system efficiency and η_{PV},η_W consider the power losses in the PV modules and wirings.

These efficiencies vary with device models and working conditions with the overall efficiency usually in the range of 30-40%.

The daily required hydraulic energy can be obtained by considering the daily water demand and total dynamic head by using equation 3.3.

$$E_h = \rho g W g (TDH) \quad (3.3)$$

Where ρ is the density of water, g is the acceleration due to gravity, W_g is water demand expressed in m^3/ha day(1 mm/day = 10 m^3/ha day). Total Dynamic Head (TDH) depends on two factors namely total vertical lift and total frictional losses. A typical pump layout diagram depicting the vertical lift and other relevant parameters are shown in figure 3.3.

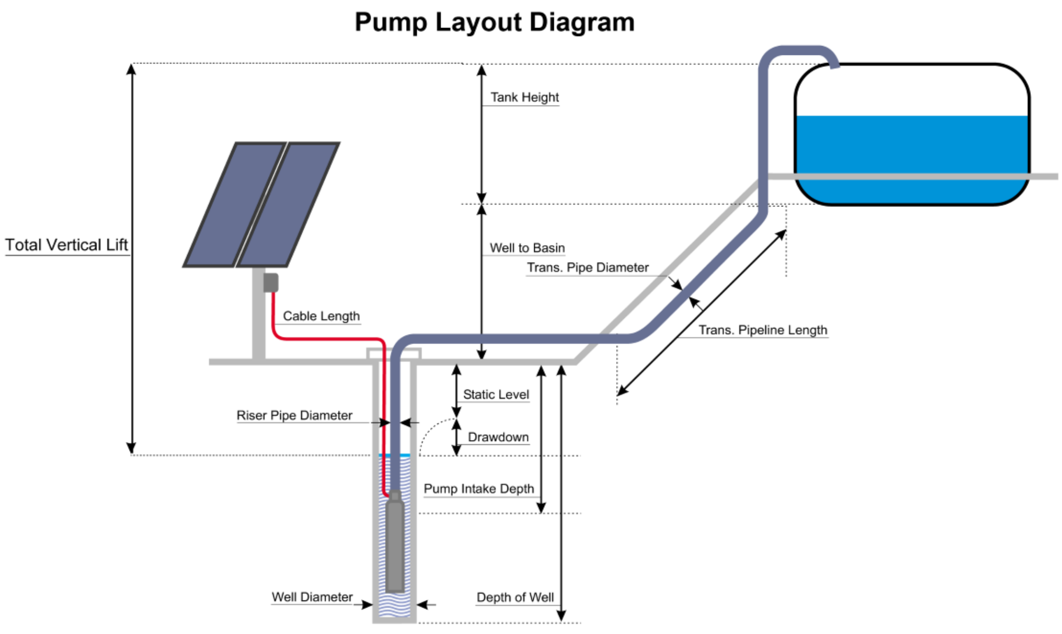


Figure 3.3: Solar Pump layout showing TDH.
Source: http://www.kgelectric.co.za/knowledge-base/solar-water-pumping.

TDH= Vertical lift + Frictional losses. (3.4)

Vertical lift = Elevation+ standing water level+ Draw down. (3.5)

Frictional losses can be taken as 0.5% of total vertical lift. Thus total dynamic head can be calculated by considering the above parameters which are site specific.

3.1.2 Motor-pump set

Motor-pump set which are used in Photovoltaic water pumping systems is designed considering the probable variations in panel outputs which depend on climatic conditions of the site. The technologies available use a power conditioning unit which alters the outputs of solar panel according to the motor requirements; it also protects motor from extreme input conditions for high as well as low voltages. Alternative technologies are also available which directly connects the solar panels to a motor which is designed to work on variable range inputs, thus avoiding the intermediate power conditioning unit.

Both AC as well as DC motors can be used for the pumping purpose. DC pumps are largely imported in India. AC pumps are locally manufactured but around 60% of the AC pump market is unorganized. A significant section of the unorganised AC pump market is laden with sub-standard products that find their way into solar pump market as well. The efficiency of these pumps is very low. As a technology, while AC technology is now catching up, DC technology is considered to be more suitable given the wider operating range and higher efficiencies. However, after sales servicing of DC pumps in India is a nagging issue that has led to limited success for these pumps. Most of the technical manpower available in the country at local level is not conversant with DC technology. Additionally, availability of spare parts for DC pumps is also a concern [30].

Motor-pump system can be sized by considering the flow rate required and the total dynamic head .The size of the motor-pump in kW can be obtained by using equation 3.6.

$$P = \frac{\rho g Q(TDH)}{1000\,\eta p} \quad (3.6)$$

where Q is the water flow in m^3/second, η_P is the overall efficiency of the motor pump system, ρ is the density of water, g is acceleration due to gravity and 1000 is a conversion factor.

3.1.3 Solar Power Conditioning Unit (SPCU)

The power conditioning unit is an interface between the PV modules and the motor pump unit with the crucial function of improving coupling performances. The SPCU can be DC/DC converter in case of a DC motor and a DC-AC inverter in case of an AC motor depending on the motor-pump system used. MPPT (Maximum Power Point Tracking) device is usually equipped in both converter and inverters to maximise the power extraction from the solar panels. Usually the SPCU efficiency varies between 85% to 95% depending on power availability and the working temperature.

The main functions of the SPCU are matching the input power from solar panels to the output power the pump receives, providing protection against too low and too high voltages by switching off the system thus increasing the lifetime of the pump and reducing maintenance.

3.2 Water Demand Estimation

The knowledge of Crop Water Requirement (CWR) is essential for the design of photovoltaic pumping system. It depends on various factors like; type of crop, type of soil, climatic conditions of the site, irrigation methods cropping pattern etc. In some cases the whole water demand can be fulfilled by the monsoon only, given that a proper monsoon is received. But the monsoon pattern is uncertain which makes the monsoon dependent crops vulnerable to damage. Water logging due to heavy rainfall and drought due to scanty rainfall are the two extremes which is a nightmare of almost all the farmers. Hence the rainfall should be supplemented by required irrigation facilities for proper crop growth. Irrigation requirement can be fulfilled by local ground water source for small fields and for larger fields local surface water sources if available needs to be utilised.

The crop water requirements (CWR), from its sowing time to harvest for a given region can be determined from climatic conditions, soil characteristics and properties of the crop. The rainfall and/or irrigation must fully satisfy the sum of the water which is to be consumed by the crop and loss by evaporation, together referred as evapotranspiration (ET) of the crop. This variable is the most important in estimating an irrigation requirement for a given crop in a given area. Estimation of ET_0 (reference evapotranspiration) which is essentially depends on the sites climate, crop coefficient (K_c) which characterises the type of crop and growth coefficient of the crop, is the first step in CWR calculation. Experimental determination ET_0 using devices like balance evapotranspirometers or drainage lysimeters have practical limitations due to the difficulty and high cost. Thus the indirect estimation process of ETo based on the empirical formulae is still widely accepted used.

Different methods to evaluate the value of ET_0 has been discussed in a meeting organised by Food and Agricultural Organisation (FAO) in collaborations with World Meteorological

Organization in Rome,1990. The committee recommended the FAO-Penman Monteith equation for calculation of the ET_0 which is expressed as below in equation 3.7.

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T+273}\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad (3.7)$$

The parameters which are used in equation [3.7] are either measured or are readily calculated from the weather data of a particular site. This equation can be used for any crop directly as crop specific parameters are also included. The estimation of ET_0 followed by effective rainfall calculation and required irrigation throughout crop life along with irrigation schedules can be performed by making use of the software CROPWAT 8.0, developed by Joss Swennenhuis, Food and Agricultural Organisation(FAO), United Nations.

Cropwat 8.0 is a computer programme for estimating the crop water requirements and required irrigation from time to time, based on various factors related to climate of the site, soil parameters and the crop characteristics. The programme also simulates the irrigation schedules for the crops by including the rainfall availability for the region under consideration. All the methods used in this particular software are according to FAO publications 3 and 4. New projects can be created for a particular region for a particular crop with the available local climatic data. Cropping pattern which includes the planting time, types and number of crops in a region and different crop stages can be defined by the user. After defining the available climatic data, soil characteristics of the site and crop specifications for a given region, the Cropwat software simulates the data’s and provides results such as effective rainfall at the site, required irrigation and irrigation schedules. The results for sugarcane crop for Lucknow district are given in Chapter 4.

3.3 Intelligent Irrigation system Prototype design

A prototype of solar intelligent irrigation monitoring and controlling facility has been designed.

3.3.1 Functional block diagram of the model

The entire unit can be broadly classified into two namely the intelligent irrigation control unit and the solar powered water pumping unit. The irrigation control unit includes a Microcontroller-PIC16F882 along with moisture sensor, water level sensors, pump controlling relays, GSM modem for feedback SMS facility. This control unit is powered by a photovoltaic panel of 40watts. Same photovoltaic panel is used to power a prototype submersible water pump. The system is designed in such a way that it can be used for any type of crop by adjusting the irrigation timings with the help of the keypad which is provided. The system continuously monitors the water level of the overhead tank facility and turns on the water pump as when needed to ensure the water storage tank not running out of sufficient water for irrigation.

The whole control system can be easily used along with a proper micro irrigation facility consisting of solenoid valves. The solenoid valve's opening and closing according to the irrigation schedule can be controlled by the automation circuitry with the help of the relays provided in the circuit. Thus an automated irrigation control unit along with a micro irrigation facility is a feasible solution for water management problem faced by Indian irrigation sector.

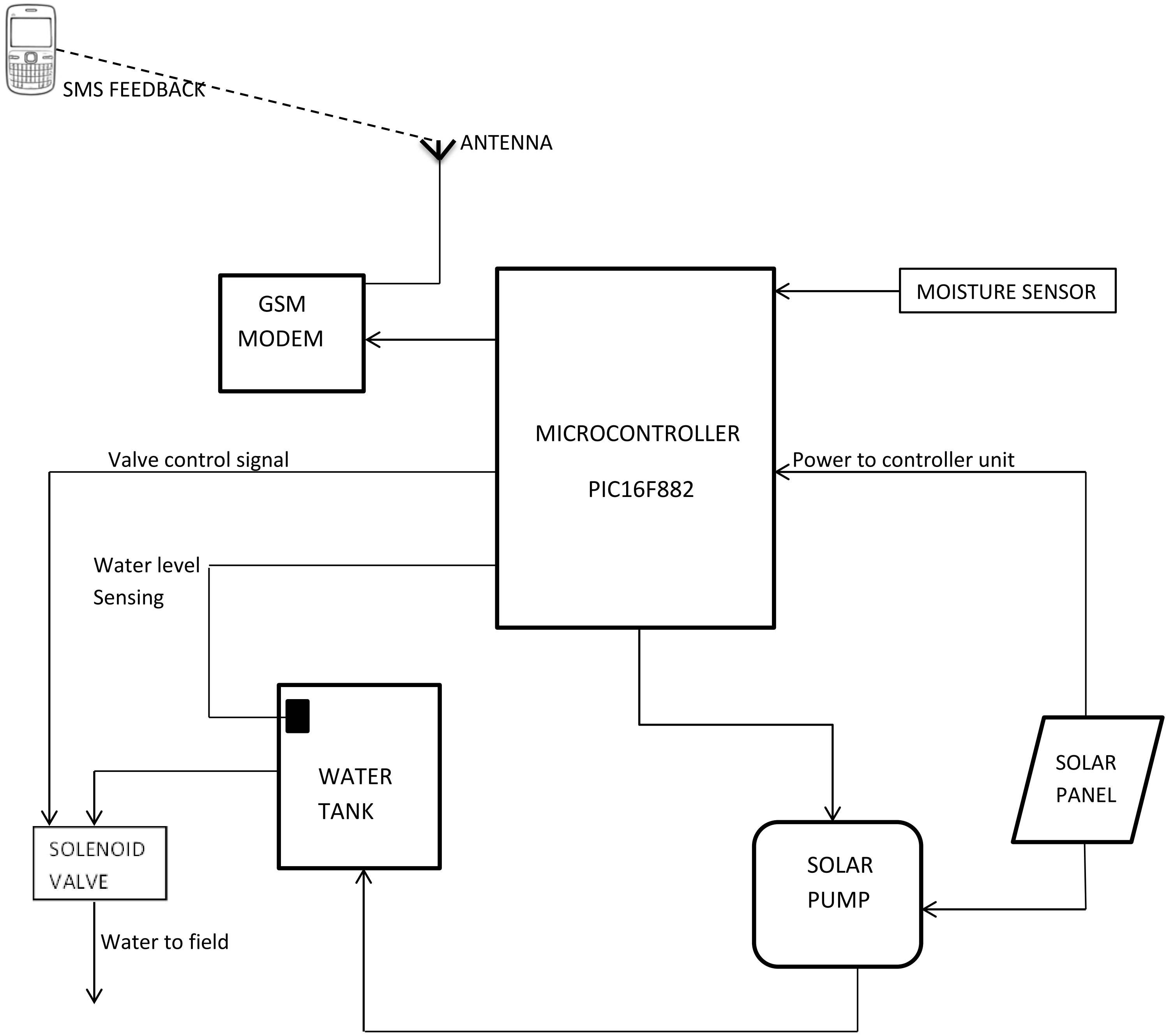


Figure 3.4: Functional block diagram of the solar powered intelligent irrigation model.

The functional block diagram clearly indicates that the microcontroller is the central console along with various components which gives inputs or receives output of the various processes taking place.

Various inputs and outputs of the microcontroller based control unit are shown in block diagram, figure 3.5 below.

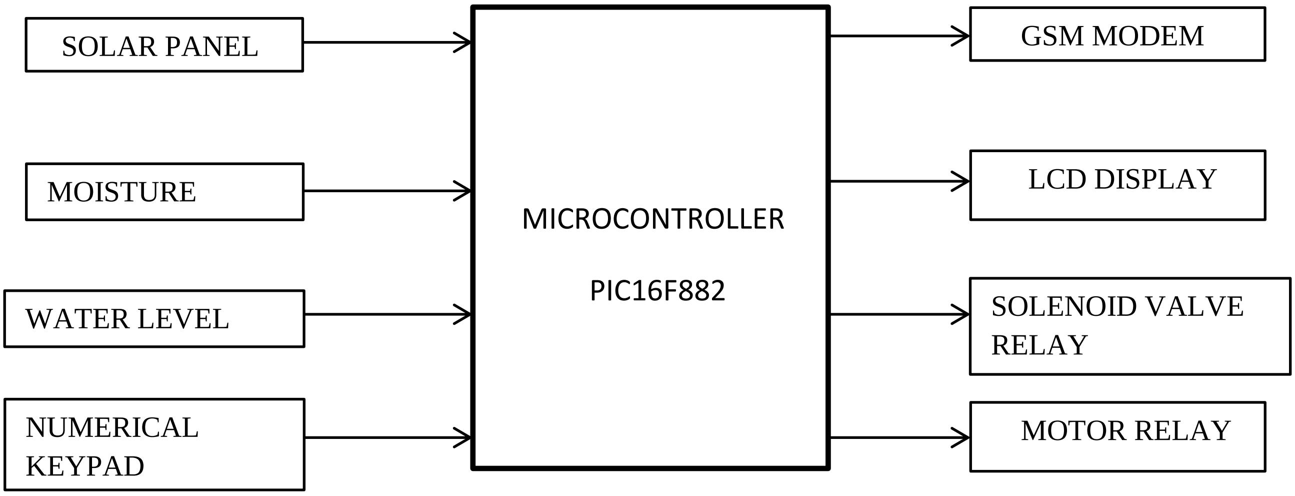


Figure 3.5: Various inputs and outputs of the control system.

3.2.2 Components of control unit

The control unit consists of a microcontroller along with moisture sensor, water level sensors, pump controlling relays, GSM modem, keypad and an LCD display unit to perform the desired functions.

Microcontroller unit: A microcontroller (usually abbreviated as µC or MCU) is essentially a small computer on a single integrated circuit(IC). It consists of a processor core, memory unit, and user programmable input and output peripherals. The IC usually includes program memory in the form of OTP ROM, ferroelectric RAM or NOR flash. An additional small RAM will be also present. Microcontrollers are proven versatile devices which are used in most of the automation and control applications such as remote controls, automobile engine control systems, power tools, office machines, wide range of appliances, implantable medical devices, toys etc. Microcontrollers dominate the control and automation applications due to its reduced size and cost, high reliability and effectiveness. Microcontrollers are able to integrate analogue components which enable it to control non-digital systems. The microcontroller used is 16f882. It is a 28 pin IC with an internal oscillating frequency of 4MHz. It has sufficient pins to include ADC (Analogue to digital converter) for moisture sensor, serial port pins for interfacing GSM module, Numerical keypad, LCD interfacing and relays for pump and solenoid valve control.

Soil Moisture sensor: Measuring soil moisture is important step in deciding the duration of the irrigation. Advanced versions of moisture sensor have options to set the desired moisture level with the rotary knob and also features wireless transfer of collected data from the field to the control unit. Cheaper sensors model can be made of two electrodes measuring the resistance of the soil between the leads. The current is passed through the probes. The resistance of the soil varies with the moisture content in it. Thus the amount of the current flow increases with the moisture in the soil. The prototype design included resistor type sensor with the desired moisture level included in the program of the microprocessor. The microprocessor is programmed in such a way that if this value is less than 250 at a time prior to irrigation then the solenoid valve will be turned ON. After the prescheduled irrigation time again moisture condition is tested. If the irrigation is not satisfactory (still sensor value less than 250), a feedback SMS will be sent to the farmer specifying “Incomplete irrigation”.

GSM Modem: The GSM module is incorporated in the unit for accomplishing the function of sending SMS to the user’s mobile phone in case of any malfunctioning of the irrigation process. The GSM module used is SIM 900. It is an ultra-compact and reliable wireless module. The GSM module can communicate with the microcontrollers by using AT commands. SIM900 support software power on and reset. After connecting the GSM module on the Arduino/AVR/PIC/ARM/FPGA board, controlling can be easily carried out using AT commands.

Figure3.6: SIM900 GSM module used in prototype.
Source: http:// store.extremeelectronics.co.in

LCD display: The LCD display unit in the controller displays the time and status of the irrigation. It also allows the user to set a security password to the controller. Numerical password should be entered by the user before making any changes to the irrigation schedule and registered mobile number. LCD used in the prototype is JHD 162A which is a 16x2 LCD display. It is a very basic module which is widely used in various devices and circuits. The LCD modules are preferable over seven segments as well as other multi segment LEDs because they are easily programmable, economical and have abilities for displaying special & custom characters, animations and so on. A 16x2 LCD is capable of displaying 16 characters per line with two such lines, making it capable of displaying a total of 32 characters. Each character is displayed in 5x7 pixel matrix in this LCD. The JHD 162A LCD consists of two registers, namely Command and Data which enables it to communicate with the control unit.

Relays: Relays are used in the prototype model for controlling the pump and the solenoid valves which enables flow of water to the desired area in the field. The relays used here are Le one SPDT 12V general purpose relay. The contact material for this relay is made of Silver alloy. Contact capacity is 7A@300VAC,Coil voltage range is 6Vdc to 48Vdc, coil power consumption is 0.36 watts, and insulation resistance is 100Megaohms.

CHAPTER 4

RESULTS AND DISCUSSION

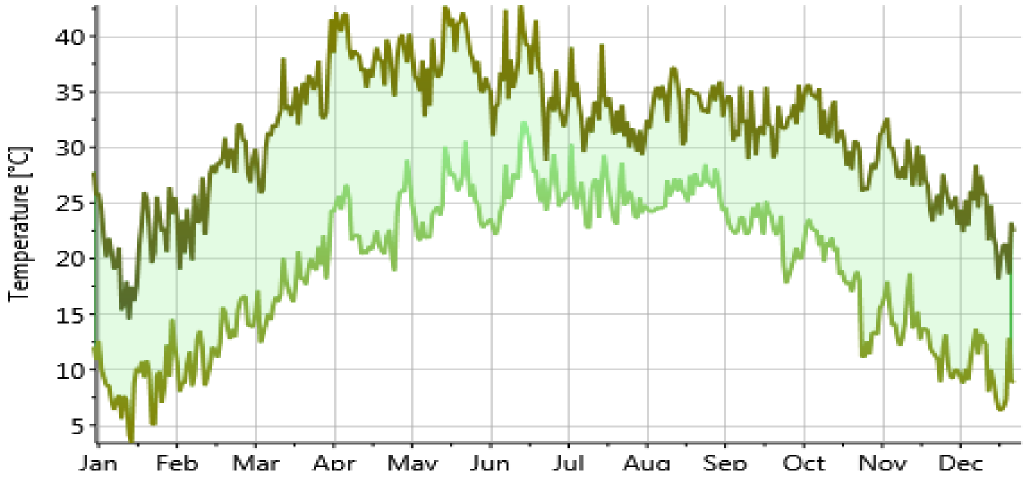
The result section shows the results regarding the assessment of solar energy, sizing of the motor-pump system, sizing of photovoltaic array and solar powered intelligent irrigation prototype design process along with the microcontroller program. In this work sugarcane crop grown in Lucknow district, Uttar Pradesh in an irrigated area of 1 hectare was considered. Sugar cane crop is considered as it is one of the thirstiest crops grown in India.

4.1 Assessment of water demand

Procedure for calculation of water demand as mentioned in Chapter 3. The process requires climatic data of the site, crop details and soil characteristics.

4.1.1Climatic data

The estimation of the water demand is done for the region around Lucknow, which is the capital city of Uttar Pradesh, India. Lucknow is situated in the middle of the Indus-gangetic plain(Latitude: 26.8^{0}N; Longitude:80.9 ^{0}E; Altitude:128 m). Lucknow has a humid subtropical climate characterized with dry and cool winters ranging from November to February and hot, dry summers from April to June with abundant sunny days in a year. The rainy season usually ranges from July to mid-September, with an average rainfall of 896.2 millimetres from the south-west monsoon and occasional downpours in January. The annual global radiation available on horizontal plane is 1825 kW h/m^2 with around 2750 sunshine hours. Climatic data’s for Lucknow were obtained from the global database provided by Meteonorm and NREL’s solar resource assessment based on satellite imagery. The variations in temperatures and global radiation (KWh/m^{2}day) of Lucknow from 1991-2010 is graphically represented in figure 4.1 and 4.2.



Minimum temperature (^oC) Maximum temperature(^oC)

Figure 4.1: Monthly Temperature variation for plot Lucknow.
Source: Elaborated by the author based on climatic data.

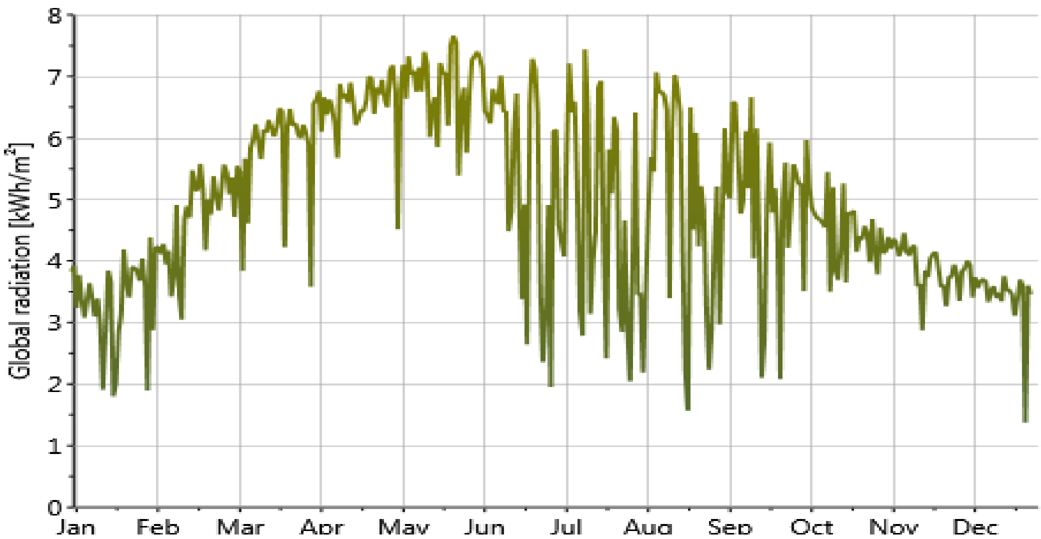


Figure 4.2: Monthly global radiation (KWh/m^2) variation for Lucknow.

Source: Elaborated by the author based on climatic data.

Relevant average monthly climatic data namely precipitation, temperature, wind speed, relative humidity, global radiation on a horizontal plane and sun hours are given in Table 4.1. The monthly climatic data were used for the estimation of the monthly average daily water demand and subsequently for the sizing of the photovoltaic water pumping system.

Table 4.1 Average monthly climate data for Lucknow meteorological observatory (Altitude128 m, 26.80 °N 80.90 °E).

Month	Minimum Temp(^{0}C)	Maximum Temp(^{0}C)	Humidity (%)	Wind (km/day)	Sun Shine hours	I_t (KWh/m^{2}day)
January	7.0	23.0	63	216	6.9	3.5
February	9.0	26.0	55	240	7.2	4.5
March	14.0	32.1	47	240	7.9	6
April	21.0	38.0	34	240	8.7	6.5
May	25.0	41.0	33	288	8.7	6.8
June	27.0	39.0	46	288	6.5	5.8
July	26.0	34.0	70	264	5.5	4.8
August	25.0	33.0	73	240	5.9	4.7
September	24.0	33.0	62	192	7.3	4.6
October	19.0	32.0	52	144	8.9	4.5
November	12.0	29.0	55	144	8.2	4
December	7.0	24.0	62	168	7.2	3.5
Average	**18.0**	**32.0**	**54**	**222**	**7.4**	**59.2**

Here: Min Temp, mean monthly minimum temperature; Max Temp, mean monthly maximum temperature; I_t, average daily total radiation; Wind, wind speed at 2 m height; Humidity, Monthly relative humidity. Various average climate data's obtained are plotted in figure 4.3 and 4.4.

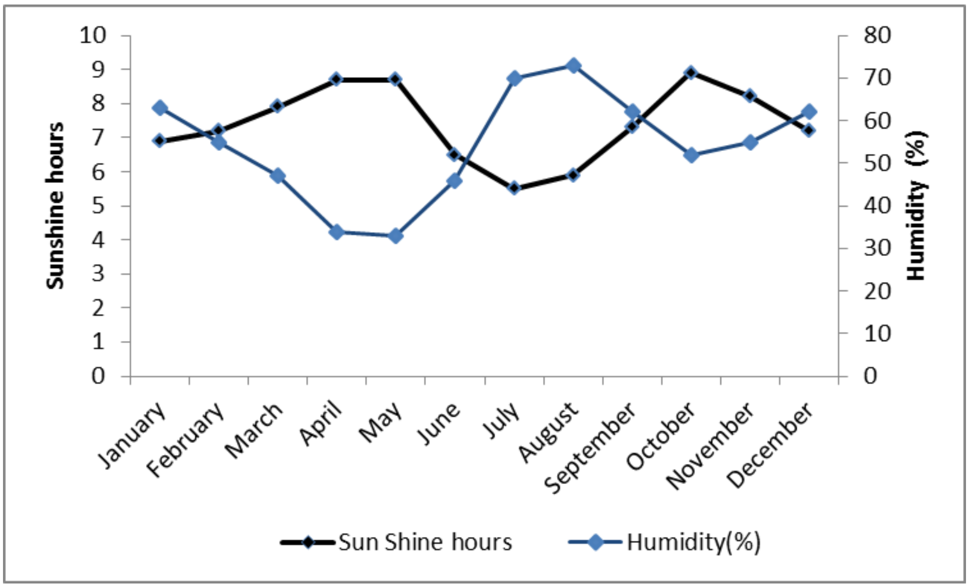


Figure 4.3: Plot of monthly Average sunshine hours and humidity
Source: Elaborated by the author based on climatic data.

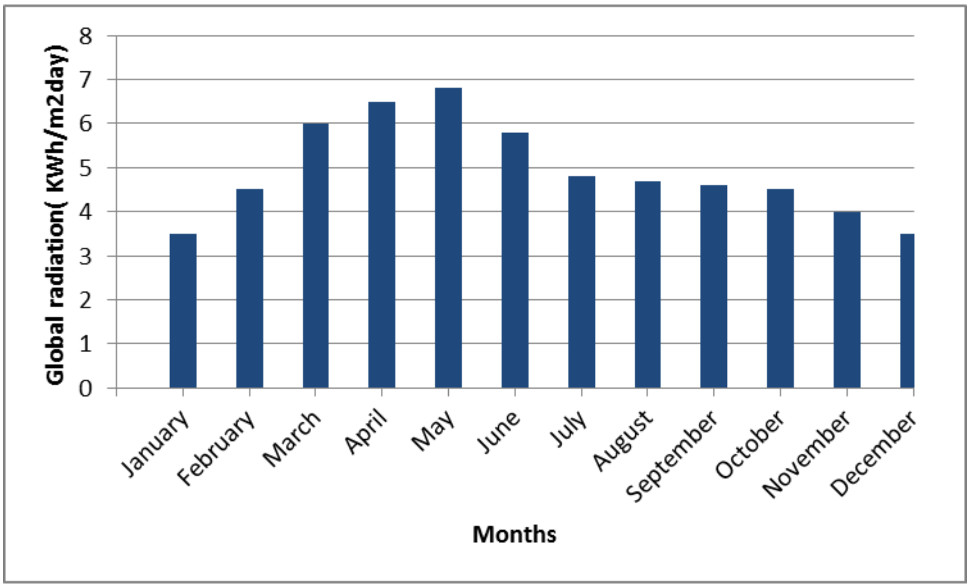
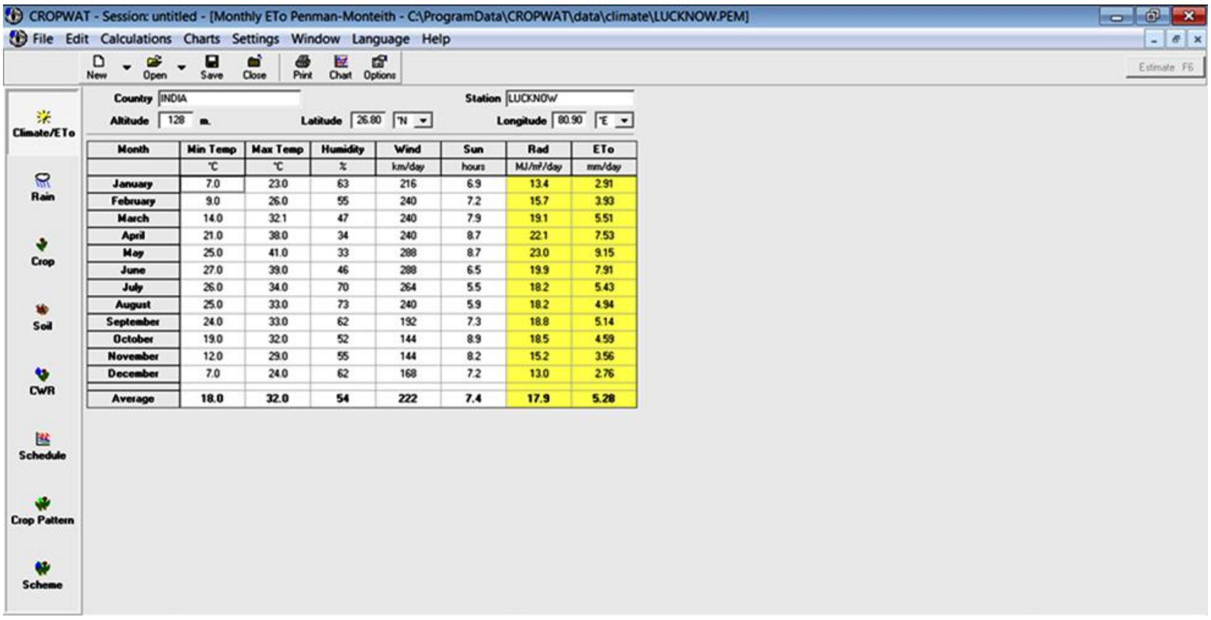


Figure 4.4: Average monthly global radiation(KWh/m^{2}day)
Source: Elaborated by the author based on climatic data.

4.1.2 Calculation of the reference evapotranspiration (ET_0)

Monthly Reference evapotranspiration values can be calculated by using Cropwat software. ETo which is crucial in determining the irrigation requirement at a particular site for a particular crop. It is calculated using Penman Monteith method as described in chapter 3 by the cropwat software as shown in figure 4.5.



Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	7.0	23.0	63	216	6.9	13.4	2.91
February	9.0	26.0	55	240	7.2	15.7	3.93
March	14.0	32.1	47	240	7.9	19.1	5.51
April	21.0	38.0	34	240	8.7	22.1	7.53
May	25.0	41.0	33	288	8.7	23.0	9.15
June	27.0	39.0	46	288	6.5	19.9	7.91
July	26.0	34.0	70	264	5.5	18.2	5.43
August	25.0	33.0	73	240	5.9	18.2	4.94
September	24.0	33.0	62	192	7.3	18.8	5.14
October	19.0	32.0	52	144	8.9	18.5	4.59
November	12.0	29.0	55	144	8.2	15.2	3.56
December	7.0	24.0	62	168	7.2	13.0	2.76
Average	18.0	32.0	54	222	7.4	17.9	5.28

Figure 4.5: Climate data input and reference evapotranspiration output from Cropwat8.0.

These simulated results are tabulated in table 4.2 which shows Monthly average ET_0 in mm/day.

Table 4.2: Monthly reference evapotranspiration values.

Month	ETo (mm/day)
January	2.91
February	3.93
March	5.51
April	7.53
May	9.15
June	7.91
July	5.43
August	4.94
September	5.14
October	4.59
November	3.56
December	2.76
Average	**5.28**

Source: Result obtained from cropwat, software tabulated by the author.

4.1.3 Monthly rain data and calculation of Monthly mean effective rainfall

Mean effective rainfall can be defined as the actual amount of rainfall which becomes available to the crops. Practically it is estimated by sampling the root zone soil and measuring its increasing moisture content after a rainfall happens. This increased moisture content added with evapotranspiration in plants gives the effective rainfall values. Various formulae are available for the same, here soil conservation formula, USDA is used for the purpose. The equations for calculating monthly mean effective rainfall are expressed below

$$P_{eff} = P_{mon} * (125 - 0.2 * P_{mon}) / 125 \quad , \quad \text{for } P_{mon} <= 250 \text{ mm.} \qquad (4.1)$$

$$P_{eff} = 125 + 0.1 * P_{mon} \quad , \quad \text{for } P_{mon} > 250 \text{ mm.} \qquad (4.2)$$

Where P_{eff} is the monthly mean effective rainfall (mm) and P_{mon} is the monthly mean rainfall in mm. Using the above equations the monthly mean effective rainfall in Lucknow district is calculated and is provided in table 4.3.

The rainfall data are monthly averages for the 49-year period 1952-2000 recorded by Indian meteorological department. The annual effective rainfall is turned out to be 669 millimetre.

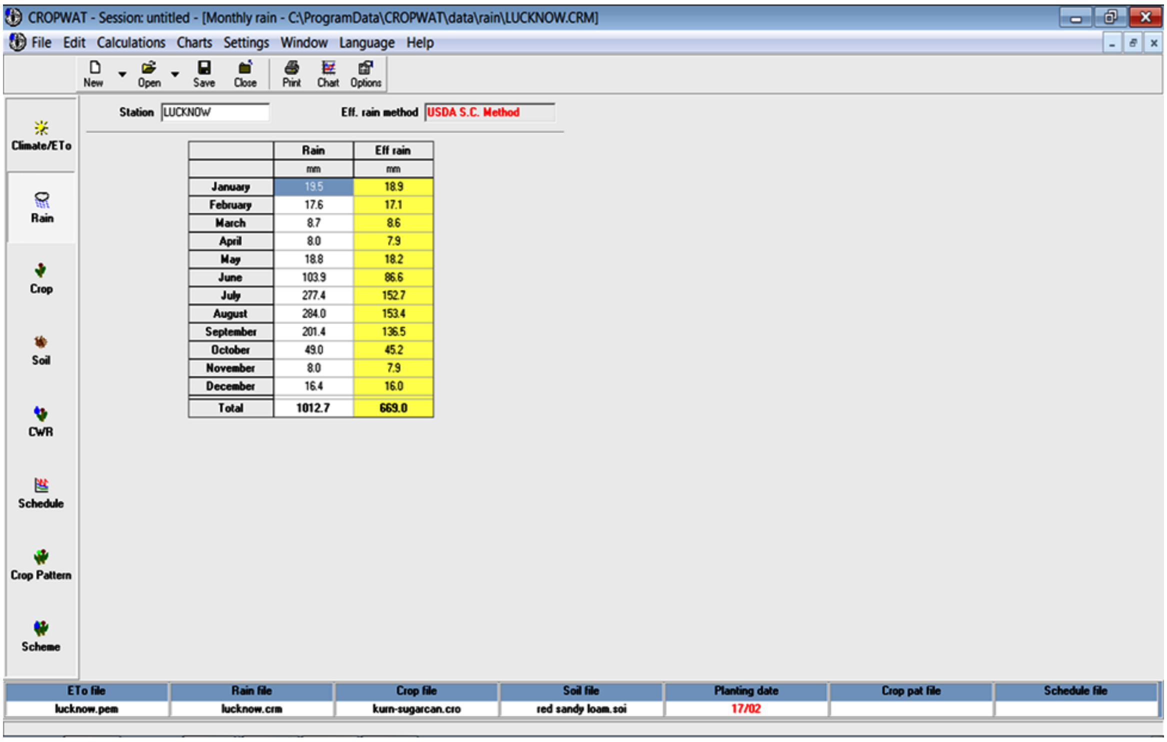


Figure 4.6: Monthly effective rain calculation by using Cropwat 8.0 software.

Table 4.3 Monthly mean rainfall data and Monthly mean effective rainfall

	Rain(mm)	Effective rain(mm)
January	19.5	18.9
February	17.6	17.1
March	8.7	8.6
April	8.0	7.9
May	18.8	18.2
June	103.9	86.6
July	277.4	152.7
August	284.0	153.4
September	201.4	136.5
October	49.0	45.2
November	8.0	7.9
December	16.4	16.0
Total	**1012.7**	**669.0**

Here: Rain, mean monthly rainfall in mm; Effective rain, mean monthly effective rainfall in mm.

Source: Rain data obtained from Indian meteriological department [2] and effective rainfall result obtained from the Cropwat software.

Mean monthly rainfall as well as mean monthly effective rainfall in mm is plotted in figure 4.7.

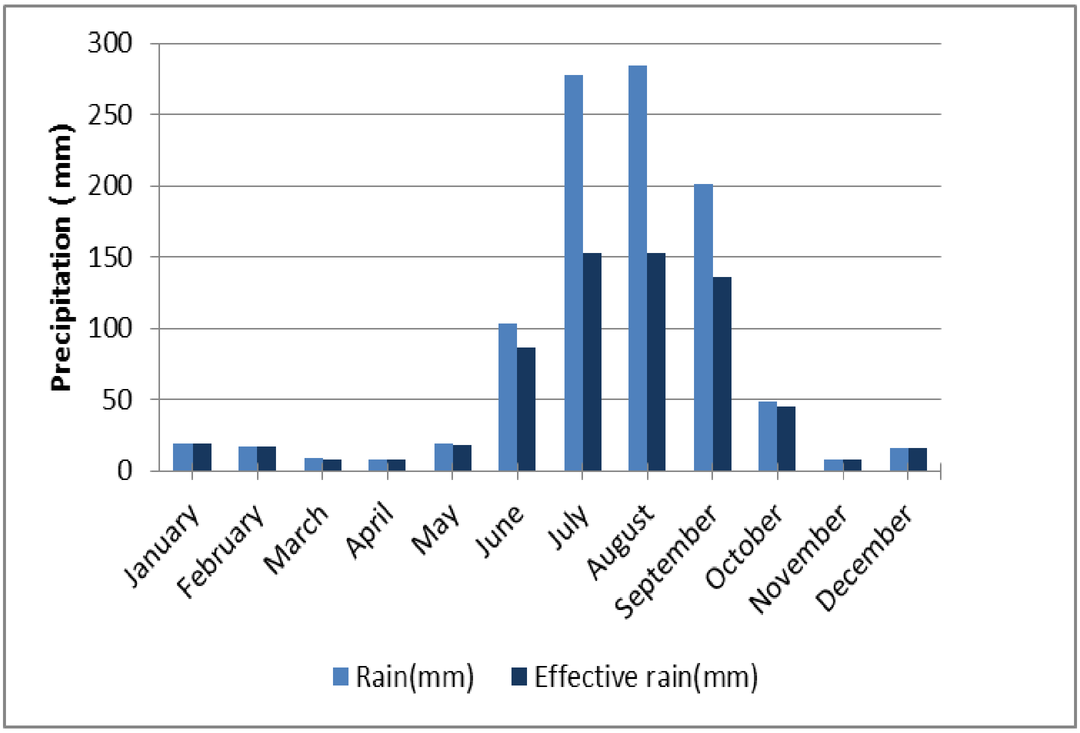


Figure 4.7: Mean monthly rainfall and mean monthly effective rainfall (mm).

Source: Elaborated by the author based on result obtained in table 4.3.

4.1.4. Crop data

For Uttar Pradesh state the most appropriate time to plant sugarcane is February-March. Optimum row spacing ranges between 60-100 cm for different situation and location. In Uttar Pradesh optimum row spacing is 90 cm for timely planting. We select the Planting date as 17th February and harvesting in January 27th (approximate).

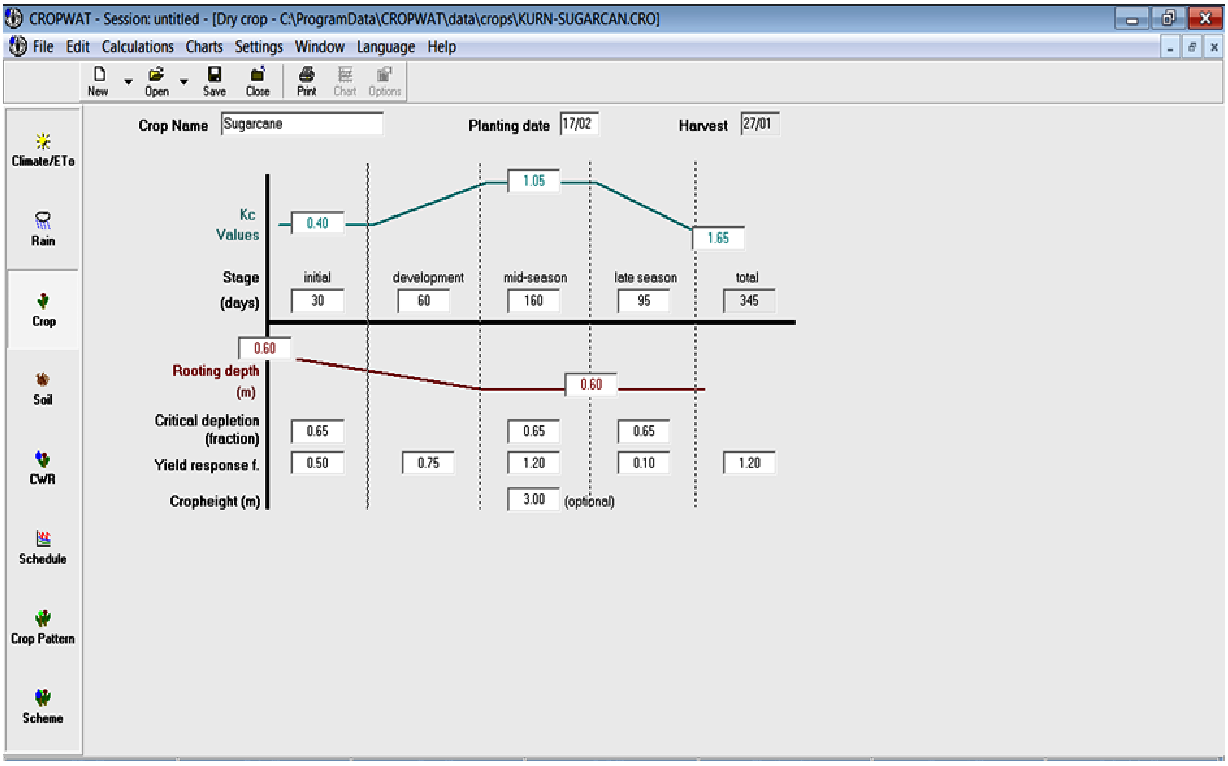


Figure 4.8: Various stages of the sugarcane crop as shown in Cropwat8.0.

Table 4.4 : Various stages of sugar cane crop.

	Initial	Develop	Mid	late	total
Stage Length (days)	30	60	160	95	345
Crop coefficient (Kc)Values	0.40	----	1.05	1.65	
Rooting depth (metre)	0.60	----	0.60	0.60	
Critical depletion factor	0.65	----	0.65	0.65	
Yield response ,f	0.50	0.75	1.20	0.10	1.20
Crop height (m)			3.0		

Here: Kc, Crop coefficient values; f, field response; stage length, length of each stage in days.

Crop coefficients are taken as prescribed by FAO.

Source: Elaborated by the author based on result obtained from the Cropwat software.

4.1.5. Soil data

Table 4.5: Soil distribution in Lucknow district.

S. No	Soil type	Area in hecatre
1	Silty clay loam	18357
2	Loamy soil	17304
3	Sandy loam	22970
4	Silt loam	99301
5	Loam	28352
6	Clayloam	8725
7	Silty clay	4526
Total		**199715**

Source: District profile, Uttar Pradesh Government.

Silt loam soil is found in almost 50% area of the Lucknow district. Loam soils are characterized with high contents of nutrients, more moisture as well as more humus than sandy soil. The drainage and infiltration of air and water are better compared to silty soils and tilling is easier compared to clay type soils. Silty loam soil, since it covers around 50% of the total area is taken for further analysis of required irrigation.

4.1.6 Irrigation requirement assessment

Various factors which determine the irrigation requirement like climatic condition, crop properties and soil characteristics were obtained. The next step in simulation is assessment of the irrigation water requirement based on these factors which are given as the input to the simulation tool. The simulated result shows decade wise irrigation requirement for each month in mm/decade for different stages of sugar cane crop starting from the planting date which was chosen was 17th February. Decade wise Irrigation requirement estimation output from Cropwat 8.0 is tabulated in table 4.6.

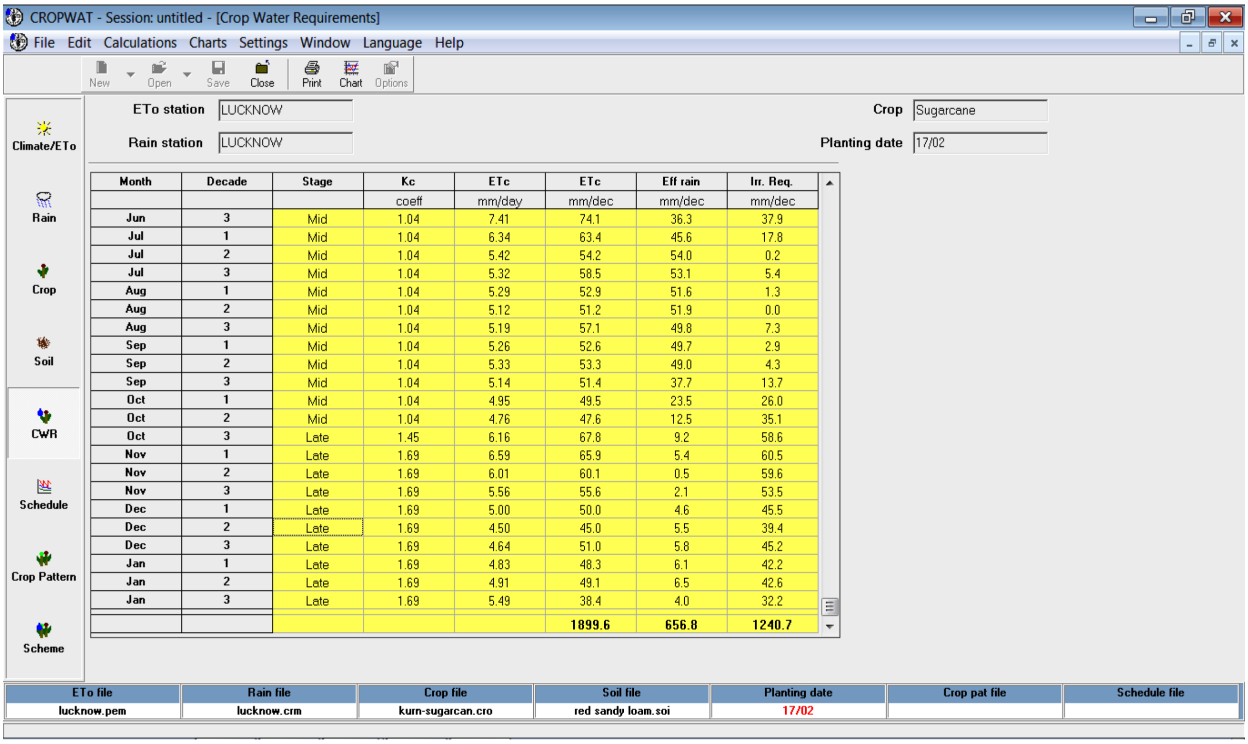


Figure 4.9: Crop water requirement output from cropwat 8.0.

Table 4.6: Decade wise Irrigation requirement estimation (in mm per decade).

Month	Decade	Stage	Kc (coeff)	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req (mm/dec)
Feb	2	Init	0.40	1.57	6.3	2.4	3.3
Feb	3	Init	0.40	1.78	14.3	5.0	9.3
Mar	1	Init	0.40	1.99	19.9	3.6	16.4
Mar	2	Deve	0.40	2.22	22.2	2.5	19.7
Mar	3	Deve	0.48	3.00	33.0	2.6	30.4
Apr	1	Deve	0.60	4.09	40.9	2.4	38.5
Apr	2	Deve	0.70	5.29	52.9	2.1	50.8
Apr	3	Deve	0.81	6.52	65.2	3.4	61.8
May	1	Deve	0.91	8.06	80.6	3.1	77.5
May	2	Mid	1.01	9.58	95.8	3.3	92.5
May	3	Mid	1.04	9.26	101.9	11.8	90.0
Jun	1	Mid	1.04	8.70	87.0	21.3	65.7
Jun	2	Mid	1.04	8.30	83.0	28.9	54.1
Jun	3	Mid	1.04	7.41	74.1	36.3	37.9
Jul	1	Mid	1.04	6.34	63.4	45.6	17.8
Jul	2	Mid	1.04	5.42	54.2	54.0	0.2
Jul	3	Mid	1.04	5.32	58.5	53.1	5.4
Aug	1	Mid	1.04	5.29	52.9	51.6	1.3
Aug	2	Mid	1.04	5.12	51.2	51.9	0.0
Aug	3	Mid	1.04	5.19	57.1	49.8	7.3
Sep	1	Mid	1.04	5.26	52.6	49.7	2.9
Sep	2	Mid	1.04	5.33	53.3	49.0	4.3
Sep	3	Mid	1.04	5.14	51.4	37.7	13.7

Oct	1	Mid	1.04	4.95	49.5	23.5	26.0
Oct	2	Mid	1.04	4.76	47.6	12.5	35.1
Oct	3	Late	1.45	6.16	67.8	9.2	58.6
Nov	1	Late	1.69	6.59	65.9	5.4	60.5
Nov	2	Late	1.69	6.01	60.1	0.5	59.6
Nov	3	Late	1.69	5.56	55.6	2.1	53.5
Dec	1	Late	1.69	5.00	50.0	4.6	45.4
Dec	2	Late	1.69	4.49	44.9	5.5	39.4
Dec	3	Late	1.69	4.63	51.0	5.8	45.2
Jan	1	Late	1.69	4.83	48.3	6.1	42.2
Jan	2	Late	1.69	4.91	49.1	6.5	42.6
Jan	3	Late	1.69	5.49	38.4	4.0	32.2
Total					**1899.8**	**656.8**	**1240.9**

Here: ET_c, crop evapotranspiration; K_C ,crop coefficient; Irr.Req , irrigation requirement in mm per decade.

Decade wise effective rainfall and irrigation requirement (in mm/decade) starting from second week of February is represented graphically in figure 4.10.

Source: Elaborated by the author based on result obtained from the Cropwat software.

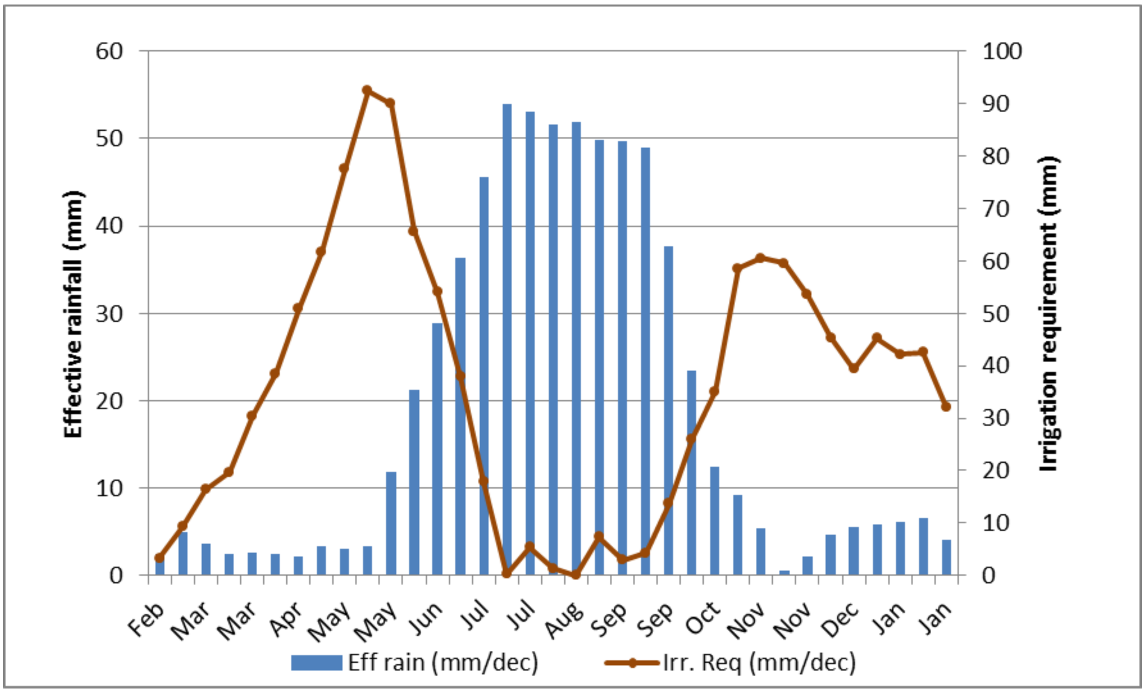


Figure 4.10: Effective rainfall and irrigation water requirement for sugarcane crop.

Source: Elaborated by the author based on result obtained in table 4.6.

4.2 Sizing of the Photovoltaic water pumping system

The optimum sizing of the water pump, photovoltaic array along with balance of the system is carried out on the basis of the water demand by the crop, total dynamic head at the site, solar energy available the site and efficiencies of the components present in the whole system. Monthly water demand by the crop and the solar energy availability at the site (Lucknow) are calculated and tabulated above. Now the system should be sized on basis of the worst month which can be obtained by the lowest ratio between monthly daily average solar radiation and monthly daily average water demand, thus ensuring the system will be rated adequately to pump enough water for any month of the year.

Table 4.7: Solar energy (Monthly daily average) and water demand(Monthly daily average) ratio

Month	**I_t (KWh/m^{2}day)**	**W_g(m^3/ha day)**	**Ratio(%)**
January	3.5	42.6	8.2
February	4.5	9.3	48.38
March	6	30.4	19.73
April	6.5	61.8	10.51
May	6.8	92.5	7.3
June	5.8	65.7	8.8
July	4.8	17.8	26.96
August	4.7	7.3	64.3
September	4.6	13.7	33.5
October	4.5	58.6	7.7
November	4	60.5	6.61
December	3.5	45.2	7.74

The lowest ratio between daily solar radiation and water demand was obtained for the month of November. Thus November was chosen for designing the size of the system. For proper irrigation of 1 hectare of sugarcane crop in selected site, for the month of November everyday requirement of water is $60.5m^3$. So the water demand and solar energy availability can be used to calculate the daily hydraulic energy according to equation [3.3]. The total dynamic head [TDH] is site specific; it varies with source of water. TDH is thus arbitrarily taken as 25 metres (shallow bore well depth). Thus the value of E_h(daily hydraulic energy required) is obtained as 4.1KWh/day. The value of average daily solar radiation for November is $6.61KWh/m^2$, given in table 4.7. The efficiency of the power conditioning unit usually varies from 80-95% depending on the input power and ambient temperature whereas the motor pump efficiency from 40-60% depending on input power, pressure and flow. Thus the value of overall efficiency η_s to be used in equation [3.2] is taken as 35%, an average of usual 30-40% range of η_s. The peak PV capacity required is obtained as $1.77KW_p$ according to equation[3.1]. The instantaneous water flow Q can be calculated from the daily water requirement after considering a pump operating hour value as 8.2 corresponding to the month of November and an average motor-pump efficiency of 50%. Then required pump power according to equation [3.6] can be obtained as 1KW or 1.5 hp. Estimated values of the system components are summarised in table 4.8.

Table 4.8: Estimated ratings of various components of Photovoltaic pumping system

Parameter	Value
1. Water demand(November)	$60.5m^3$/ha day
2. Daily operating hours(November)	8.2
3. Average daily solar radiation (November)	6.61 KWh/m^2
4. Total dynamic head (TDH)	25m
5. Overall system efficiency	35%
6. Pump power required	1KW or 1.34hp
7. Available Pump in the market	1.5hp
8. PV rating KW_{peak}	1.77KW_p
9. Available photovoltaic panel in market	1.8KW_p

Both DC and AC pumps are available in the market. AC solar pumps are widely used but DC pump market is also gearing up in the country. DC pumps with working voltages of 120V to 180 V are also practically used for irrigation purposes. The requirement can be fulfilled by an AC pump or a DC pump of 1 KW rating.

Solar panels of different manufacturers are available in the required rating of 1.8 KW_p. Voltage and wattage ratings of each photovoltaic module varies with a common voltages standards of 24V,48V,72V etc. A photovoltaic module of rating P_{max} = 225 watts, V_{mpp}= 24 V, I_{mpp}= 9.3 A can be selected for the purpose. Two such modules are connected in series to obtain a voltage output of 48V. A total of 8 modules are used so as to obtain 1.8 KW_p capacity. Solar power conditioning unit (SPCU) needed will be a boost converter which improves the voltage from 48V PV output to 120 V required by the motor in case of DC pump but in case of an AC pump an inverter along with motor drive can be employed. The converter or inverter used will be incorporated with a Maximum Power point tracking facility to ensure that always maximum power is drawn from PV arrays.

4.2.1 Overall system cost and Economic analysis.

Commonly used solar panels are monocrystalline and multicrystalline silicon type. A monocrystaline is more efficient in converting solar energy into electricity per square meter area than a multicrystaline PV. Thus the space required for the same amount of wattage is less in monocrystaline PV panel. Thus it is costlier than a Multicrystaline PV. The choice between the two depends on the area that you have for PV installation. Also the price increases as you decrease the panel wattage. So smaller the panel you buy, costlier it is.

For polycrystalline modules with 220-300W_p range, the retail price is around Rs 55-60 per KW_p.

Cost of P V array = Rs 60 * 1800W_p = Rs108000.

Cost of solar pump, controller and Balance of system= Rs 40000 to 60000.

Total Cost = Rs 140000-160000.

Government (MNRE) subsidy = 30% of Rs 160000 = Rs 48000.

Amount to be paid by the customer = Rs 112000.

Conventional pump price = Rs 13000.

Incremental contribution required = Rs112000-13000 = Rs 99000
(Solar pump less conventional pump)

Annual diesel expenditure saving = Rs 16000

Thus the incremental contribution of the customer to upgrade to solar pump from a diesel pump can be recovered within a period of 6 – 7 years in current scenario. The solar pumping system cost can come down by around 30% over the next 4-5 years. This, coupled with rise in diesel and crop prices, would translate into a break-even period for solarisation of diesel pumps to around 4 years. The benefits are not limited purely to economics of replacing diesel with solar. There are additional benefits at the national level. Replacement of 1 million diesel pumps with solar pumps would result in diesel use mitigation of 9.4 billion litres over the life cycle of solar pumps which translates into diesel subsidy saving of Rs 8,400 Crore and CO2 emission abatement of 25.3 Mn Tonnes. Replacement of, say, 1 million electric pumps with solar pumps would result in reduction of around 2,600 Mn units of electricity and could translate into CO2 emission of around 2.5 Mn Tonnes [30].

4.3 Prototype design and implementation

Optimum sizing of the solar pumping system is the first step as a solution for efficient water and energy management. Modern irrigation methods like drip irrigation and automated irrigation controlling further improves the water usage efficiency. The prototype designed aims at completely automating the irrigation procedures and providing status feedback facility through SMS. The operation of the developed system is described using the process flow diagrams figure 4.11 and 4.12.

4.3.1 Process flow diagrams

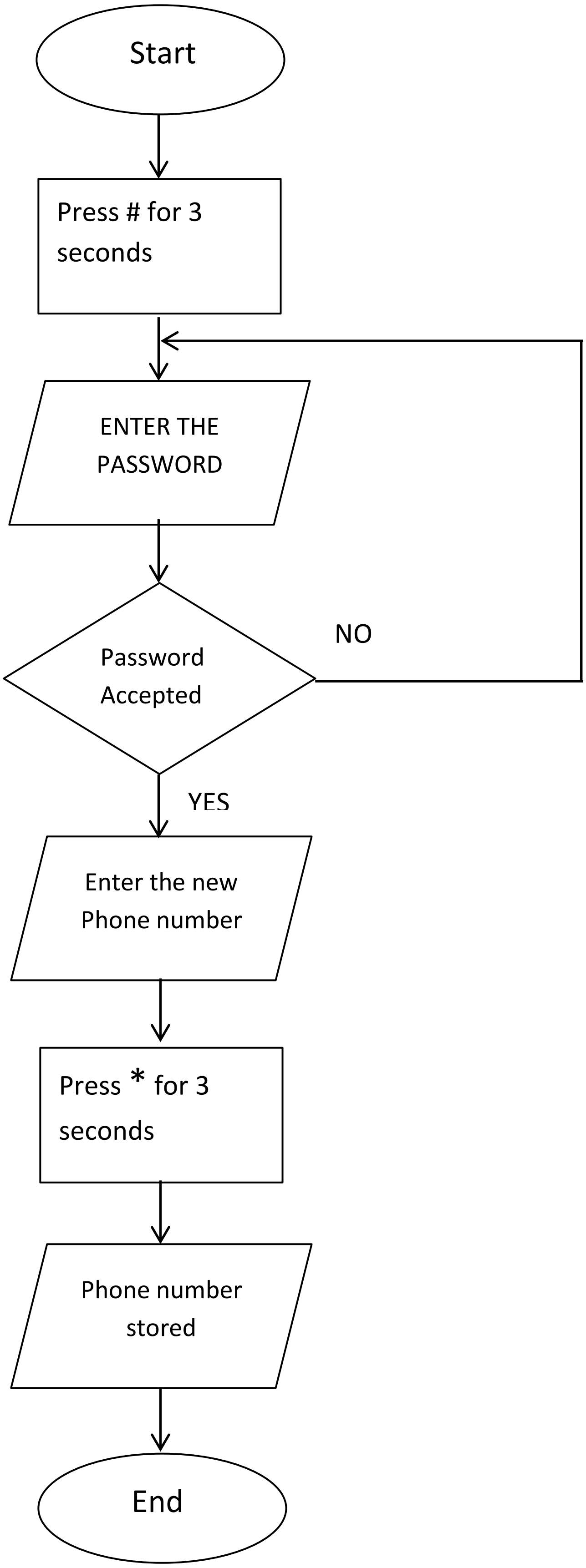


Figure 4.11: Flow chart showing procedure for setting the desired mobile number.

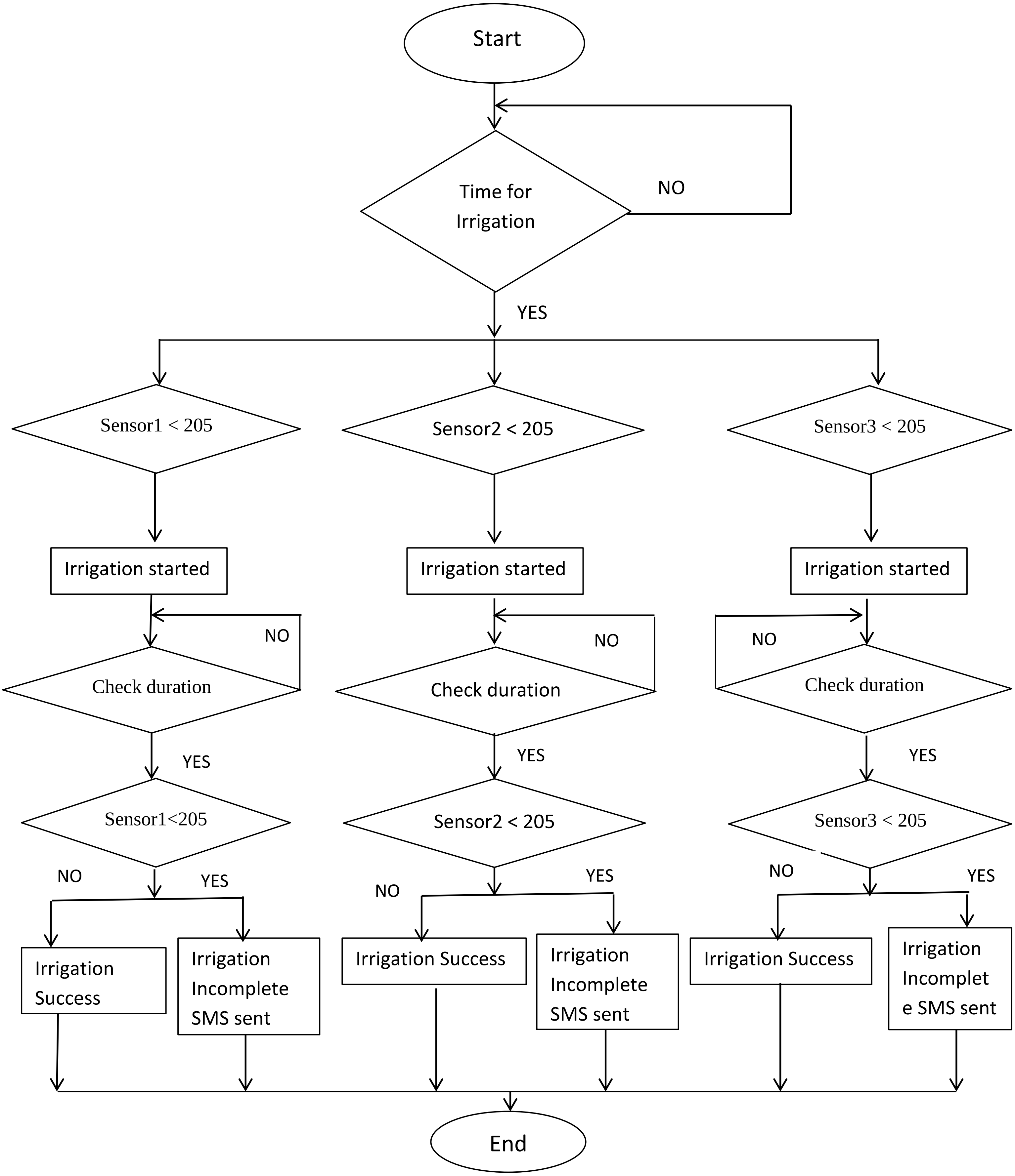


Figure 4.12: Flow chart showing irrigation process and SMS feedback

4.3.2 Hardware Implementation

The hardware control module for the solar powered intelligent irrigation system prototype was implemented according to requirements. The designed circuit diagram of the system as well as the final hardware product is shown in figure 4.13 and 4.14 respectively.

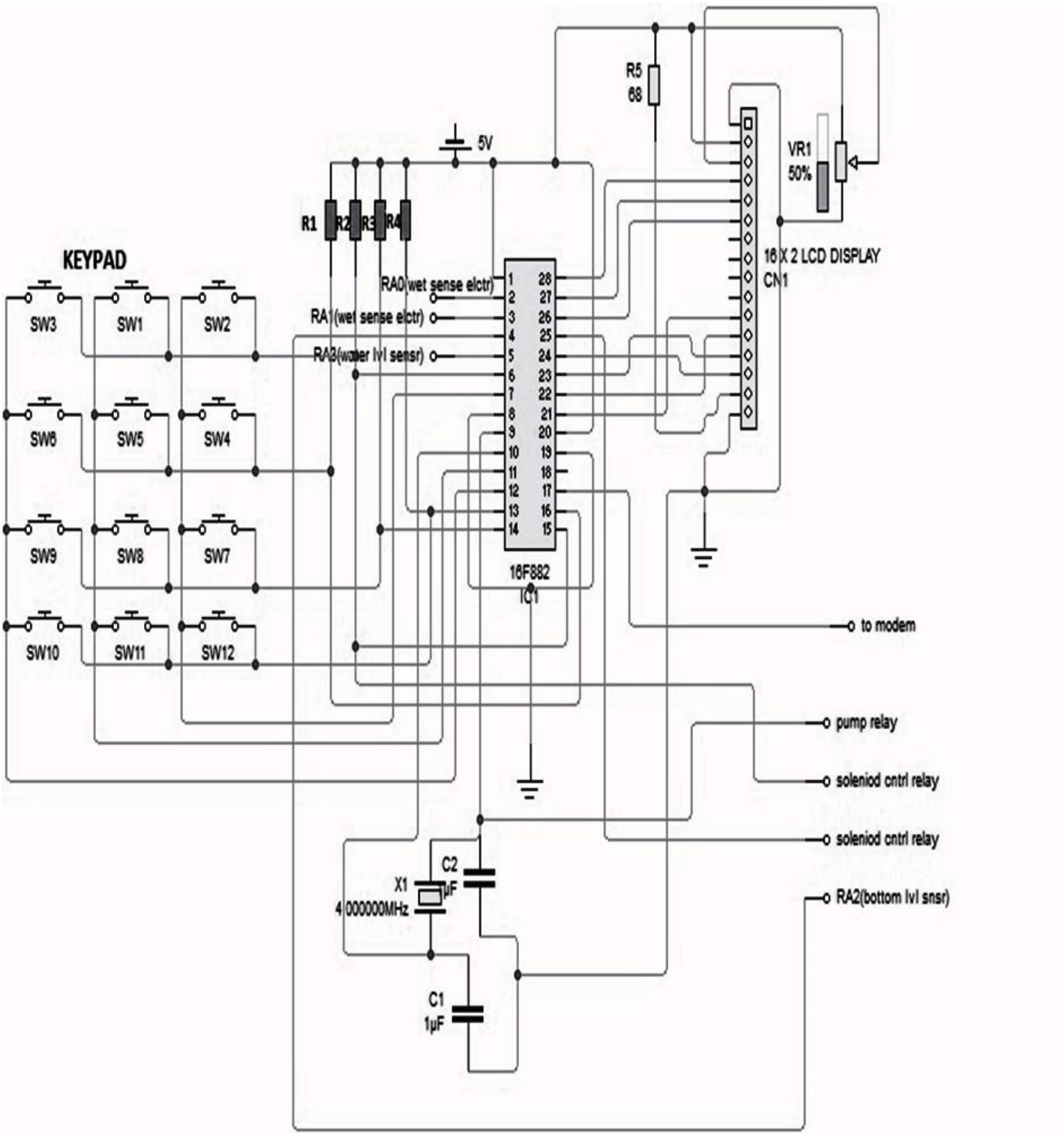


Figure 4.13: Circuit diagram of the intelligent irrigation control module.

Source: Drawn using the software Protel design systems based on the requirements.

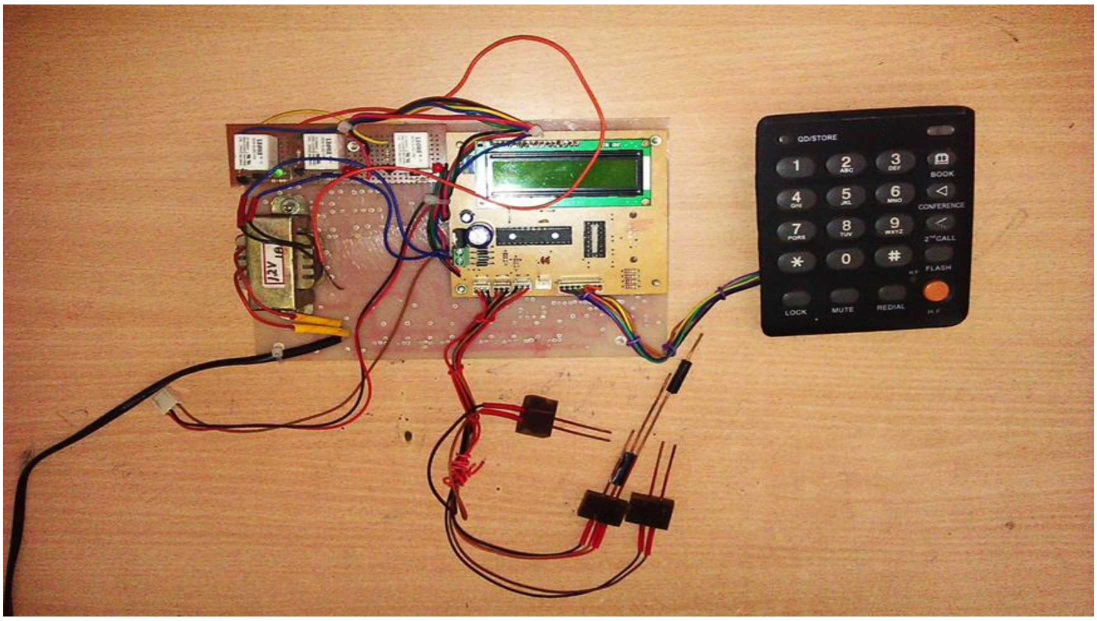


Figure 4.14: Hardware prototype implementation.

Source: Prototype of intelligent irrigation system implemented by the author.

The control module is powered with a 40 W_P solar panel which is also used to power a DC prototype pump. The hardware prototype works satisfactorily, switching the solenoid valve relays in previously set timings, sends SMS in case of any mal functioning and always maintaining desired water level in the tank.

4.3.3 Software design

A microcontroller based circuit performs the desired operations based on the coded programme which has to be burned into the microcontroller unit. All the auxiliary components connected to the microcontroller should be interfaced with the microcontroller using written code. PIC 16f882 used in the prototype circuits employs PIC-C code. A password can be set by the user to access the control unit. The desired mobile number to which the SMS has to be reached can be entered only after successful password verification. Any alteration in the irrigation timings can only be performed after password verification.

The program code for the solar powered intelligent irrigation system is given in the appendix [1] in the appendix section.

CHAPTER 5

CONCLUSIONS

A solar photovoltaic water pumping system has been sized in the present work according to the water requirement of the sugarcane crop in Lucknow district. The optimum sizing of the solar pumping facility is followed by developing a solar powered intelligent irrigation automation system which reduces the human intervention as well as improves the efficiency. The irrigation requirement for the sugarcane crop was decided based on the worst month, November. For proper irrigation of 1 hectare of sugarcane crop in selected site, for the month of November everyday requirement of water is obtained as $60.5m^3$ or 60500 litres. The required pump power as well as photovoltaic array ratings are calculated based on this worst month water demand. The peak PV capacity required to run a motor-pump unit of 1KW obtained as $1.77KW_p$. As the source of water depends on the site, an arbitrary shallow well depth of 25 metres was taken for the sizing of water pump. The overall price to be paid the customer is approximately estimated as Rs160000. The payback period for a customer switching from diesel to solar pump was obtained as 6 years approximately. A prototype solar powered intelligent irrigation system has been designed using microcontroller PIC16f882. The prototype system which includes a prototype DC submersible pump is powered by a 40 W solar panel. The developed prototype satisfactorily performs the desired operations under the test conditions and is expected to perform the same way under practical conditions too. It concludes that an optimum sizing of the photovoltaic pumping system for the selected crop and site is obtained and a solar powered intelligent irrigation prototype system has been developed.

CHAPTER 6

FUTURE SCOPE

It is believed that utilising solar pumping systems with an optimum sizing along with automated modern irrigation methods like micro irrigation method will be solution for the energy as well as the water crisis. During the present work it has been observed that there are areas that require further investigations. Some of these are given below:

1) Studies can be carried out for developing proper tool for easily assessing the required water demand for a particular crop for a particular site.

2) Poor management of water resources and changing climatic conditions results in reducing ground water table in many parts of the country. Studies can be done in proper management of ground water and surface water resources.

3) Automated irrigation systems will be a need of the future as India is going to face severe water crisis in near future.

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APPENDIX I

(1) Program (PIC C platform)

```
#include <pic.h>

#include "Delay.h"

#include "lcd.h"


 __CONFIG(WDTDIS & PWRTEN & XT & BOREN &LVPDIS & UNPROTECT);

        unsigned char ph_no_index = 0;

        unsigned char password_index = 0;

        unsigned int snsr1_value, snsr2_value,upper_snsr_value;

        unsigned char  key, sensor_no, scan_cnt;

        unsigned char J;        //J is a time slot counter

unsigned char seconds, minute, hour, sol1_count, sol2_count, sol1_on_time = 10,
sol2_on_time = 10 ;

unsigned char entr_Pword_cnt, esc_cnt, i, j, pump_count, pump_chk_time;

bit sms1_flag, sms2_flag, sms3_flag, new_key1, new_key2, new_key3, key_change,
p_word_err, enter_Pword;

bit first_time, enter_PH_no, display_flag, am, pm, irrigation_flag;

void send_string(const char *s);

void send_char(unsigned char s);

void func_display(void);

void enter_password(void);

void enter_phone_no(void);

void save_and_escape(void);

void send_sms1(void);

void send_sms2(void);

void send_sms3(void);

void read_snsr1(void);
```

```
void read_snsr2(void);

void func_irrigation(void);

void upper_snsr_read(void);

void func_pump(void);

unsigned char PH_NO[10] ="9846053455";

unsigned char PASSWORD[7]={0,9,4,6,8,0,5};

unsigned char ENTD_PASSWORD[7];


//******NAMING PORTS*******//

static bit      pump_rly          @ ((unsigned)&PORTB*8+4);

static bit      sol1_rly          @ ((unsigned)&PORTA*8+4);

static bit      sol2_rly          @ ((unsigned)&PORTC*8+7);

static bit      bottom_level   @ ((unsigned)&PORTA*8+2);


void main()

{

//PORT INITIALIZATION*******

        TRISA=0b00001011; //0x0F

        TRISB=0x00;

        TRISC=0b11111100;

        RA5=RC0=RC1 = 1;

        PORTB=0;

//****ADC CONFIGURING****

        ADCON1=0b10000100;      //adresult right justified,RA0,RA1 and RA3 are analog


//****configuring tmr1****

        TMR1H = 0x3C;
```

```
        TMR1L = 0xB0;

        T1CON = 0b00100001;         //prescaler 1:4


//configuring timer2********


        T2CON=0b01010101;                 //prescaler 1:4,post scaler 1:10,timer2 module on

        PR2 = 249;                        //to generate 1Ms * 10 = 10 Ms interrupt for
scaning keypad

//enabling interrupts*******

        TMR1IE=1;GIE=1;

        TMR2IE=1;

        PEIE=1;

        //ENABLING UART TRANSMIT MODULE

        BRGH=1;SPBRG=25;SYNC=0;SPEN=1;TXEN=1;//TXIE=1;

        lcd_init();


        am = 1;


//LOADING SAVED PH.NO.

        for(j = 0;j < 10;j++)

        {

                PH_NO[ph_no_index]=eeprom_read(j);

                ph_no_index++;

        }

        ph_no_index=0;


        DelayMs(100);
```

```
    while(1)
    {
//ENTERING PASSWORD*********************
        if(entr_Pword_cnt > 50)
        {
            key = 0;
            enter_Pword=1;
            first_time=0;          //A BIT TO ENABLE DISPLAY CLEAR
FUNCTION
        }

        if(enter_Pword)
            enter_password();
//ENTERING PHONE NO**************************
        if(enter_PH_no)
            enter_phone_no();

//ESCAPING FROM SET MODE**********


        if(esc_cnt > 15)
            save_and_escape();
//********************************
        if(display_flag)
        {
            func_display();
            func_pump();
```

```
                    display_flag=0;
            }
//IRRIGATION FUNCTION*************
            if(irrigation_flag)
                    func_irrigation();


//SENDING SMS********************


            if(sms1_flag)
                    send_sms1();


//SENDING SECOND SMS **********


            if(sms2_flag)
                    send_sms2();


//*******************************
    }
}
static void interrupt
isr (void)
{
//**********************************************
    if(TMR1IF)
    {
            TMR1H = 0x3C;
            TMR1L = 0xB0;
```

```
TMR1IF=0;
if(++J == 5)
{
    J = 0;
    display_flag = 1;
    if(++seconds == 3)
    {
        seconds = 0;
        minute++;
        if(irrigation_flag)
        {
            sol1_count++;
            sol2_count++;
        }
        if(pump_rly)
            pump_count++;
        if(minute == 60)
        {
            irrigation_flag = 1;
            minute = 0;
            if(++hour == 12)
            {
                hour = 0;
                am = !am;
                pm = !pm;
            }
        }
```

```
                    }
                }
            }

//****************************************************
            if(TMR2IF)
            {
                TMR2IF=0;
                scan_cnt++;

                switch(scan_cnt)
                {
                    case 1:
                    {
                        RA5 = 0;
                        if(RC2 & RC3 & RC4 & RC5)
                        {
                            new_key1 = 0;
                            entr_Pword_cnt = 0;
                        }
                        else if(new_key1 == 0)
                        {

                            new_key1 = 1;
                            key_change = 1;
                            if(RC2 == 0)
                                key=3;
```

```
                else if(RC3 == 0)
                        key = 6;
                else if(RC4 == 0)
                        key = 10;


                else if(RC5 == 0)
                        key = 9;
        }
        else if(key == 10)
        {
                entr_Pword_cnt++;
        }
}
break;
case 2:
{
        RA5 = 1;
}
break;
case 3:
{
        RC0 = 0;
        if(RC2 & RC3 & RC4 & RC5)
                new_key2 = 0;
        else if(new_key2 == 0)
        {
                new_key2 = 1;
```

```
				key_change = 1;
				if(RC2 == 0)
					key = 2;
				else if(RC3 == 0)
					key = 5;
				else if(RC4 == 0)
					key = 0;
				else if(RC5 == 0)
					key = 8;
			}
		}
		break;
		case 4:
		{
			RC0=1;
		}
		break;
		case 5:
		{
			RC1=0;
			if(RC2 & RC3 & RC4 & RC5)
			{
				new_key3=0;
				esc_cnt=0;
			}
			else if(new_key3==0)
			{
```

```
                        new_key3=1;
                        key_change=1;
                        if(RC2==0)
                            key=1;
                        else if(RC3==0)
                            key=4;
                        else if(RC4==0)
                            key=11;
                        else if(RC5==0)
                            key=7;
                    }
                    else if(key==11)
                        esc_cnt++;
                }
                break;
                case 6:
                {
                    RC1=1;
                    scan_cnt=0;
                }
                break;
            }
        }
}

//**********************************************************

    void func_display(void)
```

```
{
        unsigned char DIG0, DIG1;
        if(p_word_err)
        {
                if(first_time==0)
                {
                        lcd_clear();
                        first_time=1;
                }
                lcd_goto(0);
                lcd_puts("Wrong Password");
                DelayMs(200);
                password_index = 1;
                p_word_err=0;
        }
        else if(enter_Pword)
        {
                if(first_time==0)
                {
                        lcd_clear();
                        first_time=1;
                }
                lcd_goto(0);
                lcd_puts("Enter Password");

                switch (password_index)
                {
```

```
                case 2:
                lcd_goto(68);
                break;

                case 3:
                lcd_goto(69);
                break;

                case 4:
                lcd_goto(70);
                break;

                case 5:
                lcd_goto(71);
                break;

                case 6:
                lcd_goto(72);
                break;

                case 7:
                lcd_goto(73);
                break;
            }
            lcd_putch('*');
        }
        else if(enter_PH_no)
```

```
{
        if(first_time==0)
        {
                lcd_clear();
                first_time=1;
        }
        lcd_goto(0);
        lcd_puts("ENTER NEW PH.NO");
        lcd_goto(67);

        lcd_putch(PH_NO[0]);
        lcd_putch(PH_NO[1]);
        lcd_putch(PH_NO[2]);
        lcd_putch(PH_NO[3]);
        lcd_putch(PH_NO[4]);
        lcd_putch(PH_NO[5]);
        lcd_putch(PH_NO[6]);
        lcd_putch(PH_NO[7]);
        lcd_putch(PH_NO[8]);
        lcd_putch(PH_NO[9]);

}

else
{
        if(first_time==0)
        {
```

```
                        lcd_clear();
                        first_time = 1;
                    }
                    lcd_goto(0);
                    lcd_puts("AUTO IRRIGATION");
                    DIG0 = hour % 10;
                    DIG1 = (hour/10) % 10;
                    lcd_goto(65);
                    lcd_putch(DIG1 + '0');
                    lcd_putch(DIG0 + '0');
                    lcd_goto(68);
                    lcd_putch(':');
                    DIG0 = minute % 10;
                    DIG1 = (minute/10) % 10;
                    lcd_goto(70);
                    lcd_putch(DIG1 + '0');
                    lcd_putch(DIG0 + '0');
                    lcd_goto(73);
                    lcd_putch(':');
                    lcd_goto(75);
                    if(am)
                        lcd_puts("AM");
                    else
                        lcd_puts("PM");
                }
            }
//****************************************************
```

```
void send_char(unsigned char s)
{
		TXREG = s;
		while(TXIF == 0)
			continue;
}
void send_string(const char *s)
{

	while(*s)
		{

			TXREG = *s++;
			while(TXIF==0)
				continue;
		}

}
void enter_password(void)
{
	if(key_change)
	{
		ENTD_PASSWORD[password_index]=key;
		if(++password_index==7)
		{
			for(i=0;i<7;i++)
			{
```

```
                        if((PASSWORD[i])!=(ENTD_PASSWORD[i]))
                            {
                                p_word_err=1;
                                break;
                            }
                    }

                    if(p_word_err==0)
                    {
                        enter_Pword=0;
                        enter_PH_no=1;
                        password_index=0;
                        ph_no_index = 0;
                    }
                    first_time=0;
                }
                key_change=0;
            }
}
void enter_phone_no(void)
{
        if(key_change & ph_no_index < 10)
        {

                PH_NO[ph_no_index] =(key+'0');
                    ph_no_index++;
                key_change = 0;
```

```
	}
}
void save_and_escape(void)
{
	enter_PH_no = 0;
	first_time = 0;
	ph_no_index = 0;
	for(j = 0;j < 10;j++)
	{
		eeprom_write(j,PH_NO[ph_no_index]);
		ph_no_index++;
	}
	ph_no_index=0;
}
void send_sms1(void)
{
	send_string("AT+CMGF=1");
	send_char(10);
	send_char(13);
	send_string("AT+CMGS=");
	send_char('"');
	ph_no_index = 0;
	while(ph_no_index < 10)
	{
		TXREG = PH_NO[ph_no_index];
		while(TXIF==0)
```

```
                    continue;
            ph_no_index++;
        }
        send_char('"');
        send_char(10);
        send_char(13);
        DelayMs(25);
        send_string("Irrigation Incomplete.");
        send_char(10);
        send_char(13);
        send_string("SENSOR 1 FAULTY");
        send_char(26);

        sms1_flag=0;
}
void send_sms2(void)
{
        send_string("AT+CMGF=1");
        send_char(10);
        send_char(13);
        send_string("AT+CMGS=");
        send_char('"');
        ph_no_index = 0;
        while(ph_no_index < 10)
        {
            TXREG = PH_NO[ph_no_index];
            while(TXIF==0)
```

```
                    continue;
                ph_no_index++;
            }
            send_char('"');
            send_char(10);
            send_char(13);
            DelayMs(25);
            send_string("Irrigation Incomplete.");
            send_char(10);
            send_char(13);
            send_string("SENSOR 2 FAULTY");
            send_char(26);

            sms2_flag=0;
}
void send_sms3(void)
{
            send_string("AT+CMGF=1");
            send_char(10);
            send_char(13);
            send_string("AT+CMGS=");
            send_char('"');
            ph_no_index=0;
            while(ph_no_index<10)
            {
                TXREG = PH_NO[ph_no_index];
                while(TXIF==0)
```

```
                    continue;
                ph_no_index++;
        }
        send_char('"');
        send_char(10);
        send_char(13);
        DelayMs(25);
        send_string("FAULTY PUMP");
        send_char(10);
        send_char(13);
        send_string("NEED ATTENTION.");
        send_char(26);

        sms3_flag = 0;
}
//*********************************************
void read_snsr1(void)
{
        ADCON0 = 0b01000001;      //RA0 connected
        DelayUs(20);
        ADGO = 1;
        while(ADGO)
                continue;
        snsr1_value = ADRESH*256 + ADRESL;
}
void read_snsr2(void)
{
```

```
	ADCON0 = 0b01001001;	//RA1 connected
	DelayUs(20);
	ADGO = 1;
	while(ADGO)
		continue;
	snsr2_value = ADRESH*256 + ADRESL;
}
void upper_snsr_read(void)
{
	ADCON0 = 0b01011001;	//RA3 connected
	DelayUs(20);
	ADGO = 1;
	while(ADGO)
		continue;
	upper_snsr_value = ADRESH*256 + ADRESL;
}

//*************************************************
void func_irrigation(void)
{
	read_snsr1();
	if(snsr1_value < 205 & sol1_rly == 0)
	{
		sol1_rly = 1;
		sol1_count = 0;
	}
	else if(sol1_count > sol1_on_time)
```

```
        {
                sol1_rly = 0;
                if(snsr1_value < 205)
                        sms1_flag = 1;
        }
        read_snsr2();
        if(snsr2_value < 205 & sol2_rly == 0)
        {
                sol2_rly = 1;
                sol2_count = 0;
        }
        else if(sol2_count > sol2_on_time)
        {
                sol2_rly = 0;
                if(snsr2_value < 205)
                        sms2_flag = 1;
        }
        if(sol1_rly == 0 && sol2_rly == 0)
        {
                irrigation_flag = 0;
        }
}
//***********************************************
void func_pump(void)
{
        if(bottom_level == 0 & pump_rly == 0)
        {
```

```
            pump_rly = 1;
            pump_count = 0;
        }
        else if(pump_count > pump_chk_time)
        {
            if(bottom_level == 0)
            {
                sms3_flag = 1;
                pump_rly = 0;
            }
        }
        else
        {
            upper_snsr_read();
            if(upper_snsr_value > 205)
                pump_rly = 0;
        }
}
```