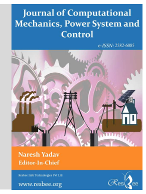
Vol.7 No.4 Oct 2024

Journal of Computational Mechanics, Power System and Control

Received 18 September, Revised 15 October, Accepted 28 October



Design and Implementation of a Solar-Powered Irrigation System for Large-Scale Farming in Kaduna State, Nigeria

Akioya Answer Ose
Department of Mechanical Engineering, Faculty of Engineering & Technology, Ambrose Alli University, Ekpoma 310102, Nigeria.
oseakioya@hotmail.com

Sule Emmanuel Oshioriameh
Department of Mechanical Engineering, School of Infrastructure Process Engineering and Technology, Federal University of Technology, Minna 920101, Nigeria.
suleoshioriameh@gmail.com

Friday Udeji
Department of Mechanical Engineering, Faculty of Engineering & Technology, Ambrose Alli University, Ekpoma 310102, Nigeria.
udejiomofriday@gmail.com

Akhimien Eromosele Samson
IAENG – International Association of Engineers, 333209.
eromoseleakhimien1@outlook.com

Abstract: This research presents the design and implementation of a solar-powered irrigation system for large-scale farming in Kaduna state, Nigeria. The complete system is designed to perform optimally as an independent functional unit from the conventional power grid controlled by the state electricity commission. Due to the population explosion, substantial efforts have been made by the science community and the world at large to ensure sustainable energy development to drive efficient food production methods. Farmers in Kaduna state face challenges such as erratic power supply from the national electricity grid and ineffective irrigation systems, hindering them from doing large-scale farming even with the availability of arid land for agriculture. This design prospect is proposed to enable farmers to manage their farmland for large-scale crop production. In this design, crucial industrial ideologies such as the basic operating mechanics of irrigation systems and solar energy generation units were analyzed, tested, and applied. The working principle and calculations employed in the evaluation of the design parameters were adopted in modeling a system that suits the needs of the designated area. This system is cheap to construct and maintain, given the demographics of Kaduna, all year large scale farming of crops such as maize, tomatoes, onions, and other crops can be achieved using the solar-powered irrigation system.

Keywords: Solar powered irrigation system, Irrigation system design, sustainable agriculture, off-grid farming, Solar energy.

Nomenclature

Abbreviation	Expansion
GDP	Gross Domestic Product
SDGs	Sustainable Development Goals
GPS	Global Positioning System
UTC	Coordinated Universal Time
WAT	West Africa Time
Hp	Horsepower
DC	Direct Current
AC	Alternating Current
PVC	Polyvinyl chloride
AGM	Absorbent Gas Mat

1. Introduction

For centuries, countries have relied on the exportation of agricultural products for the growth of their GDP and other economic benefits. Agricultural products also find application in a plethora of disciplines and industries such as production industries, food processing industries, breweries, and many other agro-allied industries that provide basic, luxurious, and industrial products for the comfort of humans [1]. Despite these innumerable benefits of agricultural products to a country, third world countries and developing nations such as Nigeria whose major source of revenue generation has been from agricultural products have recently been plagued with food scarcity and an obvious reduction in the agricultural contributions to the national GDP [2]. The irrigation system has been mapped out as a feasible provision for an efficient and sustainable system in conserving water resources and plant yield.

Energy is required for everyone's daily endeavors. Without energy, work cannot be done, nor can any challenges be overcome. Energy generation, a major problem in Nigeria, hinders farming operations and reduces farm yield. Farm farming processes can be mechanized with the introduction of renewable sustainable energy sources. Solar energy is a clean and sustainable energy that can be used in powering farming equipment and irrigation systems [3]. With the issue of global climate change, using the combustion of fossil fuels as an energy source to power irrigation systems for farming is harmful to the environment. Climate change is a global dilemma to the earth globe and has become an enigma in this present time. Rising temperatures in places globally, extreme weather conditions, and deteriorating environmental traits have become evidence today impacting our daily lives [4][3].

Clean, sustainable energy generation is needed to drive global food production and in alignment with Global SDGs. In countries like Taiwan, the ratio of agricultural products to the other products making up the GDP has been on the increase each year [5]. This is due to modern methods in farming techniques and improvements in the genetic manipulation of seeds and seedlings. Amongst other things, the most important reason for the increase in the agricultural products in these advanced countries is the adoption of proficient Irrigation techniques. In Nigeria, quite a few farmers have partially or fully adopted irrigation for the production of crops [6]. This has led to the popular seasonal farming where farmers have to wait for the rainy season to produce crops. With agricultural products making the principal sector of the national GDP of most African countries [7], it is convenient to raise the question of a counterintuitive approach to seasonal farming.

2. Proposed Site Description and Modeling

2.1 Site Description

The farmland is located in the Sabon- Gari Nassarawa district of Chikun Local Government Area, Kaduna, Nigeria, 30 acres in size and was chosen as the proposed site for the project. The GPS coordinates of the proposed site location are 10.486851°, 007.354617° or 10°29'13", 007°21'17" (Time zone: UTC+01, Africa/Lagos WAT). The position of the proposed site is shown on the Satellite Map image in Fig. 1. Maize, onions, tomatoes, pepper, and potatoes have been planted across the proposed sites by a group of farmers.

Fig.1. *Satellite Image of the Proposed sites - Sabon Gari Nassarawa, Kaduna state (Source Global Solar Atlas, January 2024)*

2.2 Solar Radiation Index at the Proposed Site

Solar irradiance at the proposed site is important to the implementation of the project. Solar irradiance on the earth's surface is calculated as the amount of radiant energy received from the sun at a given geographical location to its distance from the sun. Ranging from 109.0 MWh to 157.9MWh as shown in Fig. 2, the monthly photovoltaic power output average is high in the proposed site because the region is in the Sub-Saharan parts of Africa known to have high sun rays throughout the year. A ground-mounted large-scale PV system was used with a titled inclination of 15° and an installed capacity of 1000kWp. The radiant energy from the sun is at its peak in December during the harmattan season caused by the rushing wind moving from the Saharan desert and at its lowest in August during the rainy season influenced by the wind blowing inland from the Atlantic Ocean.

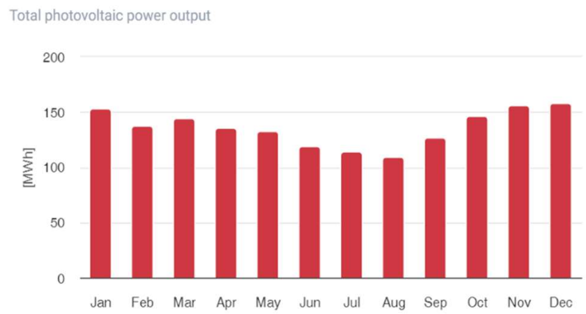


Fig 2. *Average Monthly variation of solar radiation index at the proposed site (source: globalsolaratlas.info)*

The average hourly profiles of Total photovoltaic power output [kWh] are high in November and low in August, ranging from 3,517kWh to 5,200kWh as shown in Fig. 3. This factor indicates that the Global tilted irradiation (per day) is 0.004 Gwh and total photovoltaic output is 5.670 kWh/m².

Total photovoltaic power output [kWh]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6			0.110	3.000	10.850	11.365	7.286	5.012	6.367	5.207	1.969	
6 - 7	35.602	35.366	63.221	90.615	107.412	95.052	83.530	81.532	105.372	127.371	137.967	88.778
7 - 8	255.422	233.250	234.099	249.794	243.488	214.701	190.527	192.586	249.246	308.866	358.451	317.584
8 - 9	448.061	424.474	409.666	409.900	386.163	343.424	304.157	295.041	383.265	472.969	536.624	501.398
9 - 10	596.294	577.612	549.547	538.136	498.759	445.171	397.626	373.552	491.573	599.713	661.260	635.608
10 - 11	684.910	672.893	644.706	622.274	579.783	522.410	463.651	443.926	578.715	677.597	726.507	711.000
11 - 12	720.945	715.550	684.046	659.349	613.607	557.086	518.964	497.916	623.495	702.283	740.926	734.757
12 - 13	699.192	698.706	661.397	631.832	591.957	548.534	512.574	493.416	600.583	651.981	695.923	701.329
13 - 14	617.727	620.994	577.695	545.945	517.218	485.573	463.192	443.254	509.303	545.354	596.447	610.470
14 - 15	480.853	487.103	444.532	412.496	396.581	381.206	365.652	346.319	377.329	392.318	446.715	463.509
15 - 16	305.373	314.699	279.341	255.552	240.868	241.438	239.383	231.027	219.945	211.101	256.043	278.829
16 - 17	106.383	118.624	102.531	94.336	91.093	102.682	107.366	102.069	75.026	38.005	41.266	50.230
17 - 18	0.807	2.138	1.806	3.511	5.748	12.328	17.056	10.910	2.670			
18 - 19												
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,952	4,901	4,653	4,517	4,284	3,961	3,671	3,517	4,223	4,733	5,200	5,093

Fig 3. *Average hourly profiles of solar radiation at the proposed site (source: globalsolaratlas.info)*

The sun's horizon line and path at the proposed site location are depicted in Fig.4, giving us the peak time of irradiation energy when power generation is at its highest.

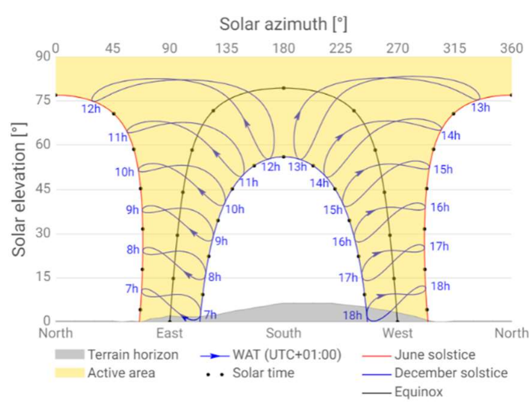


Fig. 4. *Sun horizon path at the proposed site.*

3 Methods and Design Theory

The design process began with a detailed assessment of the irrigation requirements, including crop water needs, irrigation area, and prevailing environmental conditions. This information guided the selection of components, focusing on their compatibility, efficiency, and cost-effectiveness within the system. A major key consideration was using solar panels to harness energy from the sun. Considering shading and orientation, these panels were strategically positioned to maximize sunlight exposure. The essence primarily was to align design concepts to sustainable design principles by minimizing environmental impact while maximizing energy efficiency.

The installation phase followed a systematic approach with careful attention paid to the components' layout and integration. The pump was installed to efficiently draw water from the river flowing through the proposed site and deliver it to the irrigation system. The irrigation lines were intentionally designed to ensure uniform distribution across the field, reflecting efficient and effective water management. Performance testing was conducted to evaluate the system's functionality under various conditions. This included tests to measure water flow rates, pump efficiency, and overall system reliability. Data collected through meters informed the analysis, which was used to assess the system's effectiveness in meeting the irrigation needs of the crops.

In the development process, challenges were encountered and addressed following the path of iterative design theory. Major adjustments were made based on practical insights gained from these challenges.

3.1 Components

The solar irrigation system consists of the following components.

3.1.1 The Pump

The pump is a crucial mechanical device to move fluid(water) through the system by converting electrical energy into hydraulic energy. This conversion increases the energy of the liquid per unit volume, facilitating its movement through the system. In this particular design, a centrifugal pump was selected due to its operating pressure of about 2-3 bars. Overall, the efficiency, low maintenance requirements, adaptability to varying flow rates, compatibility with solar power, and cost-effectiveness make centrifugal pumps an excellent choice for solar-powered irrigation systems.

An HP pump draws 6.91 amps at 120V per hour and stands at 746watt per hour. In 24 hours, that is 24 x 746 = 17,904watt-hour. At the average cost of ₦36.6/kWh ($0.023/kWh) with the present exchange rate of ₦1,600 peg to $1. In a day, the cost of running the pump via the conventional power grid would be:

=36.6 x 0.746 x 24

=₦ 655.28 ($0.41)

In a month, this amounts to 655.28 x 30 = ₦ 19,658.52 ($ 12.29) leading to an annual cost of 12 x 19,658.52 = ₦ 235,903.104 ($ 147.44). In five years, supposing there is no maintenance of the power systems and no hike in the price of electricity, this will amount to N1,179,515.52 ($ 737.20). On the other hand, using a solar-powered system costs below 60% of this five-year price and is also less prone to power fluctuations and unavailability. More so provided no physical damage is done to the system, the cost of maintenance, procurement, and installation of the solar power system is far less in 5 years compared to using power from the national power grid.

Pump operations and parameters can best be described by a few fundamental parameters; flow rate, pressure, head, power, and efficiency.

1. **Pump Specification**

   Motor Power = 0.5 HP
   Head = 6 – 26 meters
   Water flow= 33.6 LPM
   Max Pressure = 145 bars
   Frequency = 60 Hz

2. **The Pressure of The Pump**

Since the operating pressure of the sprinkler is about 5 bars, an attempt was made to select a pump with higher pressure to ensure that despite loss in pressure, sufficient pressure will get to the sprinklers.
Total pressure required by the 50 sprinklers = 5 x 50 = 250 bar
For safety, a pressure of 75% is used which amounts to 0.75*250 = 187.5bar

3. **The Pump Head**

A pump with a head rating equal to or slightly higher than the vertical distance from the pump to the overhead tank (5.2 meters) was selected to ensure efficient water delivery.

4. **The Pump Power**

This horsepower rating describes the useful work the pump will do to the fluid. It is calculated as follows:

$P = \rho.g.Q.H$

Where:

P is the power required by the pump (Watts).
ρ is the density of the fluid (kg/m^3).
g is the acceleration due to gravity (m/s^2).
Q is the flow rate of the pump (m^3/s).
H is the total head of the pump (m).

P = 1000 x 9.81 x 0.00336 x 11 = 371.15W

5. The Pump Efficiency

The efficiency of the pump can be calculated using the following equation

$$Efficiency\ (\%) = Pout\ /\ Pin\ \text{X}\ 100$$

Where:
Pout is the output power of the pump (Watts).
Pin is the input power to the pump (Watts).

3.1.2 The Sprinklers

The sprinklers used are rotating sprinklers with a radius of 2 meters. The area covered by one sprinkler is calculated using the formula for the area of a circle $A = \pi r\hat{}2$.

Substituting the radius r=2, we obtain $A = \pi x 2\hat{}2$ =12.57sqm.

But Total Area=24 x 24=576m^2

Number of sprinklers to cover the entire land area = $(Total\ area\ of\ land)/(Area\ covered\ per\ sprinkler)$

=576/12.57=46

3.1.3 The Reservoir

The reservoir is an overhead tank mounted on a frame 6.0 meters above the ground level. The tank was measured and found to be 2500 liters. This is adapted so that water can be pumped in from the nearby river [8]. This water is then supplied to the irrigation system when needed. The river Kaduna was adapted, and the depth of the river to the suction pipe of the pump was 1.0 meters, thus making the pump's total head from the river surface (A depth below) to the overhead tank 6m. This is within the operating specification of the pump and was tested and found satisfactory.

Thus, pressure delivered from the reservoir is:

$$Pout = \rho g h$$

Pout=1000 x 9.81 x 6.0
Pout =58860N/m^2
Pout =0.6bars

3.1.4. The Hose

The hose is a flexible pipe for fluid supply. It acts as a conduit for fluid supply in the solar-powered system. Its diameter is consistent through its length and it is larger than that of the delivery pipe. The design was designed with the necessary flexibility to accommodate and withstand high pressures [9]. The proper hose diameter is determined according to the maximum flow rate and the selected fluid speed.

$$d = \surd\left((4\ \text{X}\ Qmax)/(\pi\ \text{X}\ v)\ \right)$$

Where:
d = Hose inner diameter(meters)
$Qmax$ = Maximum flow rate (cubic meters per second)
v = Fluid mean velocity (meters per second)

3.1.5 The Pipe

The pipe consists of the suction line (rubber hose) and delivery PVC pipe, having dimensions 0.75 inches and 0.5 inches respectively. The suction line has a greater diameter than the delivery pipe to increase the velocity and pressure of the flow at the delivery point. The delivery pipe is connected to the rotating sprinklers which dispense the water at a 12.57 square meter per sprinkler within optimal operating pressure. However, due to many factors, there is a dramatic loss in operating pressure between the net pressure head and the delivery head of the sprinklers. According to theoretical considerations, there are two types of losses during the flow of fluid through pipes.

- Minor losses
- Major losses

Minor losses: these are losses that occur whenever there is a change in the cross-section of the pipe. They are caused by the disruption of the flow due to the installation of appurtenances, such as bends and other fittings in the piping system.

1. **Head loss due to sudden expansion:** It is a type of minor loss at the end of a pipe or when a smaller pipe meets a pipe with a larger diameter due to sudden enlargement in the area of the flow this results in a drop in pressure and an increase in.
2. **Head loss due to sudden contraction:** It is a type of minor loss when a large-diameter pipe meets a small-diameter pipe attached to a water reservoir due to a sudden decrease in the area of the flow.

3. **Head loss at entry:** This is the loss of energy at the entrance of the piping system.
4. **Head loss at exit:** This is the loss of energy at the exit of the fluid from the piping system. Head loss in bends and pipe fittings.

Major losses: these are losses that occur in the pipe because of friction. It is termed a major loss because there is a significant loss of energy because of friction.

During the flow of fluid through the pipe unit Bernoulli's equation and Darcy-Weisbach equation are needed to calculate power in the system and also losses in the system.

3.1.6 Fittings

Fittings or adapters are used in the systems to connect straight sections of pipes or tubes, adapt to different sizes, and change the direction of flow. These fittings were made such that there were no leakages at the joints by the use of water-proof glue.

3.1.7 The Solar Panels

The solar panels are a part of the power supply unit for the solar-powered irrigation system, their major function is to absorb solar energy in the form of radiation and convert it to direct current which will be transmitted to the inverter.

The panels chosen for the design of the solar-powered irrigation system are monocrystalline solar panels among other panels namely, polycrystalline solar panels and thin film solar panels due to the following reasons:

- Monocrystalline solar panels have the highest efficiency rates, typically in the 15-20% range, the high-efficiency rate means the solar panels produce more power per square meter and are therefore very space efficient.
- They perform better than similarly rated polycrystalline solar panels at low-light conditions.
- Monocrystalline solar panels tend to be more efficient in warm weather. Performance suffers somewhat as temperature goes up, but less so than with polycrystalline solar panels.
- The panels used are 200W rating, during the design of the overall system. It was found that the design needed 8 panels to work effectively.

Panel Estimation

(a) Amount of sunshine in a day

In Kaduna on 29th September, 2021 at latitude 6°45'.

Solar declination $\delta = 23.45° \, sin\left[360/365 \, \left(284 + n\right)\right]$

where $n = 31 + 28 + 31 + 30 + 31 + 30 + 31 + 31 + 29 = 272$

Therefore, $\delta = 23.45° \, sin\left[360/365 \, \left(284 + 272\right)\right]$

$$\delta = 23.45° \, sin\left[360/365 \times 556\right]$$

$$\delta = 23.45° \, sin\left[548.22°\right]$$

Since $sin\left(548.22°\right) = -0.143$ (approximately),

$$\delta = 23.45° \times \left(-0.143\right)$$

$$\delta \approx -3.35°$$

To estimate the amount of sunshine in a day, we use the solar declination and the latitude of the location.

Hour angle (H) is calculated using:

$$H = arccos\left(-tan\left(\varphi\right) \, tan\left(\delta\right)\right)$$

Where:

$$\varphi \, \left(latitude\right) = 6°45' = 6.75°$$

$$\delta \, \left(solar \ declination\right) = -3.35°$$

Convert degrees to radians:

$$\varphi = 6.75° \times \pi/180 = 0.1178 \, radians$$

$$\delta = -3.35° \times \pi/180 = -0.0585 \, radians$$

Calculate the hour angle:

$$H = arccos\left(-tan\left(0.1178\right) \times tan\left(-0.0585\right)\right)$$

$$H = arccos\left(-0.1181 \times -0.0584\right)$$

$$H = arccos\left(0.0069\right)$$

$$H \approx 1.563 \, radians$$

Convert hour angle from radians to degrees:

$$H \times 180 / \pi \approx 89.57°$$

Day length can be calculated using:

$$Day \ length = 2H / 15$$

Convert degrees to hours:

$$Day \ length = 2 \times 89.57° \ / \ 15 \approx 11.94 \, hours$$

3.1.8. The Inverter

The inverter is the component of the power supply unit that converts the DC from the panels to AC. The inverter has a rating of 2.5KVA so it can work effectively with the other components of the power supply system.

3.1.9. The Charge Controller

The charge controller is a regulatory component of the power supply unit of the solar-powered irrigation system that controls the direction of flow of current from the inverter to the battery and from the battery to the pump. The solar charge controller ensures that the deep cycle batteries are not overcharged during the day and that the power doesn't run backward to the solar panels overnight and drain the battery.
The charge controller chosen for the design of the solar-powered irrigation system has a rating of 60Amp

3.1.10. The Battery

Irrigation is usually done at cool hours of the day when the sun is not at its peak. This means that there is a need to give motion to the water at those times. Knowing that the sun which is supposed to be the source of power for the system is not at its peak at those times, there arises a need to store the power generated at those periods and make it available when it is needed. An example of such periods is at night when there is little light. Another function of the battery is to store the excess energy the solar panel system generates.

The rating of the battery is 200 Amp-hour, and it was designed that two batteries will be needed for the solar unit to work effectively.

Battery specification:

Rated voltage = 12V
Rated Ampere-Hour = 200AH
Type = Deep Cycle AGM

Capacity (Ah) = (daily energy load consumption (Wh)/max panel volt(v).

3.1.11. The Cables

The cables consist of all the wiring used during the assembly of the solar-powered irrigation system such as

1. Wiring is used for earthing the solar-powered irrigation system to protect the design from electric shock.
2. Wiring from the solar power unit to the pump.
3. The cables needed in the connection of all the solar panels for easy supply of direct current to the Inverter.

3.2. Design Specifications and Calculations

The design is intended to be mounted in mixed cultivated farmland. Some equations were applied that govern the operations of the irrigation system and the energy interactions at various points.

3.2.1. Equations of Fluid Motions

1. **Conservation of Energy:** The conservation of energy in fluid dynamics is a fundamental principle that accounts for the total mechanical energy per unit mass of fluid which remains constant along a streamline in a steady flow. This principle is mostly expressed through Bernoulli's equation which relates the pressure, velocity, and elevation of fluid along a streamline.
2. **Bernoulli's equation:** This is a fundamental principle in fluid dynamics that shows the relationship between pressure, velocity, and elevation of fluid. According to Bernoulli for a steady and incompressible flow of a fluid with negligible viscosity, the total mechanical energy per unit mass of the fluid remains constant. The equation is expressed mathematically as:

$$P + (pv\hat{\ } 2) / 2 + \rho gh = constant$$

Where:

P is the fluid pressure.

ρ is the density of the fluid.

V is the velocity of the fluid.

g is the acceleration due to gravity.

h h is the height above some reference point.

For the irrigation system, Bernoulli's equation is applied to understand how the pressure, velocity, and elevation of water change as it flows through pipes. It was generally used to optimize the design of the whole system to ensure water reaches the intended locations with the required pressure and velocity for efficient irrigation. During the application, 3 types of energy were considered:

3. **Potential Energy:** This is the energy associated with the elevation of the fluid above some reference point. In this context, it is the energy due to the height of water in a reservoir or the elevation of water in a pipe.
4. **Kinetic Energy:** This is the energy associated with the movement of fluid due to its velocity. The faster the water is moving, the more kinetic energy it possesses, and vice versa.
5. **Pressure Energy:** This is the energy associated with the pressure of the fluid. It represents the potential to do work by exerting force over a distance. In this context, it is the pressure exerted by the water on the walls of the pipes. According to Bernoulli's equation, the sum of these energies remains constant for an idea fluid (assuming no energy is lost due to friction of other dissipative forces).
6. **Conservation of Mass:** This states that the amount of fluid flowing into a system must be equal to the amount flowing out, irrespective of the changes in density within the system. For the irrigation system, the law of conservation of mass is important as it ensures that the water supply matches the demand for irrigation while accounting for losses due to evaporation, leakages, or absorption by the soil. This helped in the design to optimize the system to efficiently distribute water to crops.

Mathematically,

$$\text{Flow rate in} = \text{Flow rate out}$$
$$\rho 1\ A1\ V1 = \rho 2\ A2\ V2$$

Where:

$\rho(1,2)$ is the densities at points 1 and 2.

$A(1,2)$ is the cross-sectional area at points 1 and 2.

$V(1,2)$ is the velocities at points 1 and 2.

3.2.2. Loses of Energy in The Piping System

During the flow of fluid in the irrigation pipe system, energy losses occur along the way. These losses are usually due to friction between the fluid and the wall of the pipe, changes in cross-sectional area bends, fittings, and other obstructions in the path of fluid motion. For efficient system design, understanding and quantifying these energy losses are crucial. They include:

1. Frictional Losses (Head loss):

Friction between the wall of the pipe and the fluid flow results in loss of energy called head losses or frictional losses. They are usually quantified using the Darcy-Weisbach equation:

$$h\_f = fL / DV^\wedge 2 / 2g$$

Where:

h_f is the head loss due to friction

f is the Darcy-Weisbach friction factor (depends on Reynolds number).

L is the length of the pipe.

D is the diameter of the pipe.

V is the velocity of the fluid.

g is the acceleration due to gravity.

2. Loss of head to sudden enlargement (he)

$$He = (V1 - V2)^\wedge 2 / 2g$$

Where:

$V1,2$, and g are the velocities of sections 1 and 2 and the acceleration due to gravity.

3. Loss of head to sudden contraction (Hc)

$Hc = 0.5V2^\wedge 2 / 2g$ with the same parameter definition as above.

4. Loss of head at the exit and entrance of the pipe

$$Entrance = 0.5V2\hat{}2/2g$$

Where V = Velocity of the liquid in the pipe

$$Exit = V\hat{}2/2g$$

Where V = Velocity of the liquid in the pipe

5. Loss of head due to bend in the pipe

$$Hb = kV\hat{}2/2g$$

Where V = Velocity of the liquid in the pipe and K is the coefficient of bend.

6. Loss of head in various pipe fittings

$$Hf = kV\hat{}2/2g$$

Where:
V = Mean velocity of the liquid in the pipe
K is the value of the coefficient and it depends on the pipe fittings.

3.2.3. Irrigation Flow Rate

This refers to the rate of water application in overhead irrigation. The irrigation flow rate is expressed in units of $m3$/Hr. To minimize soil erosion and the draining away of water, the irrigation flow rate was planned properly.

$Quantity\ of\ water\ used\ in\ a\ minute\ is\ 10\ litres\ Thus\ quantity\ used\ in\ 10\ minutes$=10 x 6 = 100 $Liters\ per\ irrigation\ session$ Assuming homogeneity of tubing and pipes, then the quantity of water at a sprinkler point is 100/46 = 2.17 litres.

4 Result, Testing, and Discussion

During and after the design process, many test was carried out and inferences were drawn. The various components of the solar-powered irrigation system were tested to determine their output and input voltage and currents for different loads, discharge rate head efficiency, and cost of the solar-powered system. From the test performed with the use of a multimeter, thermometer, and pressure gauge, the following results were obtained.

Table 1. *Time, pane; voltage, and battery voltage (without load)*

Time (H)	Panel Voltage (V)	Battery Voltage (V)	Temperature (Deg C)	Charging Current (A)	Wattage (W)
10:00	35.7	26.5	34.6	0.76	20.1
10:30	35.9	26.5	35.0	0.75	19.9
11:00	36.4	26.6	35.7	0.76	20.2
11:30	36.6	26.6	36.0	0.76	20.2
12:00	37.2	26.6	36.4	0.75	20.0
12:30	37.2	26.6	36.7	0.74	20.0
13:00	37.5	26.6	37.0	0.74	20.0
13:30	37.9	26.5	37.1	0.75	20.0
14:00	38.2	26.7	37.4	0.77	20.6
14:30	38.5	26.7	37.3	0.79	20.9
15:00	38.7	26.4	37.1	0.82	21.5
15:30	38.9	25.9	36.8	0.90	23.3
16:00	36.6	25.6	35.9	0.95	24.32

Table 2. *Volumetric and pressure test values*

Time (minute)	Volume (L)	Volume(m3)	Flow rate (m3/min)	Net pressure delivered from reservoir base	Pressure at the end of sprinklers
1	6.2	6.20 x 10^-3	6.20 x 10^-3	5.23	2.2
5	12.5	0.012	2.40 x 10^-3	5.21	2.19
10	62.1	0.062	6.20 x 10^-3	5.23	2.17
15	93.3	0.091	6.00 x 10^-3	5.22	2.15
20	125.0	0.125	6.25 x 10^-3	5.21	2.14
25	155.7	0.156	6.24 x 10^-3	5.20	2.14
30	188.0	0.188	6.26 x 10^-3	5.19	2.11

4.1 Performance Evaluation

Fig. 5: Temperature variation during the day.

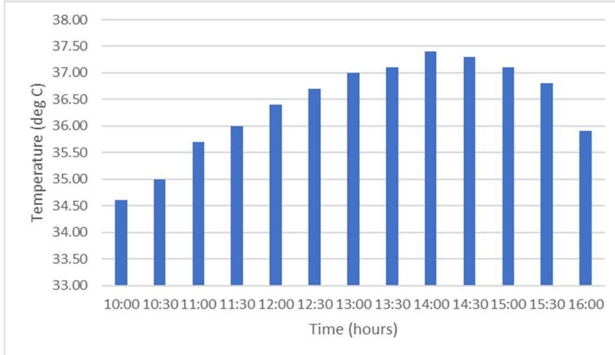


Fig. 5. *Variation of charge current during the day*

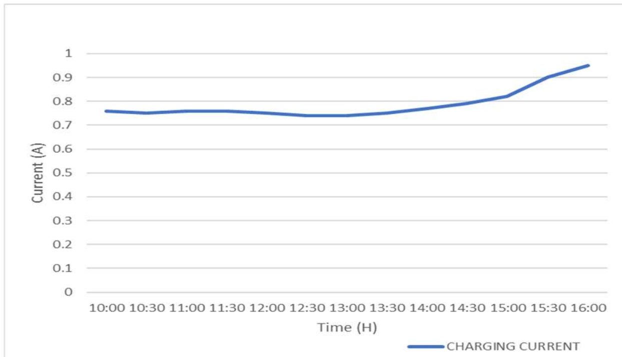


Fig. 6. *Voltage variation with change in temperature*

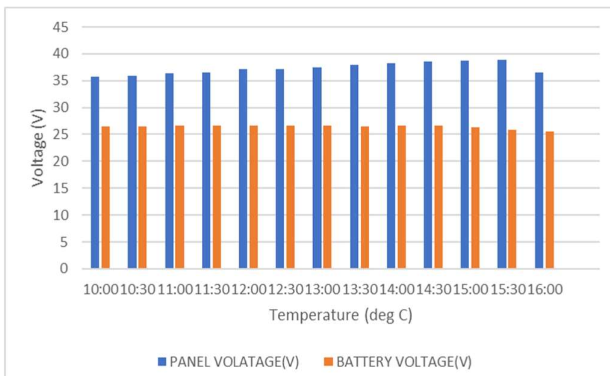


Fig. 7. *Correlation between Temperature and solar voltage*

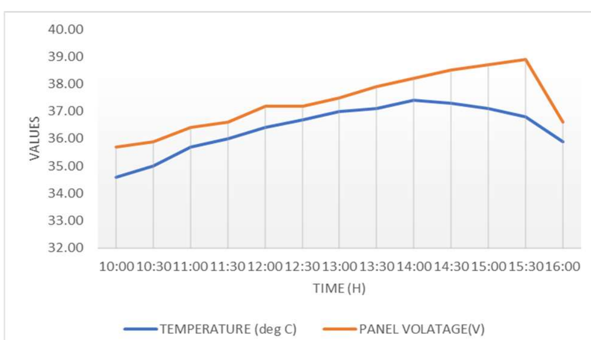


Fig. 8. *Temperature and panel voltage*

4.2. Discussion

From the table of results and the graphs obtained, the values of the voltage increase as the solar radiation increases as observed in the temperature measured at corresponding time intervals. It is also noted that there is a corresponding decrease in the amperage drawn as the temperature declines (see Fig. 4.1 to 4.4)

From Table 4.2 there is a pressure drop delivered from the tank as the water continues to flow. This is because the working head of the water reduces as the volume of the water in the reservoir reduces.
The discharge rate of the sprinkler is measured to be 0.1 liters/sec. Therefore, the volume rate in 1 minute is 6.2 liters/Min.

4.3. Principles and Mode of Operation of the Solar Powered Irrigation System

The chosen irrigation system is surface irrigation, specifically utilizing an overhead irrigation system, involving permanent sprinklers.

The solar-powered irrigation system operates by harnessing solar energy through solar panels. Photovoltaic cells convert this solar energy into direct current, which is then passed through an inverter to convert it into alternating current usable by the AC pump. Generated electricity powers the pump and other accessories via the inverter, with surplus energy stored in batteries for later use during periods of low solar input or when the pump is not operational.

Water is drawn into the overhead tank and flows via gravity through hoses and pipes to the sprinklers, irrigating the designated land area. To preserve battery life, the system is designed to run the pump only during tank filling, rather than continuously during each sprinkling session.

Sprinkling sessions typically occur before sunrise or after sunset, lasting 10-20 minutes to saturate the selected land. Since solar power is unavailable during these times, stored energy from the batteries is utilized, emphasizing the importance of battery storage and the overhead tank in maintaining irrigation operations.

5 Conclusion

The objective of attaining an independent solar-powered system for the irrigation of a specified land size is attainable. Despite fluctuations in weather conditions, the average sunshine levels are potent enough to sustain the system at optimal pressures, voltage, and current values. The feasibility and economic sense of the system can be well appreciated as it perpetuates for years without being subjected to the inconsistencies and fluctuations of the conventional power grid.

For sustainable development, renewable energy has become a haven for all nations to explore. This system is cheap and given the demographics in Kaduna state, all-year farming of crops such as maize, plantain, cassava, tomatoes, and other crops can be achieved using the solar-powered irrigation system.

5.1 Recommendation

This research project proposes the following recommendations:

- Given the global imperative for significant carbon-free electricity production to mitigate greenhouse gas emissions, it is crucial for developing nations like Nigeria to augment food production sustainably. This can be achieved by investing extensively in solar energy technology to power irrigation systems, thus increasing food output without contributing to carbon emissions from electricity generation.
- Designing and integrating solar assembly components into the national power grid presents significant challenges. It is imperative to engage experts in the field to develop system simulations and optimize performance. Through simulation outputs and performance optimization, various options can be compared and evaluated to make informed decisions.
- Enhancements can be made to sprinkler design to increase land coverage and reduce rust formation within parts.
- Improvement in the piping of the irrigation system is necessary, focusing on material selection and accurate inner diameter specifications. Often, these factors contribute to reduced mass flow rates from the reservoir tank to the irrigation sprinklers.
- The current manual timing and regulation of the solar-powered irrigation system can lead to issues such as waterlogging or inadequate water supply, resulting in suboptimal irrigation. Implementing an automatic timer within the system's operation is recommended to address these concerns and optimize irrigation efficiency.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

Reference

[1] S. I. Ogbonna, C. K. Osondu, and C. O. Emerole, “Formal Credit Supply Determinants of Agricultural Contribution to Gross Domestic Product (GDP) in Nigeria (1992-2012)”, Asian Journal of Agricultural Extension, Economics & Sociology, vol. 9, no. 3, pp.1-11, 2016.
[2] M. O. Adenomon, and B. A. Oyejola, “Impact of Agriculture and Industrialization on GDP in Nigeria: Evidence from VAR and SVAR Models”, International journal of Analysis and Applications, vol. 1, no. 1, pp.40-78, 2013.
[3] B. Bairwa, S. Kumar, J. Niharika, Sagar, B.S., Nithyashree, R., and Prem Kumar, S., “Modeling and simulation of solar irrigation system with im drive using pwm controller”, In AIP Conference Proceedings, vol. 2461, no. 1, 2022.
[4] L. Judijanto, I. W. G. Suacana, and E. Rusdiyana, “Facing Climate Change Challenges: Adaptation And Mitigation Policies For A Better Future”, International Journal Of Society Reviews, vol. 2, no. 5, pp.1194-1207, 2024.
[5] L. I. Hangfei, and Y. A. N. G. Lin, “Effect of China's Taiwan Agricultural Investment in China's Mainland: Based on the Model of VAR and VEC”, Journal of Resources and Ecology, vol. 15, no. 2, pp.293-303, 2024.
[6] A. O. Oyefolahan, N. Achara, S. U. Mohammed, and I. O. Oyefolahan, “Design and simulation of solar powered water pumping system for irrigation purpose in Kaduna, Nigeria, 2017”.
[7] R. Osabohien, B. A. Iqbal, E. S. Osabuohien, M. K. Khan, and D. P. Nguyen, “Agricultural trade, foreign direct investment and inclusive growth in developing countries: evidence from West Africa”, Transnational Corporations Review, vol. 14, no. 3, pp.244-255, 2022.
[8] S. J. Sarkar, S. K. Sahoo, T. K. Panigrahi, P. S. Patro, B. C. Kumar, and C. K. Sahoo, “Designing of a microcontroller-less overhead tank controller for solarised homes”, In 2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP), pp. 1-6. IEEE, 2022.
[9] D. Bhavsar, B. Limbasia, Y. Mori, M. I. Aglodiya, and M. Shah, “A comprehensive and systematic study in smart drip and sprinkler irrigation systems”, Smart Agricultural Technology, Vol. 5, pp.100303, 2023.