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# Design and Implementation of a Solar System

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## ABSTRACT

*This project presents the design and implementation of a solar system. It was designed to meet the growing power demand in Nigeria because of the present low power capacity generated, and inconsistent supply to it citizens. It was designed to consist of solar panels, an inverter with a built-in charge controller, which is the core component of the system and a battery bank. The solar panels convert solar energy from the sun into electricity in DC form, these panels were connected in strings (series)-array (parallel) to maximize the inherent capacity of the inverter. The charger controller which is built into the inverter regulates the charge in the battery bank. The inverter takes up direct current from the battery bank and converts it to an alternating current suitable for use by various electrical appliances. This was achieved through voltage elevation with the help of the boot converter and AC waveform generation using Pulse Width Modulation (PWM) techniques, often employing components such as MOSFETs, step-up transformers, and microcontrollers for control and timing. The battery bank stores the energy from the solar panels. The solar system was tested using MATLAB Simulink, and it met the required output from the MPPT power output and the voltage output of the boost converter which confirmed that it can be implemented in real life.*

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## INTRODUCTION

Nigeria is among the tropical countries that fall between 4 degrees and 13 degrees and enjoys sunshine of 6.25 hours daily. Presently, public electricity covers only 40% of Nigerian home and this is not still on a consistent basis. As of late, 85% of the people in the world, the majority of which are women and children living in remote communities, cannot boast of clean and affordable energy [1]. Due to the inconsistent power supply in Nigeria, people have started embracing the culture of generating their own power supply.

The use of fossil fuels as a means of generating electricity has become expensive, making the cost of living very high, especially in rural parts of the country. Also, the use of fossils has brought above pollution to the environment which in turn is not safe for our health. It releases carbon dioxide which causes the greenhouse effect. This brings about the deforestation of land also the pollution of air and water. Further, it also causes the ozone layer to be depleted. These mentioned phenomena can cause several events to occur such as acid rain, air pollution, land pollution because of the excavation operations, etc. solar energy, also known as green energy, is gotten solely from the sun and as a result does not emit carbon dioxide which prevents the green-house effect [2]. Nowadays solar energy is becoming one of the most reliable sources of energy because of its surplus and environmentally friendly.

## LITERATURE REVIEW

Solar system is a photovoltaic (PV) system, or a system that works by converting energy from the sun into electric energy. This system consists of several components that are interconnected together for the sole aim of making electric energy available in a form (either as direct

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current or alternating current form) suitable for utilization by various electrical appliances.

There are several research works that have been done on solar system installation and various methods of determining the solar irradiation and the temperature of the given location like the one in [3] where the HOMMER software was used to determine the solar irradiance and temperature of the Ewu Market Edo State in Nigeria. Also, due to the large area occupied by solar power [4] implemented Solar PV trees as a new method of capturing sunlight. It lessens the PV system's footprint on land. The various components that make up the solar system include the solar panels and are also known as photovoltaic panels, the charge controllers, the battery bank, the inverter and the interconnecting cables.

**Solar Panel**

The solar panels, consisting of photovoltaic (PV) modules and cells, converting sunlight into DC electricity via the photoelectric effect, that is, the release of electrons when sun rays fall on the surface of the solar panels. The solar cells are made up of two types of semiconductor materials, one is N-type, and the other is P-type. In the solar power generation system, many solar cells are required to produce high power, so they are connected in the form of solar module or solar panel and for a higher capability form an array is needed which is the connection of several solar panels in parallel [5]. Solar panels can be connected in parallel (array) or in series (string) depending on the Maximum Power Point Tracking (MPPT) voltage range of the hybrid inverter or charge controller for optimal efficiency of the solar system. In general, solar panels are categorized into three types which are monocrystalline, polycrystalline and thin film [6].

The monocrystalline is made from a single, continuous silicon crystal, these are the most efficient and have the highest performance but are also more expensive. They require less space for the same power output. The polycrystalline is made from multiple silicon crystals, these are less efficient than monocrystalline but are also less expensive to manufacture. The thin-film are a newer technology, thin-film panels are lighter and more flexible, but have lower efficiency and require more space. They are often used for larger commercial projects or where flexibility is needed.

For optimal utilization of the solar panel, the solar panel tilt angle is important, that is the angle to which the solar panel needs to be tilted to. The solar panel angle of your solar system is different depending on which part of the world you are. Solar panels give the highest energy output when they are directly facing the sun, but the sun moves across the sky and will be low or high depending on the time of the day and the season. For that reason, the ideal angle is never fixed. To get the most sun reaching the panel throughout the day, you need to determine what direction the panels should face and calculate an optimal tilt angle. This will depend on where you live and what time of the year you need the most solar energy [7].

To get the total number of solar panels needed for a given solar system installation, first divide the total energy by the peak sun hours, that will give you the total power to be supplied by the solar system, then divide this value by a derate factor say of about 0.8 or by the system efficiency to account for power loss, the result obtain is divided by the power rating of one solar panel and the final result gives the number of solar panels needed.

**Charge Controllers**

These devices regulate the flow of energy from the panels to the battery bank, preventing overcharging and managing the power supply. This voltage regulation is achieved by pulse width modulation (PWM) controller of the charge controller. The PWM controllers work by slowly reducing the amount of power going into the battery as it approaches capacity [2]. The charge controller is connected between the solar panel array and the battery bank. To choose a suitable charge controller we will need to know the power in watt of the solar panel and the battery bank voltage to enable us to select a charge controller that will supply a suitable charging current to the battery bank and appropriate

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charging duration. In most cases charge controllers are built in the inverter which is referred to as hybrid system or hybrid inverter.

**Battery Bank**

The collection of two or more batteries connected to store energy is known as battery bank. Energy storage is crucial, as PV systems only generate power during daylight hours. Battery banks store this energy for use when the sun is not shining. The size of the battery bank determines how long the solar system can supply energy when the sun is not shining. The connection of the battery can be in series, in parallel and in series-parallel to increase voltage, amperage and also depending on the rating of the batteries available with respect to the voltage input rating (range) of inverter in which it will be connected to, that is, the terminal voltage of the battery bank must match the input voltage rating (range) of the inverter.

It is important to note that battery bank terminal connections, paired with advanced balancing systems, can significantly extend a battery's life. Methods to prevent current and thermal imbalances are crucial, as uneven charging and discharging among cells accelerate aging, while when battery terminals are properly connected it enhance even charging and discharging which decelerate aging below is the figure which shows a proper connection to enhance even charging and discharging.

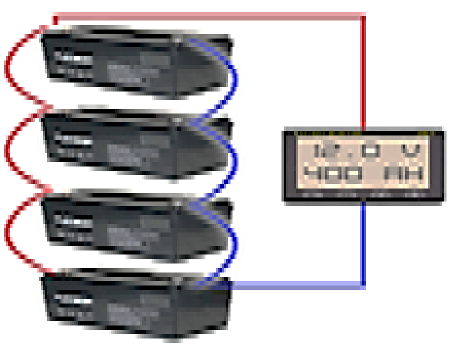


Fig.1: Proper battery connection for even charging and discharging.

Also below is the figure which shows improper battery connection that leads to uneven charging and discharging, hence accelerating aging.

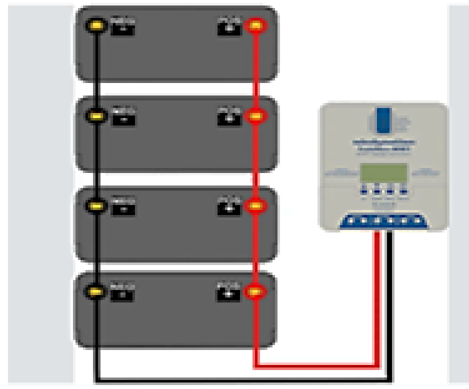

Fig.2: Improper battery connection for uneven charging and discharging

In industrial settings, inverter batteries play a crucial role in ensuring that operations run smoothly, particularly when power reliability is essential. The longevity of your inverter battery is not just about minimizing downtime but also about reducing the significant costs of frequent replacements. A well-maintained battery can extend its lifespan for years, offering better performance, higher efficiency, and more savings in the long run [8].

**Inverter**

It is important to note that to efficiently and effectively convert the DC electricity energy from the solar PV modules into AC quantity, an inverter must be incorporated into the system [13]. This component converts the DC power produced by the panels or stored in battery bank into AC power, which is used by most household appliances. The inverter is the key component of the solar system because it makes available electric energy in the form suitable for use by various appliances.

In grid connected solar power systems, the inverter plays an important role in control systems, as the power generated by the solar photovoltaics (PV) system constantly alters due to the weather condition. The alternation of generated power can cause negative impacts on

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power quality of the grid, such as voltage fluctuation, change in power factor, frequency fluctuation, the increase in the harmonic distortion, etc. The higher demand for power quality has set out a practical requirement about the necessity of having inverters that can connect flexibly, exchange power and ensure the power quality standards. The aim of the inverter is controlling power among the grid sectors to obtain the most productive capacity of the generator while avoiding sudden conflicts due to loss of transmission or the instability of the generator itself [14].

One of the key specifications of the inverter's built-in charger controller is the Maximum Power Point Tracking (MPPT) which in most cases is underutilized by the installers or solar system technicians due to incorrect connection of the solar panels. For maximum utilization of the MPPT voltage range of the built-in charge controller, the array voltage should ideally be in the "sweet spot" of the controller's operating range, not at the extreme minimum or maximum ends.

The importance of an inverter's Maximum Power Point Tracking (MPPT) rating is to maximize energy harvest by continuously adjusting the solar panels voltage and current to their optimal operating point [9],[10]. This ensures maximum power output, boosts system efficiency by up to 30%, and improves energy conversion even under varying sunlight and temperature conditions. A higher or more advanced MPPT rating means the inverter is more adept at tracking the panel's maximum power point, leading to greater electricity generation, reduced energy waste, lower electricity bills, and increased system stability.

Inverter are meant for various purpose some are standalone inverter or off-grid inverters designed for off-grid power systems with battery backup while others are Grid Connected Inverter or Grid Tie Inverter are solely intended for applications linked to the grid. These applications that are connected to the grid don't need a battery backup solution [15].

Inverters consume power as they convert DC power to AC power, and in doing so, contribute to the system load. The less power an inverter consumes the more efficient it is, which is how its efficiency rating is determined [11]. Therefore, if an inverter is to be used, the following questions must be answered; What size inverter do I need for my load? How much power does the inverter use while operating? How does it affect the total load requirements in my system?

It is also important to note that radiation data, known as the Solar Irradiation, which is defined as the measure of solar radiation energy received at a particular location during a specified period, commonly expressed as average irradiance in kilowatt-hour per square meter per day ($kWh/m^2$ per day) is equal to the hours of sunlight per day of the given location. The solar irradiation of a given location is a major determinate factor that shows if a given location is suitable for solar system installation.

Solar radiation can be categorized into four classes: levels less than 2.6 $kWh/m^2$ are classified as low solar radiation while solar irradiance between 2.6-3 $kWh/m^2$ is moderate solar radiation; irradiance between 3$kWh/m^2$ - 4$kWh/m^2$ is high solar radiation and irradiance higher than 4 $kWh/m^2$ is very high radiation. To select an inverter, match its continuous AC power rating to the highest simultaneous power demand, and ensure its input (DC) power capacity is sufficient to handle the solar array's total power output.

**Cable Sizing**

There are four primary reasons that the cable sizing is very important at design stage. First and foremost, cable sizing is important to function endlessly under full load condition exclusive of being damaged. Moreover, it is necessary to hold up the worst short circuit current flow and ensure that the protective devices are effective during an earth fault. Ensure that, the supply to the load with a suitable voltage and avoid excessive voltage drops.

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up the worst short circuit current flow and ensure that the protective devices are effective during an earth fault. Ensure that, the supply to the load with a suitable voltage and avoid excessive voltage drops [16].

Cable sizing is the process of selecting the correct cable size for an electrical application to ensure safety and proper functionality. It involves calculating the required current-carrying capacity of the cable and ensuring it can handle the load; voltage drop and short-circuit conditions. Several factors, including load current, ambient temperature, installation method, and voltage drop, influence the appropriate cable size. Sizing Cable sizing methods follow the unchanged basic step process.

Firstly, it's vital to gather data about the cables, installation surroundings, and the load that it will carry. In addition, it's crucial to find the current carrying capacity (A, ampere) and voltage drop per ampere meter (mV/A/m) of the cable [1]. The current carrying capacity of a cable is the maximum current that can flow continuously through a cable without damaging the cable's insulation and other components [2]. Short circuit temperature rise and earth fault loop impedance are significant factors to verify the cable size.

Sizing Cable sizing methods follow the unchanged basic step process. Firstly, it's vital to gather data about the cables, installation surroundings, and the load that it will carry. In addition, it's crucial to find the current carrying capacity (A, ampere) and voltage drop per ampere meter (mV/A/m) of the cable [17]. The current carrying capacity of a cable is the maximum current that can flow continuously through a cable without damaging the cable's insulation and other components [18]. Short circuit temperature rise, and earth fault loop impedance are significant factors to verify the cable size.

Optimal selection of cable's cross-section in distribution networks reduces capital investment costs and network power loss. One of the important points in the cable size selection process is taking the damage curve into account, which this curve depends on the type, insulation, and cross-section of cable. The cross-section should be selected in such a way that the cable can withstand short-circuit current until the fault is cleared. In conventional methods, damage curve is considered in optimal cable size selection (OCSS) process with assuming fixed times for fault clearing [20].

It is common knowledge that all conductors (other than some superconductors), cables, and wires are characterized by some resistance. It is important to note that resistance is inversely proportional to the conductor's diameter and directly proportional to its length. Therefore,

$R \propto \frac{L}{a}$ [Laws of resistance $R = \rho\,(\frac{L}{a})$]

The conductor experiences a voltage drop whenever an electrical current passes through it. This drop may be negligible for conductors that are of smaller length. But in the case of longer conductors and conductors with a narrow diameter, considering voltage drops is important if correct installation and safety are to be ascertained [19].

The IEEE rule B-23 mandates that voltage drop should never be larger than 2.5% of the supply voltage at any place between installation and power supply. That is, 0.025 x 415 = 10.5 volts for 3 phases and 0.025 x 240 = 6.0 volts for single phase. It therefore implies that any cable that will be selected to connect the energy source to the load must have a voltage drop within the limit of 2.5% of the system voltage. Very important to note is that there are applications for example [12] used to calculate the voltage drop and it gives variety of voltage drops and corresponding cable size that can be used within appropriate voltage limits, by simply imputing the distance of the energy source from the load, the current required to flow through the cable, the voltage type, and the voltage.

The formula for cable voltage drop depends on whether the system is single-phase or three-phase and whether you're using DC or AC. For DC circuits, the basic formula is $V_D = \frac{2IRL}{1000}$ while for an AC circuit the formula for voltage drop mis given as $V_D = \frac{IRL}{1000}$ (where I is current, R is resistance per meter, and L is length), The resistance value (R) is often found in millivolts per

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ampere per meter (mV/A/m) from the cable manufacturer's tables.

Many recent studies on solar system have focused on the details analysis on sizing a solar system based on the number of solar panels needed, the size or capacity of charge controller, the size of the batteries bank and the capacity of the inverter needed for a given load demand, and also stating key features of the charge controller which are Pulse Width Modulation (PWM) and maximum power point track Tracking (MPPT), but without detail analysis on how the MPPT specification of the charge controller can be fully utilized to determine how the solar panel can be connected either in series, parallel or series-parallel in order to maximize the effectiveness of the inverter in-built charge controller and the solar system at large.

Another major shortcoming in some studies is the omission of the radiation data of the given location where the solar system is to be installed, as this radiation data determine whether the location is fit for the installation, how the solar panels can be positioned with respect to tilt angle for optimal efficiency and also it plays an important role to determine the number of solar panels to be installed. Also, another gap identified in some recent studies of solar system installation is that detailed cable sizing with respect to the current carrying capacity of the cable used for the interconnections of the various solar system components are not given due consideration, which is very important for the safety of the system.

A detailed analysis on how a charge controller can be chosen based on the current rating of the battery bank was done by [2]. The analysis considered the practical application of the charge controller after considering the idea situation and taking note of the percentage losses during practical situation which is important in choosing the type of charge controller to use.

Based on recent research on solar system design and implementation it is evident that a detailed analysis on sizing of the various components is taken into consideration with respect to components specifications, which is very important in the design process of a solar system to ensure that the system is stable, secure and reliable. In this work for a more stable, secure, and reliable solar system we intend to maximize the MPPT rating of the in-built charge controller of the inverter for maximum power tracking, the optimal tilt angle of the solar panels and proper cable sizing for the safety of the solar system.

## MATERIALS

Data for this study was collated from the energy consumption record of one of the farms in Olam Agri Nigeria Limited Kaduna and the data collated was for the period of seven months from the daily energy consumption record book. In line with solar design requirements, we can assert that the data collated is sufficient to carry out analysis for this study. The sample of the data collated is presented in Table 3.1 below and the corresponding graphical representation in Table 1

Table 3.1: Monthly Energy Consumption

| S/N | Month/Year | Energy Consumption (kwh) |
|---|---|---|
| 1 | January 2025 | 534.02 |
| 2 | February 2025 | 621.05 |
| 3 | March 2025 | 817.24 |
| 4 | April 2025 | 721.13 |
| 5 | May 2025 | 644.61 |
| 6 | June 2025 | 580.70 |
| 7 | July 2025 | 331.03 |

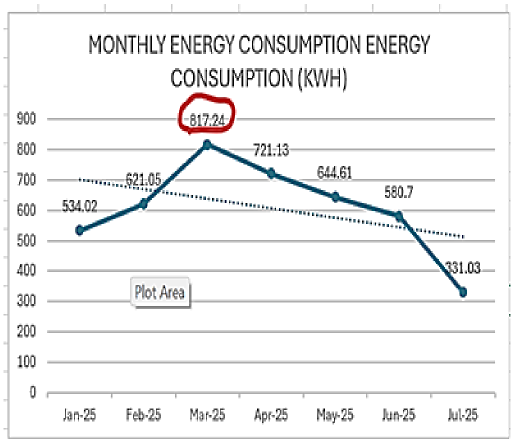


Fig.3: Graphical Representation of Monthly Energy

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Considering the scope of this work, we have a powerhouse, four identical pen houses, the water treatment plant and an accommodation unit below are the data collected for these sections:

Table 3.2: Parameters (data) For the Various Sections of the Farm

| Section | P(kW) | Q(kVar) | I (A) | D (m) |
|---|---|---|---|---|
| Pen A | 33.915 | 25.43 | 58.97 | 60 |
| Pen B | 33.915 | 25.43 | 58.97 | 50 |
| Pen C | 33.915 | 25.43 | 58.97 | 95 |
| Pen D | 33.915 | 25.43 | 58.97 | 130 |
| Water treatment plant | 4.675 | 3.506 | 8.1298 | 15 |
| Accommodation unit | 16.785 | 12.5886 | 29.189 | 75 |
| TOTAL | 157.12 | 117.8146 | 273.1988 | |

Where D is the distance of each section from the powerhouse, which is the energy source, P is the active power in kilowatts, Q is the reactive power in kilo-Var, I is the current the cable is required to carry.

**Feasibility Study and Load Analysis**

From the data collated and with the help of google map and NASA Power application as seen in Table 3.2 below. The solar radiation we got was within the acceptable range for solar system installation. The irradiation for this given location (Olams farms) which is on the coordinate (lat:$10.23^0$, long:$7.34^0$) is 5.2kwh/m2/day as seen in Figure 3.2 and considering the variation in energy consumption for various months, the peak energy consumption is 817.24kWh, which forms the basis for our design.

Table 3.2: 20-Years Meteorological and Solar Monthly and Annual climatology.

| NASA/POWER Source Native Resolution Climatology in LST | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20-year Meteorological and Solar Monthly & Annual Climatologies (January 2001 - December 2020) | | | | | | | | | | | | | |
| Location: Latitude 10.23 Longitude 7.34 | | | | | | | | | | | | | |
| SI_TILTED_AVG_LATITUDE SRB V4/CERES SYN1deg Solar Irradiance for Equator Facing Latitude Tilt (kW-hr/m^2/day) | | | | | | | | | | | | | |
| PARAMETER | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANN |
| SI_TILTED_AVG_HORIZONTAL | 5.4458 | 5.5973 | 5.7314 | 5.7605 | 5.3971 | 4.9042 | 4.3495 | 3.8966 | 4.6783 | 5.3198 | 5.717 | 5.4658 | 5.1886 |
| SI_TILTED_AVG_LAT_MINUS15 | 5.2632 | 5.4828 | 5.6734 | 5.7559 | 5.4343 | 4.9529 | 4.3817 | 3.9036 | 4.6481 | 5.22 | 5.513 | 5.2358 | 5.1221 |
| SI_TILTED_AVG_LATITUDE | 5.7792 | 5.7761 | 5.7799 | 5.6839 | 5.2291 | 4.7174 | 4.2134 | 3.8278 | 4.6774 | 5.465 | 6.0895 | 5.9038 | 5.2618 |
| SI_TILTED_AVG_LAT_PLUS15 | 6.0139 | 5.8085 | 5.6376 | 5.3683 | 4.8031 | 4.2862 | 3.8796 | 3.6055 | 4.5043 | 5.454 | 6.353 | 6.2681 | 5.1653 |
| SI_TILTED_AVG_VERTICAL | 3.8309 | 3.2642 | 2.7242 | 2.1168 | 1.9802 | 1.8271 | 1.7669 | 1.6752 | 1.9786 | 2.8337 | 3.9276 | 4.2238 | 2.6791 |
| SI_TILTED_AVG_OPTIMAL | 6.0266 | 5.8274 | 5.7806 | 5.7614 | 5.4506 | 4.9922 | 4.3994 | 3.9036 | 4.6903 | 5.4922 | 6.3677 | 6.3298 | 5.263 |
| SI_TILTED_AVG_OPTIMAL_ANG | 30 | 20 | 9.5 | -1.5 | -10 | -13.5 | -11 | -4.5 | 5 | 17.5 | 30 | 34.5 | 12 |

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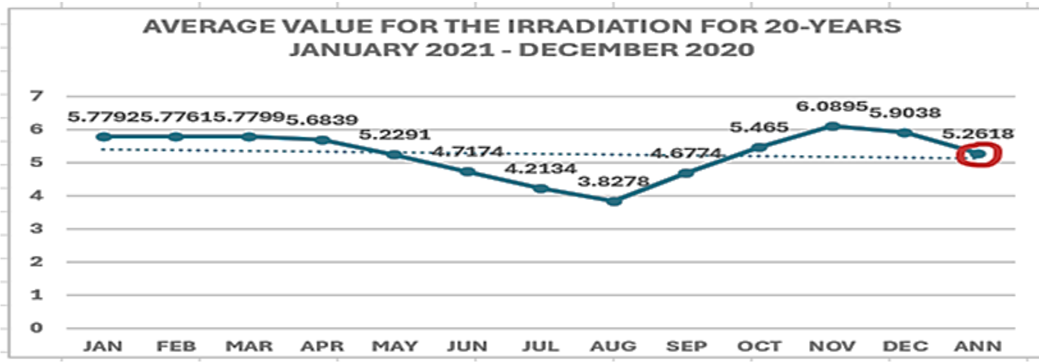


Fig.4: Graphical Illustration of Average Value of Irradiation

**Site Selection and Solar Resource Assessment**

For the selection of a suitable site which must be void of shade and any form of obstruction to sun rays, with the help of google map and NASA Power application, we were able to get the solar radiation data and overcome potential shading issues. The solar radiation we got was within the acceptable range for solar system installation. The irradiation for this given location (Olams farms) which is on the coordinate (lat:$10.23^0$, long:$7.34^0$) is in the range of 6.4286kwh/m²/day to 4.1621kwh/m²/day with an average value of 5.2kwh/m²/day approximately that is, with the solar panel tilted at an angle equal to the latitude of the location. Figure 3.2 from the previous figure shows the graph of the average annual irradiation value which is circled for the given location.

**System Sizing**

With respect to the base value for energy consumption as seen from Table 3.1, which is 817.24kWh, from the formula of energy we can obtain the power rating in kilowatts and kilovolt-ampere for the system which is given below:

E = PT$n_s$ ……….3.10

⇒ P = $\frac{E}{Tn_s}$ ……...3.11

$n_s$ =$n_b$ x $n_i$ x $n_{oth}$

$n_b$= Battery efficiency (Assume 90%)

$n_i$= Inverter efficiency (Assume 95%)

$n_{oth}$= Other component (charge controller, cable) efficiency (Assume 85%)

$n_s$= 0.9 x 0.95 x 0.85 = 0.73

where E is the energy consumption measured in kilowatt-hour, P is the power measured in kilowatt, $n_s$ is the system efficiency and T is peak sunshine hour.

For our design E = 817.24kWh, T = 5.2kwh/m²/day which is the peak sunshine hour, therefore substituting into equation 3.11 we have

P = $\frac{817.24 \text{ x } 10^3}{5.2 \text{ x } 0.73}$ = $\frac{817240}{3.796}$ = 215289.8W = 215.3kw

We know that for a three-phase system power P is given as:

P =$\sqrt{3}$ IVcosθ ………3.20

⇒ I = $\frac{P}{\sqrt{3}V\cos\theta}$ ……...3.21

where V is the line-to-line voltage measured in volt, I is the line current measured in ampere and cosθ is the power factor (pf). For this system V = 415V, pf = cosθ = 0.8, we can get a base current by substituting into equation 3.21.

Therefore, substituting we have:

I = $\frac{215289.8}{\sqrt{3} \text{ x}415\text{x } 0.8}$ = $\frac{215289.8}{1.732 \text{ x } 415 \text{ x } 0.8}$ = $\frac{215289.8}{575.024}$ = 374.4A

We can obtain the value of the apparent power of the system from equation

S = P + jQ …….3.30

Where P = 215289.8W, Q =$\sqrt{3}$ IVsinθ =$\sqrt{3}$ x 374.4x 415 x θ

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And θ = $cos^{-1}(0.8)$ = 36.9$^0$
∴ Q = 1.732 x 374.4 x 415 x Sin36.9$^0$
Q = 269111.232 x 0.6 = 161466.7392VAR
Q = 161466.7392VAR
Q =161.5KVAR
Substituting into equation 3.30 we have

S = 215289.8+ j161466.7392
S = $\sqrt{215289.8^2 + 161466.7392^2}$ $\angle \text{Tan}^{-1}(\frac{161466.7392}{215289.8})$
S = $\sqrt{72421205851.92081664}$∠Tan$^{-1}$(0.7500)

S = 269111.9∠36.9$^0$VA
S ≈ 269.1∠36.9$^0$kVA

Therefore cos36.9$^0$ = 0.8 hence 0.8 is the power factor. Hence the size of the system will have the following parameters as shown in table 3.

Table 3.4: Specification of the solar System

| S/N | PARAMETER | SIZE |
|---|---|---|
| 1 | Current (I) | 374.4A |
| 2 | Apparent power (S) | 269.1∠36.9$^0$kVA |
| 3 | Reactive power (Q) | 161.5KVAR |
| 4 | Active power (P) | 215.3kW |
| 5 | Power factor (PF) | 0.8 leading |

**Component Selection**

This section describes the basic components that was used for the implementation

***Solar Panels***

For this solar system we intend to use solar panels with the following specifications:

Maximum power (Pmax) = 550W
Maximum power voltage (Vmp) = 31.8V
Maximum power current (Imp) = 17.29A
Open circuit voltage = 38.1V
Short circuit current =18.39A
Since our solar system will be in the location with 5.2kWh/m²/day of solar energy it therefore implies that we have 5.2 peak sun hours.
Total number of panels (N) = $\frac{P}{P_S}$ …….3.51

Where P = 215.3kW
$P_S$ (power rating for one panel) = 550W
Substituting into equation 3.5 we have:
N = $\frac{P}{P_S} = \frac{215.3 \times 10^3}{550} = \frac{215300}{550}$ = 391.454
N ≈ 391

Therefore, the total number 550W of panels to be used will be 400 pieces, because it is easier and preferable to handle even numbers of panels and to make provision for future expansion. Below are the specifications for the 550W solar panel from the data sheet.

Table 3.51: Electrical Specification for the Selected Solar Panel

| S/N | Electrical Data (STC) | |
|---|---|---|
| 1 | Peak Power Watts-PMAX (Wp) | 550 |
| 2 | Maximum Power Voltage-VMPP (V) | 31.8 |
| 3 | Maximum Power Current-IMPP (A) | 17.29 |
| 4 | Open Circuit Voltage-VOC (V) | 38.1 |
| 5 | Short Circuit Current-ISC (A) | 18.39 |
| 6 | Module Efficiency η m (%) | 21.0 |
| 7 | Irradiance (W/m$^2$) | 1000 |
| 8 | Cell Temperature (°C) | 25 |
| 9 | Air Mass AM | 1.5 |
| 10 | No. of cells per Module | 110 |

Considering the MPPT voltage range (150V-850V) of the hybrid inverter we intend to use, and in order to maximize the efficiency of the inverter for maximum power tracking, which is one of the sole objective of this project we will string 20 solar panels that is, connect 20 solar panels in series which will give us 636V (20 x 31.8V) output voltage which is within the range of the MPPT rating of the inverter and more closer to the maximum limit than to the minimum limit. Therefore, for solar panel array we will connect the strings in parallel, hence the output voltage of the solar panel will be 636V which is also the input voltage to the inverter will be connected to the inverter.

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***Inverter***

Considering the specification of the solar system given as:

Current = 374.4A
Apparent power = 269.1∠36.9$^0$kVA
Active power = 215.3kW
Reactive power = 161.5KVAR
Power factor = 0.8 leading

As a rule of thumb, the inverter to be selected will have a minimum power rating of 125% of the total load. That is, 215.3kW x 125% = $\frac{215.3 \times 125}{100}$ = $\frac{26912.5}{100}$ = 269.1kW. Considering future expansion, we will round this up to 300kW. It may be difficult to get a single unit of 300kW, so we decided to choose 10 units of 30kW, primarily because of what is obtainable and realistic. Below is the specification of the PV String Input Data for the 30kW inverter.

Table 3.52.2: PV String Input Data of the inverter

| S/N | PV String Input Data | |
|---|---|---|
| 1 | Max. DC Input Power (W) | 39000 |
| 2 | Max. DC Input Voltage (V) | 1000 |
| 3 | Start-up Voltage (V) | 180 |
| 4 | MPPT Range (V) | 150-850 |
| 5 | Full Load DC Voltage Range (V) | 360-850 |
| 6 | Rated DC Input Voltage (V) | 600 |
| 7 | PV Input Current (A) | 36+36 |
| 8 | Max. PV I (A) | 55+55 |
| 9 | No. of MPP Trackers | 3 |
| 10 | No. of Strings per MPP Tracker | 2 |

***Battery Bank***

For industrial three-phase solar systems, we decided to select lithium-ion battery (Li-Ion) batteries because of their long lifespan, high energy density, safety, and minimal maintenance compared to traditional lead-acid batteries. With respect to the specification of the inverter input, the battery voltage range is 160V – 800V which is a large voltage range, therefore we will need a battery bank with a large voltage.

For this system of 300kW we have decided to use 10units of 30kW inverter. First, let determine the total ampere-hours of the system, since we have an average of 5 hours sunlight, we will therefore design the battery bank to supply energy for 18 hours.

Hence the total energy of the system is: 300kW x 18h = 5400kWh considering the efficiency of the system and the dept of discharge, to cover any losses in energy, hence the new energy will be $\frac{5400}{0.9 \times 0.96}$ = 6250kWh hence this is the recommended nameplate. Therefore, for the 10 units of 30kW we intend to use, checking current and voltage per 30kW we have:

DC power per inverter considering system efficiency to cover loss = $\frac{30}{0.9}$ = 31.25kW.

To stay within 100A input limit per inverter (for two inputs) based on the data sheet information of 50A per input, require DC volt at worst case $V_{min}$ = $\frac{31.25}{100}$ = 312.5V. To maximize system efficiency as core objective of this project, we will design around a nominal voltage range of 600V – 650V.

At 600V: Current (I) = $\frac{31.25 \, x \, 10^3}{600}$ = 52A which is above single input.

At 650V: Current (I) = $\frac{31.25 \, x \, 10^3}{650}$ = 48A this fit neatly within a single 50A input.

In conclusion we will choose a 51.2V lithium-ion battery (Li-Ion) module with 100Ah in which 12 modules will give 12 x 51.2 = 614.4V nominal. Therefore, energy per string will be 614.4 x 100 = 61440Wh = 61.44kWh then strings in parallel will hit 6250kWh nameplate. Therefore, in summary we will have 12 x 10 = 120 pieces of 51.2V, 100Ah battery so that each inverter unit has 12 pieces of the modules connected in series.

***Cabling and Protection***

For the AC section of the solar system from Table 3.2 using Victron Toolkit Application by simply inputting the distance of the energy source from the load, the current required to flow through the cable, the voltage type, and the voltage, we obtain the various cable size for connecting the power source to the various sections of the farm as seen in the table below.

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Table 3.54: Data for the various sections of the Farm

| Section | P(kW) | Q(kVar) | I (A) | D (m) | Cable Size (mm²) |
|---|---|---|---|---|---|
| Pen A | 33.915 | 25.43 | 58.97 | 60 | 16 |
| Pen B | 33.915 | 25.43 | 58.97 | 50 | 16 |
| Pen C | 33.915 | 25.43 | 58.97 | 95 | 35 |
| Pen D | 33.915 | 25.43 | 58.97 | 130 | 35 |
| Water treatment plant | 4.675 | 3.506 | 8.1298 | 15m | 10 |
| Accommodation unit | 16.785 | 12.5886 | 29.189 | 75m | 35 |

***Implementation By simulation In MATLAB Simulink***

For the implementation of the solar system installation in MATLAB Simulink, the following parameters will be required for the DC/DC boost converter circuit, which are, the parallel capacitance of the capacitor, the inductance of the inductor.

$L \geq \frac{D(1-D)^2 V_O}{2 I_O F_S}$

$C \geq \frac{D I_O}{F_S \nabla V_O}$ with this relationship we obtained the parallel capacitance and inductance as 6 x $10^{-7}$F and 4.356 x $10^{-7}$H respectively.

Below is the circuit diagram for the DC/DC boost converter circuit

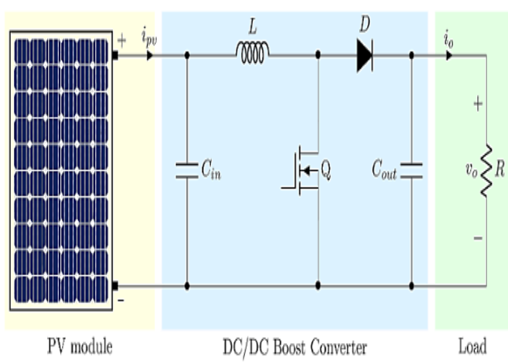


Fig.5: DC/DC boost converter circuit

For the MPPT circuit configuration below is the code in MATLAB work window.

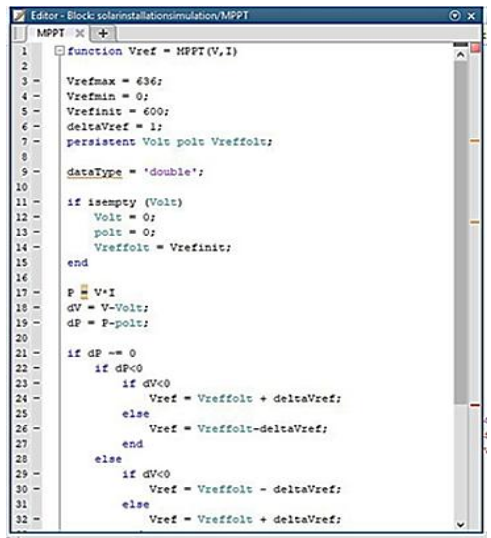


Fig.6: MATLAB work window showing the code for the MPPT section of the boost converter

**Result from Implementation by Simulation In MATLAB/Simulink**

The result from the simulation of the solar system which is to confirm that the physical system can be actualized was realized as seen from the simulation result of the PV solar array with Maximum Power point Tracking in MATLAB Simulink.

**Discussion**

The result from the PV solar array with Maximum Power Point Tracking in MATLAB Simulink shows that the system can be installed in real life as seen from the result displaced in the figures below. The display from the MPPT power output and voltage output across the load attest to the fact that the system can be implemented in real life.

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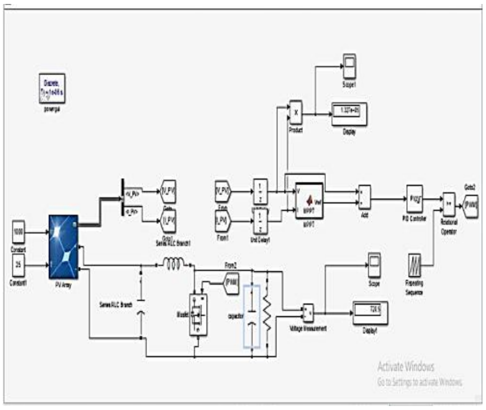

Fig.7: Simulink Block Diagram of PV solar array with Maximum Power Point Tracking

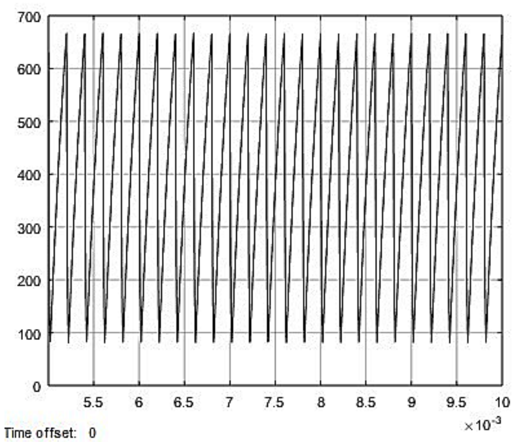


Fig.8: Voltage output across Load.

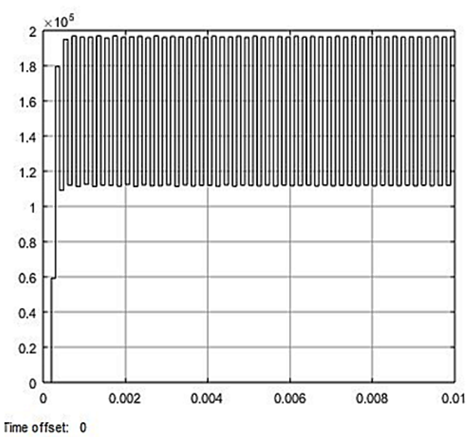


Fig.9: MPPT Output power display

**Summary**

The design and implementation of a solar system with the case study of one of the farms in Olams Farms with a capacity of approximately 200kVA was inspired based on the low power generation and the inconsistent supply of power in Nigeria to it citizen. And it was indeed an interesting research work with quite some challenges, and it was intended to provide alternative power generation and consistent supply of the power generated using the energy from sunlight which is a natural resource.

In this research work we got the required information needed for the work and to authenticate the information about the data collected, we had to do a power audit for the farm in question, and the result obtained from the power audit was realistic as compared to the data initially collected. But prior to the load analysis for the system, we carried out a feasibility study to ascertain whether the location will be suitable for the research work, and it turn out to be ok base on the solar resource assessment like the irradiation data (5.2kWh/m²/day) which is within the acceptable limit and showed that the location was fit for the research work.

During the design process of selecting the various components involved in the solar system, after a series of considerations to ensure that the system is stable, secure and reliable, we discovered that the batteries to be used for the battery bank must be a high voltage battery. After careful analysis and applying the necessary rules of thumb we were able to get the required components, and finally we had a full layout of the solar system. As part of the sole objective of the research work, we ensured to maximize the efficiency of all the system components by ensuring all connections produce an output which is within the limit of the operating voltages and right sizes of connecting cable were obtained.

**CONCLUSION**

With respect to the design and implementation of a solar system with the case study of one of the farms in Olams Farms which was inspired based on the low power generation and the inconsistent supply of power in Nigeria to

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it citizen. The implementation by simulation of the system after detailed analysis in terms of the sizing of the various components was realistic as the expected result was realized as seen from the output power display of the MPPT output and the voltage output of the boost converter section of the solar system in the MATLAB Simulink simulation, which shows that the system can be installed in real life.

Therefore, the objective of the research was to provide an alternative power generation and consistent supply of the power generated using the energy from sunlight which is a natural resource after following the different stages and processes involved, the implementation was met, as the system components were fully optimized by ensuring that we took advantage of operating each system component within the voltage range and most importantly maximizing the MPPT voltage range of charge regulation component.

## RECOMMENDATIONS

Based on my findings during the course of this research work, one of the aspect of this research work that I will really want the whole body of engineers to further explode is the aspect of the rules of thumb which I think in this work was a major concern to me, because after due consideration of the rules of thumb which has to do with taking into account safety factors, I discovered that the output values of the system specifications was high leading to addition to the system components in term of the economy aspect of the system. I believe detailed research work can still be done in the aspect of the rules of thumb, as maintaining low cost without compromising standard is key in engineering.

## Acknowledgment

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