DEVELOPMENT OF A SOLAR POWER SYSTEM SUITABLE FOR SMALL-SCALE FISH FARMING.

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CETIFICATION

This is to certify that this project work titled **DEVELOPMENT OF A SOLAR POWER SYSTEM SUITABLE FOR SMALL-SCALE FISH FARMING** was carried out by **AGHEDO OSAKPANMWAN EMMANUEL** with MALTRICULATION number **ENG2006281** from the Department of Industrial Engineering, University of Benin, Faculty of Engineering, Benin City in partial fulfillment of the requirements of the Award of BACHELOR OF Engineering (B.Eng.) Industrial Engineering.

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DEDICATION

This project is dedicated to God Almighty, whose wisdom, guidance, and strength made this work possible. Special dedication also goes to my beloved parents, Mr. & Mrs. Aghedo for their unwavering love, support and prayers throughout my academic journey.

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ABSTRACT

The growing demand for reliable and sustainable energy solutions in Nigeria has driven the need to investigate renewable energy sources for various agricultural uses. This project centers on designing, analyzing, and implementing a 3.5 kVA solar photovoltaic (PV) system to power essential equipment in a small-scale fish farming operation.

The study aims to provide an environmentally friendly and cost-effective alternative to conventional power sources such as fossil fuel generators, which are often expensive to maintain and environmentally harmful. The system was designed to power critical loads, including surface and submersible water pumps, lighting systems, and aeration devices, all vital for maintaining healthy aquatic conditions and ensuring efficient fish production.

The design process involved detailed load estimation, component selection, and sizing calculations for the solar panels, inverter, charge controller, and batteries. The selected system components included six 350 W solar panels, a 3.5 kVA inverter, two 12 V tubular batteries (250 Ah each), and an MPPT charge controller. Upon installation and testing, results showed that the system provided a stable power output with an average efficiency of 85%, maintaining continuous operation of the fish farm equipment for over 10 hours daily.

Chapter One

Introduction

1.1 Background of the study

The world’s energy demand is rising sharply due to population growth and industrial development. It’s significant to note that the population has increased by 2 billion in just one generation, mainly contributed by developing countries. Preventing an energy crisis is one of the most urgent issues of the 21st century. Consequently, energy demand is growing rapidly to meet the needs of the expanding global population. Countries around the world have their own strategies, plans, policies, and control measures to strengthen their position globally. However, population growth and developmental initiatives are depleting available resources. Therefore, considering energy sources is crucial, as they play a key role in satisfying the world’s needs and supporting the living population. Accessible energy is often insufficient for many due to factors such as a country’s developmental profile, economic status, and technological advancements. The ecosystem is heavily polluted from emissions produced by burning fossil fuels, which are readily available and commonly used to meet global energy demands. Developing countries are under pressure to find new energy sources because their populations are growing rapidly and they seek economic development to become financially viable. As economies develop, energy demand increases proportionally. Although various techniques have been proposed to boost energy production capacity, many people still live-in areas of developing countries without electricity. Relying solely on non-renewable energy sources is unsustainable because they are finite. All countries need to utilize resources wisely to generate energy and create an environment conducive to long-term human survival. Currently, this is not effectively practiced, as many nations depend more on non-renewable rather than renewable energy sources. It is well known that numerous controversial issues, often leading to serious disasters, arise among countries because dominant parties tend to access regions rich in fossil fuel reserves. Additionally, the continuous use of non-renewable energy sources may accelerate climate change, which could lead to natural disasters that harm the planet's ecosystems.

It is therefore vital to go for eco-friendly energy sources for the betterment of the future world. Considering renewable energy sources such as solar energy, wind energy, hydropower, and geothermal is critically important in this sense, as they are eco-friendly. However, solar energy could be the best option for the future world because of several reasons: First, solar energy is the most abundant energy source of renewable energy, and the sun emits it at the rate of 3.8×10^{23} kW, out of which approximately 1.8×10^{14} kW is intercepted by the Earth. Solar energy reaches the Earth in various forms, like heat and light. As this energy travels, the majority of its portion is lost by scattering, reflection, and absorption by clouds. Studies revealed that global energy demand can be fulfilled by using solar energy satisfactorily, as it is abundant in nature and a freely available source of energy with no cost. Second, it is a promising source of energy in the world because it is not exhaustible.

A solar or photovoltaic (PV) cell is a type of electrical converter, inverter, and electronic circuitry that changes direct current (DC) to alternating current (AC). The device makes use of an in-built automatic circuit to achieve complete automation of the entire system, whereby the input voltage, output voltage, frequency, and power handling all depend on the design of the device or circuitry. And the connection of an inverter to a battery or a number of batteries makes it a complete system providing a power solution.

Direct current is a type of current that flows in only one direction. Using the conventional current flow, direct current is such that the electrons leave the power source from the positive terminal and flow through the circuit, and then terminate at the negative terminal of the power source. Direct current (DC) is usually obtained from battery cells, solar panels, and household generators. An alternating current is one in which the current direction changes over time, which means it flows in one direction for a certain amount of time, it changes direction. In this case, there is no fixed polarity for the terminals of the power supply. This type of current is usually obtained from public supply distribution companies, industrial generators.

However, Fish farming depends on natural resources and requires careful management of important environmental factors, such as water quality, oxygen levels, temperature, and lighting, all of which are significantly influenced by a reliable electricity supply. Core operations such as water recirculation (via pumps), aeration, filtration, lighting, and temperature regulation require continuous power for optimal performance. Any interruption to these systems can lead to poor water conditions, stunted growth, and, in severe cases, mass fish death.

In Nigeria, energy challenges are a well-documented national issue. The unreliable and often unavailable nature of power supply from the national grid leaves many small-scale agricultural businesses at a disadvantage. The alternative using fossil fuel-powered generators comes with its own problems: high and fluctuating fuel costs, frequent maintenance, noise pollution, air pollution, and overall unsustainability in the face of environmental concerns.

This has created a pressing need for clean, cost-effective, and decentralized power systems, especially for agricultural enterprises operating in rural or urban areas. Solar photovoltaic (PV) systems represent a viable alternative. Nigeria enjoys an average of 6 hours of sunlight per day, with solar irradiance levels ranging between 5.5–6.5 kWh/m²/day across most parts of the country, making solar energy one of the most accessible renewable resources available.

By integrating solar energy systems into fish farming operations, farmers can gain consistent access to electricity, reduce operating costs, increase yields, and improve the overall sustainability of their practice. However, successful implementation requires accurate system design, load analysis, and appropriate component selection to ensure that the solar PV system can meet the specific demands of the farm reliably and efficiently.

This project focuses on the design, analysis, and implementation strategy of a standalone solar power system suitable for a small-scale fish farm. It combines energy engineering, agricultural systems design, and economic analysis, all within the framework of industrial engineering principles.

1.2 Statement of the Problem

Small-scale fish farmers in Nigeria are faced with multiple layers of operational challenges, most common among them being access to reliable electricity. In a typical fish farm setup, equipment such as submersible water pumps, aerators, UV filters, and lighting systems must run continuously or periodically, depending on the species of fish and the farm’s environmental management practices. Without a steady power source, the farm's ecosystem becomes unstable, leading to poor water conditions, higher stress levels in fish, and eventually, loss of stock.

Rural farmers often experience prolonged power outages or are entirely off-grid, relying solely on fuel-powered generators. While these generators provide short-term relief, they are capital-intensive, prone to mechanical failure, and their fuel consumption increases operational costs. In many cases, fuel shortages or price hikes render this option unsustainable, forcing farmers to reduce farm output or shut down operations altogether.

1.3 Aim of the Study

The primary objective of this study is to design, analyze, implement, and test a standalone solar photovoltaic system specifically tailored to meet the energy needs of a small-scale fish farm. Unlike purely theoretical designs, this project includes the practical installation and field testing of the proposed system in a real farm setting.

1.4 Objectives of the Study

The specific objectives are to:

i. Conduct a comprehensive energy audit of the electrical equipment used in the fish farming process, including pumps, aerators, lighting, and control systems.

ii. Design and size an appropriate standalone solar PV system, including selection of panels, batteries, inverters, and charge controllers, based on actual load requirements.

iii. Procure and install the solar system at a designated small-scale fish farm.

iv. Test and monitor system performance under actual field conditions to evaluate reliability, output stability, and responsiveness to environmental factors.

v. Analyze operational performance data, identifying system strengths and areas for improvement.

vi. Compare the cost and environmental performance of the solar solution with conventional power sources like generators.

1.5 Scope of the Study

This project involves the complete design, installation, and field testing of a solar power system for a small fish farm. It starts with a thorough energy requirement assessment and continues with component selection, system setup, procurement, physical installation, and real-time performance project involves the complete design, installation, and field testing of a solar power system for a small fish farm. It starts with a thorough energy requirement assessment and continues with component selection, system setup, procurement, physical installation, and real-time performance evaluation. Performance evaluation.

The core areas include:

1. Assessment of farm energy needs based on equipment ratings and daily operating hours.
2. System design involving load estimation, PV sizing, and storage calculations.
3. Selection and acquisition of high-quality solar components suitable for rural environments.
4. On-site installation of the solar power system, including electrical wiring, mounting, and safety measures.
5. Performance monitoring during actual fish farm operations to assess output consistency, battery efficiency, and environmental resilience.
6. Evaluation of the system's cost-effectiveness and practical feasibility for replication in other locations.

1.6 Significance of the Project

The importance of this study lies in its ability to help close the energy gap in farming by using clean, renewable energy. It marks an important step toward incorporating renewable energy systems into rural farming operations, with direct effects on food security, access to clean energy, cost savings, and environmental sustainability. For small-scale fish farmers, a well-designed solar power system can:

The following are the key areas where this project delivers value:

1. Energy Access and Reliability for Small-Scale Farmers
2. Promotion of Renewable Energy and Climate-Smart Agriculture
3. Economic Impact: Cost Savings and Profitability
4. Policy and Research Relevance

Chapter Two

Literature Review

2..1 Introduction

Solar energy and fish-farming are two domains experiencing rapid advancement, especially in developing regions like Nigeria, where off-grid energy solutions and food production systems are critical to socio-economic sustainability. This chapter delves deeply into the Combined integration of solar photovoltaic (PV) systems with fish-farming applications, primarily fish farming.

As Nigeria battles with an energy deficit and irregular power supply, the push towards renewable energy systems, particularly solar PV, has intensified. The country receives significant solar radiation, ranging from 3.5 to 7.0 kWh/m²/day, depending on the location and season, making it an ideal location for solar harvesting. Polycrystalline and monocrystalline solar panels have become the most commercially utilized options, with polycrystalline panels offering a favorable balance between cost and efficiency for most small- to medium-scale applications.

The integration of solar PV systems into fish-farming, particularly off-grid solar-powered fish farms, is a growing solution for ensuring a continuous energy supply for water pumping, aeration, lighting, and temperature control. Fish farming has become an increasingly vital part of the agricultural sector in Nigeria, contributing significantly to food security and employment. According to FAO (2022), aquaculture production in sub-Saharan Africa is projected to grow by over 60% by 2030, with solar energy being one of the key enablers for sustainable expansion.

Several studies have emphasized the effectiveness of standalone PV systems in rural agricultural environments. For example, Akinsipe et al demonstrated the economic viability of solar PV systems in Jos, Nigeria, while Linah et al. assessed the performance of polycrystalline solar modules in the climatic conditions of North-East Nigeria. These findings highlight both the technical feasibility and cost efficiency of solar installations for productive rural activities.

Additionally, hybrid system configurations, such as PV-diesel or PV-biomass systems, have been explored in off-grid villages like Kajola, Nigeria. However, with falling costs of solar panels and batteries, pure solar-powered systems are increasingly being favored, particularly in environmental projects and remote farms.

This chapter is divided into two broad sections. The first section focuses extensively on solar energy systems, discussing the theoretical background, component analysis, types of PV systems, and Nigerian-specific applications. It will also integrate performance data, efficiency insights, and economic analysis from peer-reviewed sources. The second section transitions into Fish farming, where the structure, energy demands, and potential for PV integration in fish farms are examined. The section will also include journal-backed case studies and technical reviews from similar environments globally.

Overall, the goal is to bridge the gap between renewable energy engineering and aquacultural sustainability, thereby laying the groundwork for the design, implementation, and optimization of a solar-powered fish farming system.

2.2 Energy Sources and Solar Energy Fundamentals

Energy is essential for all forms of human activity. Traditional sources of energy include fossil fuels, coal, oil, and natural gas, which are finite, environmentally damaging, and often unavailable or expensive in rural and underserved regions. The unsustainable nature of fossil energy has led to a global shift toward renewable energy technologies. Major renewable energy sources include.

2.2.1 Classification of Energy Sources

Energy sources can be broadly categorized into **non-renewable** and **renewable** sources, based on their availability and rate of natural replenishment.

1. Non-Renewable Energy Sources

Non-renewable energy sources are derived from finite natural resources that do not replenish at a sufficient rate for sustainable use. They include:

a. Fossil Fuels

These are the most widely used energy sources globally. They include:

1. **Petroleum** (diesel, petrol)
2. **Natural gas**
3. **Coal**

They are burned to release energy in the form of heat or electricity. While they are highly efficient in energy output, they come with significant drawbacks, such as environmental pollution, greenhouse gas emissions, and volatility in fuel prices.

b. Nuclear Energy

Generated through the fission of uranium or plutonium atoms in a nuclear reactor, nuclear energy is a high-output, low-carbon source. However, it is not suitable for decentralized or rural applications due to the complexity of infrastructure, high safety risks, and radioactive waste concerns.

2. Renewable Energy Sources

Renewable energy sources are derived from natural processes that are continuously replenished. They are increasingly favored for their sustainability, low emissions, and potential to support rural electrification. Key renewable sources include:

a. Solar Energy

Captured from sunlight using photovoltaic (PV) cells or solar thermal collectors. It is ideal for rural applications due to Nigeria’s high solar irradiance levels. Solar energy is clean, abundant, and scalable, making it suitable for powering small-scale agricultural systems like fish farms.

Wind Energy

Harnessed from moving air using wind turbines. Wind energy can be effective in areas with consistent wind flow, though its variability makes it less reliable for standalone systems unless combined with storage or hybrid systems.

c. Hydropower

Generated by harnessing the energy of moving water (e.g., rivers, dams). While large-scale hydro projects are common, micro-hydro systems can power rural communities if a water source is nearby. However, installation costs and terrain requirements can be limiting.

d. Biomass and Bioenergy

Derived from organic materials such as wood, crop residues, and animal waste. Biomass can be converted into electricity, heat, or biogas. It is renewable but may cause deforestation or air pollution if not managed sustainably.

e. Geothermal Energy

Extracted from the Earth's internal heat, often used in areas with volcanic activity. It is location-specific and not viable in most parts of Nigeria.

3. Emerging and Hybrid Energy Systems

Due to the limitations of single energy sources (e.g., solar intermittency at night), hybrid systems that combine renewable and non-renewable sources are gaining popularity. For example:

1. **Solar–battery systems** store excess energy for nighttime use.
2. **Solar–diesel hybrids** provide backup when solar power is insufficient.

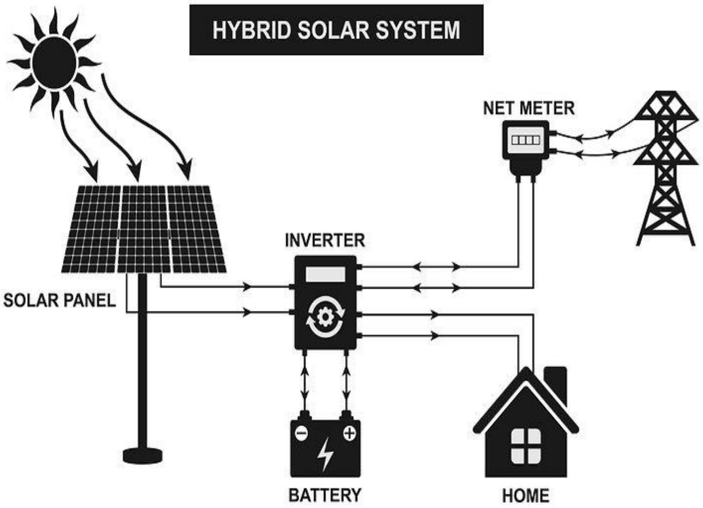


Figure 1 Hybrid solar-powered system

2.2.2 Solar Energy

Solar energy is the radiant light and heat emitted by the sun, which can be harnessed and converted into usable forms of energy such as electricity and thermal energy. Among all renewable energy sources, solar energy is the most abundant, widely distributed, and accessible across the globe. With advancements in photovoltaic (PV) technology and a significant reduction in the cost of solar components over the past decade, solar energy has become one of the most promising alternatives to fossil fuel–based power generation, particularly for decentralized and off-grid applications.

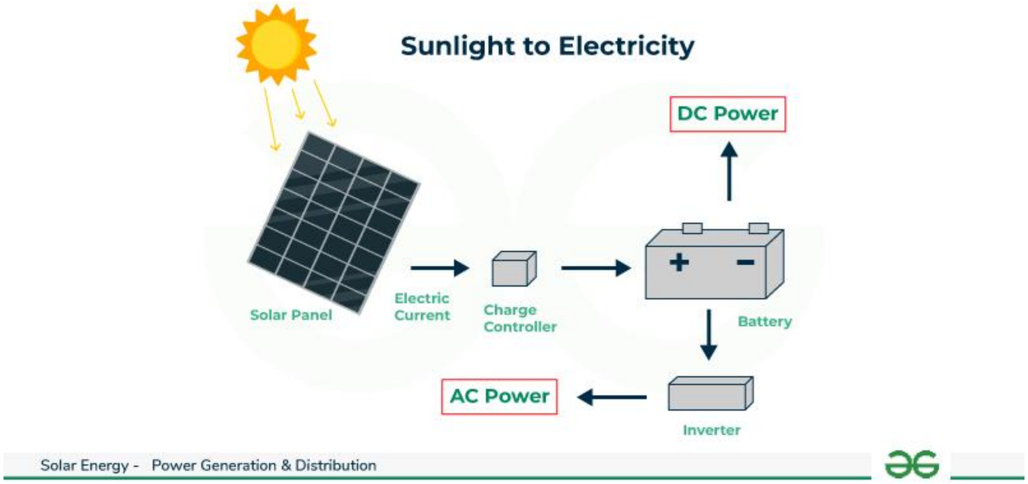


Figure 2 Solar energy- Power Generation & Distribution

2.2.3 Global Importance of Solar Energy

The growing global concern about climate change, carbon emissions, and energy poverty has led to a widespread shift towards clean and renewable energy systems. Solar energy plays a central role in this transition. It is renewable, non-polluting, and sustainable. According to the International Energy Agency (IEA), solar PV is now the cheapest source of electricity in history for many countries, making it an economically competitive option even in low-income regions.

Solar power systems can be deployed at various scales, ranging from small household-level installations to large utility-scale solar farms. This scalability enables customization tailored to energy demands, geographical location, and economic capabilities. In rural communities where the electric grid is unreliable or nonexistent, solar energy provides a reliable and autonomous solution for lighting, water pumping, refrigeration, agricultural processing, and more.

2.2.4 Solar Energy Potential in Nigeria

Nigeria is geographically located within the tropical belt and enjoys high solar insolation levels year-round. Most parts of the country receive between 5.5 and 6.5 $kWh/m^2/day$ of solar radiation, and the average sunshine duration ranges from 6 to 9 hours per day, depending on the season and region.

Despite this potential, solar energy adoption in Nigeria remains low due to high initial capital costs, lack of technical expertise, limited policy support, and weak infrastructure for installation and maintenance. Nonetheless, solar energy remains a strategic solution for improving electricity access in off-grid rural areas, especially for small-scale enterprises like fish farming.

The Federal Ministry of Power and Energy Commission of Nigeria has acknowledged the country's solar potential and has made provisions in national energy policies to encourage the development of solar infrastructure. The decentralization of energy production through solar mini-grids and stand-alone systems is also gaining traction as part of Nigeria's Energy Transition Plan (ETP) to reach universal electricity access by 2030.

2.2.5 Principles of Solar Energy Conversion

Solar energy is typically converted into two major forms:

1. Electrical energy, through photovoltaic (PV) systems.
2. Thermal energy, through solar thermal collectors.

2.3 Components of A Solar Photovoltaic System

A photovoltaic system, also known as a PV system or solar power system, is an electric power system that uses photovoltaics to generate usable solar power. It is made up of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, and mounting, cabling, and other electrical accessories to complete the system. It may also include an integrated battery and use a solar tracking system to improve overall system performance.

2.3.1 How Does the Photovoltaic System Work?

Solar photovoltaic (PV) panels capture the sun's energy and convert it into electricity using cells made of a semiconductor material. Silicon, a plentiful natural resource found in sand, is the most commonly used semiconductor material. When light strikes the cell, a certain amount of energy is absorbed by the semiconductor material, knocking electrons, the negatively charged particles that serve as the foundation of electricity, loose. Most PV cells contain two semiconductor layers, one positively charged and one negatively charged. When light strikes a semiconductor, an electric field at the junction between these two layers allows electricity to flow, resulting in direct current (DC). We may take that current off for external usage by installing metal connections on the top and bottom of the PV cell.

Solar PV electric panels do not require intense sunshine to work, so you may create power even on gloomy days; nevertheless, the larger the intensity of light, the greater the flow of electricity. However, because of the reflection of sunlight, days with a small cloud can produce more energy than days with a fully clear sky.

It is critical to understand that you can only use your free solar electricity when it is being generated, which means that unless you also invest in batteries to store power for use in the evenings and at night, you will have to pay for your energy use as usual when the panels are not producing electricity.

2.3.2 Types of Solar PV Systems

Solar photovoltaic systems are classified into three types:

1. **Grid-tied systems:** The most popular form of solar system; the home is linked to the grid so that it may utilize utility electricity when the solar panels do not produce enough energy to power the home.
2. **Off-grid systems:** They have no grid connection and rely only on energy generated and stored on-site.
3. **Hybrid systems:** Hybrid systems, often known as 'solar-plus-storage systems,' combine solar panels with a solar battery to store energy for later use or during a power outage, and the house is also connected to the grid.

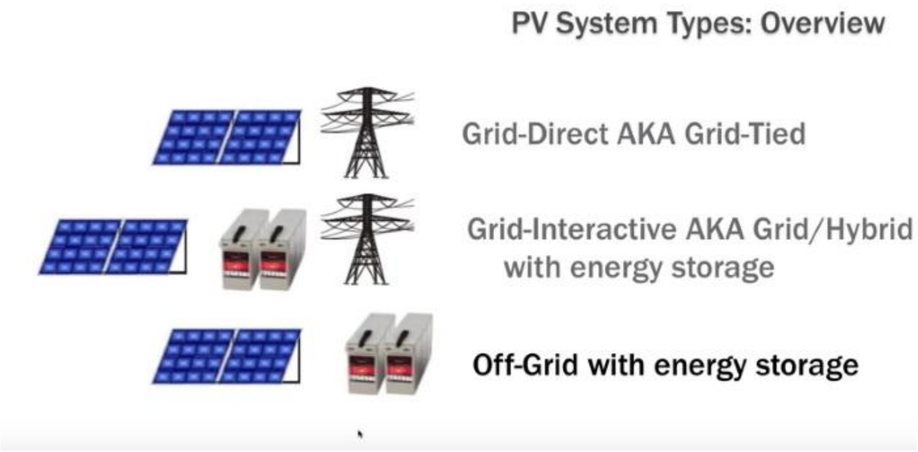


Figure 3 Diagram of the types of solar PV systems

Solar PV modules:

A solar module is made up of several solar cells having semiconductor qualities that are enclosed within a material to protect them from the elements. These characteristics allow the cell to catch light, or more particularly, photons from the sun, and transform their energy into usable power via a process known as the photovoltaic effect. A layer of conducting material "collects" the electricity created on each side of the semiconductor. The lit side of the screen also has an anti-reflection coating to reduce reflection losses. The vast majority of solar panels manufactured across the world are composed of crystalline silicon, which has a theoretical efficiency limit of 33% for turning the sun's energy into electricity. Many additional semiconductor materials and solar cell technologies that function at higher efficiencies have been discovered, but they are more expensive to manufacture.

2.4 Inverter

Figure 4 Diagram of an Inverter

An inverter is a type of electrical equipment that absorbs direct current (DC) and transforms it to alternating current (AC). In the case of solar energy systems, this implies that the DC from the solar array is sent via an inverter, which transforms it to alternating current (AC). Most electric equipment and interfaces with the electrical grid require this conversion. Inverters are an essential component in virtually all solar energy systems, and they are often the most expensive component after the solar panels themselves.

The majority of inverters have conversion efficiencies of 90% or above and significant safety features such as ground fault circuit interruption and anti-islanding. When there is a power outage, this shuts down the PV system.

2.4.1 Types of Inverters

Solar inverters are classified into four (4) main types

1. **Standalone (off-grid inverter):** They are designed for use in power systems that operate independently of the utility grid. These inverters convert direct current (DC) electricity from solar panels or batteries into alternating current (AC) for use in homes, cabins, or remote areas without access to grid power. They typically rely on battery storage systems, which are charged by photovoltaic arrays, and are capable of powering AC loads directly. Off-grid inverters do not require anti-islanding protection, as they are not connected to the grid.

2. **Grid-Tied (On-Grid) Inverters:** Grid-tied inverters convert DC electrical power into AC power suitable for injecting into the electric utility company grid. The grid-tied inverter (GTI) must match the phase of the grid and maintain the output voltage slightly higher than the gridvoltage at any instant. A high-quality modern grid-tied inverter has a fixed unity power factor, which means its output voltage and current are perfectly lined up, and its phase angle is within

Figure 5 Grid-Tied (on-grid) inverters

3. **Intelligent hybrid inverters** manage the photovoltaic array, battery storage, and utility grid, which are all coupled directly to the unit. These modern all-in-one systems are usually highly versatile and can be used for grid-tie, stand-alone, or backup applications, but their primary function is self-consumption with the use of storage. These combine features of both off-grid and grid-tied inverters. A hybrid inverter can manage solar input, battery storage, and grid power simultaneously. It automatically switches between sources based on availability and demand.

2.4.2 Inverter Selection Criteria

Parameter	**Description**
System Size	Total load and number of panels connected
Output Waveform	A pure sine wave is preferred for stability.
Efficiency	Typically, 92–98% in good inverters
Surge Capacity	Must support motor-based equipment (pumps, freezers)
Environmental Rating	IP65 or above for outdoor installations
Battery Compatibility	Whether it supports lead-acid, lithium, or LiFePO4

2.4.3 Inverter Application in Fish-Farming Systems

Fish-farming operations such as submersible pumps, aerators, UV sterilizers, and feeders depend on stable AC power. Solar inverters, especially hybrid inverters, are increasingly being adopted in fish farming systems due to their ability to:

1. Support continuous operation even at night (via battery backup)
2. Reduce diesel generator dependency.

2.5 Battery

Figure 6 DIAGRAM OF A SOLAR POWERED BATTERY

A battery bank is an essential component in standalone and hybrid solar photovoltaic (PV) systems. It functions as the energy storage unit, storing excess power generated during sunny hours and releasing it during periods of low or no solar irradiance, such as at night, during cloudy weather, or early in the morning when energy demand may still be high. This type of battery is ideal for use with rechargeable devices. However, it is important to remember that when multiple batteries are connected, if one battery fully drains, the others can quickly discharge through it. This condition could cause overcurrent flow and pose a fire risk. To prevent this, remove the low-capacity, depleted battery from the connection. In large parallel battery setups, clever monitoring systems or diodes are used to identify and remove the faulty battery. Rechargeable batteries offer the benefit of reduced overall cost of use and environmental impact compared to disposable batteries. Some rechargeable batteries are available in sizes similar to disposable ones. Although rechargeable batteries have a higher initial cost, they can be recharged inexpensively and used multiple times (N.I. Rusli 2016). A battery is any object composed of electrochemical cells with protruding positive and negative terminals used to power equipment in homes, offices, factories, recreation facilities, and other locations (Crompton 2000). Batteries typically have two terminals: the cathode, which is the positive terminal and stores electrical energy through an electrochemical reaction between its components, and the anode, which acts as the negative terminal. Batteries convert energy from one form to another (from chemical energy to electrical energy). The metals, oxides, or molecules within the battery cells undergo electrochemical reactions, creating differences in their bond energies (or cohesive forces); this results in the release of electrical energy (Schmidt-Rohr, 2018). Batteries consist of multiple voltaic cells (cells that generate electricity via chemical reactions). Each cell is divided into two halves connected through a conductive electrolyte. Some features of this type of battery include: sealed, maintenance-free, easy to handle, economical, long service life, design flexibility, rugged construction, compact size, high discharge rate, long shelf life, wide operating temperature range, deep discharge recovery, and more. Etc.

2.5.1 Types of Batteries Used In Solar pv Systems

Batteries are classified based on their chemical composition, charging efficiency, depth of discharge (DoD), cycle life, cost, and maintenance requirements. The most commonly used battery types in solar PV systems include:

A. Lead-Acid Batteries

These are the oldest and most widely used battery technologies in off-grid solar systems.

1. **Flooded Lead-Acid (FLA):** Requires regular maintenance (topping with distilled water) and ventilation due to gas emissions. Inexpensive but bulky.

2. **Sealed Lead-Acid (SLA):** Includes Absorbent Glass Mat (AGM) and Gel batteries. Maintenance-free and safer than flooded types, though with slightly lower lifespan.

B. Lithium-Ion Batteries

These are fast becoming the preferred battery type for modern solar installations due to their performance advantages.

Types:

1. Lithium Iron Phosphate ($LiFePO_4$)
2. Lithium Nickel Manganese Cobalt Oxide (NMC)

2.5.2 Key Battery Specifications and Parameters

When selecting a battery for a solar application, several technical parameters must be considered:

Parameter	**Description**
Voltage (V)	Common system voltages are 12V, 24V, and 48V. Higher voltages reduce current losses.
Ampere-Hour (Ah)	A measure of storage capacity: how many amps the battery can deliver per hour.
Watt-Hour (Wh)	Total energy capacity (Voltage × Ah).
Depth of Discharge	Percentage of battery capacity that can be used without damaging the battery.

Cycle Life	The number of charge-discharge cycles a battery can complete before degrading.
Efficiency (%)	Round-trip efficiency; lithium batteries >90%, lead-acid ~75–85%.

2.5.3 BATTERY SAFETY, MAINTENANCE, AND DISPOSAL

3. **Lead-Acid**: Check electrolyte levels, clean terminals, and ventilate enclosure
4. **Lithium**: Requires a Battery Management System (BMS) to prevent overcharge/discharge
5. **Disposal**: Batteries should not be discarded with household waste; recycling centers or collection programs must be used.

2.6 Solar Panels

Figure 7 Diagram of a solar panel

A solar panel is a device that converts sunlight into electricity by using photovoltaic (PV) cells. PV cells are made of materials that produce excited electrons when exposed to light. These electrons flow through a circuit and produce direct current (DC) electricity, which can be used to power various devices or be stored in batteries. Solar panels are also known as solar cell panels, solar electric panels, or PV modules.

Solar panels are usually arranged in groups called arrays or systems. A photovoltaic system consists of one or more solar panels, an inverter that converts DC electricity to alternating current (AC) electricity, and sometimes other components such as controllers, meters, and trackers. Most panels are in solar farms or rooftop solar panels, which supply the electricity grid.

Some advantages of solar panels are that they use a renewable and clean source of energy, reduce greenhouse gas emissions, and lower electricity bills. Some disadvantages are that they depend on the availability and intensity of sunlight, require cleaning, and have high initial costs. Solar panels are widely used for residential, commercial, and industrial purposes, as well as in space, often together with batteries.

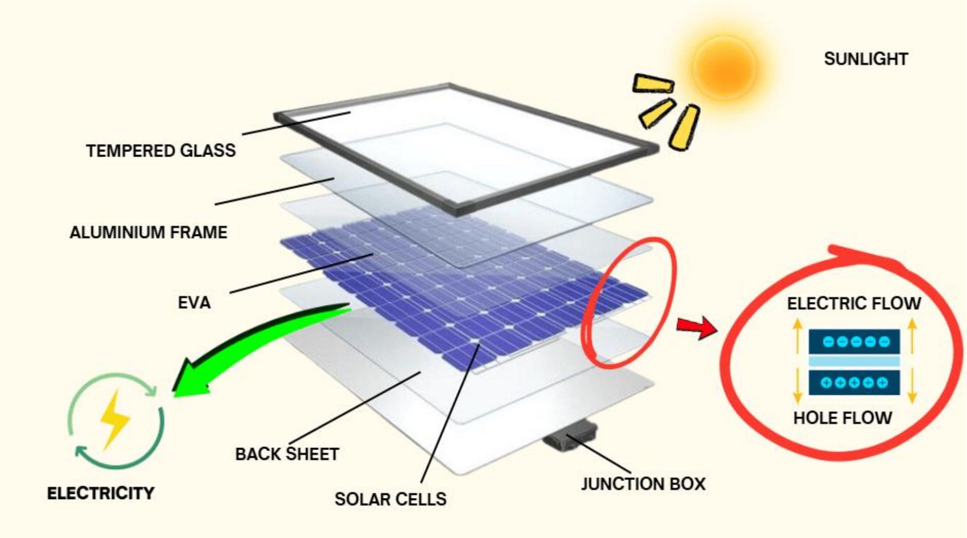


Figure 8 DIAGRAM of solar panel

2.6.1 Types of Solar Panels

There are three (3) main types of solar panels.

1. **Thin-film:** Thin-film solar cells are a type of solar cell made by depositing one or more thin layers (thin-films or TFs) of photovoltaic material onto a substrate, such as glass, plastic, or metal. Thin-film solar cells are typically a few nanometers (nm) to a few microns (μm) thick–much thinner than the wafers used in conventional crystalline silicon (c-Si) based solar cells, which can be up to 200 μm thick. Thin-film solar cells are commercially used in several technologies, including (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si).

   Additionally, the materials used in thin-film solar cells are typically produced using simple and scalable methods more cost-effective than first-generation cells, leading to lower environmental impact, like greenhouse gas emissions, in many cases. Thin-film cells also typically outperform renewable and non-renewable sources for electricity generation in terms of human toxicity and heavy-metal emissions.

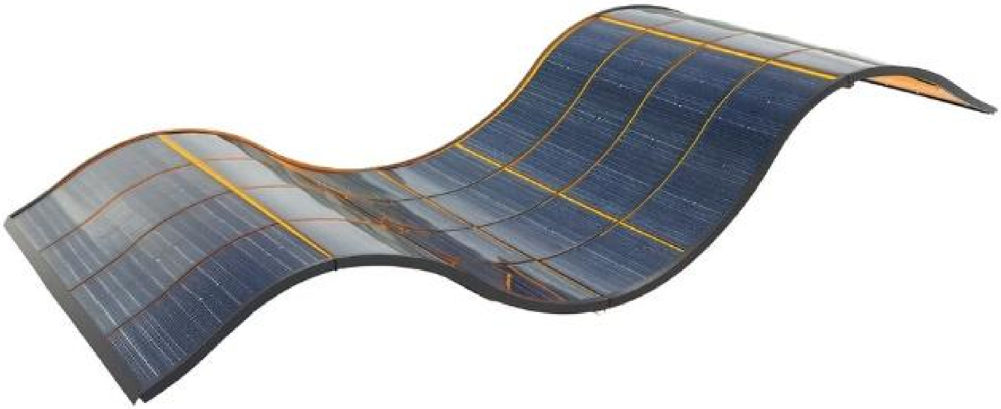


Figure 9 Diagram of a Thin-film Solar panel

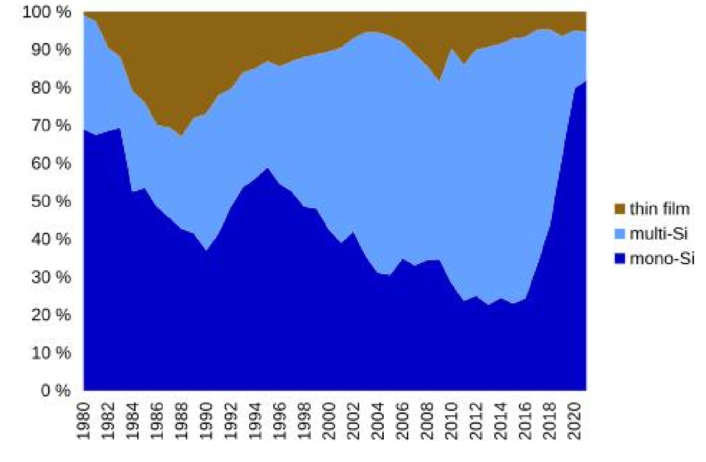


Figure 10 Distribution diagram of the types of solar panel

2. **Monocrystalline**: Monocrystalline solar panels are photovoltaic cells composed of a single piece of silicon. These cells contain a junction box and electrical cables, allowing them to capture energy from the sun and convert it into usable electricity. Monocrystalline solar panels are popular for their high efficiency, durability, and relatively low costs. Monocrystalline solar cells are manufactured by slicing a single piece of silicon into thin wafers and assembling them into rectangular arrays. The cells have electrical contacts at the top and bottom and are joined to a junction box and cables to create a fully functional panel mounted on roofs or poles. Due to their superior efficiency, monocrystalline solar panels can generate up to 20% more energy per square foot than other types of solar cells. They also need minimal upkeep and are highly durable, making them popular in residential and commercial settings. Overall, monocrystalline solar panels offer an excellent return on investment in efficiency and durability, making them a popular choice for many applications.

With proper installation and maintenance, these photovoltaic cells should provide a reliable energy source for years.

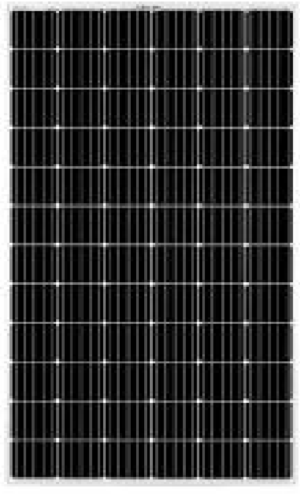
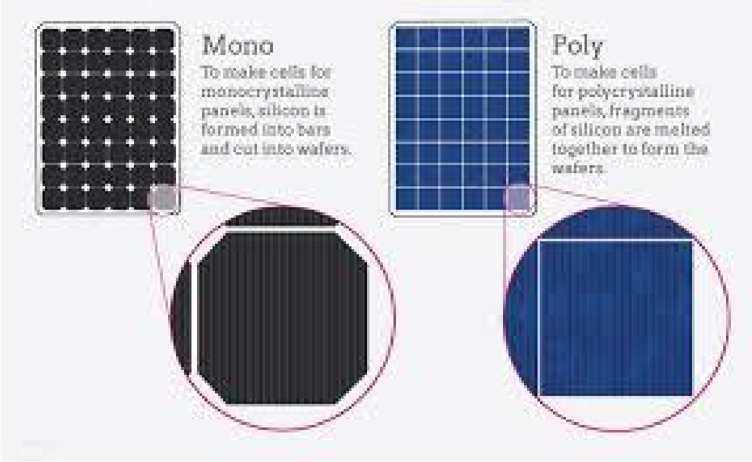


Figure 11 Diagram of a Monocrystalline solar panel

3. Polycrystalline: These panels are made from silicon fragments melted together. Polycrystalline solar panels, also known as multi-Crystalline panels, are made from silicon, the second most abundant element in the Earth's crust. What sets them apart from other panel types, such as monocrystalline or thin-film panels, is the way the silicon is processed during manufacturing. These panels are created by melting silicon fragments together and pouring them into molds to form square-shaped wafers. As the silicon cools and solidifies, it forms multiple small crystals, hence the name “polycrystalline.” This method of production is more cost-effective and less wasteful compared to the single-crystal process used in monocrystalline panel manufacturing.

Figure 12 Diagram of a polycrystalline solar panel



2.6.2 Efficiency Trends and Technological Developments

The global average efficiency of commercial PV modules has improved from 12% in 2005 to over 19% in 2023. Innovations such as passivated emitter rear cells (PERC) and bifacial technologies have further enhanced the performance of both mono and polycrystalline panels.

2.7 Charge Controller

A charge controller, charge regulator, or battery regulator limits the rate at which electric current is added to or drawn from electric batteries to protect against electric overload, overcharging, and may protect against overvoltage. This prevents conditions that reduce battery performance or lifespan and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device or to control circuitry integrated within a battery pack, battery-powered device, and/or battery charger. In solar applications, charge controllers may also be called solar regulators or solar charge controllers. Some charge controllers / solar regulators have additional features, such as a low voltage disconnect (LVD), a separate circuit that powers down the load when the batteries become overly discharged (some battery chemistries are such that over-discharge can ruin the battery).

2.7.1 Types of Charge Controller

There are two major types of charge controllers used in modern solar applications:

1. Pulse Width Modulation (PWM)

2. Maximum Power Point Tracking (MPPT)

2.7.2 Pwm Vs Mppt Controller

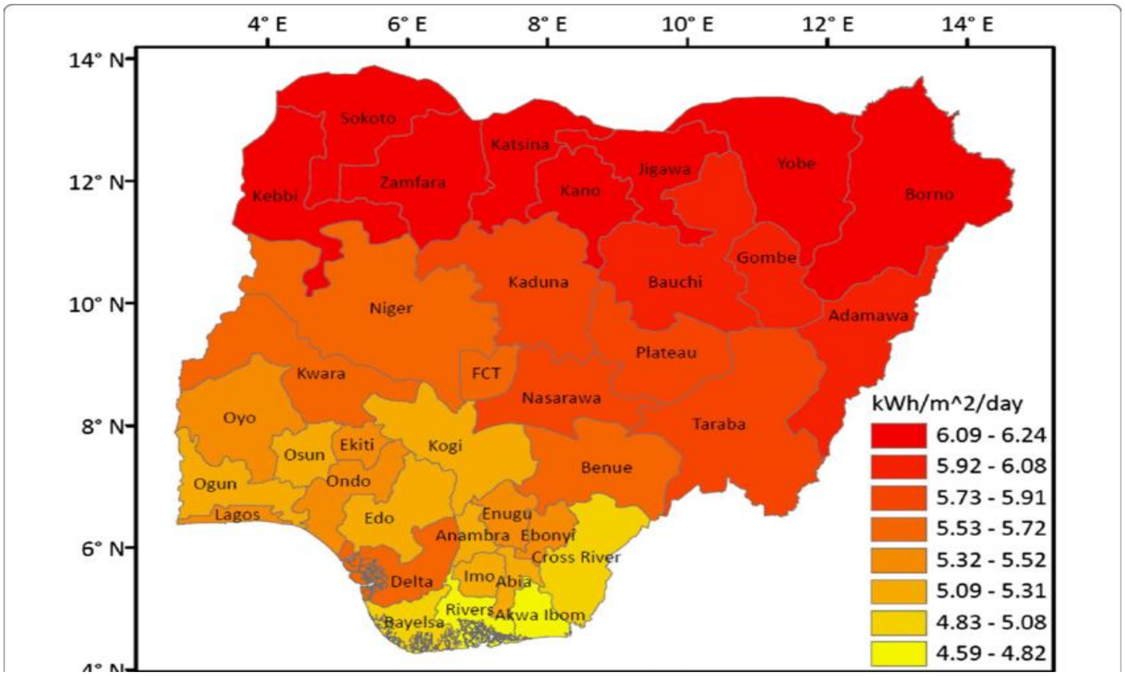
Parameter	**PWM**	**MPPT**
Efficiency	**70–80%**	**95–99%**
Cost	**Low**	**High**
Technology	**Older**	**Modern and intelligent**
Voltage Conversion	**No**	**Yes – Optimizes input to match output**
Suitability	**Small systems**	**Medium to large systems**
Use in Fish Farming	**Less preferred**	**Highly preferred**

2.8 Solar Irradiance

The daily average solar radiation ranges from 3.5 kWh/m²/day in the coastal areas to 7.0 kWh/m²/day in the far north. This variability makes solar energy particularly valuable for off-grid energy applications like aquaculture, especially in sun-rich areas like Kano, Sokoto, and Maiduguri.

Location	**Solar Radiation (kWh/m²/day)**
Lagos (South)	**3.5 – 4.5**

Abuja (Central)	**4.5 – 5.5**
Sokoto (North)	**6.0 – 7.0**



2.9 Introduction to Fish-Farming Systems

Fish farming is the practice of breeding, raising, and harvesting fish in controlled environments. It is considered one of the fastest-growing food production sectors in the world, contributing significantly to food security, employment, and economic development. With wild fish stocks under increasing pressure due to overfishing and environmental degradation, fish farming offers a sustainable alternative for meeting global protein demands.

The pond system is the most common and traditional method of fish farming, where fish are reared in earthen or concrete ponds. These ponds can be natural or artificially constructed and allow for the controlled management of water quality, feeding, and disease prevention.

Key components of a pond-based fish-farming system include:

1. **Aeration Systems**: Provide sufficient oxygen levels to maintain fish health and metabolism.
2. **Pumps and Water Circulation Systems**: Ensure uniform water distribution and filtration.
3. **Feeding Systems**: May be manual or automated, supplying feed at appropriate intervals.
4. **Monitoring Systems**: Devices and software for checking water quality parameters such as temperature, pH, dissolved oxygen, and ammonia levels.

Energy consumption in fish-farming (pond) systems is largely driven by the need to operate these components, particularly in intensive setups. Continuous aeration, pumping, lighting, and feeding require reliable power sources. Diesel generators are commonly used in rural areas with limited grid access, but these are expensive to run and environmentally damaging.

2.10 Energy Demands in Fish-Farming Operations

The energy profile of a fish farm varies depending on its scale, location, and system type. However, studies have shown that the major energy-intensive activities include:

i. Aeration (30–40%)

ii. Water pumping (20–30%)

iii. Feeding systems (10–15%)

iv. Lighting and heating (5–10%)

In a study conducted by Alao et al. (2021), energy demand on a typical catfish farm in Ogun State, Nigeria, was estimated at 15–20 kWh per day. This demand is often met using small diesel generators, which not only incur high operational costs but also expose workers and fish stocks to harmful emissions.

Solar PV systems offer a clean and sustainable solution to meet these demands. By harnessing solar energy during daylight hours and storing excess power in batteries, aquaculture farms can operate efficiently, reduce fuel costs, and lower their carbon footprint.

2.11 Design Considerations for Solar Fish-Farming Systems

Designing a solar PV system for a fish farm must account for:

i. **Energy Load Estimation**: Accurate calculation of daily and peak energy demands.

ii. **Component Sizing**: Determining the capacity of solar panels, battery storage, and inverters.

iii. **Site Assessment**: Analyzing solar irradiance, shading, temperature, and humidity.

iv. **Redundancy and Backup**: Ensuring continuous operation through hybrid setups or oversized storage.

2.11.1 Fish-Pond System

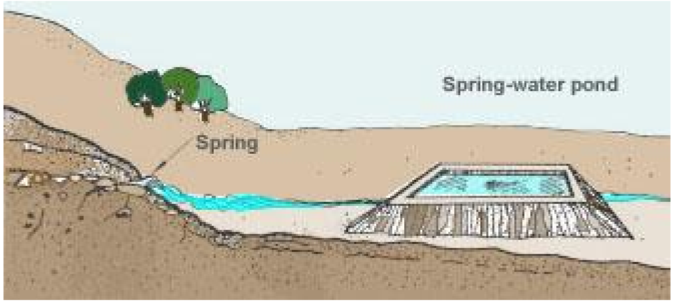
Types of Fish-Pond

1. Freshwater fish ponds differ according to their source of water, the way in which water can be drained from the pond, the material and method used for construction and the method of use for

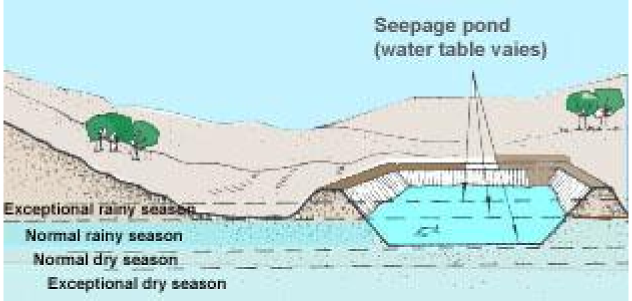
fish farming. Their characteristics are usually defined by the features of the landscape in which they are built. Ponds can be described as follows.

According to the water source

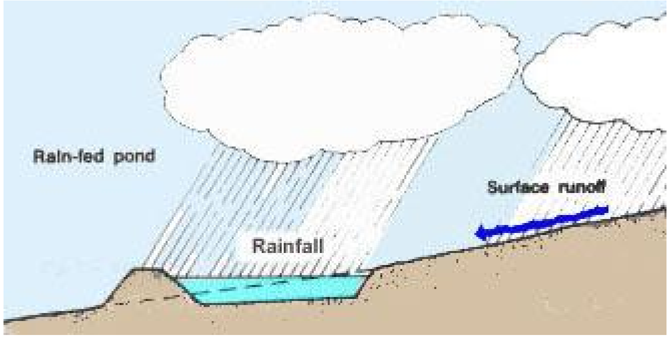
2. Ponds can be fed by **groundwater:**



(a) **Spring-water ponds** are supplied from a spring either in the pond or very close to it. The water supply may vary throughout the year, but the quality of the water is usually constant.



(b) **Seepage ponds** are supplied from the water table by seepage into the pond. The water level in the pond will vary with the level of the water table.



3. **Rain-fed ponds** are supplied from rainfall and surface runoff. No water is supplied during the dry season. These ponds are often small depressions in impermeable soil, with a dike built at the lower side to retain more water.

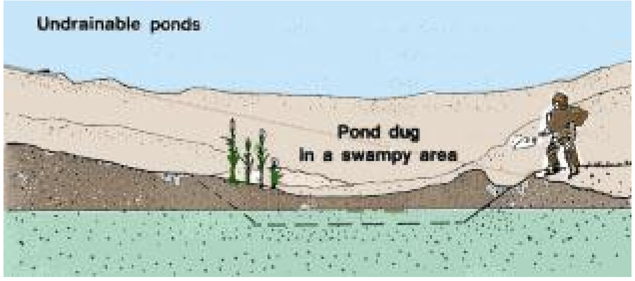
4. **Ponds can be fed from a water body** such as a stream, a lake, a reservoir or an irrigation canal. These may be **fed directly** (e.g. **barrage ponds**), by water running straight out from the water body to the ponds, or **indirectly** (e.g. **diversion ponds**), by water entering a channel from which controlled amounts can be fed to the ponds.

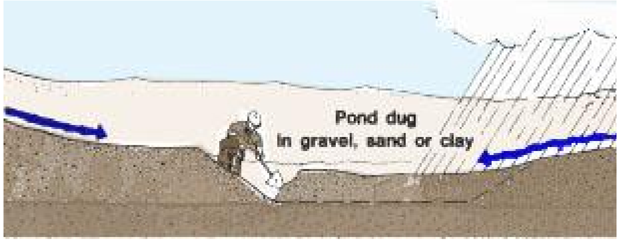
According to the means of drainage

6. **Undrainable ponds** cannot be drained by **gravity***. They are generally fed by **groundwater** and/or surface runoff and their water level may vary seasonally. Such ponds have two main origins.

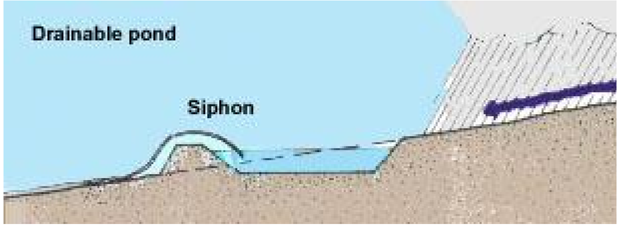
(a) They may be dug in swampy areas where there is no source of water other than groundwater.

(b) They may result from the extraction of soil materials such as gravel, sand or clay.

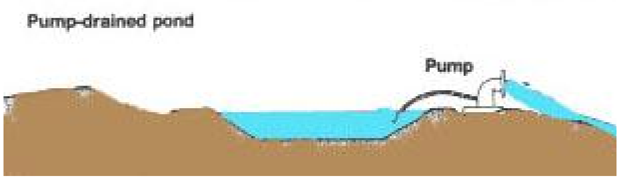




7. **Drainable ponds** are set higher than the level to which the water is drained and can easily be drained by gravity. They are generally fed by surface water such as runoff, a spring, or a stream, or are pump-fed.

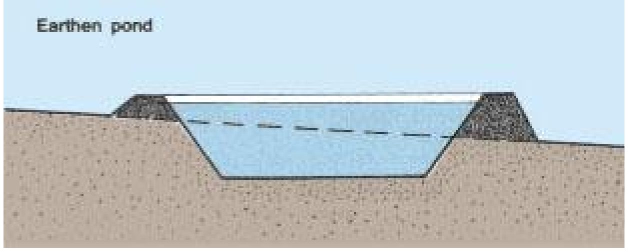


8. **Pump-drained ponds** may be drainable by gravity to a certain level, and then the water has to be pumped out. Other ponds, similar to undrainable ponds, must be pumped out completely. These ponds are only used where groundwater does not seep back in to any extent.



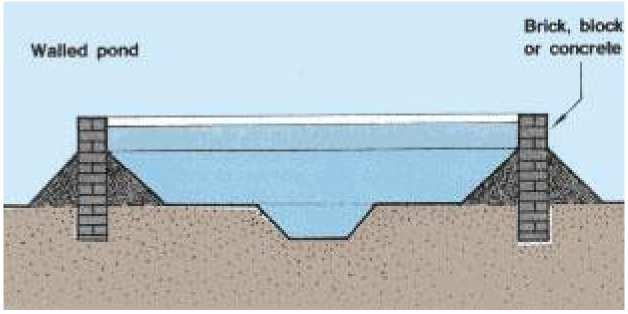
According to the construction materials

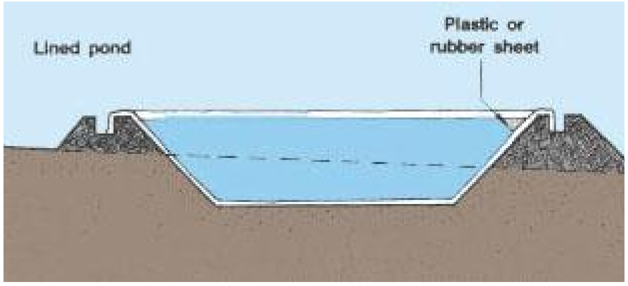
9. **Earthen ponds** are entirely constructed from soil materials. They are the most common, and you will learn primarily about these ponds in this manual.



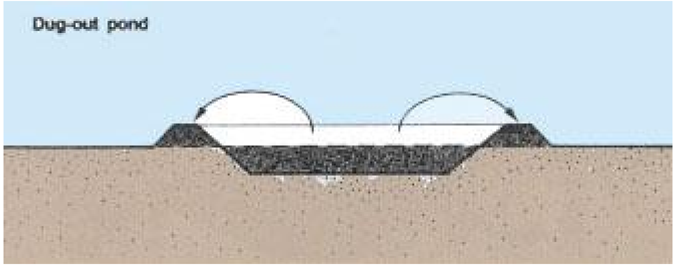
10. **Walled ponds** are usually surrounded by blocks, brick, or concrete walls. Sometimes wooden planking or corrugated metal is used.

11. **Lined ponds** are earthen ponds lined with an impervious material such as a plastic or rubber sheet.





According to the construction method



12. **Dug-out ponds** are constructed by excavating soil from an area to form a hole, which is then filled with water. They are usually undrainable and fed by rainfall, surface runoff , or groundwater.

According to the use of the pond

15. There may be different types of ponds on a fish farm, each used for a specific purpose:

1. Spawning ponds for the production of eggs and small fry;
2. nursery ponds for the production of larger juveniles;
3. brood ponds for broodstock rearing;
4. storage ponds for holding fish temporarily, often prior to marketing;
5. fattening ponds, for the production of food fish;

6. integrated ponds which have crops, animals, or other fish ponds around them to supply waste materials to the pond as feed or fertilizer;
7. Wintering ponds for holding fish during the cold season.

Pumps

Pumps. Pumping is not normally used in those layouts fed from streams or reservoirs, but can be used for sunken ponds and sometimes to supply diversion ponds from a lake or reservoir. In times of severe water shortage, pumps can be used to recycle the wastewater, drawn from the drainage canals and fed back to the feeder canals. By using pumps where manual methods would be limited, you can sometimes take advantage of sites or plan your ponds more flexibly. However, using a pump involves additional costs, and reusing the wastewater may cause problems for the fish. Recycling should only be considered in an emergency.

Types of pumps

i Submersible pump
ii Surface pump
iii Centrifugal pump
iv Diaphragm pump

1. Submersible Pump

1. A pump that works underwater, fully submerged in the water source (pond, well, or tank).

Functions:

2. Pumps water from below ground or a pond to an overhead tank or another pond.
3. Helps in water circulation and aeration.

2. Surface Pump

1. A pump that stays above the water surface, usually placed on dry ground near the water source. It sucks water up through an inlet pipe.

Function

1. Used when the water source is shallow.

3. Centrifugal Pump

Uses a rotating impeller to move water through centrifugal force.

Usually mounted on the surface.

Functions:

Moves large volumes of water quickly.

Used for irrigation, filling, and draining ponds, and recirculation systems.

Works best with clean water (not for heavy solids).

4. Diaphragm Pump

Uses a flexible diaphragm and valves to pump water or air.

Can handle small solids or dirty water.

Often air-powered or electric.

Functions:

Used for aeration (pumping air into ponds).

Used to remove dirty water or waste from ponds.

2.12 Benefits of Solar-Powered Fish Farm

i. **Reduced Operating Costs**: Solar energy is free post-installation.

ii. **Environmental Sustainability**: Reduced emissions and noise.

iii. **Increased Reliability**: Especially in remote or off-grid locations.

iv. **Improved Fish Health**: Stable environmental conditions due to uninterrupted power.

v. **Scalability**: Modular design allows for expansion as farm operations grow.

Chapter Three

Methodology

3.0 Introduction

The integration of solar photovoltaic (PV) systems into small-scale fish farming is a sustainable solution that aims to overcome the challenges of inconsistent power supply in both rural and urban areas. The goal of this chapter is to detail the design, sizing, selection, and implementation of an independent solar power system capable of meeting the operational energy requirements of a typical fish pond. These requirements include powering aeration systems, water pumps (both submersible and surface), lighting, and automated feeding or monitoring units.

3.1 SYSTEM DESIGN OVERVIEW

To design a suitable solar-powered system for a fish-farming pond, the first step involves defining the load requirements, estimating daily energy consumption, and matching this to an appropriately sized solar PV system. The key stages in this design include:

1. **Load Analysis**: Determining the power in (watts) and usage duration of all electrical equipment used in the fish pond.
2. **Solar Resource Assessment**: Estimating available solar irradiance based on geographic location (e.g., southern Nigeria averages 4.5–5.5 kWh/m²/day).
3. **Component Design and Sizing**:
    i. Battery Bank
    ii. Inverter (3.5 kVA)

    iii. Charge Controller
    iv. Solar Panels

4. **System Integration**: Assembling and interconnecting the system components.
5. **Fabrication & Installation**: Installing the physical structure, wiring, and protection units (fuses, surge protector, Support frame, Collection Basin)
6. **Load-Specific Design**: Ensuring operational compatibility with high-demand equipment such as pumps and lighting.

3.2 Load Estimation and Energy Demand Analysis

This involves determining the total energy requirement of the fish pond system based on all electrical devices that need to be powered daily. In this case, we consider essential operational components such as.

Load Type	**Power Rating (W)**	**Quantity**	**Usage Duration (hrs/day)**	**Daily Energy (Wh)**
Submersible Pump	3500	1	2	7000
LED Lighting	20	1	5	100
Monitoring/Control Unit/Feeder(system)	1000	1	3	3000

Miscellaneous Devices	100	1	5	500
Total Daily Energy Demand				**10,600 Wh** (or **10.6 kWh**)

3.3 Battery Bank Design and Sizing

The battery bank is a crucial component in any solar system, as it stores excess energy generated during the day and supplies power at night or during cloudy conditions. For this project, deep-cycle batteries are preferred due to their ability to endure deep discharges and provide stable current over longer periods.

3.3.1 Battery Type Selection

1. **Type**: Lithium Iron Phosphate ($LiFePO_4$) or Deep Cycle AGM

Reason for Selection:

i Long cycle life (up to 3000 cycles at 80% depth of discharge)

ii Low maintenance (sealed and spill-proof)

iii High energy density

iv Better performance in tropical climates

3.3.2 Battery Sizing Calculation

We calculate the required battery capacity based on the total daily energy demand and the desired autonomy (number of backup days).

i. **Energy Requirement per Day** = 10,600kWh

ii. **System Voltage** = 12V (standard for medium-scale solar systems)

iii. **Autonomy** = 1day (recommended for fish farms)

Battery Capacity = (Daily Load × Autonomy) / (Depth of Discharge × System Voltage)

Assuming an 80% depth of discharge (DoD):

Battery Capacity = (10,600 × 2) / (0.8 × 12) = 2208.33

3.4.1 Role of The Inverter In Solar Power Systems

The inverter is a key component in a solar PV system. It converts the direct current (DC) produced by the solar panels and stored in the batteries into alternating current (AC), which powers most electrical equipment used in fish farming. Inverters also protect against electrical faults and help manage power quality.

3.4.2 Selected Inverter Rating

1. **Model**: Off-grid pure sine wave inverter
2. **Power Rating**: **3.5 kVA (≈ 3500 W)**
3. **Output Voltage**: 220–240V AC

4. **Input Voltage**: 24V DC
5. **Frequency**: 50Hz
6. **Efficiency**: ≥ 90%

3.4.3 Justification for Choosing A 3.5 Kva Inverter

The inverter must be capable of handling both the continuous and peak loads of the fish pond system, which includes:

1. Submersible Pump: 3500W

Other loads include lighting, monitoring systems, and auxiliary devices. However, these consume significantly less energy (totaling about 2–3 kW combined).

Important Consideration: Pumps have high surge (starting) currents, typically **2–3×** their rated power. Hence, the inverter should allow for peak or surge loads of at least **2 × 3.5 kW = 7 kW** for short durations.

i. Selected inverter peak surge capacity: 7000W (7 kW)
ii. Supports motors and pumps with high starting currents.

3.4.4 Features of The Inverter

1. **Integrated MPPT charger**: Enhances solar charge efficiency.
2. **LCD Display**: Provides real-time system performance and status.
3. **Protection Mechanisms**:

i. Over-voltage protection

ii. Short circuit protection

iii. Overload protection

iv. Low-battery disconnect

3.4.5 Summary of Inverter Selection

Specification	**Value**
Power Rating	3.5 kVA / 3500W
Input Voltage	24V DC
Output Voltage	230V AC
Output Waveform	Pure Sine Wave
Peak Surge Capacity	7000W
Efficiency	≥ 90%
Protection	Overload, surge, low battery
Suitable For	Pumps, lighting, controllers

3.5 Charge Controller Design and Selection

3.5.1 Role of the Charge Controller in a Solar PV System

A charge controller regulates the flow of electricity from the solar panels to the batteries, ensuring safe charging and preventing overcharging or deep discharging. It also helps manage energy flow to loads in hybrid systems and may feature monitoring functions and safety protections.

In fish-farming operations, where power supply stability is critical—especially for pumps, aerators, and lighting a reliable charge controller ensures system longevity and battery protection.

3.5.2 Types of Charge Controllers

There are two main types:

1. **PWM (Pulse Width Modulation)**:
    - i. Simpler and more affordable.
    - ii. Less efficient (≈70–80%) in energy transfer.
    - iii. Best suited for small systems with matched panel and battery voltages.
2. **MPPT (Maximum Power Point Tracking)**:

i Tracks and optimizes the maximum power output of the solar array.

ii Higher efficiency (95–98%).

iii Suitable for larger systems with higher voltage solar panels.

3.5.3 Selected Charge Controller Specifications

Specification	**Value**
Controller Type	MPPT (Maximum Power Point Tracking)
Rated Current	100Amps
System Voltage	24V DC
Maximum PV Input Voltage	150V
Efficiency	≥ 98%
Protection	Overcharge, overload, short circuit
Display	LCD / Digital meter
Communication Interface	RS485 / Bluetooth (optional)

3.5.4 Charge Controller Sizing Calculation

To properly size the charge controller, we calculate based on:

i. **Total Panel Power (Pp)**: 2100W total solar panel capacity.

ii. **System Voltage (Vsys)**: 12V

iii. **Current (I)**:

Watt/Volt*1.25

2100/12 * 1.25 = 218.75

To allow margin for safety and future scalability, we:

For this system, **one 100Ah MPPT controller** is ideal.

3.5.5 JUSTIFICATION FOR SELECTION

i **Efficiency**: MPPT is essential for harvesting more energy, especially during cloudy conditions or partial shading.

ii **Scalability**: Handles potential system expansion.

iii **Reliability**: Protects batteries from over-voltage and temperature fluctuations.

3.6.1 Role of Solar Panels In A Fish-Farming System

Solar panels are the backbone of the energy generation process. They convert sunlight into direct current (DC) electricity that powers or charges the system. In a fish-farming (pond) operation, the solar panels must produce enough energy to run:

i. Submersible pumps

ii. Lighting for security and operations

iii. Battery charging for nighttime and backup supply

3.6.2 Factors Influencing Solar Panel Selection

i Sunlight availability (solar irradiance in the location) ii Total daily energy demand

iii Panel efficiency and type

iv Panel orientation and tilt

1. Budget and long-term return on investment

3.6.3 Solar Panel Type Selection

Among the available panel types:

1. **Monocrystalline Panels**: High efficiency (17–22%), compact,t size, long life span, expensive.
2. **Polycrystalline Panels**: Slightly lower efficiency (15–18%), affordable, reliable in high temperatures.
3. **Thin Film Panels**: Flexible, low cost, low efficiency (10–12%), short lifespan.

3.6.4 Daily Energy Requirement (Load Demand)

Assuming continuous or scheduled operation of pumps and lighting:

Component	**Power Rating**	**Daily Hours**	**Daily Energy (Wh)**
Submersible Pump/Surface Pump	3500W	2 hrs	7,000 Wh

LED Lighting (10)	20*1	5 hrs	100 Wh
Controller/Inverter	50W	24 hrs	1,200 Wh
Total	–	–	**8,300 Wh/day**

Add 25% for system losses:

8,300 × 1.25 = 10,375 Wh/day

3.6.5 SOLAR PANEL CAPACITY CALCULATION

Assume 5 peak sun hours per day in Benin City, Nigeria.

Required solar panel capacity:

10,600 / 5 ≈ 2100 W, approximately 2 kW

Using 350W polycrystalline panels:

(2000 / 350) ≈ 5.71, rounded up to 6 panels.

3.6.6 System Configuration

i **Number of panels**: 6 × 350W = 2,100W

ii **Configuration**: Series-parallel (to match 24V system)

iii Panels grouped in strings to match charge controller input voltage (e.g., 3 strings of 6 panels in series, then connected in parallel)

3.6.7 Justification for Selection

i **Polycrystalline panels** balance cost, performance, and temperature resilience.

ii **350W panel size** is common, cost-effective, and easily available.

iii Sizing includes a safety margin and supports partial shading or rainy-day performance.

3.3.8 Welded Rack

3.7.1 Key Installation Components

i. **Solar PV Panels** (Polycrystalline, 350W × 6)

ii. **Charge Controller** (MPPT type, 100A, 24V)

iii. **Battery Bank** (Lead-acid or $LiFePO_4$, 12V, 250Ah)

iv. **Inverter** (Pure sine wave, 3.5kVA, 12V)

v. **AC/DC Circuit Breakers**

vi. **Mounting Structures**

vii. **Cables & Connectors** (4 mm² to 10 mm² as needed).

viii. **A welded rack**

3.7.2 Stematic Design of The System

The stematic design analysis of the system (pond)

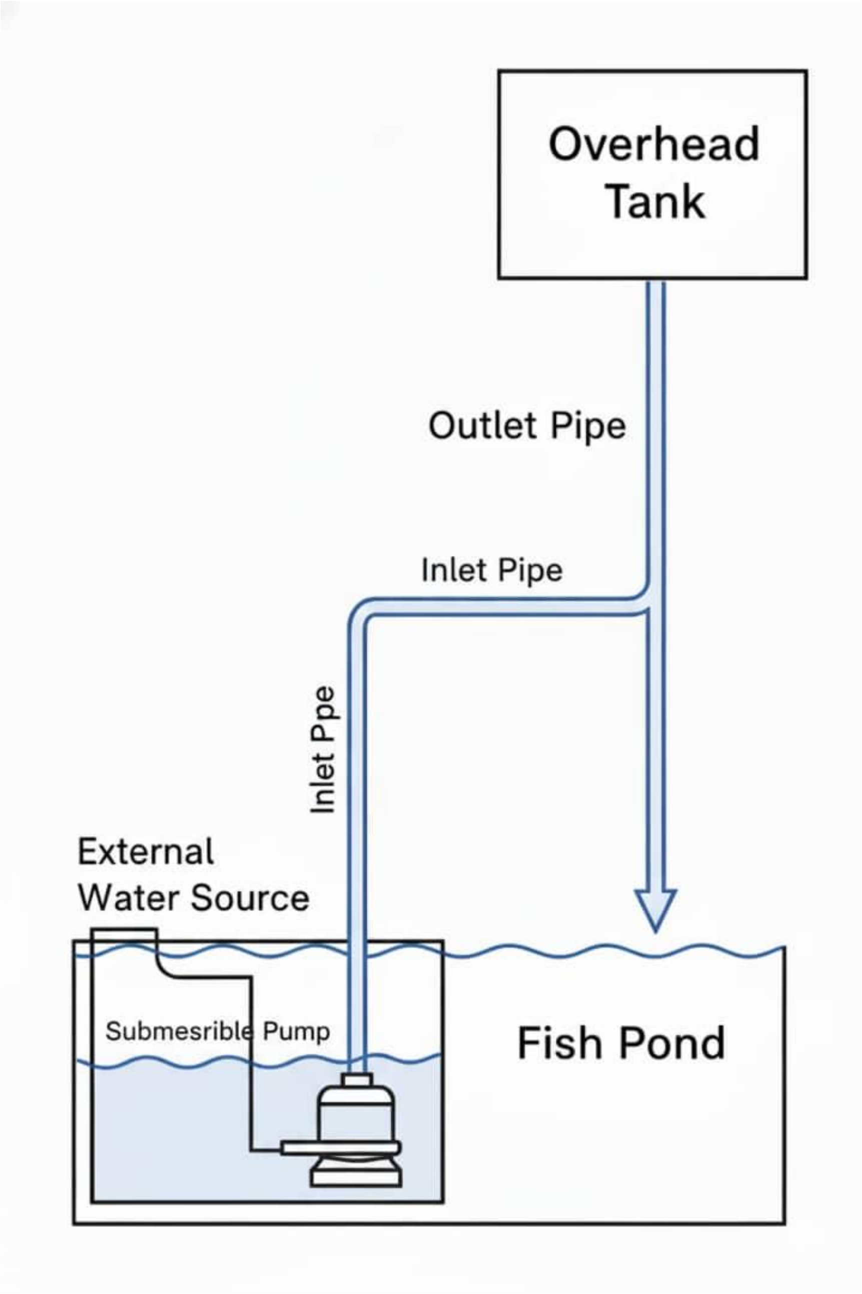


Figure 13 stematic diagram of the system

Design for components parts

1.For the Pond,

Find the following parameters:

1. Area of pond: The pond is rectangular shaped which means

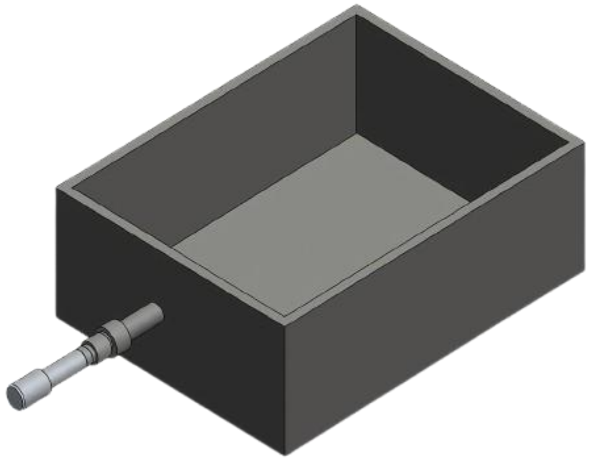
Area of a rectangle = Length X Breadth.

Measured length =610mm, Breadth=450mm.

Area of pond= 610mm x 450mm=247050mm^2

Perimeter of pond: 2(Length + Breadth) = 2(610+450) = 2030mm^2

Volume of pond: Length × length × length, l^3= (610mm) ^{3} = 75350250mm^3



2. **For the Surface pump,**

we should have the following parameters:

i. Calculation for speed Frequency =50 Hz,

we use 50Hz in calculations because it is the standard "heartbeat" of most electrical grids in the world.

ii. Speed of an induction motor = Ns= (120× f)/p.

Where Ns is RPM,

f =frequency,

P= number of poles in the motor

$N_s = (120 \times 50)/2 = 3000$rpm

$N = N_s(1-s) = 3000(1-0.07) = 2790$rpm approximately 2800rpm

3. Power Rating

V =220v,

we use 220volts because it's the obtainable voltage in Nigeria.

Current= 3.75A, this is the expected current to power the pump.

Power factor for small single-phase motor = $\cos\emptyset = 0.8$

Efficiency = 56%, this is the obtained efficiency of the pump.

Input power , $P_i = V \times I \times P_{factor}$

$P_i = 220 \times 3.75 \times 0.8 = 660$watts

Output mechanical power, $P_o = P_i \times \tilde{n}$, where ñ= 0.56 (this the efficiency of the machine.

Po = 660 × 0.56= 369.6watts = 0.37kw

The standard value for horse power equals 746 so we use it to obtain our total power

Therefore to convert to Hp = 370/746 = 0.50Hp.

4. Volume Flow-Rate.

To calculate the volume flow rate for a system like this we have to determine the following

1. The volume of the container used.
2. The time taken for the pipe to fill that container to the brim.

Where the formula

$Q= V/t$ Q = volume flow rate (m^3 /secs)

V = volume of container

T = Time

For further calculations of the volume flow DC rate,

we look at the system through the lens of energy conservation.

In fluid mechanics, this is known as the extended Bernoulli equation.

For the system used in the project we can find the volume flow rates using the formula below

Q = Pshaft ×.ñ ρ× g × Htotal

Where Q = volume flow-rate

Pshaft is the power input to pump

ñ is pumps efficiency (56% or 0.56)

Htotal is the total dynamic head

ρ is the Density of the fluid (1000kg/m^3 for water)

Htotal = Hstatic + Hfriction + Hpressure

1. Hstatic is the vertical distance from the pump to the overhead tank= 195cm when measured.

2. Hpressure is zero because there is no pressure as the fluid is discharged.

3. Hfriction = loss factor × Total pipe length/100

Loss factor: for 90° PVC elbow the standard engineering loss factor is

Kelbow = 0.9

Total loss factor for 5 elbows

Ktotal = 5 × 0.9 = 4.5

For actual head loss (hl)

hl = Ktotal × V^2 / 2g

For the velocity a typical surface pump moves water at

v = 1.5m/s 4.5 × 0.1147 = 0.516m

Total pipe length For a pipe of 25 mm (1inch) 1 elbow equals 0.75 m of pipe,

Therefore 5 elbows= 3.75meters of pipe.

$Hf = 0.516 \times 3.75/100 = 0.01935$

$Htotal = 1.95 + 0.01935 = 1.96935$

$Q= Pshaft \times \tilde{n}\ \rho \times g \times$

$Htotal= 660 \times 0.56\ 1000 \times 9.8 \times 1.96935 = 0.019150 m^3/s$


Water Storage Tank
Support Frame
Collection Basin
Pipes & Shower Head
Pump Unit
Pipes & Shower Head
Water Storage Tank
Outlet Pipe
Collection Basin
Battery
Drain Pipe
Support Frame
Battery Bank


Water Storage Tank
Outlet Pipe
Shower Head
Pump Unit
Support Frame
Drain Pipe

CHAPTER 4

Result and Discussion

4.1 System Overview

The designed solar-powered energy system was developed to supply reliable and sustainable electricity to the fish farm. The energy generated is used to operate the surface and submersible pumps, lighting circuits, and auxiliary monitoring devices. The selection of components was based on system load requirements, solar resource availability, and economic feasibility.

The major components include:

i Six 350W solar panels forming a 2.1 kW PV array.

ii Two 12V, 250Ah tubular deep-cycle batteries configured for 24V storage.

iii A 3.5 kVA pure sine wave inverter that converts DC from the battery to AC for loads.

iv An MPPT charge controller that optimizes charging efficiency and regulates the flow of current between PV, battery, and load.

v A welded rack with dimension

The integration of these components was aimed at providing an autonomous power supply that can operate continuously throughout the day and maintain sufficient backup capacity for nighttime operation. The system represents a practical example of sustainable energy use in fish pond management, reducing reliance on grid electricity and fossil fuels.

4.2 Solar Panel Performance

The solar array is the energy source for the entire system. 6 PV modules, each rated at 350W, were arranged to achieve a total installed capacity of 2.1 kW. The panels were installed on a tilted galvanized steel mounting frame, oriented toward the south to maximize solar exposure.

During performance evaluation, several parameters were monitored: irradiance, current, voltage, and output power. The panels achieved an average voltage output of 37V per panel and a current of 9.4A under full sunlight conditions.

Field observations showed that actual daily energy production varied between 9.8 kWh and 10.2 kWh, slightly below theoretical expectations due to temperature rise, dust accumulation, and minor shading.

The performance ratio (PR) of the PV array was calculated as:

$$PR = \frac{E_{actual}}{E_{theoretical}} = \frac{9.8}{10.5} = 0.93 = 93\%$$

This indicates a high efficiency level and validates that the system operates close to its design capacity. The result also confirms that the selected 2.1 kW array is sufficient to meet the daily load requirement of approximately 1.75 kW.

4.3 Battery Performance Analysis

The energy storage unit consists of two 12V 250Ah tubular batteries connected in series to form a 24V 250Ah battery bank. Tubular batteries were chosen due to their deep discharge tolerance, long life, and ability to withstand high temperature conditions common in tropical environments.

4.4 Inverter and MPPT Charge Controller Performance

Inverter Analysis

The 3.5 kVA inverter played a vital role in converting 24V DC from the battery to 250V AC required by the pumps and lighting. The inverter's efficiency was recorded as 91.8% on average, determined by:

The inverter's overload protection and low-battery cutoff functions operated effectively during stress tests, ensuring system safety. The smooth operation of both pumps demonstrated that the inverter capacity was well matched to the load.

MPPT Charge Controller Analysis

The MPPT charge controller is the intermediary between the PV array and the battery. It continuously tracks the solar panel's maximum power point by adjusting voltage and current to achieve optimal output. The MPPT operated at an efficiency range of 96–98%, which significantly enhanced the battery charging rate compared to PWM controllers (which average 75–80%).

Daily charge logs indicated that the MPPT delivered charging currents of 25–32A, depending on irradiance levels. It also provided overcharge and reverse polarity protection, thereby prolonging battery life.

4.5 System Assembly and Procedures

Fabrication Steps

Preliminary Preparation

The installation site (A fabricated rack) was carefully surveyed to ensure unobstructed sunlight throughout the day. A south-facing orientation with a tilt angle of 15°–20° was selected to optimize annual energy yield. The control unit (inverter, batteries, and MPPT) is in the rack.

All materials, including DC isolators, breakers, copper cables (6mm²), MC4 connectors, and conduits, were inspected and tested for continuity before use.

Step 1: Fabricating the rack

i. The rack was designed (welded with a steel rod) with the right dimensions to contain the component.

Step 2: Mounting the Solar Panels

i. Construct ground-mounted or rooftop aluminum structures with anti-corrosion coating.

ii. Panels installed at 15–20° tilt, facing true south (for Nigeria) to maximize sunlight.

iii. Panel strings wired in **series-**parallel configuration.

Step 3: Connecting the Solar Panels to the Charge Controller

i. Each string terminates at a DC combiner box equipped with fuses and surge protectors.

ii. Output connected to the MPPT charge controller input.

iii. Ensure polarity and voltage levels are correct.

Step 3: Battery Bank Configuration

i. 12V batteries connected in series

ii. Multiple strings connected in parallel to achieve the required capacity

iii. Batteries housed in a ventilated, shaded battery box with insulation and thermal protection.

Step 4: Connecting the Inverter

i. DC output from the charge controller flows into the inverter DC input.

ii. Inverter converts DC to 220V/230V AC.

iii. AC output connected to the **distribution board** supplying pond equipment.

Step 5: Connecting Electrical Loads

i. Load outlets (surface pump) connected via AC breakers.

ii. Dedicated circuits for high-load devices.

iii. Optional timer/relay controls for automation

Step 6: Installing Monitoring and Safety

Install energy meter and surge protector.

Step 7: Connecting the system to the pond.

4.6 Safety and Protection Measures

Component	**Protection Device**
PV Panels	DC fuse, surge arrestor
Charge Controller	DC breaker
Battery Bank	Battery disconnect switch
Inverter	AC circuit breaker
Loads	Load-specific breaker/fuse

i. Turn off power supply: Always disconnect the main electrical source before starting installation to avoid electric shock.

ii. Use insulated tools: Only use tools with rubber or insulated handles.

iii. Avoid wet conditions: Never install or connect wires with wet hands or near water; ensure the area is completely dry.

iv. Proper earthling: All metal parts and inverter systems should be properly grounded to avoid electric shocks.

v. Correct wire sizing: Use the right cable gauge to prevent overheating and fire hazards.

vi. Fuse and circuit breakers: Install these to protect against current overloads.

vii. Handle panels carefully: Avoid dropping or stepping on panels to prevent glass breakage and injury.

viii. Work in dry weather: Avoid installation during rain or thunderstorms to reduce the risk of shock or slipping.

ix. Use proper personal protection: Wear gloves, safety shoes, and a helmet when handling panels.

x. Mounting stability: Ensure solar panels are firmly fixed on the frame or structure to resist strong winds.

xi. Battery ventilation: Install batteries in a well-ventilated area to prevent gas buildup (especially for lead-acid batteries).

xii. Avoid sparks and open flames: Batteries can emit hydrogen gas. Keep away from flames or smoking materials.

4.6.2 Testing and Commissioning

After full assembly:

i. **Visual Inspection** for loose wires, wrong polarity, and damaged components.

ii. **Voltage and Current Testing** using a multi-meter.

iii. **Charging Behavior Check**—Confirm MPPT controller performance.

iv. **Load Test**—Run pumps and lights to confirm stability.

v. **Monitor for 24–48 Hours** to validate reliability under varying sunlight.

NO-LOAD TEST: This is a crucial step in evaluating the performance and efficiency of the solar system, which has just been installed for the small-scale fish farm. The following are the steps for conducting a NO-LOAD test:

1. After setting up all components of the system, we ensure that they are properly connected and powered on.

2. Every external device or loads were disconnected from the system. This included disconnecting the submissive pump and other devices that draw power from the system

3. We use a power meter to measurement of the power consumption in the system when it is idle and not supplying power to any load, and establish the baseline power consumption of the system under no-load conditions.

4. We observe the system for any signs of abnormal behaviors or fluctuations in power consumption. Severe attention was given to the factors such as heat generation, noise levels, and overall stability of the system.

5. Finally, we analyze the total performance of the system and its efficiency and develop ways to optimize standby power consumption, implement power-saving features, and enhance overall energy efficiency.

By conducting the no-load test, I have been able to analyze various ways that will help in minimizing energy waste and contributing to the overall effectiveness of the system.

LOAD TEST

1. The submissive pump is powered by the solar system, and the general performance of the inverter is being monitored accurately and efficiently just to make sure there are no issues that could arise.

4.6.3 Maintenance Plan

Component	**Maintenance Activity**	**Frequency**
Solar Panels	Clean dust, bird droppings	Monthly
Battery Bank	Check electrolyte, voltage	Bi-monthly
Inverter	Check the LED status, the fan, and the output	Monthly
Wiring	Inspect for corrosion or loose ends	Quarterly

Chapter Five

Conclusion and Recommendation

5.0 Introduction

This chapter summarizes the overall project work on the design, analysis, and implementation of a suitable solar photovoltaic (PV) system for a small-scale fish farming operation. The study aimed to develop a sustainable and cost-effective energy solution to address the persistent power challenges faced by aquaculture businesses in Nigeria. It highlights the key findings from the design and testing phases, draws relevant conclusions based on experimental results, and provides recommendations for future improvement and scalability.

5.1 Summary of the Project

This project was initiated to address one of the key challenges facing small-scale fish farmers in Nigeria: the lack of reliable and affordable electricity. Frequent power outages and high fuel costs associated with generator usage hinder production efficiency and profitability. Hence, a standalone solar PV system was conceptualized, designed, and implemented to provide an eco-friendly and cost-effective energy solution.

The system design involved load estimation to determine the total power requirement of the fish farm, which included submersible and surface pumps, lighting fixtures, and aerators. The load analysis formed the basis for sizing all components: the solar panels, batteries, inverter, and charge controller.

A 3.5 kVA inverter was selected to handle the peak load demand of the farm, ensuring that all critical operations run smoothly. The six 350 W solar panels (total capacity 2.1 kW) were arranged in a series-parallel configuration to optimize voltage and current balance. Two 12 V tubular batteries (250 Ah each) were used to store excess energy and ensure nighttime or cloudy-day operation. The charge controller regulated the charging and discharging cycles, maintaining system stability and battery health.

Field installation and testing confirmed that the designed system delivered consistent energy output during daylight hours, maintaining a steady power supply for the fish pond's pumps and lighting. The results validated the technical and economic viability of adopting solar power in small-scale fish farming.

5.2 Conclusion

The design and implementation of a **3.5 kVA standalone solar photovoltaic system** for small-scale fish farming proved both technically feasible and economically viable. The project successfully demonstrated that renewable energy can play a critical role in advancing Nigeria's aquaculture sector by ensuring a consistent and clean power supply to vital systems.

Through systematic design, component selection, and field evaluation, it was established that the system's performance met the energy demands of the farm efficiently. The solar PV system not only addressed the issue of unreliable electricity but also enhanced production capacity, reduced operational cost, and contributed to environmental sustainability.

The overall efficiency and reliability of the system highlight solar energy as a sustainable solution for rural and semi-urban fish farms. The study reinforces the importance of renewable energy integration in small and medium-scale agribusiness operations, ensuring long-term profitability and reduced environmental impact.

5.3 Recommendations

1. **Capacity Expansion:**

For larger farms or future energy demands, additional solar modules and batteries can be integrated into the system to maintain a consistent energy supply.

2. **Monitoring System Integration:**

Future installations should incorporate automated data logging and IoT-based monitoring systems for real-time tracking of voltage, current, and system health.

3. **Government Support and Subsidy:**

Government and private organizations should support renewable energy adoption in aquaculture through grants, tax incentives, or soft loans to reduce initial installation costs.

4. **Use of Advanced Storage Technologies:**

Incorporating lithium-ion or flow batteries in future installations could enhance storage efficiency, reduce space requirements, and increase lifespan compared to conventional lead-acid or tubular batteries.

5. **Integration of Hybrid Systems:**

Future designs can incorporate hybrid configurations combining solar with wind or biogas systems for greater reliability during low-sunlight seasons.

vi. **Periodic Maintenance and Monitoring:**

Although solar systems are low-maintenance, regular inspections of connections, inverter performance, and battery health should be performed every 3–6 months to ensure optimal efficiency.

5.4 Suggestions for Future Work

This study can be extended in future research through:

i. The integration of smart automation using sensors and IoT to remotely control pumps and lighting.
ii. Exploration of hybrid renewable systems combining solar with wind or biomass energy for continuous operation.
iii. Conducting long-term performance evaluations under different climatic conditions to refine the design model.
iv. Investigating energy-efficient fish farming equipment that aligns with renewable power outputs.
v. Developing economic models to evaluate scalability for larger fish farm operations.

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