Design and Analysis of a Solar Water Pumping for a Fish Farm in Pakistan

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A Thesis Submitted to the School of Graduate Studies in partial fulfillment of the requirements of a Master of Mechanical Engineering

Memorial University of Newfoundland
Faculty of Engineering
Faculty of Engineering and Applied Science

October 2022

St. John's, Newfoundland and Labrador, Canada

Abstract

Aquaculture is a multibillion-dollar industry growing worldwide, especially in developing countries. This thesis focuses on a comprehensive study of off-grid fish farming in rural areas of Pakistan. A suitable site is selected for a fish farm. The solar PV system was designed and optimized for this fish farm on their annual load requirements, which are 100% renewable. Results demonstrated that the designed Solar PV system fulfilled the fish farm load smoothly and sufficiently throughout the year. Initial cost and maintenance are also estimated using HOMER Pro. Data were collected from the site survey and found there was not any system for water pumping system operations. The water pump operated manually through labor based on the visual determination of water level in ponds, Which increased production cost, electricity consumption, and wastewater. For this problem, Proposed a water pumping system automation and control using TinkerCAD. As a result, the system worked efficiently using an ultrasonic water level sensor and a low-cost motor with a microcontroller. The designed system works automatically when the water level drops to the threshold and stops. The major part of this thesis is designing and implementing an IoT-based real-time health monitoring system for the fish farm. Microcontroller Arduino Uno and Wi-Fi module ESP8266 used for the proposed system and designed a system to monitor the most critical metrics of the fish farm using an ultrasonic sensor temperature sensor, pH sensor, and dissolved oxygen sensor. ThingSpeak Cloud platform is used for data storage and display. Aquafarmers can access the fish farm health monitoring system through the web interface and phone App.

Acknowledgment

First of all, Thanks to the Almighty God, who gave me enough courage, ability, and strength for this path towards the master of Mechanical Engineering.

I want to express my sincere profound gratitude to my supervisor Dr. Mohammad Tariq Iqbal, who supervised me through every stage of this thesis. His encouragement and guidance helped me to complete this thesis.

I also would like to thank the School of Graduate Studies and the Department of Engineering and Applied sciences for supporting the research work. I thank my parents and everyone who inspired and helped me in this journey.

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List of Abbreviations

PV	Photovoltaic
MATLAB	Matrix Laboratory
HOMER	Hybrid Optimization Model of Electrical Renewables
MPPT	Maximum power point tracking
FAO	Food and Agriculture Organization of United Nations
IoT	Internet of Things
GHI	Global Horizontal Index
NREL	National Renewable Energy Laboratory
Hp	Hose power
IDE	Integrated development environment

CHAPTER 1

INTRODUCTION

1.1 Introduction

Renewable Energy is the energy obtained from natural processes that is restored at a rate equal to or faster than the consumed rate. Different forms of renewable energy are directly or indirectly from the sun or heat generated deep within the earth. Energy can be generated from solar, wind, geothermal, hydropower and ocean resources, solid biomass, biogas, and liquid biofuels. A more comprehensive range of technologies and equipment for energy production has been developed over the decade. The world is moving to renewable energy and reducing the use of fossil fuels for energy production and other benefits for many reasons like cost-effectiveness, environmental hazard, and long-term usability [1]. Over the decade, energy consumption has increased, and most countries have minimal resources of fossil fuels for energy production. Solar Energy is clean, renewable, and plentiful Energy in nature. Solar Energy is in focus these days and playing a pivotal role in energy production. Due to rapidly developing low-cost photovoltaic technology, PV-based applications have been developed and are highly in demand. Off-grid systems have been used in many applications like remote dwellings, boats, recreational vehicles, electric cars, roadside emergency telephones, and electric lights. One of these applications is a standalone photovoltaic power system for Off-grid villages pumping water [2].

Over the last few decades, Overfishing has made wild capture fisheries increasingly unsustainable. Efforts are being made to reduce ocean harvesting to maintain the marine environment's ecosystem [3]. As a result, aquaculture is overgrowing, particularly in developing countries in the Asia-Pacific region [4]. According to the Food and Agriculture Organization (FAO) of the United Nations, 18 million people are involved in aquaculture in the Asia Pacific region [5], and 90% are categorized as small-scale fish farming. Most fish farms are located in rural areas and increase the production of fisheries, which meets the world food security and their annual income [6]. Remarkably, the modern aquaculture farming industry can make life more sustainable in the rural areas and prevent immigration to the large cities because 65% population of Pakistan lives in rural areas. Their primary concern is sustainable income for maintaining living standards.

Aquaculture is dependent on freshwater daily for achieving production targets and healthy fisheries. Pakistan is already facing water shortage problems, with water availability of around 5000 m^3 per capita in the 1950s. Still, current studies indicate incredible results, about 1000 m^3 per capita [7], and a short waterfall is expected to reduce 150.8 million acre-feet by 2025 [8]. Water pumps and tube wells are installed to meet the water supply shortage, and on the other hand, electric power shortfall increases to 5000 MW due to water shortage problems [9]. So, in Rural areas where electric power transmission lines are impossible, local farmers use fossil fuels to meet their agriculture and other needs. In this scenario, Pakistan has few fossil fuel resources and depends on imports of 346,400 barrels daily from other countries [10]. In Pakistan, there is enormous renewable potential, around 167.7 GW [9]. In renewable energies, Pakistan has the potential for photovoltaics around 100,000 MW, and the average solar insolation for the country is about 5.5 $kWh/m^2/day$ [11].

All the above scenarios encourage installing solar water pumping systems for aquaculture and using renewable energy sources, which could reduce the usage of fossil fuels in Pakistan. The Primary aspect is Pakistan does not have enough resources for fossil fuels. On the other hand, Pakistan has excellent potential for Solar energy-based systems that can overcome energy requirements for running water pumps for aquaculture.

The solar water pumping system consists of five main components shown in Figure 1: PV panels, energy storage system (battery bank), dc to the ac power converter, and water pump [12].

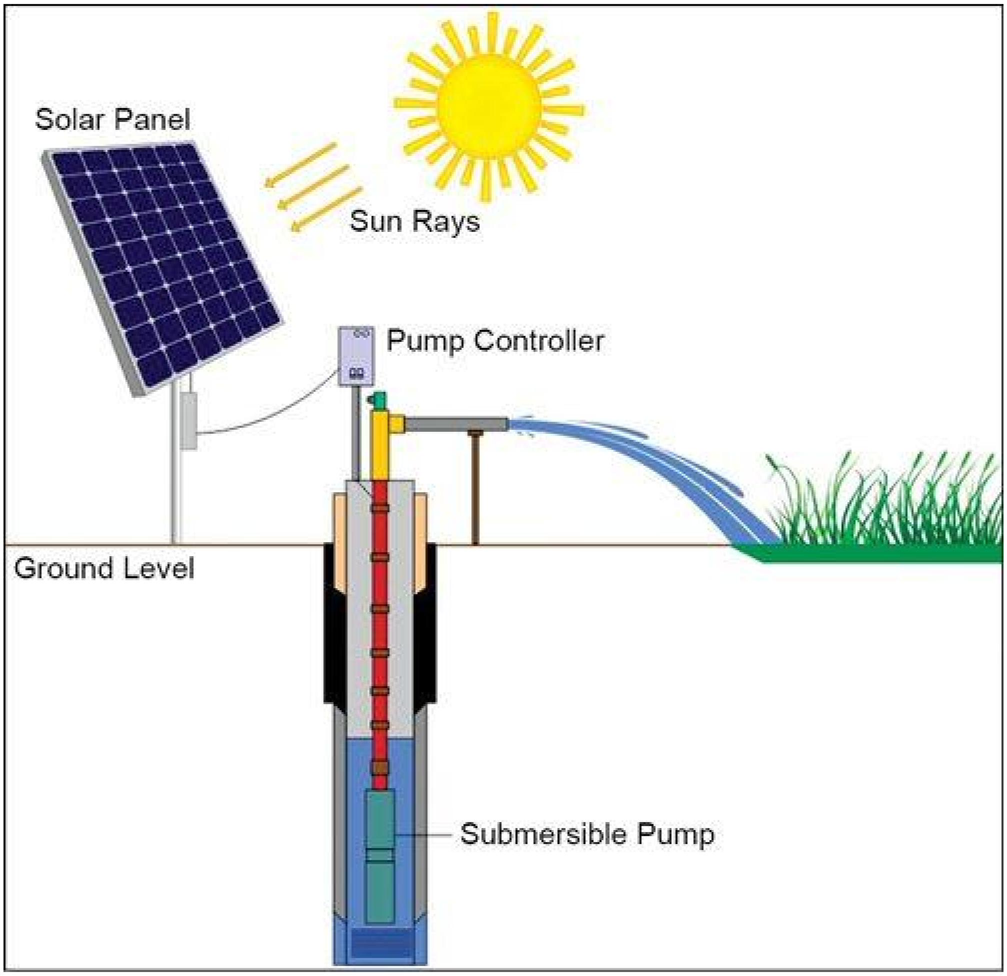


Figure 1.Structure of a solar water pumping system

1.1.1 Types of PV panels

Photovoltaics is called the conversion of light into electricity by using semiconductor materials with photovoltaic effects. Several types of PV panels are in the market for different needs and purposes. Distinguishing between types of solar panels means differentiating between single-junction and multi-junctions solar panels or first, second, or third generations. The numbers of layers on the solar panel differ in single-junctions and multi-junctions that will observe the sunlight. The classification by age focuses on the materials and efficiency of the different solar panels.

- Monocrystalline Solar panels (Mono-Si)
- Polycrystalline Solar Panels (Poly-Si)
- Thin-Film Solar Cells (TFSC)

Monocrystalline solar panels (Mono-Si)

These solar panels made of monocrystalline silicon can easily be recognized from their uniform dark look and rounded edges, as shown in figure 2. These panels have the highest efficiency rates because of highly pure silicon, and the latest panels reach above 20% efficiency.

Mono-Sci Panels have high power output, are long-lasting, and require less space. That also means they are expensive compared to the others, but they tend to be slightly less affected by high temperatures. Recent development in producing these panels reduces the thickness of Si material in cells and decreases the production cost. The main disadvantage of these panels is the initial high cost and mechanical vulnerability (brittle) [13].

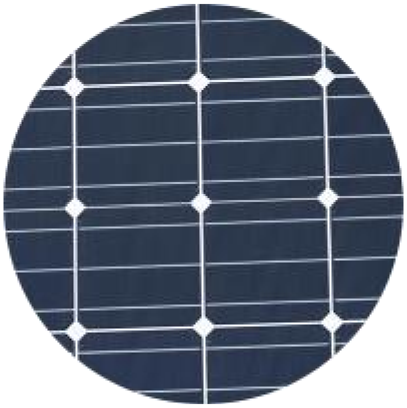


Figure 2. Monocrystalline solar panel

Polycrystalline solar panel (Poly-Sci)

These panels in Figure 3 can easily distinguish by the blue, speckled look and squares on them. Multi-grains and plates make polycrystalline cells of silicon crystals into thin wafers. It has low production because panels are made with melting raw silicon, a faster and cheaper process than monocrystalline panels. But also have low efficiency of around 15% and a shorter lifespan. The main disadvantage is they are affected by hot temperatures to a greater degree [14].

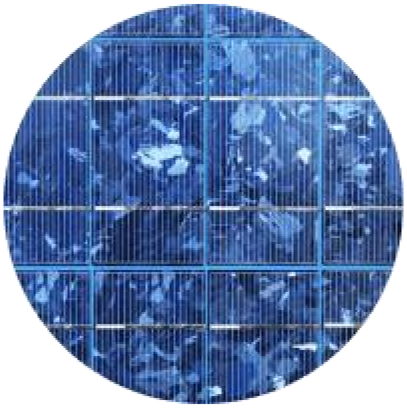


Figure 3. Polycrystalline solar panel

Thin-film solar cells (TFSC)

Thin-Film Solar panels in Figure 4 are manufactured by depositing one or more photovoltaics materials such as silicon, cadmium, or copper indium gallium selenide (CIGS) films. They are also flexible, less affected by temperature, and less expensive than others. But it has low efficiency and needs more space. Unsuitable for residential installation.

Figure 4. Thin-film solar cell

1.1.2 Types of inverters

Electricity produced by solar energy is in the form of direct current (DC) electricity, and direct current cannot use for all appliances, so here is the inverter that comes into play for converting direct current (DC) to alternating current (AC)—extensively used not only for converting DC power to AC power but also for high efficiency, power reduction costs and versatile applications.

Inverters are characterized based on their output, So there are three different types of inverters based on production.

- The Square Wave inverter
- The Modified Sine wave inverter
- Pure Sinewave inverter

The square wave inverters:

Square wave inverters are one of the oldest and most cheap simple inverters and are used to convert straight DC signal to a phase-shifting AC signal but not with pure output. But it is a square wave—the construction of a square wave inverter achieved by using an on-off switch shown in Figure 5.

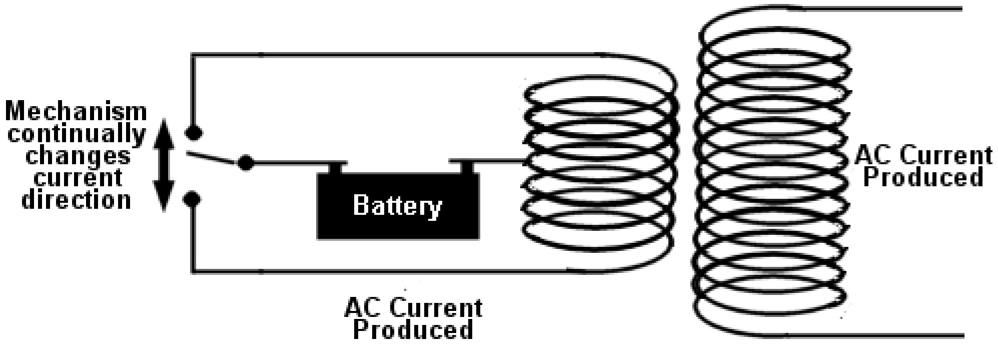


Figure 5. The Circuit of the square wave inverters [15]

Modified sine wave inverter:

These inverters have a waveform with an additional step like a waveform. Compatible with most equipment but compromises the efficiency of the equipment. Motor pumps, refrigerators, and fans consume more power with these inverters. Modified sine wave inverters have higher frequencies, so motors consume 20% more power. These inverters are noisy, like buzzing and humming [15]. In Figure 6 modified sine wave can see.

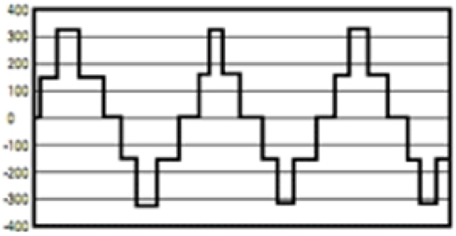


Figure 6. Modified sine wave [15]

Pure Sinewave inverters:

All local utilities and generators' rotating AC machinery produce a sine wave. Main advantages of these inverters are most of the equipment is designed for sine wave. The increase in need and design for most applications makes these more expensive than others.

1.1.3 Types of batteries

Photovoltaic-based solar energy systems use electrochemical storages system for energy storage. Batteries are the main storage component for this energy system. There are mainly two types of batteries that can be used for our proposed photovoltaic Solar energy system.

- Lead Acid Battery
- Lithium-Ion Battery

Lead acid battery:

These batteries were invented by a French physician named plante in 1859 [16]. This is one of the most popular and efficient batteries commercially available. This battery has 12V and six lead-acid cells connected in series. The working of the lead-acid battery is based on exciting chemistry with a massive chemical reaction process. Lead battery involved in charging and discharging method. The diluted sulfuric acid H_2SO_4 molecules break into two parts upon acid dissolves, creating 2H+ positive and ions SO_4- negative ions. Anode and Cathode are two electrodes connected with plates. And Cathode attracts the positive ions, and Anode attracts the negative ions. Electrons interchange resulted in the bonding of Anode and SO_4- and Cathodes with 2H+. Further reaction with H20 (Diluted sulfuric acid, Sulfuric acid+ water) [16].

Lead Acid Battery Consists on Plates, Separator, Electrolyte, Hard Plastic case as shown below in Figure 7.

Figure 7. Lead acid battery structure [16]

Lithium-ion battery:

The battery in Figure 8 is made of an anode, cathode, separator, electrolyte, and two current collectors (-,+), and lithium is stored in the anode and cathode. Positive charge lithium-ion carries by electrolyte from anode to the cathode through the separator. The Lithium ions generate free electrons in the anode, which creates charge at the positive current collector. Then electric current flows towards the negative current collector through the powered device, and the separator breaks the current flow inside the battery [17].

Figure 8. Lithium-ion battery [17]

1.1.4 Types of water pumps

The water pump is used for circulation and raising water. There are two main types of water pumps upon use.

- Submersible Solar Pumps
- Surface Solar Pumps

Submersible solar pump:

These pumps can lift water up to 200 meters and are used in a big well, and as the name indicates, the pump can be submerged. The primary use is for wells and boreholes. Pumps in Figure 9 only push the water instead of sucking because pumps remain in the water [18].

Figure 9. Submerge pump [18]

Surface solar pumps:

Surface pumping systems in Figure 10 are not submerged and are located above the surface, as indicated in the name. They are mainly used in lakes, agriculture, ponds, and pumping water into storage tanks. These portable pumps can quickly move from one place to another upon need and are available in the market for commercial and residential use. These pumps can pump water from the 20-meter depth inside the surface [19].

Figure 10. Surface pump [19]

1.2 Literature review

Detailed literature was studied for this thesis, including the evolution of solar system design for fish farming in rural areas, especially off-grid. Different methods were found based on manual computation for the solar system creation.

Water is the primary source for fish farming, and a lot of research has been conducted on designing and optimizing a PV-based water pumping system. There are two main methods for designing solar systems: manual formulation and computational methods using some software.

1.2.1 Manual formulation methods

The Manual method is the most uncomplicated way of designing a solar system. Under this method, a simple mathematical formulas-based MS excel sheet is used to determine the total load of the system and then calculate the absolute numbers of the PV panels and batteries considering the fixed tilt angle of panels that can meet their load [20]. Another method is based on the loss of load probability (LLP) for PV panel sizing. Another technique requires four coefficients to design the standalone PV system [21].

1.2.2 Computer-based methods

The computational design system is based on simulations for deep analysis. These analyses are being held using different computer software. The software provides results of PV sizing, power generation, battery requirements, power converter size, and load mapping in specific interval time based upon the input of each component operated by solar power [22]. There is much software for steady-state analysis of the solar system design. A few of them are RETScreen, PVplanner, PVSyst, SolarPro, SAM (System advisor model), HOMER (Hybrid Optimization Model for Electric Renewables), etc. Some software is used for dynamic modeling to analyze the PV systems' conditions: LABVIEW, MATLAB, and ANSYS [23]. An analysis was performed in six different states of Nigeria to design a 6MW PV system grid-connected using RETScreen Software. Overall sizing of the system, emission analysis, and cost analysis was performed in this work. It resulted in the best option for designing the 6MW grid-connected system in all six states [24]. The solar system was developed using the Brown-Gibson model and RETScreen and evaluated the net value of the proposed approach, payback duration period, and carbon emission saving [24]. 110KW Solar system design on top of the roof of the hostel residential building in MANIT Bhopal, India, using PVPlanner software. Analyzed one of the best PV panels using four different panels and found that the amorphous silicon PV panel is the best [25]. The dynamic modeling was performed of the overall system using MATLAB. The system consisted of a battery bank without a battery tank and a water tank [26].

1.2.3 Previous work on solar PV system for fish farming

PV-based application designed for cage fish farm for pumping cold water from the depth of the dam to cool the cage. Temperature sensors were used to determine the cage's temperature, and a motor driver was used to speed up the pump according to the water temperature. PLC and HMI systems monitor the system, and the total required Energy supplied by the PV system [27]. PV system was designed for an aeration system for a fish farm in the Selman District, Indonesia. An aeration system is used to dissolve oxygen in fishponds to maintain water quality for fish health. The object of this work was to optimize the sizing of the electric power system for the aeration of the fish farm using HOMER software. Resulted from optimal sizing of the PV panels, batteries, inverter, and cost of energy 0.769$/kWh [28]. A Solar-powered management system designed for the fish farm. The autonomous management system consists of a floating node, sensors, and food dispense, controlling the water temperature and measuring the dissolved oxygen level and water pH level. Simulation results show that the management system successfully controlled the measures for the fish farm, and results were obtained using PSIM and MATLAB [29].

1.2.4 Conclusion regarding the suitable computer-based method

After conducting a literature review, HOMER Pro software was chosen for designing and optimizing the Solar PV system for an off-grid fish farm in rural Pakistan. The fish farm location and chosen and system design & optimization work presented in chapter 3.

1.2.5 Water pumping system automation and control

Some studies related to solar-powered pumping system automation and control in the literature. In the [30] study, the EPS32 microcontroller was used for water pumping automation for an irrigation system. The programmable sensors detect temperature, humidity, and soil moisture levels. The microcontroller sends results to the webserver so the user can operate the irrigation system far from the field by a simple ON/OFF [30]. The water management system is designed for the home to reduce water consumption that can reduce global water crises. PIC1650 microcontroller used in this system, made by General Instrument's Microelectronics Division. Water level sensor used in the water storage tank. The water pump automatically turns on when the tank water level is low and then turns off when the water tank is full [31]. GSM module and a PIC16F877A microcontroller are used to automate the water pump for irrigation purposes. The system operates through the mobile phone to start or stop the water pump. The water level is also monitored through the mobile phone. This project optimized the power and saved 22% of the water wastage [32]. ATMEGA 3 GSM microcontroller is the heart of this system and is used to automate farmers' 3-phase water pump control. Automation of the water pump monitored the electricity supply, water flow rate, and water level in the reservoir and took care of short circuit conditions related to the irrigation pump [33]. Automation of the water pumping station of Kurutie community using a programmable logic controller (PLC). The system consists of two parts one is hardware, and the second is software. The hardware unit used a Mitsubishi Fxis-20mi-001 switch mode power supply, micrologic 1000 PLC, six OMRON MYAN-1 relays, ten pilot lights, and a float level sensor. The software codes were written in ladder logic using RsLogix1500 and RsLinx driver for communication [34]. An automation system for fishpond water circulation designed using Arduino UNO. The system consisted of a ph sensor, water level sensor, and water pump. Using this system, the farmer can monitor the water pH and water level in the pond. The system is helpful for water circulation in the pond [35].

1.2.6 IoT-based real-time fish farm health monitoring system

The literature review found some studies and work on various existing technologies and solutions already available and presented below details of works.

An IoT-based aquaculture monitoring and control. The IoT method in [36] used technologies in water quality management systems. Raspberry Pi-3 is used instead of Arduino because of its advancement and module connected with turbidity, pH, temperature, and water level sensors. Time series charts display the system quality metrics using the Wi-Fi module. Aqua monitoring system using AWS [37] is another technology available for data storing and analysis. The ESP32 microcontroller and DHT11 were used to monitor the temperature, water level sensor, and fish feeder for the fish farm. Data can be accessed anywhere using the Amazon web services dashboard MQTT protocol chosen for transmitting the data to the AWS cloud from the microcontroller. Another work found in [38] wireless sensor network model for shrimp culture monitoring using open source IoT. Arduino microcontroller used with pH, dissolved oxygen, and temperature sensors. An open source IoT is created using ThingSpeak channels. The system is not included a Phone app and web interface, which is inefficient for displaying the data.

1.3 Research objectives

In this research, the above studies and facts encourage the use of renewable resources. The fish farm can be designed and optimized in off-grid locations. In this thesis, an off-grid site was selected for a fish farm and designed a self-sufficient Solar PV power system. Simulation results demonstrated that power generation is enough for fish farm operations throughout the year, and fish farm can operate without power from an electric grid station. The estimated cost is a one-time investment and affordable. Fish farms primarily require an uninterrupted water supply for fisheries, so fish farms must have a water pumping system to maintain the water level in the fishponds. Data collection from the site has shown that there was no water pumping system in the fish farm, and the labor operated the water pump based on observing the water level in the ponds. Using a water pump causes high labor costs, high usage of electricity, and maximum chances of human error in determining water levels in the ponds. This thesis designed a water pumping automation and control system for the fish farm. The water pumping system operates automatically when the sensor detects the ponds' low water level. The proposed system is affordable low cost, reduces electric power usage, and has low labor cost and an efficient operating system for the aquafarmers. The final part of the thesis focused on the health management system of a fish farm. Based on data collected from the site, there were no systems for health measurement of the fish farm and traditional methods used for maintaining the water quality of the fishponds. So, in the final part of the thesis, we proposed the fish farm health management system which can monitor important water metrics from the fishponds. Aquafarmers can monitor fish farm health using IoT technology through the web interface and phone app. Studies show that maintaining water quality for the fisheries can increase their growth and production and prevent them from serious diseases.

The primary purpose of this thesis is to reduce the consumption of fossil fuels and use renewable energy in Pakistan, which can reduce the import of fossil fuels and reduce carbon emissions. Pakistan has great potential for Solar energy. Fish farming is ramping up business in developing countries. This work can encourage aquafarmers living in off-grid locations to start sustainable aquaculture businesses in their areas.

1.4 Thesis structure

This thesis consists of six chapters, and details are below.

Chapter 1

The first chapter starts with a brief introduction and literature review of the fisheries production and demands in the world and aquaculture businesses' growth and scalability in the world, especially in rural areas of developing countries. Fish farming requires an uninterrupted water supply and electric power. The literature review is conducted for water resources, electricity production, and Solar radiation resources for electricity generation in Pakistan.

Chapter 2

The second chapter briefly explains the fish farming operation and sit selection. The chapter also covered the fish growth and life cycle nursery to market.

Chapter 3

The first chapter presents the Solar PV system design and optimization for an off-grid fish farm in rural Pakistan. HOMER Pro software used for designing and optimizing solar PV systems. The software provided a site selection feature for extracting information about solar radiation and clearance. The site location was selected, and fish farm daily electricity consumption load information added to the software. Load information was based on electric component rating and operations hours used in the HOMER Pro for sizing and optimization as an input. Based on the simulation results, HOMER Pro provided a comprehensive designed and optimized system for the fish farm. The proposed system provided components rating, quantity, and initial cost estimation.

Chapter 4

In the 4th chapter, a selected site survey was conducted and found no water pumping system. The water pumping system operated through labor using simple ON/OFF switches by checking the manual water level. Based on the survey, Proposed a solar-powered water pumping automation and control system for the fish farm using ThinkerCAD software. The system consists of Microcontroller Arduino Uno, relay, motor, ultrasonic water level sensor, and LCD Screen. After designing the system and simulated it online in software, the system worked efficiently at a low cost.

Chapter 5

In this Chapter, an IoT-based real-time health management system is designed for the fish farm and considered the most required health metrics for the fish farm. Used four primary sensors: water level, temperature, pH, and dissolved oxygen. Sensors connected with microcontroller Arduino Uno R3 and ESP 8266 wi-fi module are used for data transmission to the IoT source ThingSpeak. The designed system could access online through the web interface and phone App for aquafarmers. The sensor data was accurate, and the system worked as designed.

Chapter 6

This chapter will discuss the results obtained from the above chapters and the limitations, conclusion, and recommendations for future work.

CHAPTER 2

FISH FARM INTRODUCTION AND OPERATIONS

2.1 Introduction

The success rate of a project for fish farming depends on the appropriate site selection. Many research papers have been published to guide the proper site selection for fish farming. This chapter summarized the factors that can be investigated and considered for the projects related to aquaculture. Some factors can be considered for the suitable site selection that are explained below.

2.2 Ecological factors

These factors are necessities for every project related to aquaculture. Some ecological factors are given below.

a) Water supply

When selecting a fish farming site, it should be ensured that water is sufficient and has quality. One should investigate the trustworthy source of water. The statement from Water Authority or Irrigation Division is required to know how much water is available and the water supply restrictions, such as maintenance time in the irrigation channel [39].

The water source can be irrigation deep or dug wells, rainfall-runoff, spring, lake, reservoir, creek, river, and canal. It can be supplied through the pipeline, storage tank, or feeder canal via pumping or gravity towards the pond. Gravity is said to be the method most economical. A minimum water supply of about 51/sec/ha is required for the whole year if the pound is suitable for built-in soil.

If the rainfall-runoff, the water is stored in the reservoir and sent to the ponds. For the catchment area, a ratio of 10 – 15 ha to 1 ha of the pond is required, and if the site is posture, then slightly more water is needed, and for the under-cultivation land, a few amounts of water is enough.

There is also a need to investigate the possibility of drainage when selecting the site for fish farming. The drainage of type Gravity is preferable. In the drainage process of the pond by gravity, the bottom of the pond should be at a higher level because, in the harvesting periods, the maximum water table should reach.

b) Water quality

When selecting a site for fish farming, the most crucial factor is water quality. Water quality must be investigated by taking multiple samples from the proposed water source to analyze the purpose of microbiological, biological, chemical, and physical properties and for hazards related to health. The various procedures must be performed to test the quality of water. According to the production point of view, the following emphasis can be taken [40].

a. Biological Properties – plankton density and quality

b. Micro Biological Properties – parasites quantity and species

c. Chemical Properties – ammonia, dissolved solids, salinity, alkalinity, free movement of carbon dioxide, the demand of biological oxygen, dissolved oxygen, all are toxic and useful either the origin of industry or agricultural pollutant is present.

d. Physical Properties – suspended solids, transparency, turbidity, odor, color, temperature

c) Land

It should also ensure that the selected site has suitable land. The good land would be with the slops, but it should not be steeper than two percent. The cost can decrease if the wasteland is selected that is not suitable for agriculture or other purposes. The flood level and land elevation are crucial factors determining land suitability. The land chosen should be from floods in which it can be seen that the levels of floods should not be higher than the top of dikes. The expected flood heights can be determined from the waterflood marks on the bridges or questions asked by the local people. The size and shape of land can also be considered, and land that has a standard form and is extendable for future expansion is the ideal land for fish farming. The site should not be selected in areas with a risk that the future area can become an industrial area and create pollution in air and water.

Similarly, the land selected near the densely populated place also risks decay. But some wastes generated from agriculture and industries are usable for fish farming. In this case, there is a need to conduct a special investigation into the utilization of waste.

The utilities available underground must be rendered. Otherwise, the selected site can become unsuitable. In the pond area, radio masts and poles of high electrical power are also not required.

The vegetation density and type are dependent on the elevation of the land. The vegetation is also used for indicating the type of soil and water table elevation. The clearing method of the site can be determined by using the tree root systems through the vegetation density and variety. Also, the vegetation calculates the cost and time of construction [41].

Figure 11. Land for fish farm

Figure 11 shows the land of the fish farm taken during the survey. Grassland, land covered by low shrubs or open woodland, abandoned paddy fields, and brushes reduce the cost of construction compared to the ground with swampy trees or thick jungle. But the areas with strong winds or cyclone belts must have high and wide dense vegetation windbreak against the prevailing wind direction.

2.3 Operational and biological factors

Before selecting a site for the aquaculture project, the following factors should be considered.

- Stoking material availability and resources such as fingerlings or fry and spawners
- Aquaculture species must be cultured
- Project type
  - Large scale project
  - Small Scale project
- Adoption of a cultural system
  - Intensive

  - Semi-intensive
  - Extensive
- Method of operation
  - Integrated
  - Polyculture
  - Monoculture
- Size estimation of the required area
- Production target

2.4 Fish farming operation

The site layout is governed by the combined requirements of site operation and conditions. All the information should be collected before designing work, including the data and technological requirements related to the site. The operations of fish farming structures with their purposes are explained below Figure 12.

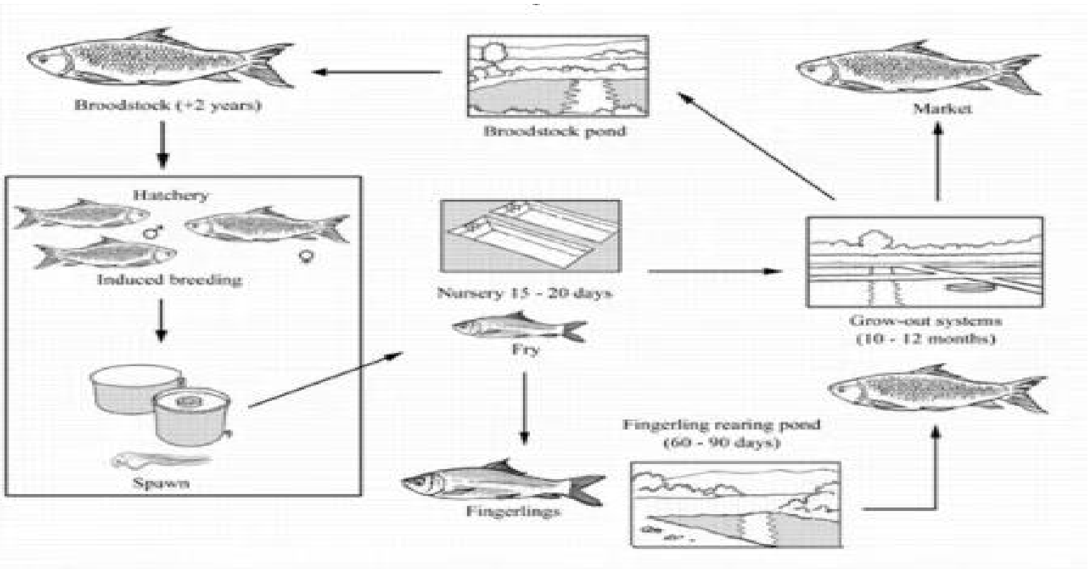


Figure 12. Fish life cycle [42]

2.4.1 Hatchery

The hatching house is an essential structure in the artificial reproduction technological process. The following operations are carried out in the hatching house.

- Before stripping the breeder’s preparation
- Breeder's treatment includes stripping, tranquilization, hypothesis treatment, etc.
- Eggs spawning, fertilization, treatment
- Larvae treatment
- Fry first feeding
- Artificial reproduction laboratory functions (medical and chemical dosages, fish pests’ detection, analysis of eggs, analysis of water)
- Fry packaging

In the hatchery house, equipment is required, such as vessels for fry holding, hatching jars, stripping, hypothesizing tables, and tanks for breeding [43].

2.4.2 Basins and fry rearing ponds

In the basins and fry rearing ponds, the small fry is reared from 4 to 5 days’ age to 3 to 54 weeks' duration. The small fry should be kept on imperious soil and close to the hatching road and house sheltered from the wind.

The fry rearing pond's preferable size range is from 100 to 1000-meter square. The fry rearing ponds' size also depends on the number of fries that can be introduced within 1 to 2 days. That’s why its size can be adjusted according to the hatching house capacity.

The water supplied to the fry-rearing pond must be mixed with oxygen and should not contain any biological pollution or chemical. The water supply system can also exchange the water in the pond twice a day. The perforated pipes distribution network can be provided in densely populated ponds, and pipes can be attached at the bottom of the pond with uniform distribution for proper flow. The fry-rearing ponds contain concrete or stone.

The diameter of a circular basis ranges from 4-6 m, and the depth is about 1 m. For water maintenance, freshwater is introduced in the permanent circulation in the pipe nozzles. From the center of the basin, the effluent is withdrawn.

2.5 Nursery ponds

The fry reared from the fry ponds are now transferred to the nursery ponds for further growth at the rate of 100,000 each hectare. The nursery ponds have a size ranging from 1-10 ha and a maximum limit of the size of 30 ha. That depth of water can be 1 – 1.5 meters. The nursery ponds must be close to the fry ponds so that the fry reared can be transferred directly to the nursery ponds along with the water. In figure 13, nursery ponds, the supplied water must be clean biologically and chemically. The flow is not required in such ponds, but to avoid losses in water, the provision can be made.

Figure 13. Nursery ponds

The essential requirement is rapid and complete pond drainage. Due to this, there must be a slope at the bottom of ponds towards the outlet, which is constructed during the construction stage of the ponds. The 100 g body weight is attained in the nursery ponds for 160 – 220 days. The external cropping pits are preferable for fishing.

2.6 Production ponds

The production ponds grow yearlings in it for the full-grown fish. The design of such types of ponds is according to the below-given specifications.

The size of the production ponds ranges from 20 – 100 ha, and the largest size can be calculated by considering the production of total fish, and the size of fish production in total should not increase by 100 t. For instance, if a pond has a total yield of 2.5 t/ ha, then the size of the pond must be within the limit of 40 ha.

The depth of ponds must range from 1.2 – 1.8 meters, and it has a depth of 1.8 meters in the elevated temperatures region. The production can be reduced if the water depth is less than 0.6 meters.

The process of pond filling must be within 2 to 10 days, according to the size of the pond. In these ponds, the flow of water is not required, and in the growing seasons, there is a need to compensate for the losses due to seepage and evaporation of water. The production ponds must have a system of drainage and fill to allow drain and fill independently from other ponds.

For intensive fish production, a complete drainage system is required. The essential criteria in the drainage system dimensioning is that number of days needed for draining a pond must be equal to the pond area square root per hectare. For instance, 30 ha growing pond of draining sluice can be dimensioned as under root (30), equal to 5.5 days. Furthermore, the drainage requirement is that the entire fish farm period must be less than twice the square root of the total area of the pond. For instance, the 500 ha drainage canal fish farm can remove water from all ponds towards the fish farm within two under root (500), which is equal to 45 days. Production ponds can be seen in Figure 14.

Figure 14. Production ponds

The fish with a body weight of 100g is stocked in the fish form with the rate of 3000 /3 per 500 ha, and in the 300 days, each fish gain weight of about 1500 g.

The external cropping pits must be provided for advanced fishing. There is also needed to store the fertilizers, manure, and feed in the vicinity of the pond. A sound road must be available for transporting the fish and feed.

2.7 The facilities of fish-holding

The holding ponds store the harvested fish before processing or marketing. The holding unit's capacity is calculated by production composition according to the species, fishing schedule time, yield envisaged, and processing or marketing. The breeding stock must be stored in production ponds other than holding units.

The ponds of 0.2 – 10 ha or basins of 500 to 2000-meter square must be provided for holding purposes. According to the climate conditions, just like Hungary, the basins are replaced with wintering basins or ponds. The holding pond's average depth must be range from 1.8 – 2.2 meters.

For the holding ponds, the essential requirement is that there must be some dissolved contents of oxygen in the water, and its level should never sink less than 2 mg per liter. The supplied oxygen can be introduced with the feeding water by air, injecting oxygen, or allowing water to flow through the pond. The air is injected when water flows through the pond during the removing process of metabolism. The flow rate can be reduced when the rate of injecting air is higher.

For the flow rate estimation or rate of air injection in the ponds, some information related to the oxygen consumption of stored fish, feedwater oxygen contents, and air injection system efficiency.

The oxygen consumption rate depends on the water temperature or body temperature. As the temperature increases, the consumption rate of oxygen is also increased. Cold water can absorb more oxygen as compared to warm water. For instance, the Consumption of oxygen in each hour of carp of 1kg weight of the average body is 10cm^3 at 5 °C, 25cm^3 at 10 °C, 50cm^3 at 50°C.

Each liter of saturated water has the following oxygen amount:

8.91 cm^3 at 5°C

7.87 cm^3 at 10°C

7.04 cm^3 at 15°C

If there is a need to estimate the necessary flow, then keep in mind the first does not consume the entire contents of oxygen in the water for breathing; that's why in the ponds, the content of residual oxygen is around 1 cm^3 per liter.

The holding ponds flow rate can be estimated by 1 L / sec for stored fish of each ton when accurate computations are unavailable. The holding ponds fish allowable density ranges from 5 – 15 kg per meter square for the pond area [43].

2.8 Arrangements for fishpond

The conditions of topography usually dictate fishponds arrangement for particular fish farm sites. The three types of arrangements for the ponds are given below.

1. Barrage ponds
2. Contour ponds
3. Paddy ponds

The first two types of arrangements are used in the rolling terrain, and paddy ponds type arrangement is adopted for the flat land. Each arrangement differs from the other in terms of operation, structure, and construction.

2.8.1 Barrage ponds

These types of ponds are constructed in a flat valley having a medium longitudinal slope through the valley closing with the low dam at the suitable site. The best-suited site would be if the smallest dam can create the largest suitable pond. Due to these reasons, the dam's construction cost can be reduced if built in a valley. Through the ponds, floods can pass, but they can be released without damaging the dikes, structures, dams, and fish can also escape. A spillway can also be provided.

2.8.2 Contour ponds

These types of ponds are built in the valley with the longitudinal hike and are not affected by storms or floods. These types of fishponds are constructed on one side of the valley. To create gravitational supply to ponds, a weir is used to block the stream, and the direction of water is changed using gating towards the supply canal. There is a need to fill each pond separately, and separate drainage is required for the original stream bed only in normal conditions. The stream bed allocated to each pond must be able to take the flood safely, and the longitudinal dike crust running in parallel with the stream must be raised above the design flood level. This type of arrangement is only suitable for the wide valley floor [43].

2.8.3 Paddy ponds

A dike surrounds the fish farm ponds in the flat plain areas. The opportunity is offered by the flat terrain for the pond favorable arrangement when helps to fil and drain the pond independently that can make the possibility of intensive fish farming.

2.9 Fish control structures

Different measurements must be taken to escape fish from the upstream pond. The possible solution is the fish screen and fish deterrent based on electricity. The fish screen must be extendable to the level of a flood. There is a need to clean the fish screen at the food times so that operator can have a working platform. The screen mesh width or racks bars spacing depends on the fish size in the pond. The bar spacing of 2 cm is sufficient in the production ponds [43].

CHAPTER 3

DESIGN AND ANALYSIS OF A SOLAR SYSTEM FOR FISH FARMING

3.1 Site selection

A suitable site is selected for the fish farm where a solar system can also be implemented. A site location is “Saif Khosa Fish Farm’’ located near the bank of river Indus near Wasti Mahermani, Kot Haibat, District Dera Ghazi Khan, Punjab, Pakistan. Location coordinates are 30° 6' 40.88753" E, 70° 38' 56.34821"N [45]. The Fish farm area is approximately 8 acres, and fish farm water is circulated to the nearby agricultural land for cultivation after a certain time.

The Khosa Fish Farm can be seen in Figure 15. There are five fishponds on this farm and are surrounded by agricultural land. The small black circle in the figure shows the water pump located on the fish farm.

Figure 15.Fish farm google map view [44]

3.1.1 Solar isolation

The solar isolation index was extracted from the National Renewable Energy Laboratory (NREL) through HOMER software. The Global Horizontal Index (GHI) between 3.234 to 7.09 kWh/m²/day clearness index varies between 0.581 to 0.659, as shown below in Figure 16.

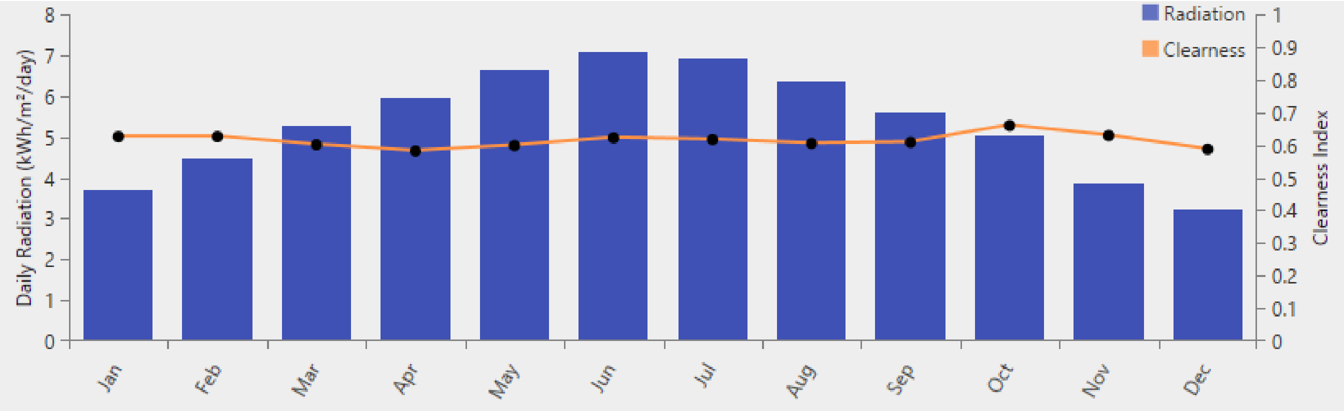


Figure 16. NREL Insolation and clearness Index of fish farm location

3.1.2 Load collected from the fish farm

a) Water pump

Data is collected from the site for solar water pump load as follows. Water is required for the fish farm according to the size of each pond shown in Table 1.

Table 1. Water volume of each pond of fish farm

Ponds	Surface area (m²)	Average water depth (m)	Water volume (m³)
1	10052.84	1.5	15079.26
2	6045.34	1.5	9068.02
3	2841.63	1.5	4262.44
4	5366.36	1.2	6439.63
5	1003.84	1	1003.84

The above table indicates each pond's area and depth in the fish farm and required water volume. According to the above-required water volume, 230 m³/hour water flow is suitable for the fish farm. Based on the selected flow rate, 156 hours are required to fill the water into the ponds as needed.

A water pump is selected to fulfill the fish farm's daily water requirement throughout the year. The following measure has been taken for the right pump size and rating.

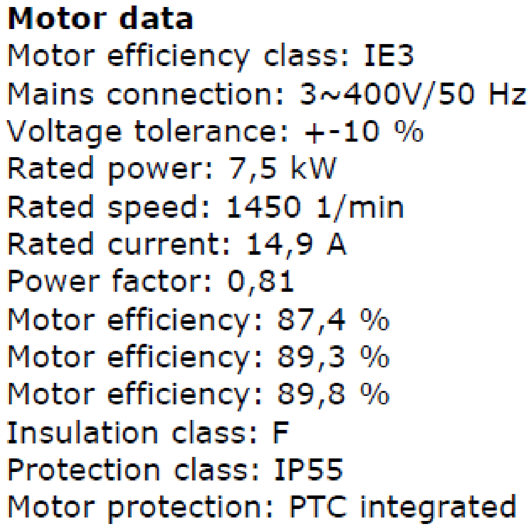
Water level = 15ft= 4.57m

Dynamic head = 25ft= 7.62m

Pipe diameter= 6 inch

Water flow requirement = 230 m³/h

The used online tool for accurate motor/pump size was selected [45]. The motor size came out in result is 10 HP. The motor details are described in below Figure 17. The proposed pump model is Atmos GIGA-B 150/180-7, 5/4 Single-Stage centrifugal pump.



Motor data
Motor efficiency class: IE3
Mains connection: 3~400V/50 Hz
Voltage tolerance: +-10 %
Rated power: 7,5 kW
Rated speed: 1450 1/min
Rated current: 14,9 A
Power factor: 0,81
Motor efficiency: 87,4 %
Motor efficiency: 89,3 %
Motor efficiency: 89,8 %
Insulation class: F
Protection class: IP55
Motor protection: PTC integrated

Figure 17. Motor specifications

Water pumping depends on weather and freshwater replacement in the pond throughout the year to maintain the water level and temperature. The water pump runs mainly in the daytime daily throughout the year, and the particular hours are described in the table 2 below.

Table 2. Water pump yearly schedule

Schedule	Months	Time	Daily Hours
1	November to May	09:00-16:00	7
2	June to July	06:00-18:00	12
3	August to October	08:00- 16:00	8

b) Aeration system and lights

This system is simply working as an air blower in the water, and its purpose is to allow oxygenation of the pond, especially in the nursery pond. This fish farm nursery pond size is 10805 ft² and 0.25 acres. Regular aeration can displace 325,900 gallons of water every 24-48 hours, adding 3.2 lbs of oxygen per horsepower per hour. If the fish farms are located in warmer climate areas are needed a 0.5 hp aeration system because of 2 hp aeration per surface acre for warmer climate areas [46]. The aeration system is only used at nighttime for the nursery pond to maintain the oxygen level in the pond.

There is also 4 LED Light bulb used in the fish farm, which is used in the nighttime. Each light size is 23W. Load details are in the below table 3 of the aeration system and lights.

Table 3. Aeration system and lights load details

QTY	Component	Load	Time	Daily Hours
1	Aeration System	0.5 hp	22:00-6:00	8
1	Indoor Light	23W	18:00-22:00	5
4	Outdoor Light	23W	18:00-06:00	12

c) Load profile

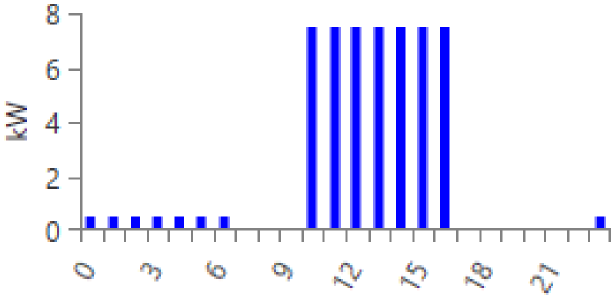


Figure 18. Daily load profile

Hence, the load profile is generated in HOMER Pro based on the above loads in Tables 2 and 3. This load profile in kW in 24 hours daily in Figure 18. The maximum load observed was 64.63 kW during the daytime.

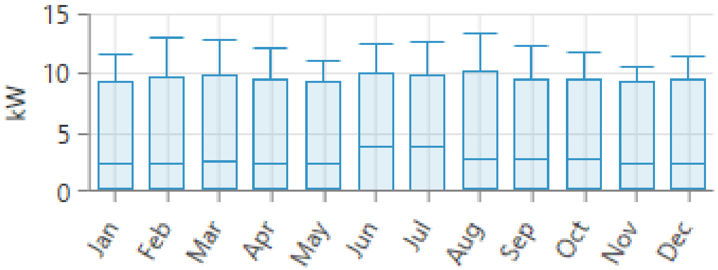


Figure 19. Seasonal load profile

Another Seasonal load profile can be seen in Figure 19. The peak load of 13.48 kW is in August, and the minimum load is generated in November at 10.55 kW. However, the minimum average load shown in the middle of the bar was 2.26 kW in February.

3.2 Sizing and design the solar system

We used HOMER software for sizing and designing purposes, and the above-given load details in Tables 2 and 3 were used as an input into the software with the fish farm location.

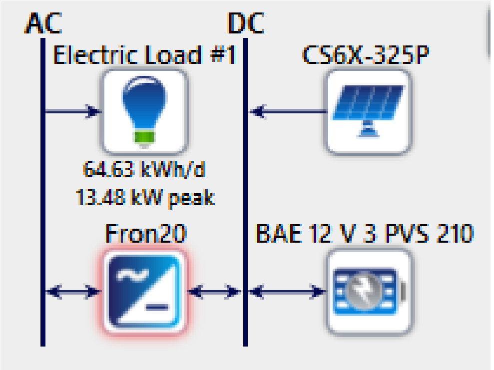


Figure 20: Model of solar PV system in HOMER Pro

As a result, generated simulation with an optimum rating of all required components for the solar power system for the fish farm. The diagram of the PV system for the fish farm can be seen in Figure 20. The Daily calculated load is 64.63 kWh/d, and the peak load is 13.48 kW. HOMER proposed the PV panels of Canadian solar max power CS6X-325P [47], batteries BAE secura solar 12V 3 PVS 210 required 60 in numbers [48] and inverter offered is 20kW of Fronius Synmo 20.0-3-M to fulfill the 100% renewable solar-powered PV system for the fish farm [49].

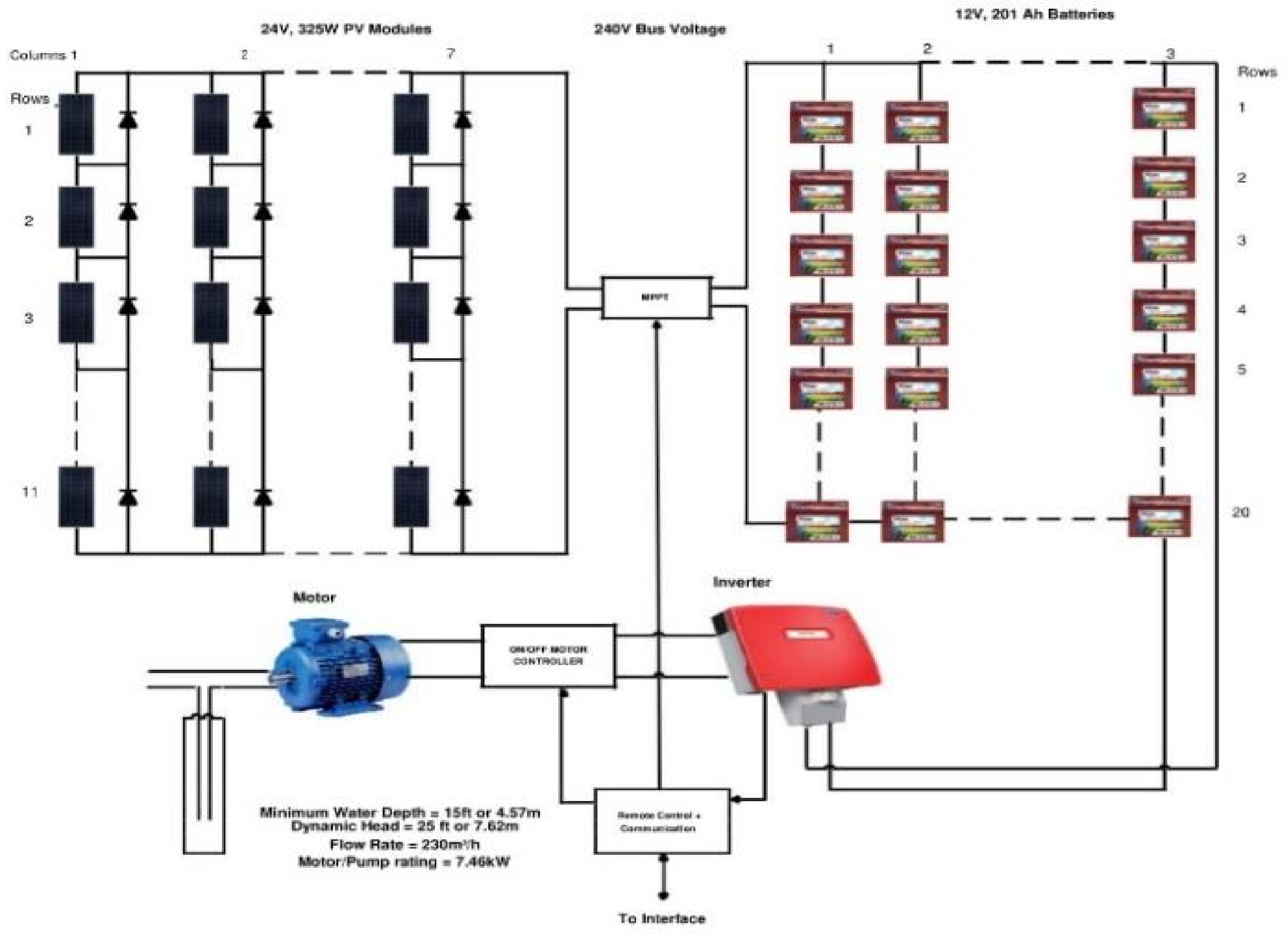


Figure 21:HOMER Pro proposed system diagram

Figure 21 is the diagram of the PV solar system and describes the Solar PV panel source of 24.7 kW. About 77, 325W PV modules can be connected in 7 strings, with 11 modules in each string. 60 batteries proposed with this system, placed in 3 stings and 21 batteries in each string, meaning a bus voltage of 240v.

3.3 Results

The simulation was carried out through HOMER Pro. This Include financial analysis, monthly power production by the system, cash flow, and operation & maintenance cost. Cost analysis is provided in Pakistani rupees (PKR). Currency conversion is 1 USD is equal to 176.95 PKR.

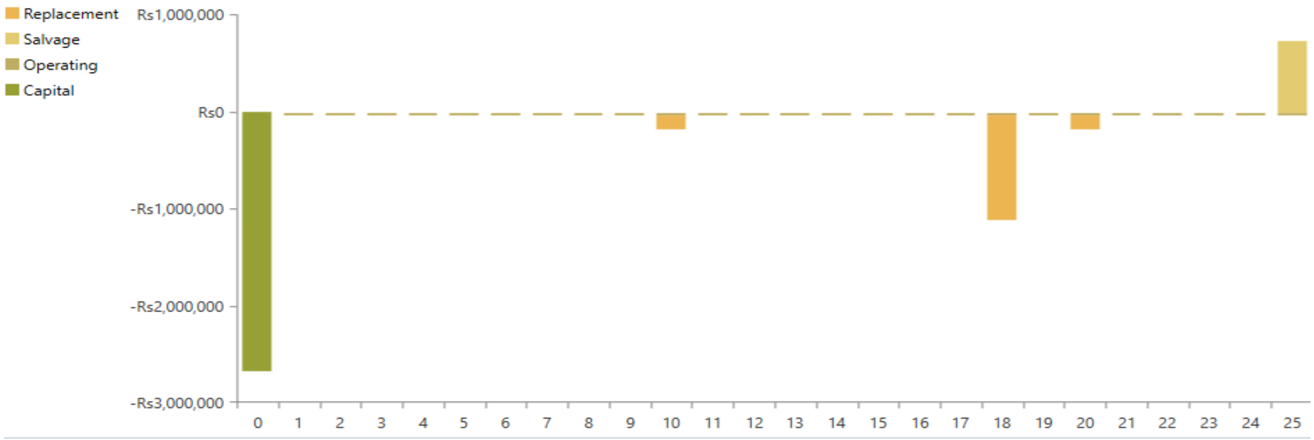


Figure 22. Cost summary of the system

The economic analysis completed 25 cycles over the life cycle in Figure 22. The cost of the summary of the system is shown above, and the overall total net present (NPC) of the system is 3,395,740 Pakistani Rupees (PKR). The Levelized cost of the system is 11.14 Pkr, and the operating cost is 55,193.50 Pkr per year.

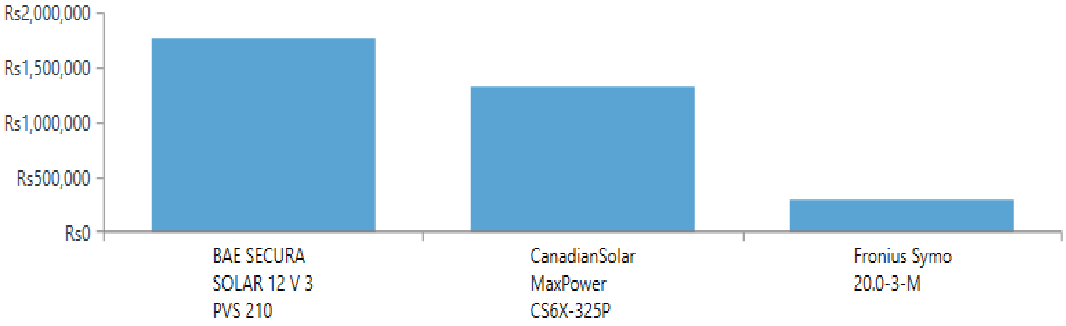


Figure 23. Cash summary of the system

Figure 23 indicates cash flow over 25 years calculated for the proposed system. The total initial cost of the system is offered 2,682,224.97 Pkr, and the annual operation & maintenance cost is 375,556.07 Pkr is required for the next 25 years of the system life cycle. Initial Cost breakdown for components are following batteries 1,302600 Pkr, Solar PV panels 1,235,507.68 Pkr and Inverter 1,44,117.29 Pkr.

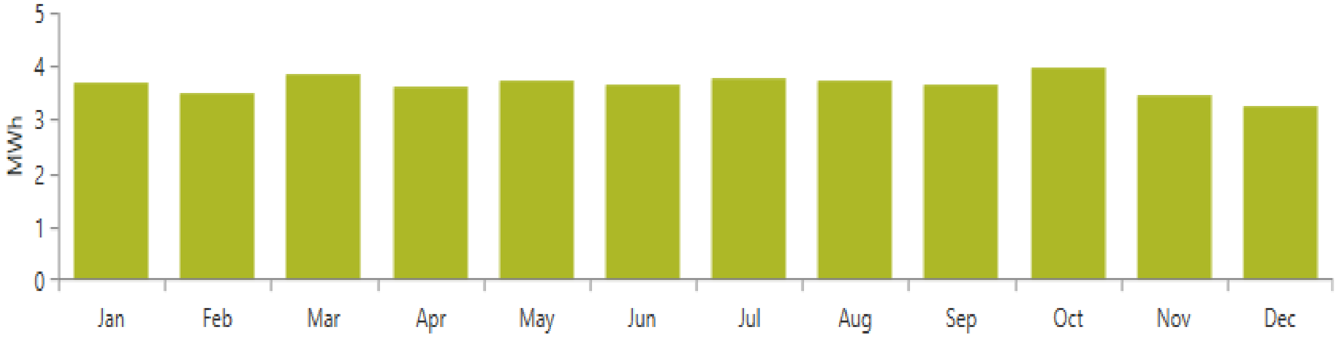


Figure 24. Monthly electric power production by the solar panels

The monthly electric power production simulation result is shown in Figure 24. The proposed PV solar system can see maximum power production in October and March. The electric power production is 100% generated by a Solar PV system of 43,841 kWh/yr.

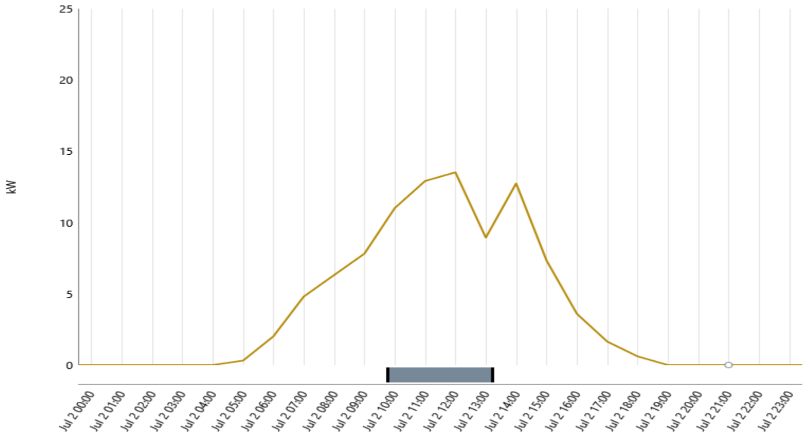


Figure 25. Daily solar output by the solar panels

As shown in Figure 25, the selected day is 2nd July, and the daily solar power output and the maximum power output is 13.5 kW of the PV solar panels. It means the chosen location has plenty of solar energy in the peak daytime. The site is selected Dera ghazi khan, south Punjab, Pakistan. Summer months have a maximum duration of sunlight.

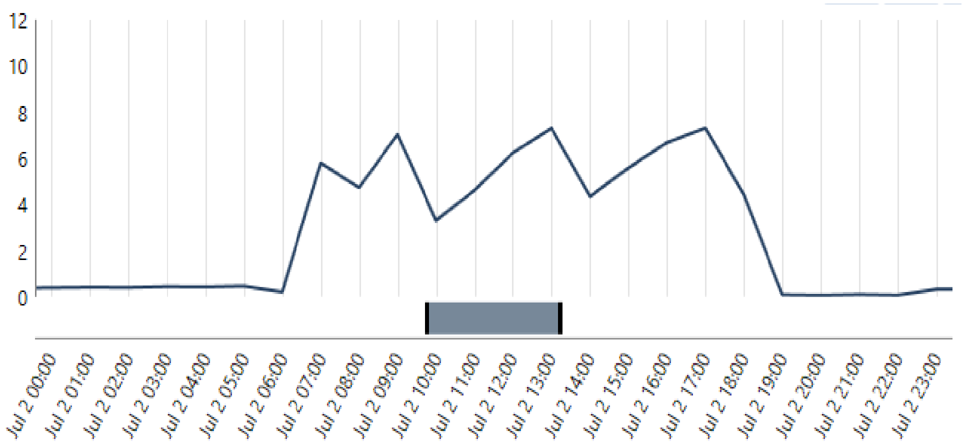


Figure 26. Electrical load served by solar panels hourly

Figure 26 shows the total electrical load served during a day. The water pump runs in the daytime to refill the water in the fishponds. The maximum load served in the daytime is 7.31 kW, and the minimum load is served at 3.31 kW during the day.

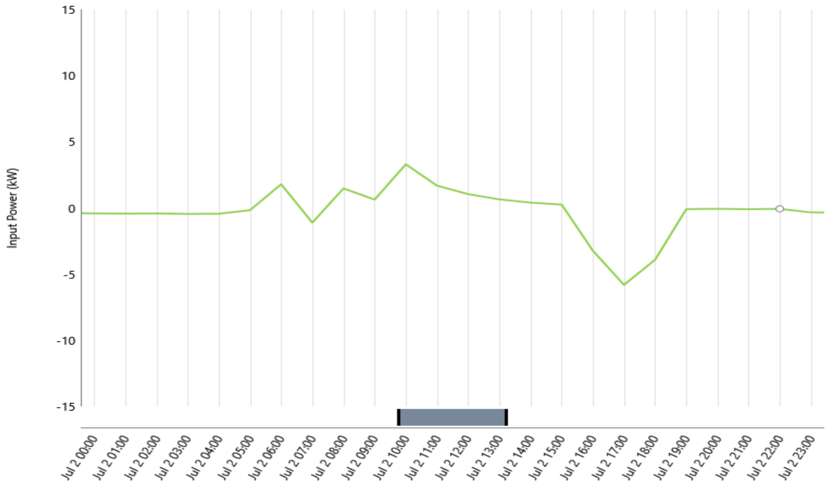


Figure 27. Battery input power to the system

In Figure 27, at the start of the day battery remains on charging mode, and before evening when the sun is down, the battery starts inputting to the system at a maximum of -5.82 kW. The battery shows negative when the load is served for the system and when in charging mode, it shows positive

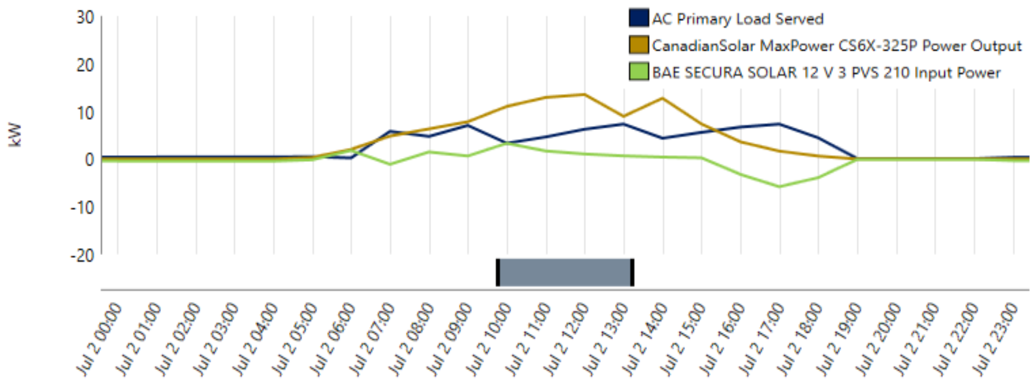


Figure 28. Power sources comparison

Figure 28, Shows the comparison of PV panels, Ac load, and batteries. Early in the morning, Ac load is served through batteries -1.12kW when PV panels output noted 4.80 kW and load power required 5.79 kW. The rest of the day can be seen PV solar panels production is 13.52 kW when the required load is 6.23 kW, and batteries remain on charging at 1.04 kW. So, when sunset time is close in the evening, the system again turns on batteries at -5.82 kW, when the load is 7.31, and PV Solar panel production reduces to 1.65 kW.

3.4 Conclusion

This chapter presents the basic design of a solar PV system for the fish farm off-grid in the rural area of Pakistan. HOMER Pro software is used to design and optimize the solar PV system, which is 100% renewable energy. The proposed system can be seen in figure 19. The system required a 24.7kW photovoltaic source, which can be obtained through 77 of 325W PV panels using 7 strings, and each string has 11 panels through series connections, as shown in figure 20. The power converter required a commercially available 20kW inverter that fulfills 13.8 kW. The system proposed 60 batteries for smooth running the electrical power 24/7 for the fish farm as per requirement. Three strings are offered for batteries, and each string has 20 batteries. The battery capacity proposed is 12V 201Ah. Proposed system cost also analyzed initial cost and operation & maintenance cost is acceptable and one-time investment for the fish farm at economical maintenance cost. Simulation results show a smoothly working solar PV system design accommodating the fish farm electric power requirements.

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CHAPTER 4

AUTOMATION AND CONTROL OF WATER PUMPING SYSTEM

4.1 Site Survey and Data Collection

On 4th February 2022, A Site visit survey was conducted on the Fish farm with local fish farm owners and gathered all information from the fish farm and pictures taken during the visit.

Figure 29. Fish farm pond refilling after cleaning

The above Figure 29 was taken during the survey from the fish farm while refilling the water in the pond after the yearly pond cleaning. Solar PV panels can be seen in the picture. The Fish farm was ready for the new season.

Figure 30. The water pumping system of the fish farm

The water pumping system can be seen in Figure 30. The water pumping system is powered by solar PV panels. The water pumping system was manually operated by labor based on the water level observed in the pond. The fish farm production cost and electrical consumption increased using the conventional this method. The labor cost was found high in this favor.

Figure 31. Nursery ponds and aeration blower in operation at the site

Nursey ponds can be seen in Figure 31. The Aeration blower was in operation, which is used to maintain oxygen levels in the ponds. Fisheries can not survive and grow if oxygen levels are not maintained between 8-20mg/L in water. The aeration system is needed to maintain the level of oxygen in the water.

4.2 Proposed Control System

Based on the fish farm survey and collected information, there was no automated water pumping control system. Here, we proposed an automation and control system for turning fish farms into modern fish farms, low cost and featured with current technologies. For design and simulation purposes, we are using TinkerCad Software. This software is used for 3D modeling and circuit design, and simulation. TinkerCad also generates code for programming Arduino microcontroller.

4.2.1 System components

The following components are used for the control and automation of the pumping system

i- Arduino UNO micro controller
ii- Ultrasonic Sensor for water level measurement
iii- Motor for the pump
iv- Relay for the motor control
v- LCD Screen for local display

i. Arduino UNO

Arduino UNO is a microcontroller board based on the ATmega328P in figure 32. It has 14 digital input/output pins, six analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, ICSP header, and a reset button. Simply can connect to the computer through a USB cable. This microcontroller is readily available at a low cost [50].

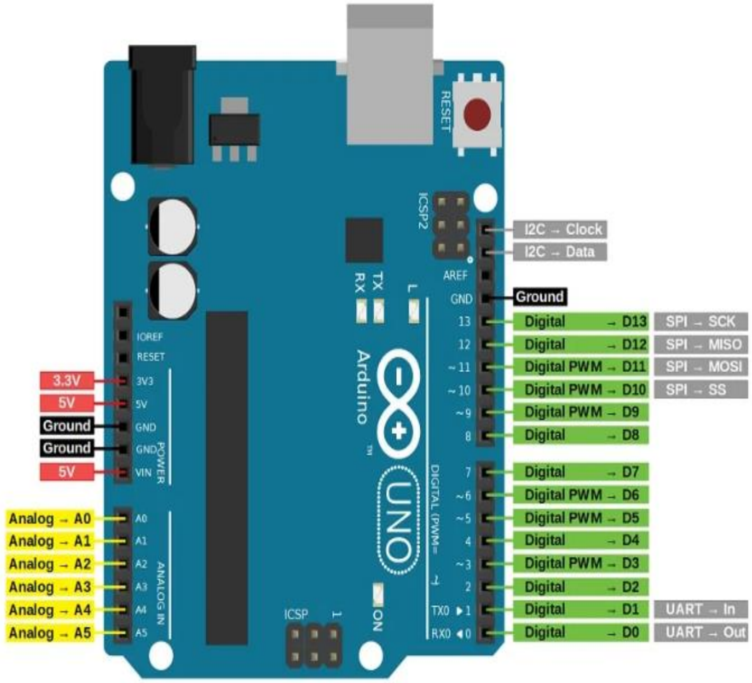


Figure 32. Pin Configurations of Arduino Micro Controller [50]

ii. Ultrasonic sensor

An ultrasonic sensor is an electronic device used for the measurement of the distance of any object by ultrasonic waves and converts the reflected sound into an electric signal. In Figure 33 HC-SR04 model is used for automation and control of the pumping system. The sensor consists of receiver and transmitter parts that process the signals as input and output. Ultrasonic water level sensor PING is also low cost and easily available in the market. Approximately range is 1inch to 10 feet and dimensions are 0.81x1.8x0.6 in. operating temperature range: +32 to +158 F (0+70C) [51].

Figure 33. Ultrasonic sensor

iii. Motor

The motor is used from the library of the TinkerCad and the part of this system. The motor converts electrical energy to mechanical energy. In the designed system, the Motor attachment to the microcontroller demonstrates the water pump run by an electric motor.

iv. Motor relay

A relay is a switch that opens and closes the circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing another circuit. In this system, Relays are attached to the motor in a series connection using TinkerCad.

v. LCD screen

In Figure 34, liquid Crystal Display (LCD) 8-bit used from the TinkerCad Library allows system display. LCD accepts the computer's serial input and uploads the sketch to the Arduino, and characters are displayed on the screen.

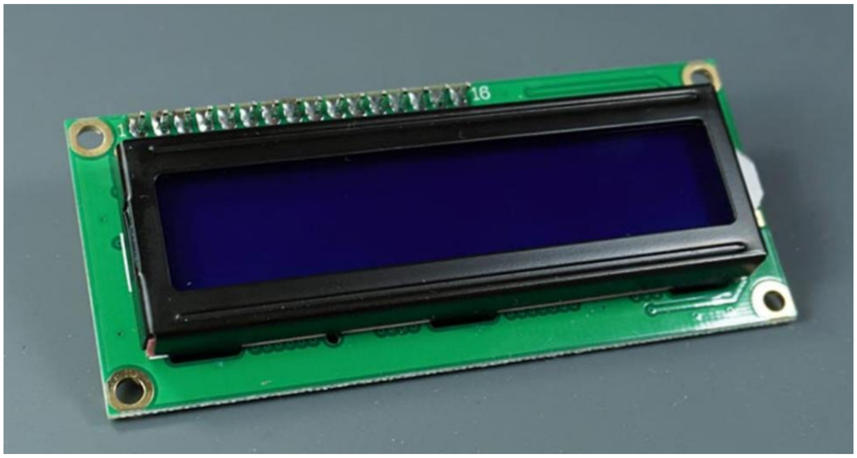


Figure 34. LCD screen

Name	Quantity	Component
R5	1	220 Ω Resistor
U7	1	Arduino Uno R3
U8	1	LCD 16 x 2
PING1	1	Ultrasonic Distance Sensor
T1	1	NPN Transistor (BJT)
R6	1	1 kΩ Resistor
M1	1	DC Motor
S4	1	Slideswitch
K1	1	Relay SPDT

Figure 35. Design system components list

Figure 35 shows the components list used from the TinkerCAD library for the system design.

4.2.2 Flow chart of the system

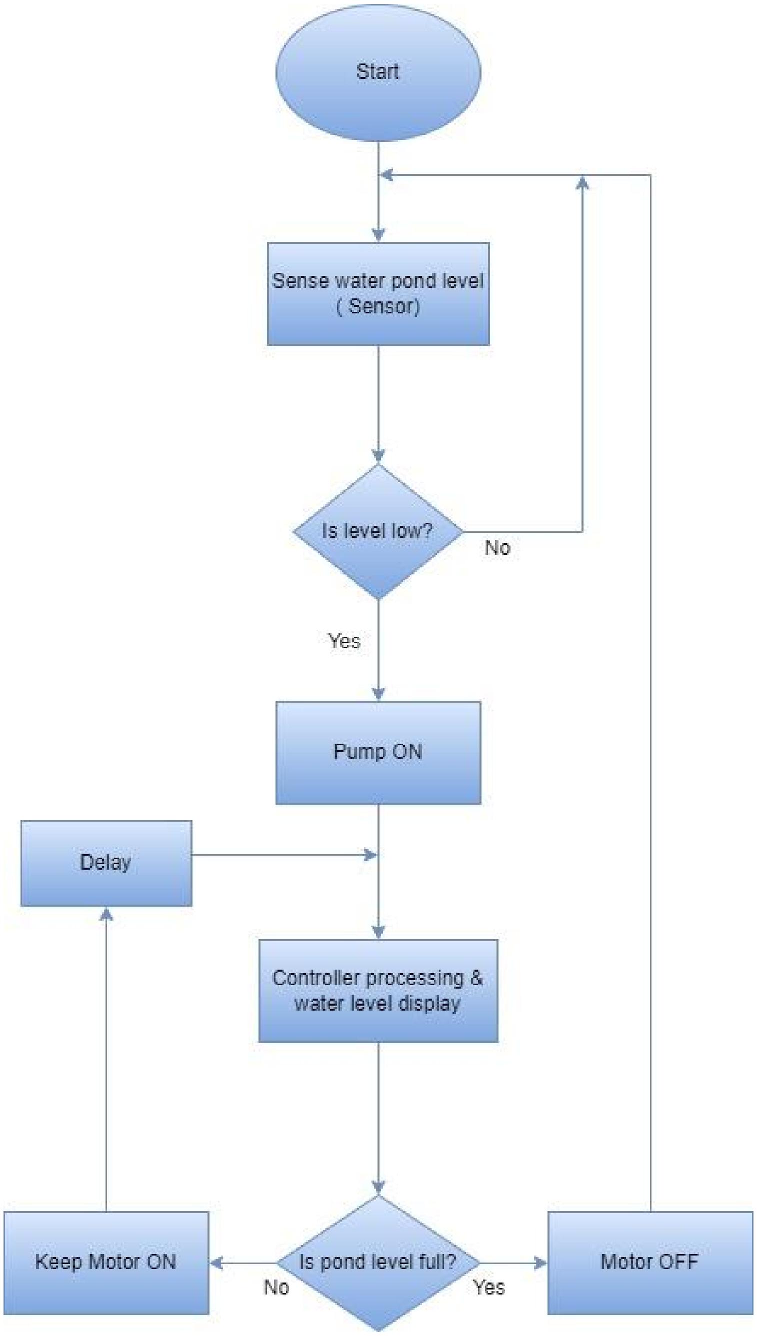


Figure 36. Flow chart of the system

The Solar PV panels Produce 64.63kWh/d, and a 20-kW inverter converts this variable direct current (DC) output into alternating current (AC). This AC power is used to power the water pump. The water pump is used to lift water from the groundwater, and water goes to the fish farm ponds. The microcontroller is used to control the water pumping system. The ultrasonic water level sensor is programmed with the microcontroller and based on water level information, and the microcontroller turns ON/OFF the water pumping system. The system algorithm is shown in Figure 36.

4.2.3 System design

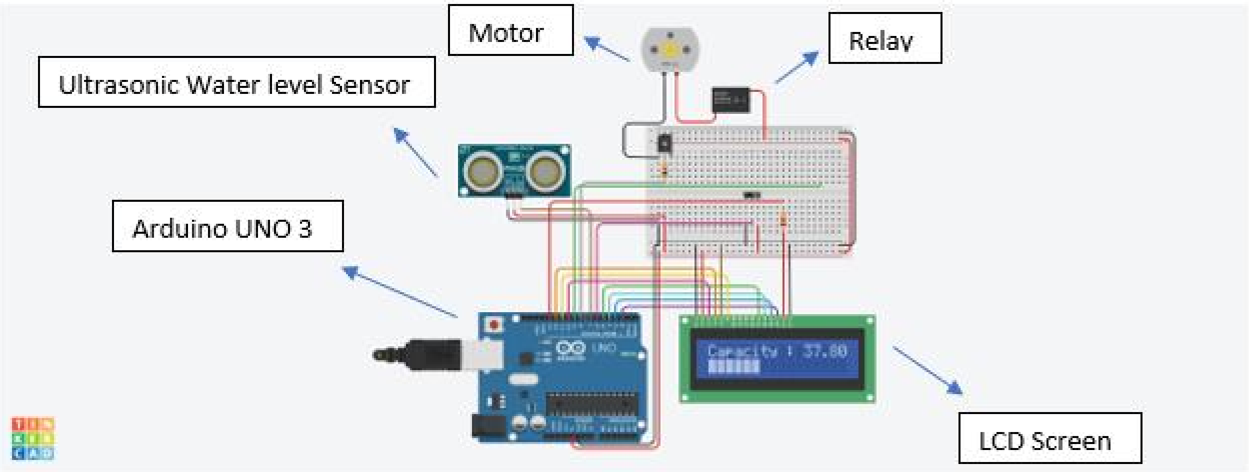


Figure 37. Automated water pumping control system

The running system captured in Figure 37 can be observed to run smoothly when the pond water capacity is noted at 37%, and the water pump starts switched ON for refilling the pond. The Proposed Control system is based on the Arduino UNO R3 microcontroller device. Figure 37 shows all system components of the system. Design components are a motor, relay, Display screen, Arduino UNO, and water sensor. Usually, the water level required in the ponds is between 1-2 meters. An ON/OFF sliding switch is placed in the center of the breadboard for powering the system. The water level sensor gives the information to the microcontroller, and based on this information microcontroller turns the ON/OFF motor, and the system works as designed. An Ultrasonic sensor in Figure 38 used for measurement of the water level in the aquaculture pond.

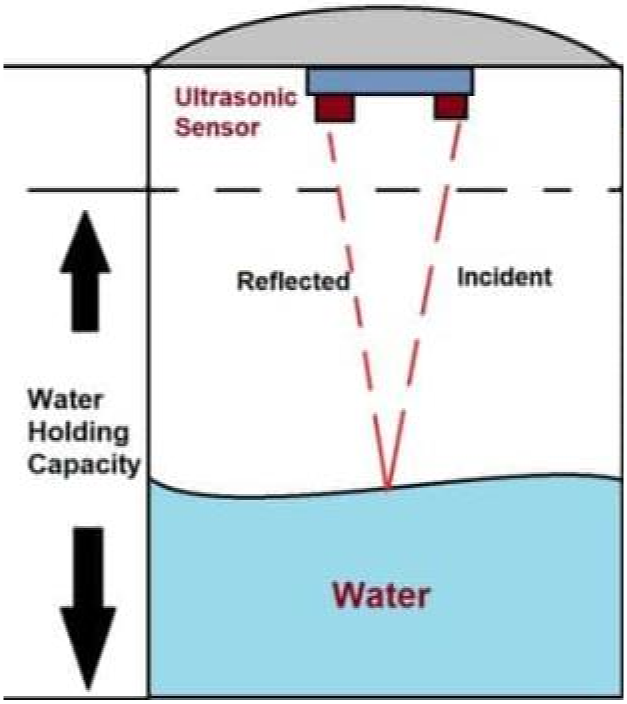


Figure 38. Ultrasonic sensor used for water level measurement

Table 4.Observation Table

SR.NO	OBSERVATION	MOTOR STATUS	POND LEVEL
1	Motor Switch	ON	Empty
2	Filling the Ponds	ON	1m
3	After reaching the level Motor Switch	OFF	1.5m

Table 4. Explains the system working—water level required in the pond maximum 1.5m. Using Tinkercad software water pumping automation and control system is designed, and the ultrasonic sensor is programmed at a 1.5m water level maintained in the pond. ThinkerCAD simulation shows that the

microcontroller turns ON the water pump when the water level remains below 1.5m and starts filling the water pond. Three observations were noticed in the simulation results first, when the pond level is empty, and second when the water level is below 1.5m. In both conditions, the water pumping system turned ON. The third condition observed when water remained at 1.5m only this condition water pumping system turned OFF automatically.

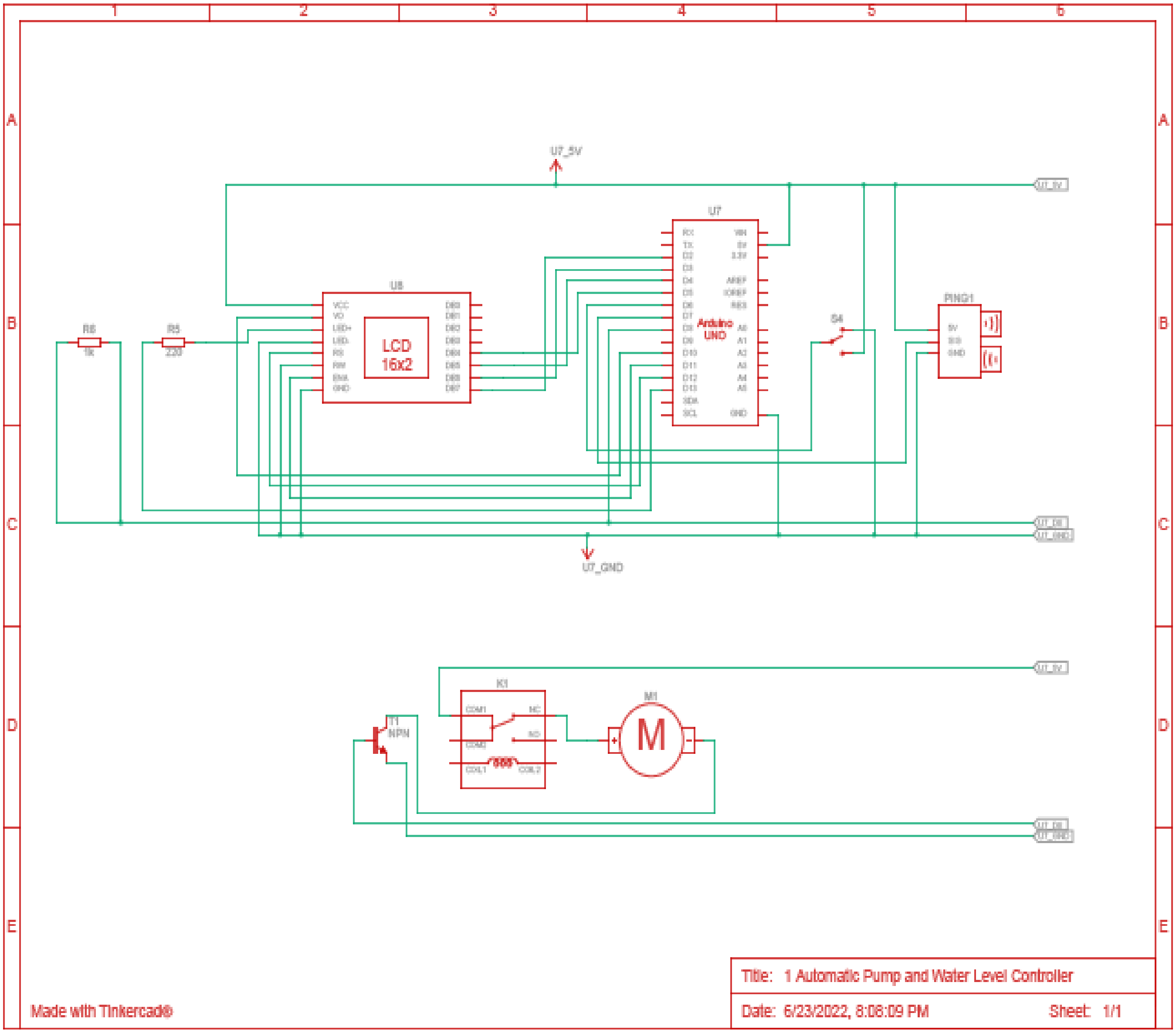


Figure 39. Complete circuit diagram

Figure 39 diagram shows component ports and can easily understand the connections between each component. Green lines indicating the wire connections between components and components are indicated with red color. The diagram is auto-generated by the TinkerCad after simulation results.

4.3 Conclusion

The proposed control system is beneficial for a low-cost automated solar water pumping system, a modest solution for the fish farm business in developing countries. This system can reduce labor costs, electricity usage, and production cost for aquafarmers. The industrial microcontroller and sensor can be used for aquaculture's water pumping system automation, which is very economical and affordable for aquaculture businesses in developing countries.

CHAPTER 5

FISH FARM HEALTH MONITORING SYSTEM

This chapter is based on the fish farm health monitoring system after the data collected through the site survey. Fish farming is mainly dependent on water quality throughout the year. In this aspect, there must be a system required 24/7 for monitoring the water quality. In this chapter, a low-cost system design is presented to monitor 24/7 water quality for aquaculture remotely.

5.1 Water quality

Aquaculture requires intense water quality and production care, and in this section, we describe the metrics that need to be monitored. Fish and shrimps are the most widely consumed seafood in around the world. The main parameters should be considered in terms of water quality.

Temperature

Water temperature is an essential variable in aquaculture but is uncontrollable in aquacultures and is determined by solar radiation, air temperature, or the temperature of the water passing through the culture unit. Aquaculture must be timed correspond with water temperature, and measurement accuracy is necessary for efficient operations [52]. Aquatic animals cannot regulate their body temperature and rely on the temperature of their surroundings to survive. There are a few types of species (cold water, warm water, and tropical). Most of the fisheries required 20 to 25 Celsius water temperature for survival. The reproduction of aquatic animals is likely to be hampered by rising water temperature caused by climate change [53].

pH

pH is like a temperature-determined value based on a recognized scale. The pH scale span from 1 to 14 is used to determine the degree of acidity in water. The 7 value is neutral, meaning it is neither nor basic; values below 7 are acid, and over 7 are basic. The aquaculture pH level of water must be controlled because fisheries will die in case of high or low levels of pH in water [54]. The aquaculture recommended pH value is 6.5-9.0. and 12 pH is considered chemical or heavy metal solubility and toxic water [55].

Dissolved-oxygen

In aquaculture fisheries, low dissolved-oxygen concentration is the primary cause of stress, poor appetite, slow growth, illness, and mortality. The minimum daily dissolved-oxygen content in aquaculture is 6-20 mg/L. During the 24 hours, dissolved oxygen levels can be high. Still, the response of fisheries can be seen to be predominantly influenced by the low level of dissolved oxygen during the night [56].

5.2 Problem statement

It can be observed in the literature review that aquaculture is one of the most growing industries in developing countries. The practice of rearing marine fisheries in an artificial environment such as ponds and tanks is known as aquaculture. While production of these fisheries in artificially designed environments, many factors come into consideration. Financial development and food production are critical in this activity and facing enormous global challenges. The most significant are viral, bacterial, and fungal diseases. All of them were discovered as a result of water quality.

Water quality changes can stress the fisheries and threaten their survival. To determine water quality parameters, most aquacultures rely on manual methods. Manual testing takes time and produces inaccurate results because of the parameters and, on the other hand, insufficient facilities close to their aquaculture. Parameters of water measurement change regularly and are inconsistent.

5.3 Objectives

Our proposed system's primary goal is to assist aquaculture in measuring the water quality parameters in real-time using IoT and cloud technology. Our designed system is centered on an automated system that measures and displays the Water level, water temperature, water pH level, and dissolved-oxygen level of water on the website and phone App. Aquafarmers can also access the system anywhere in the world remotely with a real-time health monitoring system. Using Ultrasonic water level sensor, Temperature sensor, water pH sensor, and dissolved-oxygen sensor to monitor the water quality metrics. All sensors are connected to an Arduino UNO R3 microcontroller.

The Data of the real-time health monitoring system are recorded and saved in the cloud. Data display in the form of time series charts ad histograms available, alongside the senor reading on the website and phone App.

5.4 Main contribution

1. Monitoring water level, Temperature, pH, and dissolved oxygen level in the water.

2. Remote Access to the Health monitoring System through website and Phone App

3. Timer series charts of water level, Temperature, pH of the water, and dissolved-oxygen level.

4. Data visualization that helps aquafarmers analyze fish farm health and improve production at a low cost

5. Real-time health monitoring system for aquaculture

5.5 System design and implementation

The Solution of the problem statement and implementation of the system hardware and software are described below.

5.5.1 System design

This System design consists of two categories. The first is the hardware setup, and the second is software implementation. First, assembling and calibrating sensors and connection with microcontroller Arduino UNO R3. The second part is programing the Arduino and establishing a connection with Wi-Fi for sending data to the server.

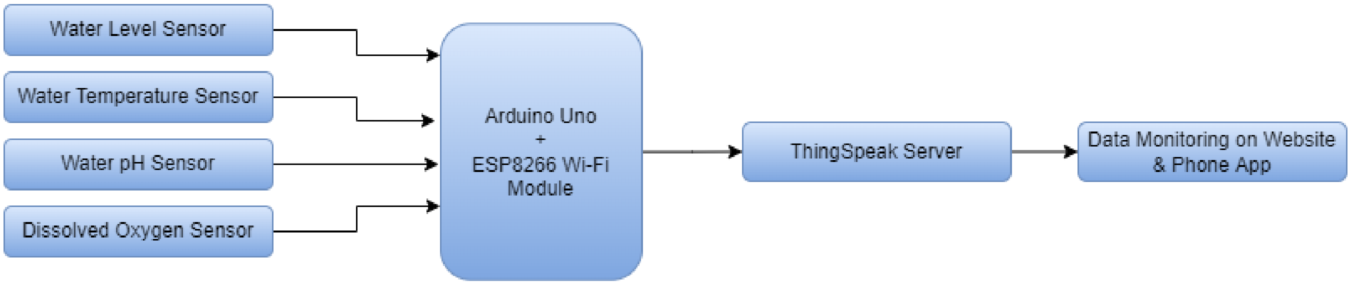


Figure 40: Block diagram of the proposed system

Figure 40 describes the block diagram of the proposed system. The system depends on four primary sensors and is connected to the microcontroller. Wi-Fi module ESP8266 used with Arduino UNO R3 for communication with server ThingSpeak. The Fish farm is off-grid and operates through a 100% solar-powered PV system. So, the health monitoring system can also be accessed through a website and phone App.

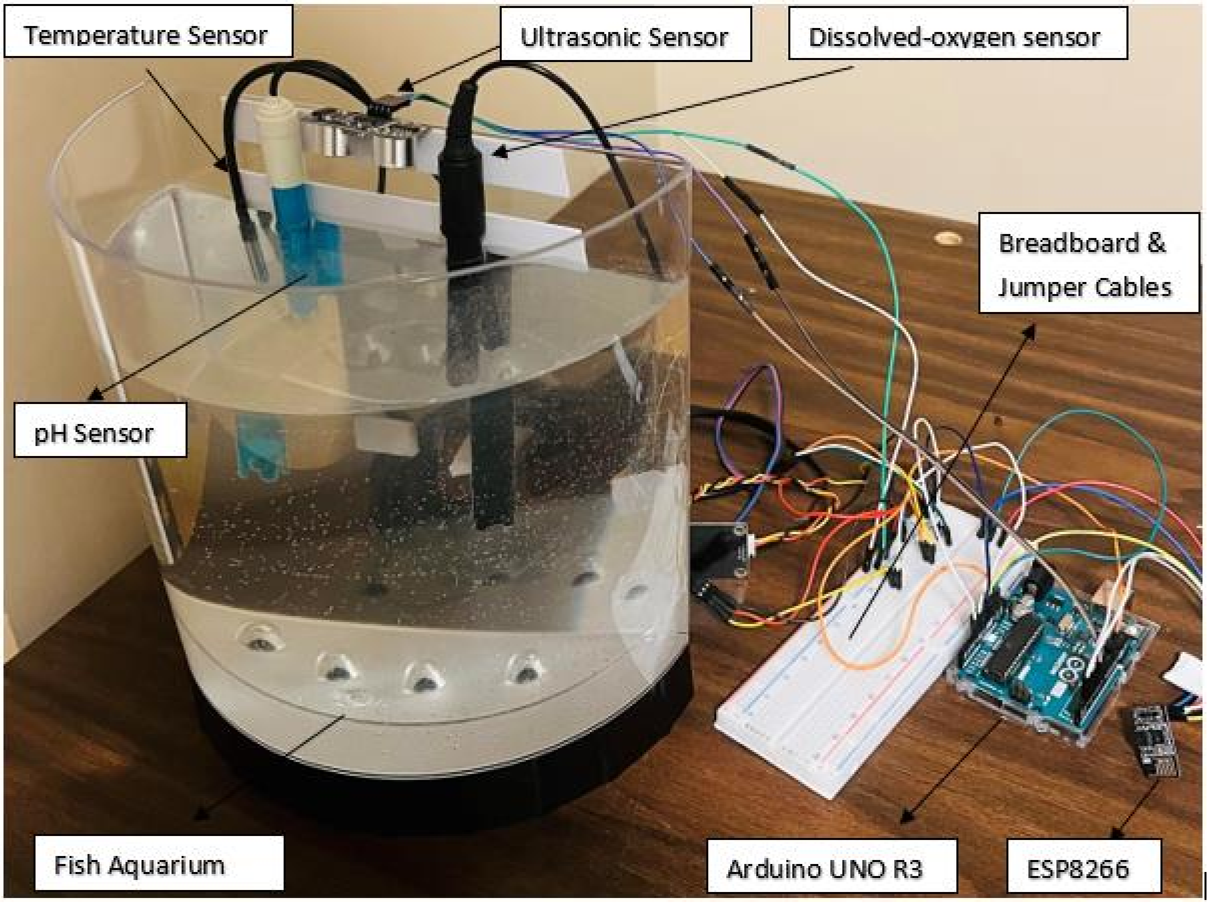


Figure 41: Proposed health monitoring system

The hardware assembled proposed system is illustrated in Figure 41. The micro-controller Arduino Uno R3 is used with the ESP6288 Wi-Fi module. The system is designed for the four most crucial water metrics measurements, and these values are taken by using water level, temperature, water pH, and dissolved oxygen sensors. The fish aquarium is used for system testing. An aquarium with tap water and sensors hung into it to get data from the sensors. Sensors are calibrated before installation and precisely checked using standard techniques such as pH sensor in buffer solution, dipping the dissolved oxygen sensor in zero dissolved solution, temperature sensor, and ultrasonic sensor reading using physical scale.

i) Arduino Uno R3

Figure 32 shows Arduino UNO is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins, six analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, ICSP header, and a reset button. Simply can connect to the computer through a USB cable. This microcontroller is readily available at a low cost [50].

ii) Ultrasonic sensor

An ultrasonic sensor is an electronic device used for the measurement of the distance of any object by ultrasonic waves and converts the reflected sound into an electric signal. HC-SR04 model is used for automation and control of the pumping system. The sensor comprises a receiver and transmitter side that process the signals as input and output. The sensor is shown in Figure 33 in previous chapter 4.

iii) Temperature sensor

The waterproof temperature sensor DS18B20 measures the temperature in Figure 42. This sensor is capable of any liquid in wet conditions for measuring temperatures ranging from -55C to 125C and can be powered by a 3.0v to 5.5v power supply. The sensor cable is coated with PVC. The best is to keep using under 100C. The dallastemperature.h downloaded through the IDE library, which is required to use this sensor with Arduino Uno R3. Sensor specification is described in Table 5, and pin connections in Table 6.

Table 5: Specifications of DS18DS20

voltage	3～5 V.
Measuring range	-55～+125 °C.
Accuracy	±0.5°C.
Conversion time	750ms at 12-bit.

Table 6: Temperature sensor and Arduino pin connections

Pin Connections	
Temperature sensor Pins	**Arduino Pins**
Red wire	5V.
Black wire	GND
Yellow wire	12.

Figure 42: Temperature Sensor

iv) pH sensor

Water pH level is the essential part of this designed system. Figure 43 DFRobot SEN0101 sensor used, which is known for accuracy in the market and readily available. Results found this sensor is ideal for water quality testing and aquaculture. This sensor is an analog pH sensor designed for Arduino and Raspberry Pi. The sensor works on the electrical potential principle produced. pH value determines based on the measurement electrode and the sensor' reference electrode. Obtained value first received in millivolts, then converted it to the pH using the formula in the code during programming. Sensor specification is described in Table 7 and pin connections in Table 8.

Table 7: Specifications of SEN0101

voltage	5 V.
Measuring range	*0~14 pH.*
Operating Range	0~60°C.
Accuracy	0.1 pH
Response time	Less than 1 min.

Table 8: pH sensor and Arduino pin connections.

Pin Connections	
pH sensor Module Pins	**Arduino Pins**
Signal/ A	AO
-	GND
+	5V

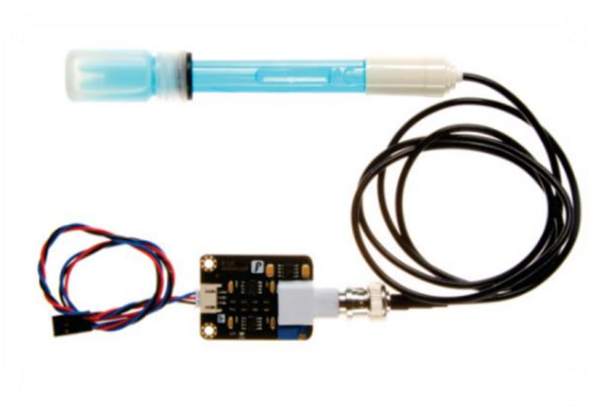


Figure 43: pH sensor.

v) Dissolved-oxygen sensor

Another critical parameter is the dissolved-oxygen level in the aquaculture pond for fisheries life. Fisheries could die in low levels of oxygen in the water. For this reason, maintaining oxygen level in the water and monitoring oxygen value is most important. Figure 44 shows SEN0237 dissolved-oxygen sensor found for aquaculture and environment monitoring is compatible with Arduino micro-controller. Sensor specification is described in Table 9 and pin connections in Table 10.

Table 9: Specifications of SEN0237

Input voltage	3.3-5 V.
Measuring range	*0~20 mg/L*
Operating Range	0~*40*°C.
Pressure	0~50 PSI
Response time	90 seconds

Table 10: Dissolved oxygen sensor and Arduino pin connections

Pin Connections	
pH sensor Module Pins	**Arduino Pins**
Signal/ A	A2
-	GND
+	5V

Figure 44: Dissolved oxygen sensor

5.5.2 Sensor calibration

Sensor calibration must be imported using standard techniques to obtain accurate data before connecting with Arduino. Without calibration using, sensors may be resulting inaccurate measurements. To avoid inaccuracy in measurement values, calibration must be completed before use. The below subsections details describe the calibration of the proposed system sensors.

pH sensor calibration

Simple and quiet calibration needs for pH sensors compared to other sensors. Buffer solution provided in the packaging used for dip sensor probe, measuring the values, and comparing. Verify the values of the sensor on the serial monitor with buffer solution values.

Dissolved-oxygen sensor calibration

A similar method was used to calibrate the dissolved oxygen level sensor. Mainly Sodium Hydroxide (NaOH) solution is required to calibrate the sensor. NaOH solution was prepared and obtained from the chemical laboratory of the university under the safety measures because NaOH is hazard marked chemical and required proper handling with care. NaOH could affect the skin with irritation, burning sensation, and not allowed to smell. 0.5M NaOH has required one-time calibration for the sensor membrane. Single point calibration is recommended and the most common way to use it. First, open the membrane cap, fill it with 0.5M NaOH, close its lid and leave it in the open air for a few seconds, then dip it into sample water for 90 seconds at a temperature of 23 C. This time is to write down the voltage value of the sensor by using a serial monitor display and add this value into the code under the calibration command code. The chemical solution can see in Figure 45.

Figure 45: NaOH flakes and solution

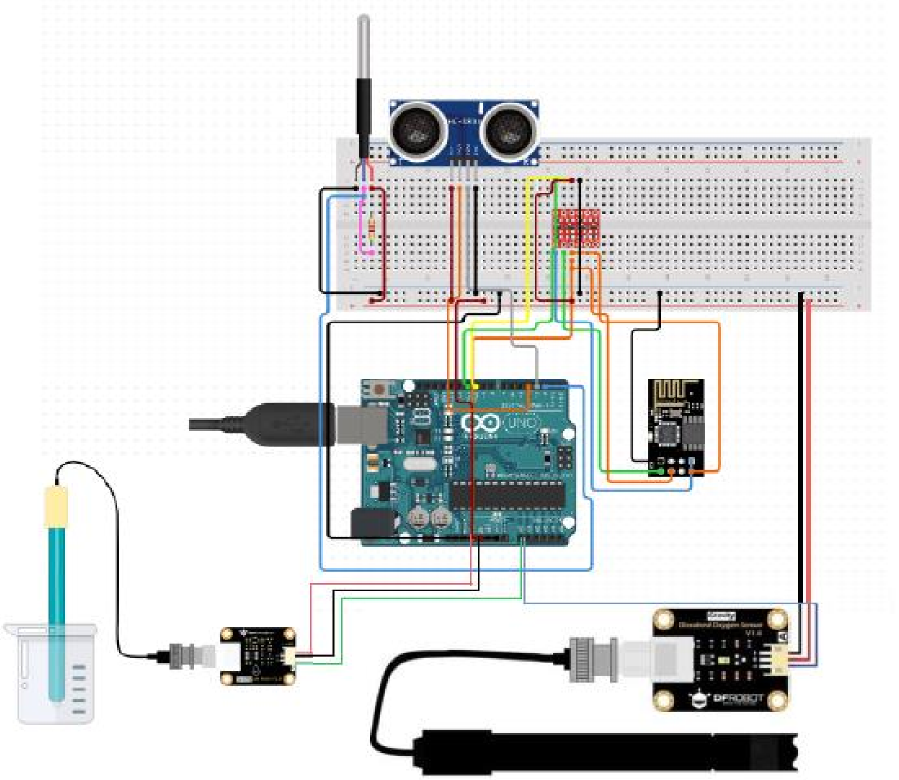


Figure 46. Diagram of the circuit

Figure 46 is the connection diagram of the designed system. Arduino Uno connections with ESP8266, ultrasonic water level sensor, temperature sensor, water pH sensor, and dissolved oxygen sensors are shown in the figure above.

5.5.3 Software implementation

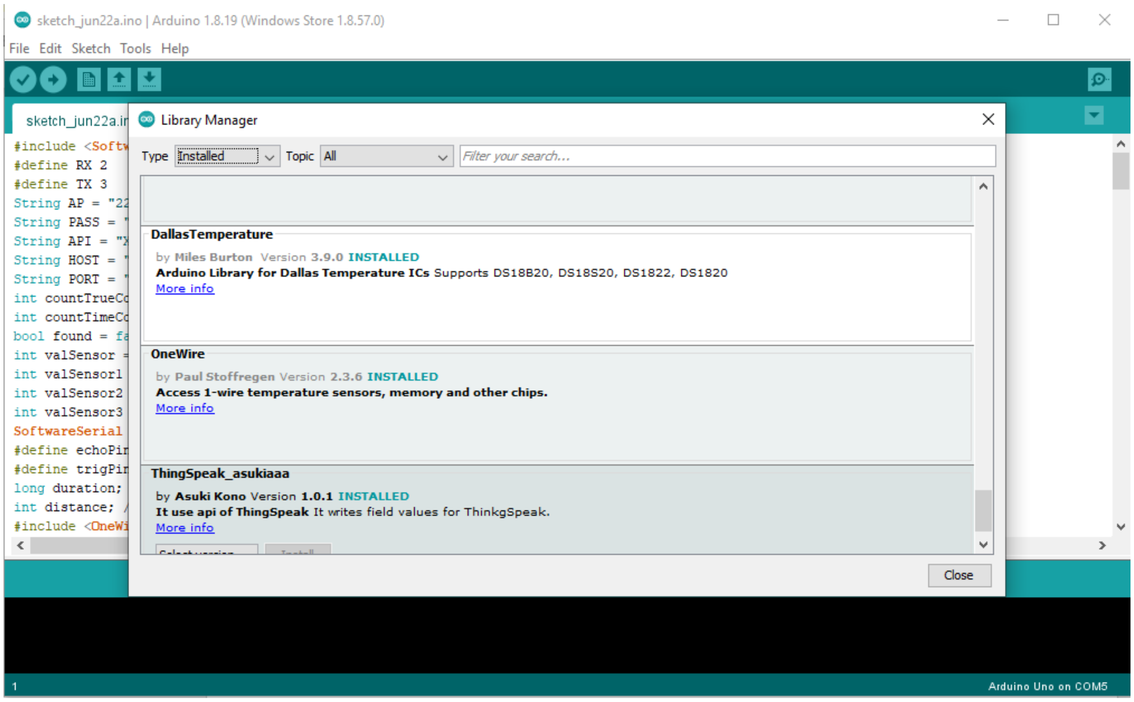
After hardware setup, the second part is software implementation required for the system configurations. On the other hand, suppose the hardware is the backbone of the system. In that case, software implementation is the skin of the system. The software communicates between components, obtains the results from the hardware, and displays the result with time series on the web server and over the phone. Three sub-sections define the software part implications below.

1. IDE for Arduino Programming
2. Writing Data to the Cloud server
3. Reading Data on website and Phone App

5.5.3.1 IDE for Arduino programming

IDE Stands for (Interpreter Developed Environment) designed by Arduino.cc. IDE is available open-source online and compatible with all Arduino modules microcontrollers, ESP32, MKR1000, Arduino Uno, Arduino Mega, and Arduino Nano. IDE could use online and install in all windows operating systems. IDE provides two main parts an editor and a compiler. The compiler is used for compiling and uploading code to the Arduino module by using codes in the editor. C and C++ languages can use to write the code in IDE [57].

After installing the IDE in the Operating system, Editor prompts up while opening the IDE and using Tools from the tab bar to install the required libraries according to the microcontroller module and sensors. After installing the required libraries, the editor is ready to write the code.



```
#include <Softw
#define RX 2
#define TX 3
String AP = "22
String PASS = "
String API = "
String HOST = "
String PORT = "
int countTrueC
int countTimeC
bool found = fa
int valSensor =
int valSensor1
int valSensor2
int valSensor3
SoftwareSerial
#define echoPi
#define trigPi
long duration;
int distance; /
#include <OneWi
```

DallasTemperature
by **Miles Burton** Version **3.9.0** **INSTALLED**
Arduino Library for Dallas Temperature ICs Supports DS18B20, DS18S20, DS1822, DS1820
More info

OneWire
by **Paul Stoffregen** Version **2.3.6** **INSTALLED**
Access 1-wire temperature sensors, memory and other chips.
More info

ThingSpeak_asukiaaa
by **Asuki Kono** Version **1.0.1** **INSTALLED**
It use api of ThingSpeak It writes field values for ThinkgSpeak.
More info

Figure 47: IDE editor and library manager

Arduino Uno microcontroller was chosen for the proposed system. Therefore, Arduino Uno was installed to connect the microcontroller from the library manager, and also installed ESP8266 Library for data transmission through the wi-fi. We also required sensor libraries for the Ultrasonic sensor, Temperature sensor, pH sensor, and dissolved oxygen sensor. ThingSpeak server is used for data transmission and displays wirelessly so that the ThingSpeak library can be seen in Figure 47. After installing the required libraries, start writing and compiling the code. If any error detects in the code button black console displays the errors. Setting up the correct code after error removal, upload the code to the microcontroller, and can see the values of the system on the serial port by clicking up the Toolbar. The system flow chart below can be seen in Figure 48.

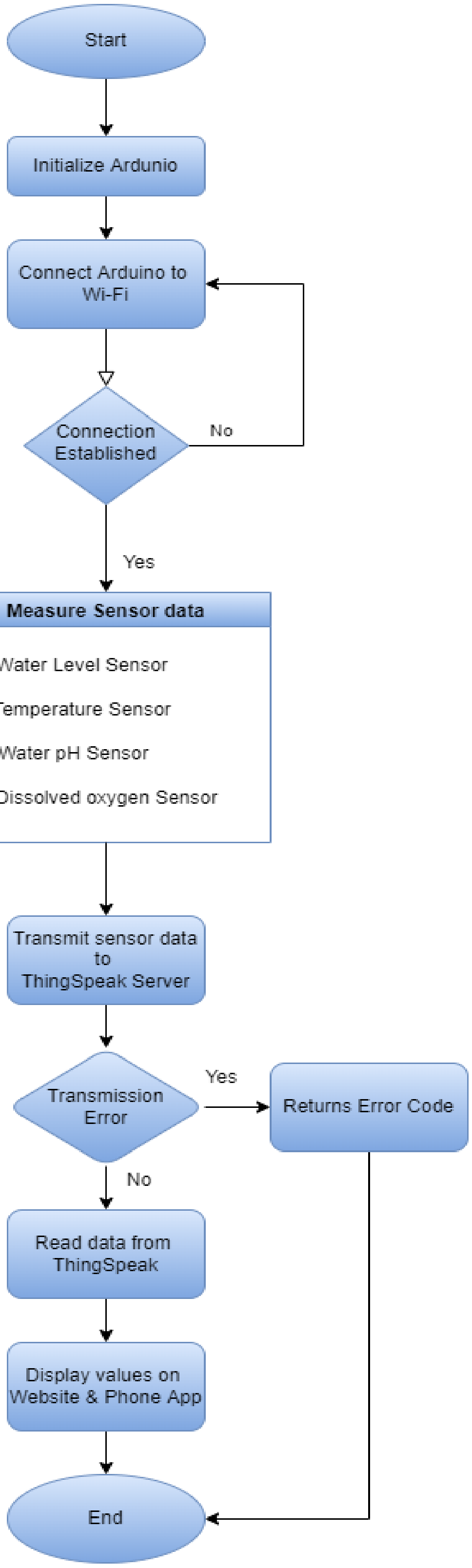
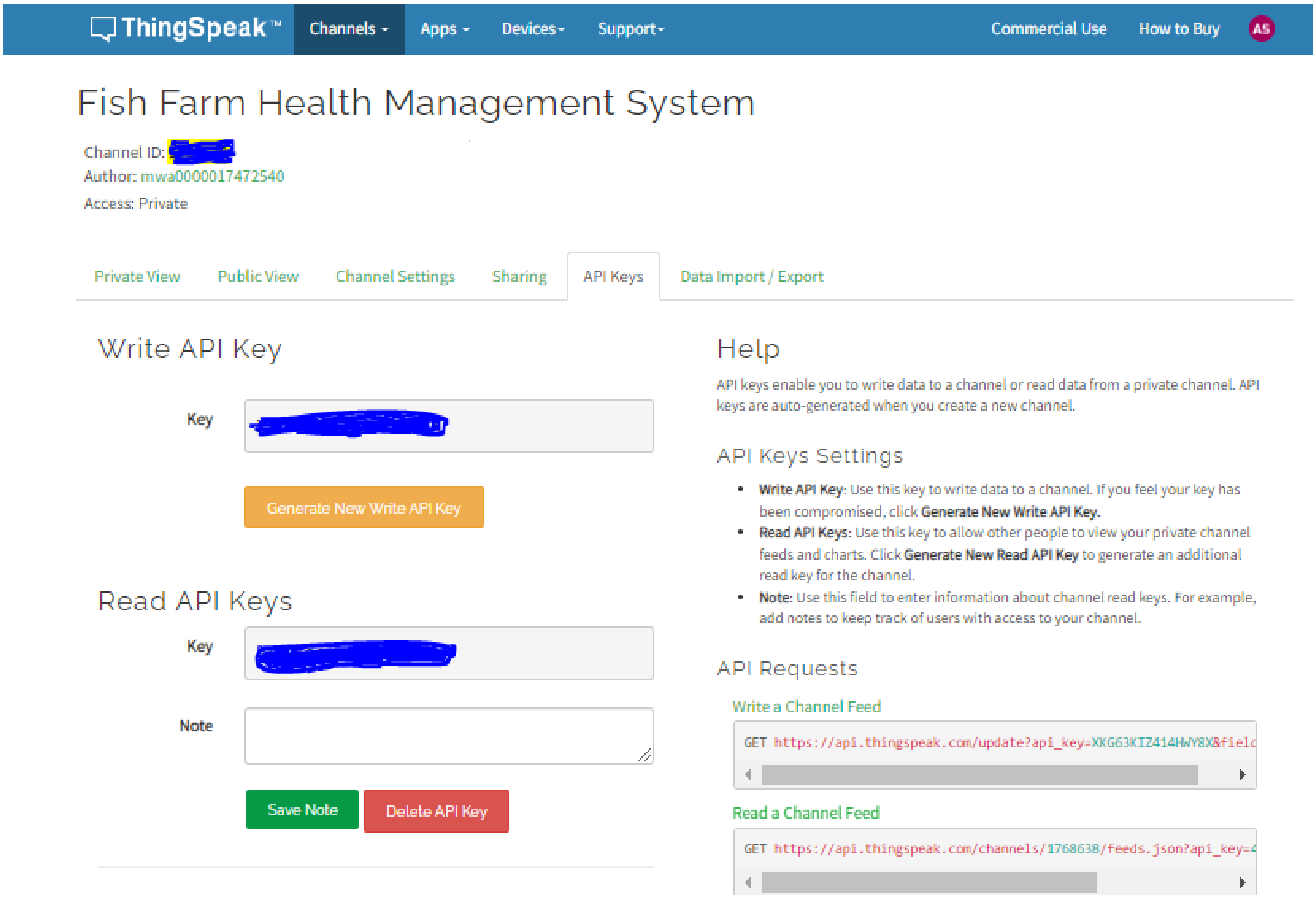


Figure 48: Flow chart of the proposed system represents the functions

5.5.3.2 Writing data to the cloud server

Cloud technologies are renowned these days and transformed the world by providing data storage and IoT services. Many cloud sources are available online Azure, AWS, ThingSpeak, and many more. ThingSpeak was chosen for this proposed system because of its free and open source IoT analytics platform and data storage. On the other hand, other sources are more expensive. The ThingSpeak library is available on IDE, which makes the user very easy to configure. ThingSpeak offers 8 channel fields to access for reading the data. It means 8 sensors could be set up one-time using ThingSpeak.



Fish Farm Health Management System

Channel ID: [redacted]
Author: mwa0000017472540
Access: Private

Write API Key

Key [redacted]

Read API Keys

Key [redacted]

Note

Help

API keys enable you to write data to a channel or read data from a private channel. API keys are auto-generated when you create a new channel.

API Keys Settings

- **Write API Key**: Use this key to write data to a channel. If you feel your key has been compromised, click **Generate New Write API Key**.
- **Read API Keys**: Use this key to allow other people to view your private channel feeds and charts. Click **Generate New Read API Key** to generate an additional read key for the channel.
- **Note**: Use this field to enter information about channel read keys. For example, add notes to keep track of users with access to your channel.

API Requests

Write a Channel Feed

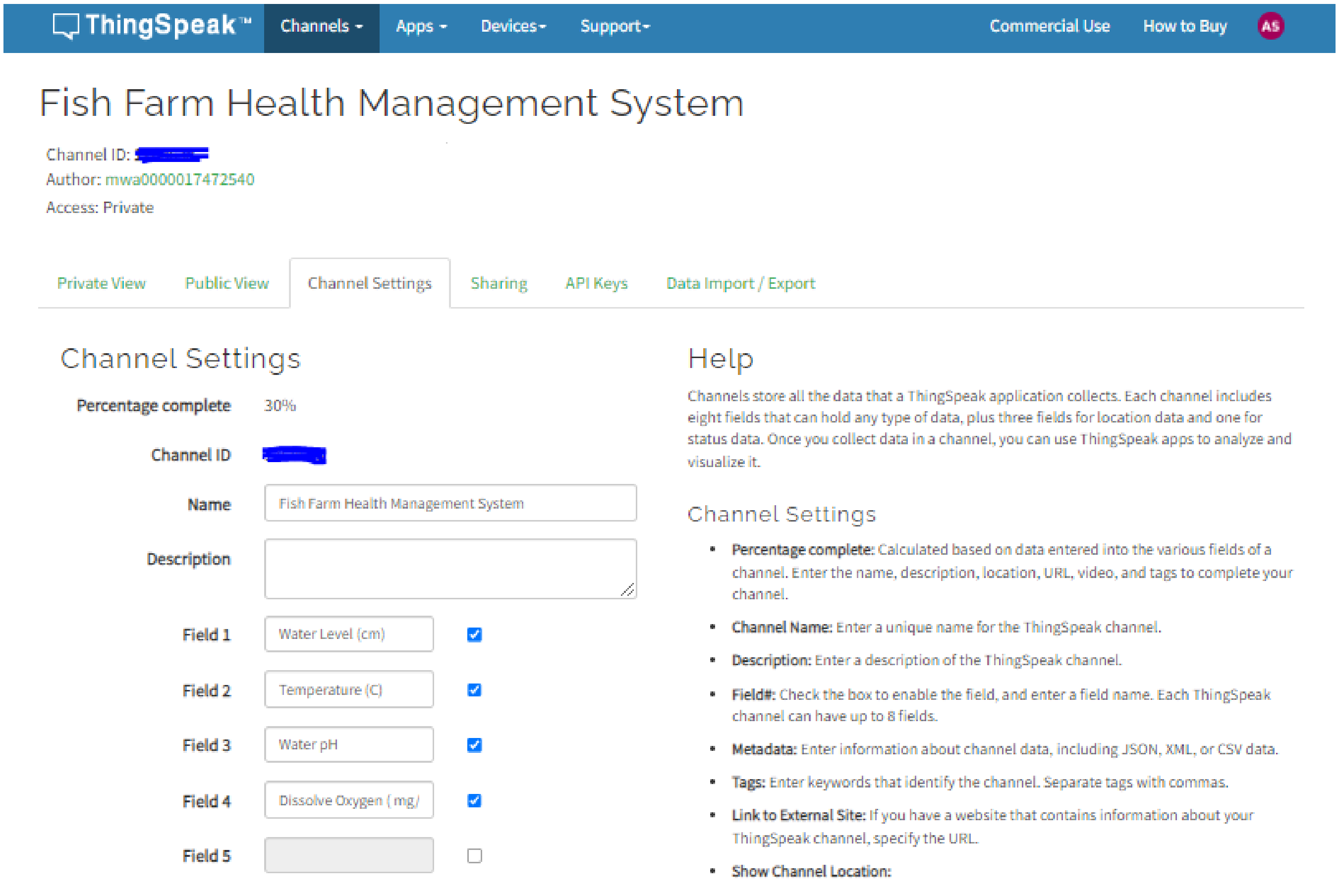
```
GET https://api.thingspeak.com/update?api_key=XKG63KIZ414HWY8X&fielc
```

Read a Channel Feed

```
GET https://api.thingspeak.com/channels/1768638/feeds.json?api_key=4
```

Figure 49: ThinkSpeak channel ID and API keys

After writing the correct codes, Microcontroller connected to the Wi-Fi through ESP8266. ThingSpeak Channel was created on the name of our proposed system in Figure 49. Then unique channel ID and API keys are generated for the system. These API keys are used in the code to transmit the data from Arduino to the ThingSpeak channel. Using ThingSpeak Channel ID, API keys, and local Wi-Fi credentials, writing the final code and uploaded it to the Arduino Uno microcontroller. Write API key used for data transmission and read API key displays the data on the dashboard into the designated field channel of every separate sensor.



Fish Farm Health Management System

Channel ID: [redacted]
Author: mwa0000017472540
Access: Private

Channel Settings

Percentage complete 30%

Channel ID [redacted]

Name: Fish Farm Health Management System

Description:

Field 1: Water Level (cm) ☑
Field 2: Temperature (C) ☑
Field 3: Water pH ☑
Field 4: Dissolve Oxygen (mg/ ☑
Field 5: ☐

Help

Channels store all the data that a ThingSpeak application collects. Each channel includes eight fields that can hold any type of data, plus three fields for location data and one for status data. Once you collect data in a channel, you can use ThingSpeak apps to analyze and visualize it.

Channel Settings

- **Percentage complete:** Calculated based on data entered into the various fields of a channel. Enter the name, description, location, URL, video, and tags to complete your channel.
- **Channel Name:** Enter a unique name for the ThingSpeak channel.
- **Description:** Enter a description of the ThingSpeak channel.
- **Field#:** Check the box to enable the field, and enter a field name. Each ThingSpeak channel can have up to 8 fields.
- **Metadata:** Enter information about channel data, including JSON, XML, or CSV data.
- **Tags:** Enter keywords that identify the channel. Separate tags with commas.
- **Link to External Site:** If you have a website that contains information about your ThingSpeak channel, specify the URL.
- **Show Channel Location:**

Figure 50: Channel fields set up

After uploading the code using the API key into the Arduino, we set up the channel fields in the ThingSpeak and created 4 fields named with the water level, water temperature, water pH, and dissolved oxygen level. To display the data with time series added widgets for sensors and data visualizations. Figure 50 shows the field channel settings, and ThinkSpeak also provides MATLAB analysis and visualizations.

5.5.3.3 Reading data on website and phone App

Data was successfully transmitted from Arduino to ThingSpeak, and all sensor data was displayed on the ThingSpeak Channel on their website. ThingSpeak offers online channel access in private mode, and data visualization by time series can be seen.

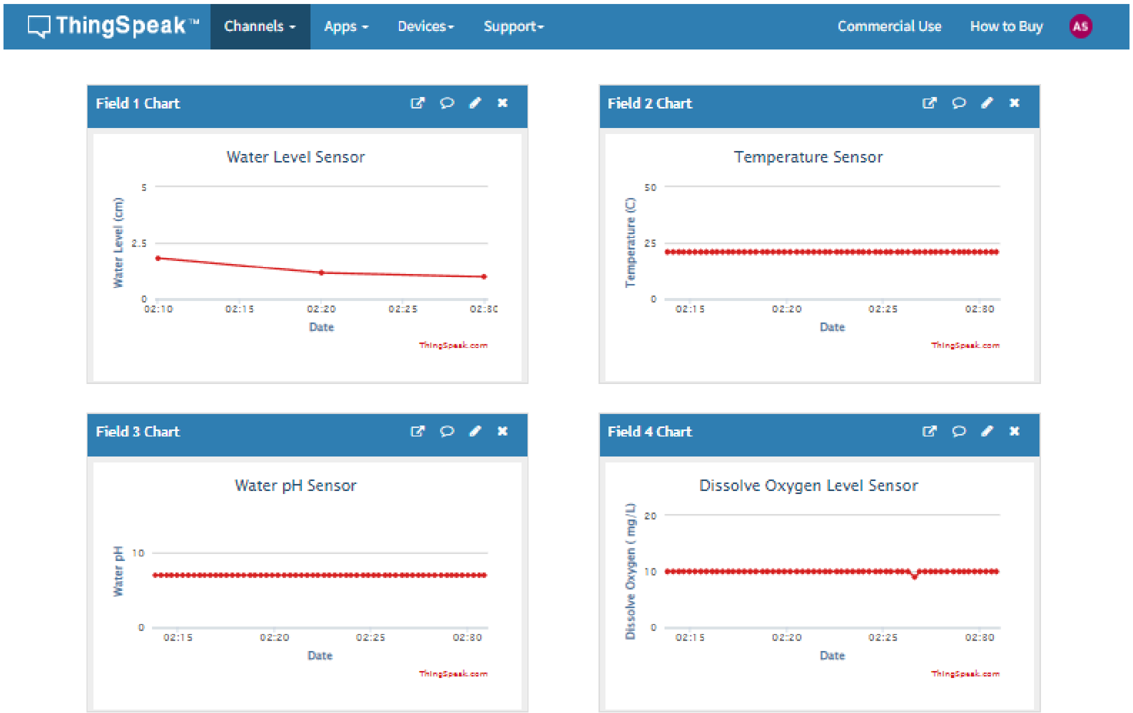


Figure 51: Data display dashboard on ThingSpeak

Data display can be seen in Figure 51 on the dashboard of the ThingSpeak channel. 4 Fields established for four sensors, and data transmission was accurately observed in all four fields. Data displayed with time series and measurement unit mentioned on the y-axis. Field 1 is for water level, field 2 is for water temperature, field 3 is for water pH, and field 4 is for dissolved oxygen.

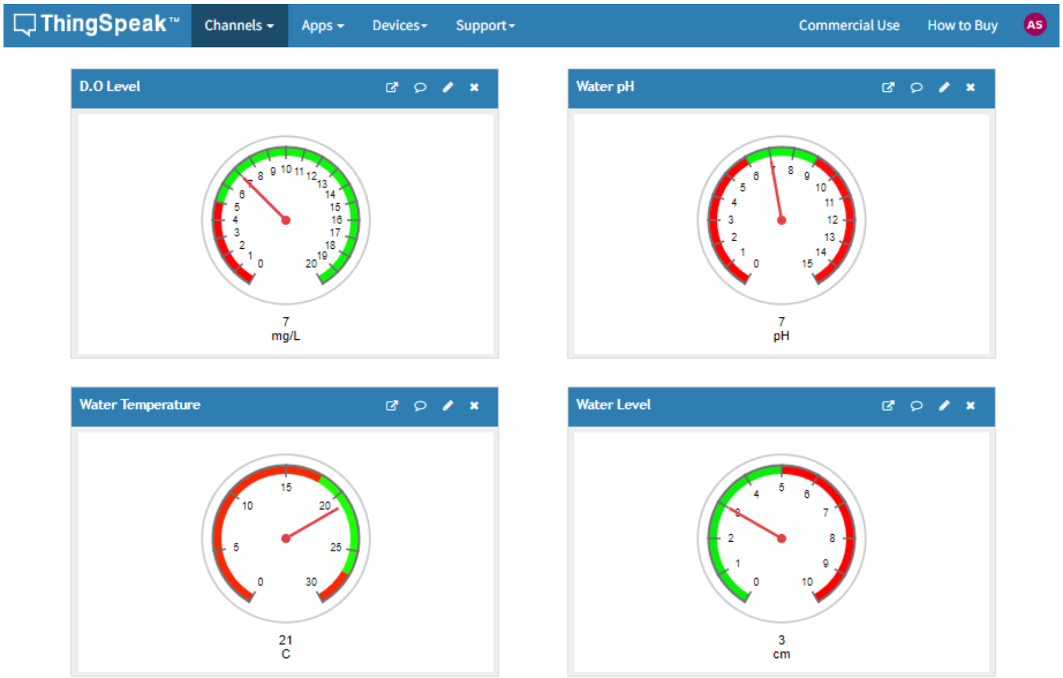
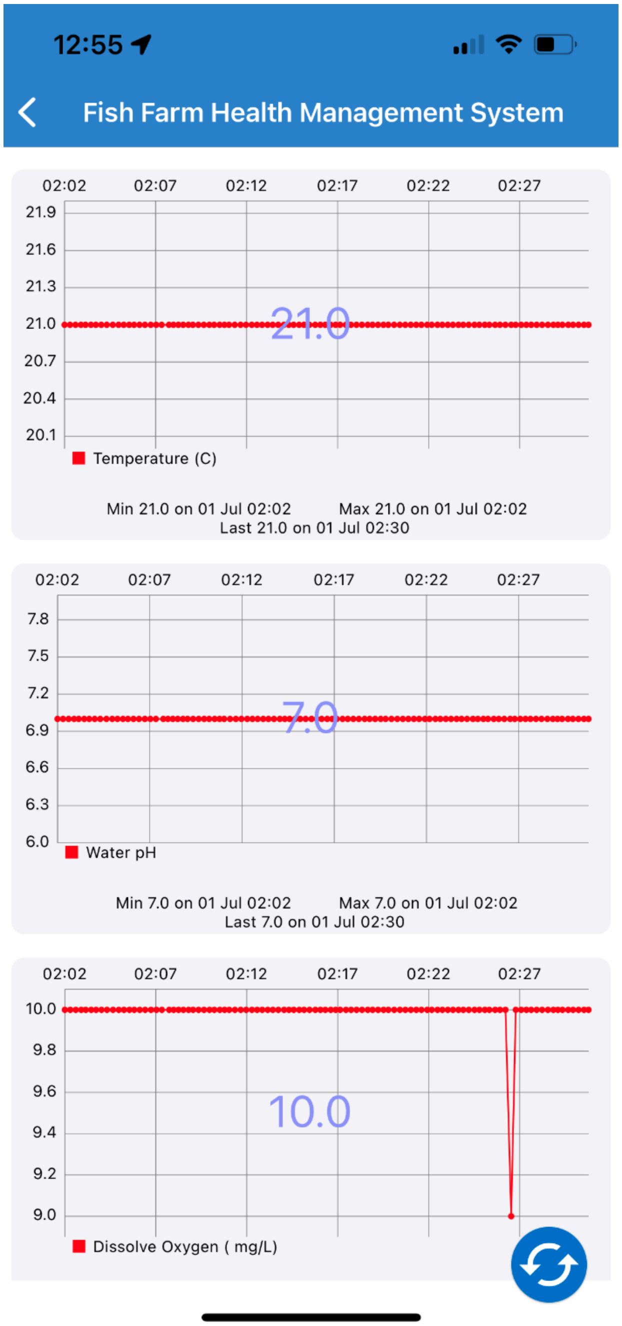


Figure 52: Dashboard widget display

Another display can be seen in the Figure 52 dashboard widget. These gauges are set up according to each sensor type. Each gauge is designed to be a sensor measurement unit and value range. Gauges are colored red and green, which indicates the value ranges. The green color range indicates the average level for health aspects; on the other hand, red colored values indicated the threating or unacceptable values per fish farm required health standard. We use simple tape water for designed system testing, and all values from the sensors are under the green range of the gauges, which means water quality is acceptable. Dissolved oxygen level observed at 7 mg/L, which is good as required between 6-20 mg/L, water pH level indicated 7 pH which is the neutral value of pH level, water temperature observed 21 Celsius fish farms required between 20-27 Celsius. The water level is observed at 3 cm. If the water level goes down from 5 cm, then consider the low water level in the aquarium as per our physical system. Hence, all values from the sensor are correct.



Fish Farm Health Management System

Min 21.0 on 01 Jul 02:02 Max 21.0 on 01 Jul 02:02
Last 21.0 on 01 Jul 02:30

Min 7.0 on 01 Jul 02:02 Max 7.0 on 01 Jul 02:02
Last 7.0 on 01 Jul 02:30

Figure 53: Phone App dashboard display

The proposed system could successfully access the Phone App provided using the API key and channel ID by ThingSpeak. Aquafarmer can access the fish farm health monitoring system remotely using their phone. This IoT-based system can increase the production and profit of the fish farm because of the real-time aquaculture health monitoring system. Easily could maintain standard health parameters in Fish farm at low cost. The phone App display can be seen in Figure 53.

5.6 Conclusion

The designed system shows that real-time fish farm health monitoring is suitable for fish farms and can be used in aquaculture, such as hydroponics, riverbed, tank fish farms, etc. The proposed system continuously monitored the health measure of the fish farm and displayed them on the phone and website in real-time. The system must be evaluated on full-scale industrial trials before being employed on a large scale. It is a low cost, easy to use, and efficient system for developing countries

CHAPTER 6

CONCLUSION & FUTURE WORK

6.1 Conclusion & research contribution

a) Solar PV system design and optimization

This thesis conducted a detailed design and cost analysis of a solar PV system for an off-grid fish farm in rural Pakistan using HOMER PRO. The designed system requirement came out, a 24.7kW photovoltaic source, which can be obtained through 77 of 325W PV panels using 7 strings, and each string has 11 panels through series connections. The power converter required a commercially available 20kW inverter that fulfills 13.8 kW. The system proposed 60 batteries for smooth running the electrical power 24/7 for the fish farm as per requirement. Three strings are offered for batteries, and each string has 20 batteries. The battery capacity proposed is 12V 201Ah. Proposed system cost also analyzed initial cost and operation & maintenance cost is acceptable and one-time investment for the fish farm at economical maintenance cost. The simulation result shows a smoothly working solar PV system accommodating the fish farm electric power requirements.

b) Water pumping system automation and control

In February 2022, a Site survey was conducted on the fish farm. Required data and information collected from the fish farm came to our knowledge that there was no water pumping control and automation system installed. The labor manually operated the water pumping system using the ON/OFF switch of the water pump based on the visual determination of water level in ponds. It increased the fish farm's labor, production, and electrical consumption.

We proposed the water pumping automation and control system. The system was designed using a microcontroller Arduino Uno, an Ultrasonic water level sensor, a Motor, and a screen on TinkerCad. The simulated and observed water pumping system runs automatically when water level reaches the threshold and turns OFF when water level comes to the required setup level. The design system estimated low cost, electricity-saving, and efficiency for aquafarmers.

c) IoT-based real-time fish farm health monitoring system

In the last part of the thesis, There was no fish farm health monitoring system used on the fish farm site. So, we proposed the IoT-based real-time health monitoring system for the fish farm. The designed system was implemented using Arduino Uno R3, ESP 8266, and four sensors. We used water level, pH, temperature, and dissolved oxygen sensors. These are the primary aquaculture health metrics for fisheries growth and health. Hardware system connected and configured through Wi-Fi for data sending to the IoT platform ThingSpeak for remote viewing and data storage.

System designed, implemented, and tested successfully. Aquafarmers can use this system for real-time health monitoring of their fish farm through the Phone App and the web interface remotely. Dial gauges are also set up on the ThingSpeak dashboard and could be helpful to monitor the fish farm health parameters in their ranges determined by green and red color ranges.

6.2 Research contribution

In this research, the above studies and facts encourage the use of renewable resources. The fish farm can be designed and optimized in off-grid locations. In this thesis, an off-grid site was selected for a fish farm and designed a self-sufficient Solar PV power system. Simulation results demonstrated that power generation is enough for fish farm operations throughout the year, and fish farm can operate without power from an electric grid station. The estimated cost is a one-time investment and affordable. Fish farms primarily require an uninterrupted water supply for fisheries, so fish farms must have a water pumping system to maintain the water level in the fishponds. Data collection from the site has shown that there was no water pumping system in the fish farm, and the labor operated the water pump based on observing the water level in the ponds. Using a water pump causes high labor costs, high usage of electricity, and maximum chances of human error in determining water levels in the ponds. This thesis designed a water pumping automation and control system for the fish farm. The water pumping system operates automatically when the sensor detects the ponds' low water level. The proposed system is affordable low cost, reduces electric power usage, and has low labor cost and an efficient operating system for the aquafarmers. The final part of the thesis focused on the health management system of a fish farm. Based on data collected from the site, there were no systems for health measurement of the fish farm and traditional methods used for maintaining the water quality of the fishponds. So, in the final part of the thesis, we proposed the fish farm health management system which can monitor important water metrics from the fishponds. Aquafarmers can monitor fish farm health using IoT technology through the web interface and phone app. Studies show that maintaining water quality for the fisheries can increase their growth and production and prevent them from serious diseases.

The primary purpose of this thesis is to reduce the consumption of fossil fuels and use renewable energy in Pakistan, which can reduce the import of fossil fuels and reduce carbon emissions. Pakistan has great potential for Solar energy. Fish farming is ramping up business in developing countries. This work can encourage aquafarmers living in off-grid locations to start sustainable aquaculture businesses in their areas.

6.3 Future work

The future work can be a dynamic analysis of the designed solar-powered system using MATLAB/Simulink to validate the system. Dynamic analysis of the water pumping system automation and control can be performed for the already designed system in TinkerCad for validation.

Using cloud technology to track the data would make monitoring and controlling the system more accessible. A dedicated cloud service can be used to reduce the size of the device and is easy to install in industrial applications. To increase the data storage, other sources can be used SQL, AWS, and Azure.

In the future, an automation alerting can be designed to let the aquafarmers know through notifications when any parameters fall below the threshold value. By adding industrial-grade sensors to the system, aquafarmers could get more precise readings, low maintenance costs, and a long-life system.

6.4 Publications

1- Adnan Sarwar, M. Tariq Iqbal, Design and Optimization of Solar PV system for a Fish farm in Pakistan, presented at IEEE Annual Computing and Communication Workshop and Conference (CCWC) 2022.

2- Adnan Sarwar, M.Tariq Iqbal, Solar Powered Water Pumping System Automation and Control Using a Microcontroller for Aquaculture, Published in European Journal of Electrical Engineering and Computer Science

3- Adnan Sarwar, M.Tariq Iqbal, IoT-based Real-time Aquaculture Health Monitoring System, Published in European Journal of Electrical Engineering and Computer Science

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