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PHASOR ANALYSIS OF DECENTRALIZED GRID-CONNECTED RESIDENTIAL SOLAR FARM: ADDRESSING NIGERIA ELECTRICITY CAPACITY ISSUES

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ABSTRACT

Addressing Nigeria's energy capacity issues, this paper presents a Phasor-evaluation of a simulation comparing the feasibility of using a Photovoltaic (PV) system with backup power for home use at a large-scale solar farm with a Residential Energy Storage System (RESS) in Nigeria. The Hydro-Québec Research Institute (IREQ) designed a standard power operation system for the simulation, which is essential. The findings, displayed in phasor mode, aim to assess energy storage and solar intensity, potentially revolutionizing the energy landscape for Nigeria's rural and urban residents.

Keywords: *Battery storage systems, Energy storage systems, Grid operators, Sustainable energy, Solar technology, Solar farm*.

INTRODUCTION

Nigeria is Africa's most populous country, with around 230 million people. Yet, according to a 2021 Energy Policy report, 40 percent of Nigerians don't have access to the power grid. The country mainly uses gas, hydropower, and oil for electricity, as detailed in Table 1. Due to frequent power outages, many people and businesses use their generators for backup power, with those who can afford it opting for gas-powered ones. This trend highlights that having reliable electricity is becoming more of a financial issue than just a technical one (Ajao, Haddad, & El-Shahat, 2019).

Table 1: Nigeria Energy Structure

Electricity	**Contribution**
Fuel & Diesel	*50.00%*
Hydro-electric	< 10.0 %
Natural Gas	<10.0 %
Coal	<14.0 %
Renewable Energy	< 20.0 %

Nigeria faces a significant electricity crisis due to financial, structural, and geopolitical issues, unlike the United States. This vulnerability makes the power grid a target for criminal acts and sabotage. The United Nations has set 17 sustainable development goals (SDGs) to ensure prosperity and safety on a sustainable planet by 2030. Among these, addressing climate change is vital and is connected to the goal of creating a system for affordable and clean energy (Tsalis, Malamateniou, Koulouriotis, & Nikolaou, 2020).

UN research indicates that if greenhouse gas emissions persist, global warming could increase temperatures by 1.5°C in the coming decades. It's crucial to pinpoint the sources of these emissions to curb the global temperature rise. Figure 1 illustrates that coal, oil, and gas are the main fuels contributing to CO_2 emissions globally. These emissions have risen sharply, from 5 billion tons annually in 1950 to 35 billion tons in 2017 (Ohunakin, Adaramola, Oyewola, & Fagbenle, 2014).

This study aims to explore Nigeria's power crisis and suggest practical solutions. The paper is structured as follows: Section II reviews previous studies on the complexity, adaptability, and effectiveness of modern energy storage systems. Section III discusses the design elements and principles of a solar farm. Section IV outlines the design and simulation methods used in this study for the residential energy storage model. Section V presents a comparative analysis, and Section VI details the simulation outcomes, phase analysis, and findings, including the efficiency of solar power, its economic impact, and potential future applications.

Nigeria faces a significant energy crisis, leading to widespread research into the issue. Many Nigerians don't have reliable electricity and often depend on gas-powered generators. Currently, only about 45% of Nigerians have regular access to electricity (Aboagye *et al.*, 2021). To address this, a study comparing the use of photovoltaic panels with energy storage between the United States and Nigeria was conducted. This study shows how much energy is stored and the intensity of solar radiation, helping communities make better decisions about reducing their reliance on the grid (Kumar and Kandpal, 2005).

There's an urgent need for the government and Power System Operators to improve power infrastructure with an investment of about 8.1 trillion Naira (Zeyad *et al.*, 2021). Nigeria's heavy dependence on oil and coal has hindered interest in renewable energy. However, adopting a Renewable Energy Master Plan could develop up to 2.9 GW of clean energy by 2035 (Brown *et al.*, 2018).

Effective renewable energy production requires careful consideration of the energy sources and storage technologies (Varma & Salama, 2011). Learning from countries with similar challenges might encourage Nigeria to act. A major challenge is managing decentralized grid-connected systems to avoid power outages and manage the load between power distribution networks and consumers. Another issue is integrating these systems with renewable sources like solar and wind to maximize electricity production (Ebaid, Qandil, & Hammad, 2013). There's also a continuous need for research into decentralized systems that can adapt to changing conditions and stabilize the energy system in Nigeria (Ajao, Haddad, & El-Shahat, 2019).

Solar Farm (Today's Cash Crop)

As more people turn to clean energy, solar power is becoming popular among farmers and landowners across the country. It's often called the new "cash crop" because it can be more profitable than traditional farming crops like corn or soybeans. Many property owners are exploring the possibility of generating solar energy on their land (Babatunde, Abbasoglu, & Senol, 2018). Solar farms use large arrays of solar panels to produce electricity on a big scale. They can be cheaper to build and maintain than smaller rooftop systems and they provide power directly to the electric grid. There are two main kinds of solar farms: utility-scale and community solar farms. Utility-scale solar farms are very large and supply power to the electric grid, while community solar farms are smaller and provide power to people who buy a share of the electricity produced. The demand for solar energy is growing as more people look for ways to reduce their impact on the environment and tackle climate change.

In the U.S., the Copper Mountain Solar Facility is one of the biggest, with a capacity of 816 MW. Another significant project is the Mammoth Solar Project in northern Indiana, which is expected to have a total capacity of 1,670 MW when it's finished. Worldwide, the largest solar farm is in India—the Bhadla Solar Park, which can generate 2,245 MW and covers 14,000 acres. These large projects show that solar energy is becoming a practical and economical choice for many (Venkatramanan & John, 2019) (Shezan, 2019).

A. Energy Supply VS. Demand

The basic idea of supply and demand is very important in the electricity industry. Here, 'supply' means how much electricity is being made and available for people to use, while 'demand' refers to how much electricity people need or want. The usual way of making electricity centrally has some problems, like losing some power in transmission and being more exposed to interruptions or complete shutdowns. Solar energy offers a different method that could overcome these problems by producing electricity closer to where it's used. However, the availability of solar energy can change based on the weather and the time of day, leading to a supply that isn't always steady, which makes storing energy important (Elsir, Abdulgalil, Al-Awami, & Khalid, 2019).

Several methods and technologies are being developed to blend solar energy into the electricity network effectively and to keep supply and demand balanced. This includes using energy storage systems, demand response strategies, and smart grids. These solutions aim to make the electricity network more adaptable and able to handle the ups and downs of solar energy while still meeting consumer demands. Keeping supply and demand balanced is crucial to ensure the electricity system stays stable, especially when unexpected problems occur, like short circuits or generator breakdowns.

Adding renewable energy sources, which don't add to the grid's inherent stability, can make it harder to keep the grid balanced. Because of this, it might be necessary to have backup systems that use fuel to help prevent blackouts now and then. To keep an electricity system stable and reliable, it's crucial to maintain a perfect balance between how much power is being produced and how much is needed in real time. Adjustments to production or demand might be needed to control the flow of electricity to each point in the network (Ajao, Haddad, & El-Shahat, 2019).

B. Generation, Transmission, and Distribution (GT&D)

Nigeria's electricity setup is struggling because of old equipment, not enough investment, and poor upkeep. Several companies manage power distribution, but they often face criticism for not investing enough in infrastructure, setting high prices, and offering weak customer service. The Nigerian government has started projects to make the sector better and draw private money, especially to bring electricity to rural areas. Yet, ongoing investment and changes in policy are needed to solve problems with how policies are put in place, the rules around them, and improving the infrastructure to boost access to electricity, which is crucial for Nigeria's economic growth and development.

The Generation, Transmission, and Distribution Network is an essential part of the electricity grid that helps get electricity to users. It consists of two connected systems: the high-voltage transmission and the lower-voltage distribution systems. The high-voltage transmission system moves electricity across long distances from power plants to distribution substations within the national grid, ensuring there are multiple routes for electricity to get to the right substation. The lower-voltage distribution system includes many miles of power lines that link distribution substations to around a million customers (Rajeev & Sundar, 2013).

C. Energy Dispatchability, Inverter, and Battery Capacity

Dispatchable sources are types of energy that can be turned on or off quickly anytime needed. When deciding when to use these sources, it's important to think about several factors such as how long it takes to start them, how much power they provide, how long they can run, when and where they are needed, and their cost. There are three main types of dispatchable sources: slow/non-dispatchable like large power plants that take time to turn on, irregular/non-dispatchable like wind or solar that depend on weather, and rapid/dispatchable like backup generators and batteries that can quickly react to sudden changes in electricity demand to keep the power stable (Jegajothi, Yaashuwanth, Prathibanandhi, & Sudhakar, 2022). To figure out what size inverter you need at home, first, add up the wattage of all the appliances you use to find the highest amount of power you might need at once.

For example, if you have two fans that use 50 watts each and a microwave that uses 500 watts, you'll need an inverter that can handle at least 600 watts. To work out how much energy you use in a day, multiply the wattage of each appliance by how long you use it each day and add those numbers together. Since some appliances use more power when they start up, multiply the total by 1.5 to make sure your inverter can handle it. Then, decide how many days you need your storage battery to last without sunshine—usually, 2 to 5 days is good, depending on how often it's cloudy where you live. If it's often cloudy, you might want a bigger battery, and if it's usually sunny, a smaller one might be enough. It's also a good idea to choose a slightly bigger inverter and battery to be safe (Pierre Giroux *et al.*, 2015). To find out how much a storage battery for a solar system should be able to charge, follow these steps:

1. Calculate the Ampere-hour capacity of the device to be installed. For instance, if an irrigation pump is rated at 160 mA for 24 hours, you can determine its ampere-hour capacity by comparing it to a lithium battery designed for the solar PV system using the following formula:

$$C = X \times T \qquad (1)$$

Where: X is the amperage, and T is the time. In this example, $C = 0.16 \times 24$ equals 3.84 Ah.

2. Compare the result with the capacity of the lithium battery. Select a lithium battery with a capacity greater than 3.84 Ah. Remember that discharging the battery entirely is not advisable if used in a cycle (e.g., solar panel batteries). Over-discharging the battery beyond 50% of its capacity should be avoided. Therefore, divide the ampere-hour capacity of the device obtained earlier by 0.5 to determine the minimum battery charging capacity required. The battery charging capacity in this scenario should be 7.68 Ah or higher.
3. Identify the voltage in the battery bank. Battery enclosures are often designed to provide 12 volts of power, 24 volts, or 48 volts of electricity based on the system's capacity. The voltage increases when batteries are connected in series. For example, connecting two 12V batteries in series creates a 24V system. To make a 48V system, eight 6V batteries are used in the series.
4. Select the appropriate battery bank size. For a 10 kWh per day off-grid home using lithium batteries, a 12.6 kWh battery bank is required, which is equivalent to 1050-amp hours at 12 volts, 525-amp hours at 24 volts, or 262.5-amp hours at 48 volts.

The manufacturer specifies the solar panel's maximum peak power (Wp) in the technical data, but it can only be achieved when the panel receives sunlight at a 90° angle. The panel's output decreases if the illumination or angle deviates from this ideal. On an average sunny summer day, solar panels provide roughly 45% of their peak output for 8 hours (Rajeev & Sundar, 2013). To calculate the necessary solar panel size for recharging a battery, the following formula should be used; therefore, the solar panel's peak power must be 16.39 Wp or higher:

$$(59 \text{ watts per hour} / 8 \text{ hrs}) / 0.45 = 16.39 \text{ wattage power} \qquad \textbf{(2)}$$

D. Charge Controller Selection

When choosing a charge controller for a solar power system, the main thing to consider is the module current. During battery charging, the solar module is cut off from the battery and instead, it's short-circuited through the controller. This is to stop the voltage from getting too high and causing damage. The module current for the charge controller needs to be at least as high as the solar module's maximum short-circuit current. If you have multiple solar modules connected, you'll need to add up all of them short-circuit currents to figure out the total module current the charge controller must handle (Nguyen & Pearce, 2010).

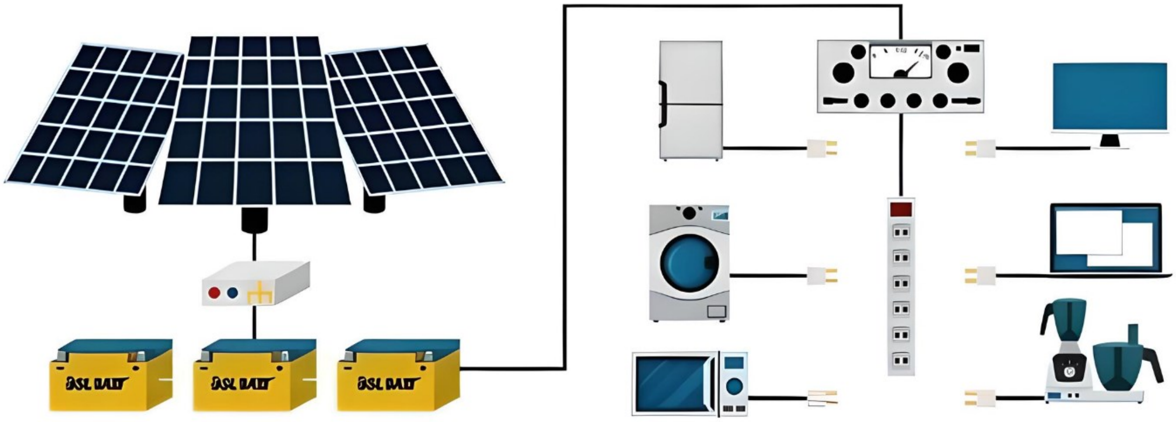

Figure 1: The Off-Grid Solar Model

The charge controller monitors the 3-system's energy consumption. If the system drains the battery during the rainy season, the controller will disconnect it from the storage battery to avoid further discharge. Equations (3), (4), (5), and (6) for the off-grid Solar System with battery backup are shown below (Nguyen & Pearce, 2010). These equations were utilized to calculate the average daily amperages per hour the solar battery storage system needs.

$$\frac{\frac{AC\ Average\ Load}{Inverter\ Efficiency} + DC\ Average\ Load}{System\ Voltage} = Mean\ Daily\ Amperages\ per\ hrs \tag{3}$$

$$Mean\ Daily\ Amperages\ per\ hrs\ x\ Days\ of\ Autonomy = Total\ Ampere\text{-}hrs \tag{4}$$

$$No.\,of\ Batteries\ in\ Parallel = \frac{Total\ Ampere-hours}{(Discharge\ Limit\ x\ Selected\ Battery\ Capacity)} \tag{5}$$

$$No.\,of\ Batteries\ in\ Series = \frac{System\ Voltage}{(Selected\ Battery\ Voltage)} \tag{6}$$

To figure out how many batteries you need for an off-grid solar power system, you first need to calculate the average daily ampere-hours. This tells you how much power your system uses on average each day. Here's how you do it: Divide your total daily power usage (both AC and DC) by the efficiency of your inverter and the system's voltage. Then, to cover days when there might not be enough sunlight, multiply this number by how many days you want your backup to last (this is called days of autonomy). Next, to work out how many batteries you need, divide the total ampere-hours by the maximum amount each battery can be safely drained (this is called the discharge limit) and the capacity of the batteries you're considering. This tells you how many batteries you need in parallel. To figure out how many batteries you need to connect in a row (in series), divide the total system voltage by the voltage of one battery. This setup will ensure you have enough power stored to meet your needs.

E. Energy Storage System (ESS)

Table II highlights the potential uses and benefits of energy storage systems (ESS). ESS provides many advantages, changing the way electricity is generated and delivered to users. Renewable energy sources like solar and wind are affordable when used within certain limits. However, without big battery storage systems, these renewable sources can't function effectively on a large scale.

Table 2: Uses and Advantages of Energy Storage Systems

OPPORTUNITY	USAGE	ADVANTAGES
Enhance Efficiency	Optimize Load Factor	Cost-effectiveness
System Stabilization	Aligning Supply/Demand	Cost Efficiency
Regulate Prices	Lower Prices	Customer Satisfaction
Regulate Voltage Levels	Grid Voltage Stability	Improved Power Quality
Integrate Renewables	Emergency Power backup	System Improvement
Support Services	System Stabilization	Improved Power Quality

An Energy Storage System (ESS) saves extra electricity produced when there's a lot of sunlight and keeps the power supply steady when there's less sunlight. Traditional ESSs, like battery banks, give a steady flow of electricity. But, using battery packs to quickly release a lot of power can shorten their life, even though they can hold a lot of energy. This makes them not great for immediate power needs.

One way to fix this is by using batteries together with supercapacitors. Supercapacitors are good at providing quick bursts of power. In a combined system, the battery provides a steady source of energy, and the supercapacitor handles the sudden power needs. This setup uses a stand-alone hybrid system combining solar panels, batteries, and supercapacitors, with a special method to manage how energy is stored and used throughout the system.

System Model Design and Simulation

The model design and simulation were done using MATLAB software. It included a Residential Energy Storage System (RESS) that connects to the electrical grid through an inverter, storing energy in either standard battery packs or supercapacitors. This simulation was set up and refined using MATLAB/Simulink. The model includes four main parts: the electricity distribution system, a dynamic load model that changes over time, data for typical weather conditions, and the RESS model itself. The electricity distribution system follows the standard North American Utility Distribution System. The dynamic load model handles a 3-phase, 3-wire load that changes hourly.

The weather data system turns sunlight into electrical power, which is then converted to current in the solar power setup. The RESS has a sophisticated control system, a device to monitor for failures, a calculator to keep track of stored power, and a step-up transformer to increase voltage. The diagrams in Figures 6 and 7 show the expected battery temperatures for solar power systems in parts of the United States and Nigeria throughout the year. The solar farm setup includes four arrays of solar panels, each capable of producing up to 100 kW of power when the sun's radiation is at 1000 W/m^2. Each array consists of sixty-four parallel strings of solar panels, with each string having 5 SunPower SPR-315E modules connected in series. These panels are linked to a standard model DC/DC converter, which boosts the output to a common 500 V DC bus. Each boost is managed by its own Maximum Power Point Tracker (MPPT) using the "Perturb and Observe" method to maximize power output. Finally, a 3-phase system equipped with a Voltage Source Converter (VSC) changes 500 V DC to 260 V AC, maintaining a constant power factor. A 400-kVA 260V/25kV three-phase transformer connects the converter to the power grid. This grid has typical 25-kV distribution lines and a bigger 120-kV transmission system. The model simplifies the converters into average voltage sources, calculating the AC voltage over one cycle of switching frequency. This keeps the important dynamic behaviour caused by interactions between the control system and the power system, but it doesn't show details like harmonics.

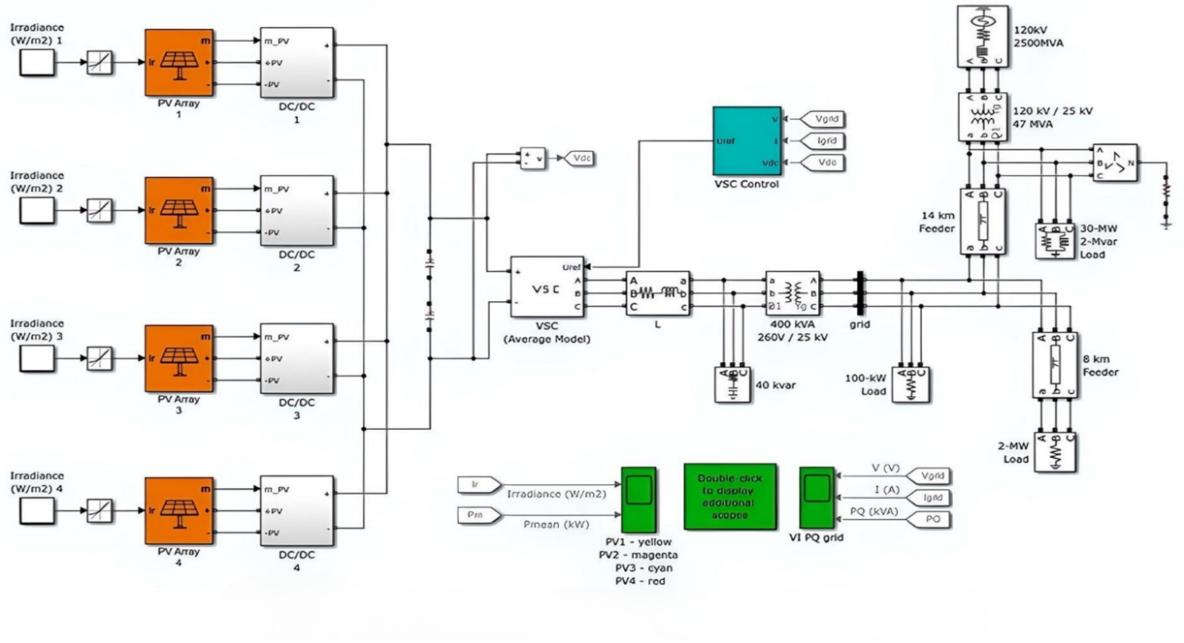

Figure 2: RESS Designed Model

Table 3: Model Parameters

MODEL OF THE RESS	DATA STORED
Solar Radiation Intensity $(W/m^2)^2$	1000
Photovoltaic Rated Output (kWh)	400
Initial Energy Reserve	94%
Overall System Efficiency	92%
Maximum Grid Power Supply (kW)	1000
Peak Power Output (kW)	100 x 4 PV
Maximum Nighttime Charging Power (kW)	150 - 180
LOAD CHARACTERISTICS	**PHOTOVOLTAIC (PV) FARM**
Nominal Voltage (L-L) = 600	Global Horizontal Irradiance
Nominal Load = 1500 KVA	Total Photovoltaic Surface Area = $3000m^2$
Power factor = 0.95	Performance of the System's Efficiency = 90%

This model allows for quicker simulations using larger time steps (50 microseconds), with results shown in phasor format on different display screens. Paired with the Residential Energy Storage System (RESS), it helps optimize how each solar panel array operates under different sunlight levels. For simplicity, a basic scenario was used to estimate the model's power and capacity. The simulation parameters for both case studies in the U.S. and Nigeria were kept similar, as shown in Table 3. Figures 10 and 11 display the simulation results, including power from the grid, stored energy, home energy use, and power produced by the solar panels in both countries.

Case Study: Comparative Analysis

This study focuses on the major global challenges of achieving clean air, minimizing environmental contamination, and tackling climate change. These issues have accelerated the development of alternative energy sources like wind and solar power. Since 2008, the United States has seen a dramatic increase in the installation of solar power capacities, growing from 1.3 gigawatts to about 35 gigawatts, enough to power over 9.5 million average American homes.

The aim here is to evaluate Nigeria's potential for solar energy by comparing it to the United States. The study includes a simulation to test the economic viability of using a residential energy storage system in a rural, industrial area of Georgia, USA. This system connects to the local power grid, and the total energy stored over one year is calculated using solar output and typical meteorological year (TMY3) data. The results show significant solar energy potential in the southern United States. The study also looks at the solar capacity in a less-served rural area in northeastern Nigeria. As shown in Figure 3, this area could receive a high amount of solar energy, averaging 16.8 megajoules per square meter per day with about 6 to 7 hours of sunlight. This study underlines the strong potential for solar power generation in Nigeria's northeastern and western regions (Ajao, Haddad, & El-Shahat, 2019).

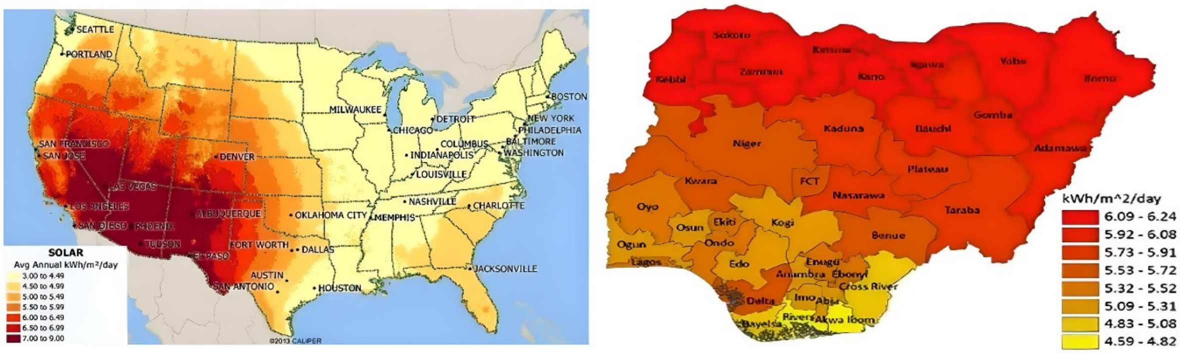

Figure 3: Comparative Solar Map (USA & Nigeria)

In addition, a comparison analysis was performed utilizing IREQ Hydro-Quebec's Residential Energy Storage System (RESS) modeling. The model used publicly available solar information from TMY3 records and solar information obtained from NASA Surface Meteorology and Solar Energy (NASA-SSE) accessible through the web (Giroux *et al.*, 2015). TMY3 downloads are online data sets taken from the National Solar Radiation Data Base (NSRDB) repositories that give hourly solar radiation values for one year. The electrical grid's power was estimated by combining the electrical power provided by the photovoltaic system with the energy stored in the ESS, as shown in equation (7).

$$P_G = P_F + P_B \tag{7}$$

Where: P_G represents grid power, P_F represents solar farm power, and P_B represents the total energy stored in the batteries.

DISCUSSION AND RESULTS

West Africa is a developing region where energy consumption and demand are increasing rapidly due to population growth. Nigeria has abundant solar power resources with high solar energy intensity, especially in the northeastern region, where sun levels are high and the dry season prevails (Ajao, Haddad, & El-Shahat, 2019). However, inadequate infrastructure and capacity for solar farm implementation exist in both the western and northern parts of Nigeria, hindering the integration of the grid system with a Solar PV farm model.

A. Performance Ratio for Solar Cells

The performance ratio of a solar power cell is the ratio between the actual yield (average annual electricity generated and distributed) and the intended or needed output. This ratio remains unaffected by irradiance levels and is helpful for system comparison. Monitoring the performance ratio throughout the system's operation is crucial for identifying the causes of yield losses, as deterioration can reveal valuable insights. Equation (8) further explains the solar cell's performance ratio (Ajao, Haddad, & El-Shahat, 2019).

$$PR = \frac{Actual\ Yield_{AC}}{Target\ Yield_{DC}} = \frac{E}{hA\eta_{nom}} = \eta_{pre}\,\eta_{rel}\,\eta_{sys} \tag{8}$$

B. The Target Output

Equation (9) below is used to estimate the energy capacity (E) required or targeted to be delivered by a Renewable Energy Storage System (RESS), considering various efficiency factors (Xiao, Yu, Yang, & Que, 2014). These factors include the efficiency at pre-conversion η_{pre}, the efficiency of the system $\boldsymbol{\eta_{sys}}$, the efficiency of the relative module $\boldsymbol{\eta_{rel}}$, the efficiency of the nominal module $\boldsymbol{\eta_{nom}}$, The total sum of global radiation from the sun obtained yearly h**,** measured in kilowatt hours per square meter [kWh/m^2]:

$$\frac{A}{E} = h\eta_{pre}\, \eta_{rel}\, \eta_{sys}\, \eta_{nom} = PRh\eta_{nom} \qquad (9)$$

Expressing the energy yield relative to the peak power of the module is a common practice. This peak power is standardized at $1{,}000\ W/m^2$ (with $H_0 = 1{,}000\ W/m^2$) and remains independent of the module's surface area. Equation (10) introduces the concept of energy per rated power, stating that the maximum power evaluated in the computation relates to the module's peak power, not the system's installed rated capacity. The latter is calculated as $P_{sys} = P_{module}\, \eta_{sys}$

C. Energy Per Rated Power

$$\left(\frac{E}{P_{peak}}\right) = \frac{h}{H_0}\eta_{pre}\eta_{rel}\eta_{sys} = \left(\frac{E}{A}\right)\frac{1}{H_0\eta_{nom}} = PR\frac{h}{H_0} \qquad (10)$$

To assess the effectiveness of solar panels in this region, the solar efficiency formula is employed by dividing the output power by the input power, multiplying the result by 100%, and calculating the global solar radiation (GSR) in the area, using variables such as sunshine duration, sunset hour angle, solar declination angle, cloudiness index, and sky view factor. Equation (11) is crucial in determining the efficiency of a solar panel in generating sufficient electrical power. Additionally, it enables the assessment of whether a solar panel and, consequently, a solar farm can produce enough photovoltaic energy for storage and distribution.

$$GSR = (0.25 + 0.5\, n/N)\ [24 \times \frac{60}{\pi} / GSCdr\ (\omega s \sin \emptyset \sin \delta + \cos \emptyset \cos \delta \sin \omega s)]$$

$$N = \frac{2}{15}\omega s = \frac{2}{15} \cos\text{-}1\ (-\tan \emptyset \tan \delta)$$

$$\delta = 23.45 \sin\left(\frac{102240 + [360 + J]}{365}\right)$$

$$CI = \frac{\hat{c}}{GSR}$$

$$SVF = \frac{\pi}{2} . \sin\left(\frac{\pi.(\pi - 0.5)}{2N}\right) . \cos\left(\frac{\pi.(\pi - 0.5)}{2N}\right) \qquad (11)$$

The equation includes various parameters, such as ***GSR*** for global solar radiation, N for the entire length of the day, n for sunshine hours, ***Ws*** for the sunset hour angle, $\boldsymbol{\emptyset}$ for the latitude of the station in degrees, $\boldsymbol{\delta}$ for the solar declination angle of the earth, ***J*** for the day of the year ranging from J1 for January 1st to J365 for December 31st, ***CI*** for the cloudiness index, and ***SVF*** for the sky view factor.

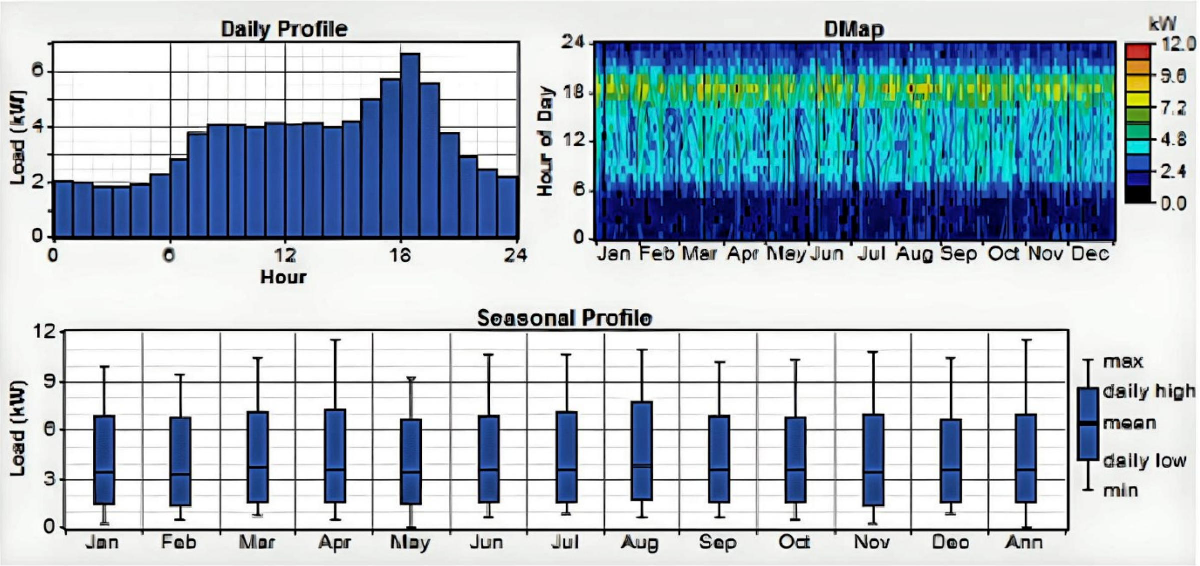

Figure 4: Residential Load Profile

This equation is essential as it enables simulation results to demonstrate the significant investment opportunities for Solar Energy Companies in West Africa. GSR determines the photovoltaic radiation that a specific region, such as Nigeria, receives (Singla, Singh, & Yadav, 2016). The cloudiness index refers to the level of cloud cover in the sky, while the sky view factor denotes the unobstructed view of the sky from the ground, free from buildings and other obstacles.

This information makes it possible to identify the most suitable location for solar farm installation by selecting areas with minimal obstructions, limited cloudiness, and adequate solar radiation for efficient electrical energy conversion from the solar panel and storage. The temperature coefficient is critical when evaluating the effectiveness and resilience of photovoltaic cells, as lower coefficients produce better outcomes. Solar panels typically have temperature coefficients ranging from -0.2%°C to -0.5%°C. A coefficient close to 0 indicates higher performance.

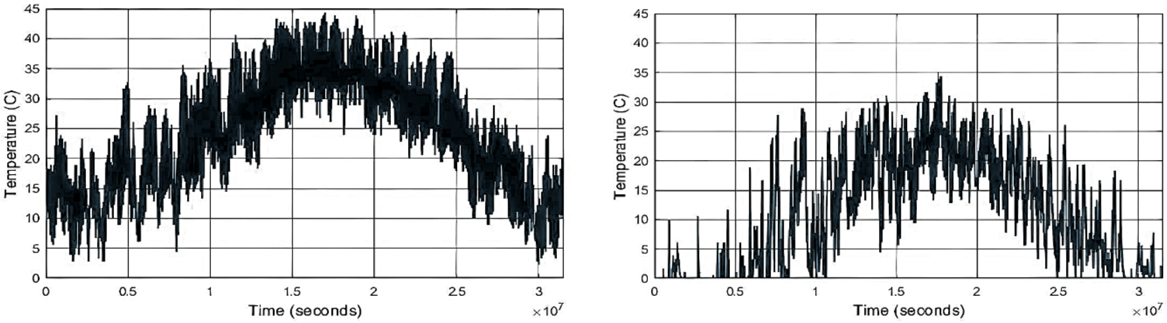

Figure 5: Estimated Solar PV Cell Temperature (Dry & Rainy Seasons)

Figures 5, 6, and 7 show the estimated solar power cell temperature, PV farm integrated component capacity, and generated energy that the RESS can store, respectively. At the same time, the load remains constant, as indicated in Figure 4. This demonstrates the amount of solar power that can be generated at each site depending on the intensity of sunlight The amount of sunlight reaching Earth fluctuates throughout the year and seasonally, shifting during the day depending on where the sun is positioned and weather conditions. The energy density of radiation from the sun at air heights is believed to be roughly 1,368 W/m2, but it lowers on the Earth's surface, with an estimate of 1,000 W/m2 on a surface horizontal to the sun's beams at sea level on a clear day. The model RESS results for this case were obtained on an open airport field, potentially influenced by the site's location and nature. Solar cells can reach temperatures as high as 65°C, reducing panel efficiency and efficacy (Ajao, Haddad, & El-Shahat, 2019).

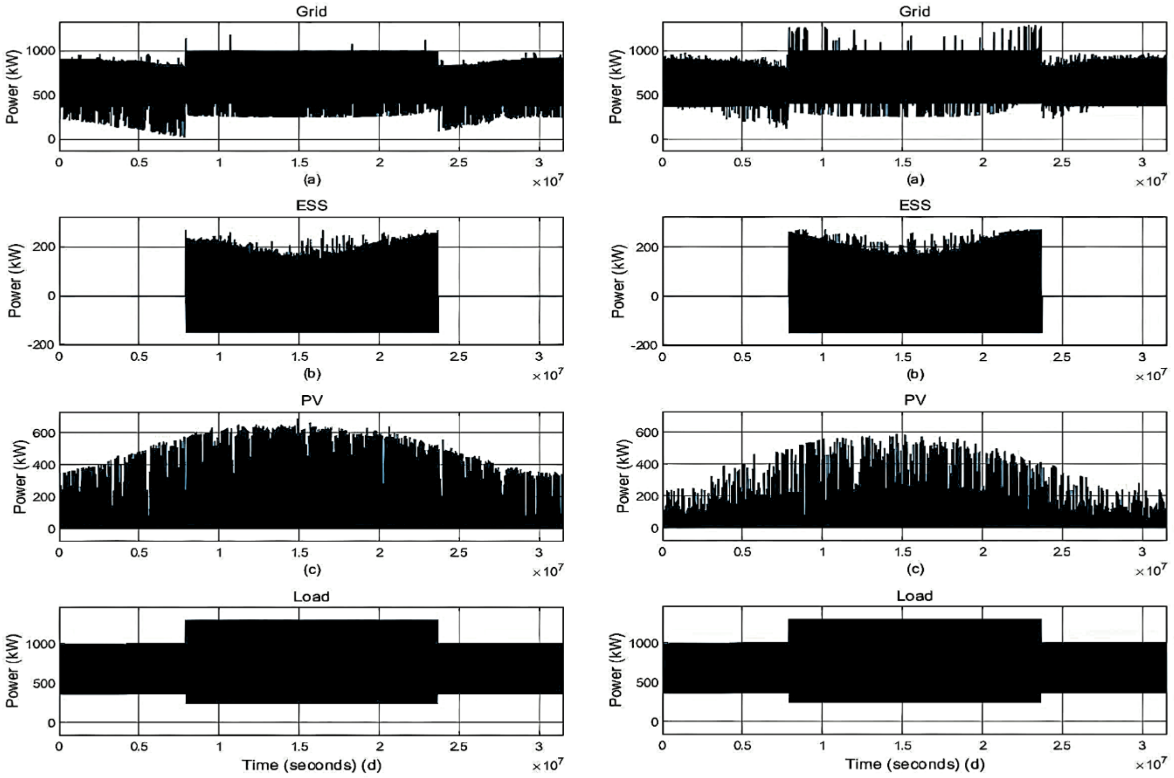

Figure 6: (a) Estimated Grid Power(b) RESS Capacity (c) PV Potential (d) Load (Dry & Rainy Seasons)

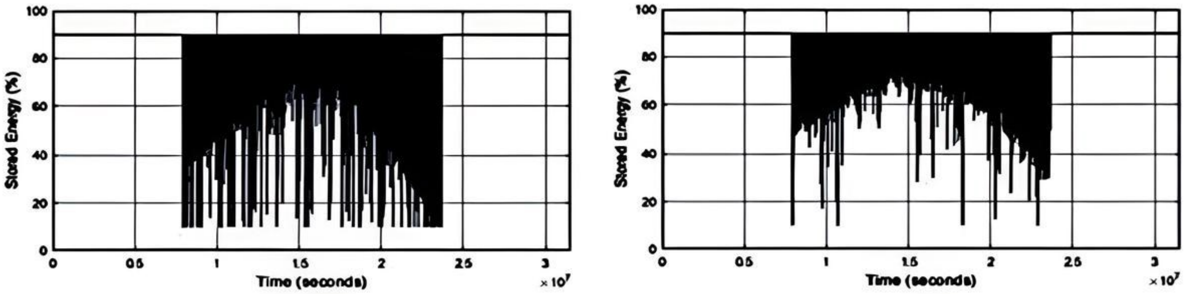

Figure 7: Estimated Energy Stored (Dry & Rainy Seasons)

Figures 8 and 9 represent the phasor outputs of the modelled Photovoltaic connected off-grid and on-grid scenarios, respectively. The findings show that the RESS operates at its peak capacity between 10 a.m. and 6 p.m. The analysis finds that localities can reduce their dependency on the national grid during these hours and instead use the solar energy generated.

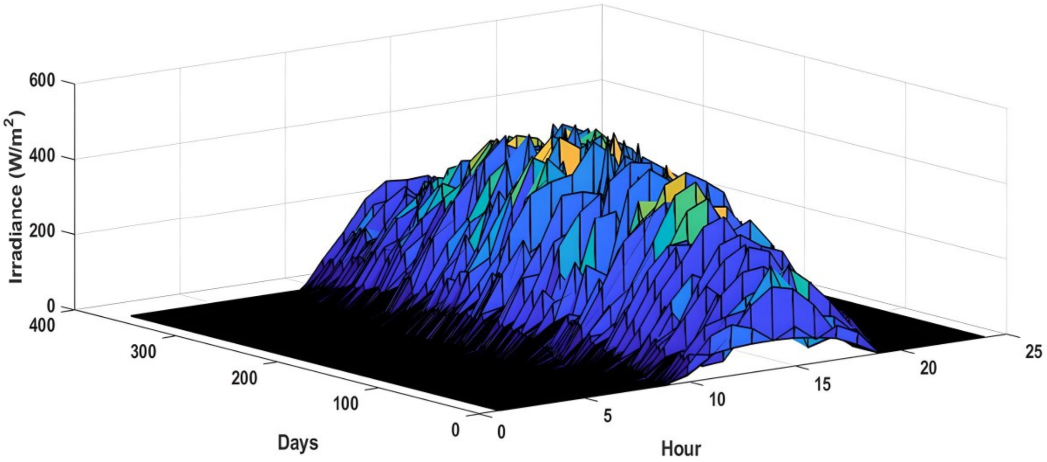

Figure 8: Simulated Solar PV Off-Grid (peak hours)

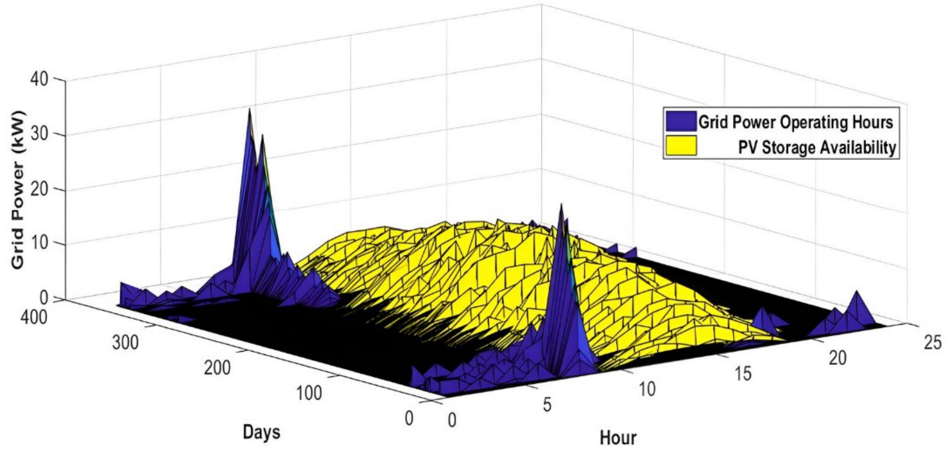

Figure 9: Simulated Solar PV Grid-Connected (peak hours)

This study used mapping techniques to explore the possibility of producing solar energy on a large scale in Nigeria by building a map that shows how much sunlight different areas get. Researchers created a detailed map using data from satellites on sunlight patterns, types of land surfaces, and landscape features to pinpoint the best places for solar farms (Makade & Jamil, 2018). They found that many areas in Nigeria, especially in the north, are well-suited for generating solar energy. These findings lay a strong groundwork for more research and development in renewable energy, which is important as the Nigerian government is pushing for more renewable energy to improve energy security and reduce the negative effects of using fossil fuels (Chanchangi *et al.*, 2021).

The outcomes of this research could boost investment in Nigeria's solar energy sector, helping the country move forward with solar power projects that are both connected and not connected to the national electricity grid. The potential for solar power in Nigeria is huge—it could greatly reduce the country's reliance on traditional energy sources and open chances for sustainable economic development. Given the global push towards solar power because of the rising levels of greenhouse gases from burning fossil fuels, Nigeria and other West African countries are encouraged to adopt this cleaner energy source.

There's a chance for West African countries to enhance their capabilities by adopting the residential energy storage system model from IREQ, which is crucial in integrating transportation, electrification, and solar energy storage. Studies show that Nigeria gets a lot of sunlight all year round, which is perfect for boosting solar energy production. Countries like the US and China could also help West African nations in managing land and energy use more efficiently. Nigeria should look to these countries for ways to harness solar power effectively, aiming to power its nation while cutting down on reliance on the traditional power grid and lessening environmental harm (Ajao, Haddad, & El-Shahat, 2019).

CONCLUSION

Nigeria requires a robust, efficient, and functional energy industry to become a developed country. This country has enormous potential, with numerous renewable energy sources that are virtually unexplored. However, large-scale extraction of petroleum and natural gas, pervasive corruption, a lack of transparency and sensitivity in the energy industry and worries about monetary backing systems for clean energy sources all pose challenges to their exploitation. Several nations have welcomed decentralization, while Nigeria has opted for the opposite approach. The 2005 Regulatory Act on the Energy Industry mandates central regulation of all energy sources associated with the country's thirty-six states and their local governments. Decentralizing the energy industry, a move that has proven successful in other countries, could be a starting point for addressing these difficulties. It could lead to increased efficiency, reduced costs, and improved service delivery. However, this may be challenging due to conflicting legislation in the power industry. The northeastern area of Nigeria can produce enough solar energy to power the whole region. However, it does not have the infrastructural and architectural capacity to generate enough electricity to cater for the nation's demand. Permanent investment in renewable energy across the country has the potential to create considerable, long-term advantages. The anticipated capacity for concentrated solar energy, intensity, and photovoltaic generation is approximately 427 GW. The PV-based domestic energy storage system model can be expanded and adapted to work in various parts of the country. Additionally, the system could provide an alternative solution that reduces electricity costs for consumers nationwide, making electricity more affordable and reliable.

CONFLICT OF INTEREST DISCLOSURE

The authors declare no conflict of interest.

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