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A Stratified Power Scheduling Model for Energy Management in Microgird

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ABSTRACT

In countries like Nigeria that have low electrification rates, companies use distributed generation (DG) as suitable alternative to meet their energy demands. With distributed generation come several challenges such as power quality assurance from the several generating stations, balancing energy demand and supply, security issues, smart metering for tariff management, etc. However, conventional energy management system (EMS) lacks the capacity to adequately cope with these challenges. Thus, there is need to develop an improved energy management strategy in order to optimize the power supply within a microgrid. The aim of this work is to develop a hierarchical power scheduling model for energy management in a smart solar microgrid. The specific objectives include: to characterize the test bed in terms of load demand so as to determine the accurate load profile; to develop a mathematical model that will give the optimum number of batteries, controllers and photovoltaic (PV) array sizing for varying load; to develop energy management model that covers all the specified energy sources contained in the microgrid; to develop power scheduling algorithm that solves the load discrepancy issue in the microgrid while boosting user satisfaction and reliability of the power system; and to investigate the performance of the system in terms of load balancing and cost effectiveness of operation. In this thesis, an optimal configuration algorithm for sharing energy resources in a microgrid using data collected from an existing microgrid located at Electronic Development Institute, Abba Town Anambra State Nigeria was developed. The data collected were used for sizing the system testbed, which has majority of its activity running between 8am and 4pm, and this was used to model the existing system. The optimal algorithm developed was used to schedule the different sources on the microgrid in order to minimize the load variance and operational cost. Using the Homer software, four simulation scenarios were considered for evaluating the performance of the system namely scenario 1 (all energy sourced from solar panels), scenario 2 (energy sourced partly from utility grid, partly from generator and partly from solar panels), scenario 3 (same as scenario 2 but includes battery storage), scenario 4 (energy sourced from partly from solar panels and partly from generator).

1. INTRODUCTION

1.1 Background to the Study

According to the reports provided by the Electricity Generating Companies, the average power supply in Nigeria is 3, 851 MW. The peak averaged power supply was fixed in January 2017 and was around 4, 425 MW. There was an estimate of over 12 Total Breakdown in Transmission Company of Nigeria (TCN) in one month resulting in total blackout in the country. Since 2005, some section of the power sector was privatized, and yet there seem to be benefit to the masses and no increase in generated power. In 2012, Nigeria generated approximately 5,000 MW of power for the population of over 150 million people. You may compare this situation with the second largest economy in Africa which is South Africa which produces over 40,000 MW of energy for 62 million people you may see the real problem of unstable power supply in Nigeria.

The energy consumption in the entire universe is projected to be between (25-35) Tera Watts (TW2) by 2050 and to stabilize the atmospheric CO_2 by then, there should be a generation of 20Tera Watts (TW) of non- CO_2 energy. Hence, sustainable and renewable resources like Solar Photovoltaic (PV) and others have to take up a major share in electricity generation in order to achieve this target.

With environmental concerns on the increase, and yet ever increasing electricity demand, the interest toward renewable based electricity generation, in present years, is a suitable approach to fulfill world's energy demand in the years ahead. The government is under compulsion to overhaul the facilities in power grids and to increase the reliability of power delivery. However, old facilities are not the only problem for the current power grid (Cao, Fang & Todem, 2017). It requires more efforts in many aspects to create an enhanced power grid. Meanwhile, we have to face the challenges from depleting fossil fuels, global climate change, increasing power demand etc. Fortunately, the advanced science and technology in many fields may help us to improve the existing power grid. Based on this, an innovative power grid is born – the microgrid.

Distributed Energy Resources is to provide a greater incentive to perform a research on integration and incorporation of Solar Photovoltaic (PV) into the new/improved power system. Due to insufficiency of transmission line capacity to attend with the increasing demand, more concern is growing towards distributed generators and microgrids. With large incursion of the Distributed Energy Resources DER in future power systems, operation of grid in coordination with these small generators is a big exception and micro-grid concept seems to cope with this exception. This accumulation of small Distributed Energy Resources DERs called micro-grid is capable of operating independently as well as in connection to the central grid. Hence, the control of individual participating DERs to control voltage and frequency of the microgrid is a viable area of research.

Statement of the problem

The general social and economic life line in Nigeria is threatened by the situation of poor power supply in Nigeria. The situation is very serious due to the high cost of depending on diesel, fuel and operating the business with generators and poor plants instead of using the funds to buy more goods and services to grow their various businesses. Constant power outages is rampant in Nigeria, many companies are relocating from Nigeria to other countries due to the situation. The consequence of this situation is job displacement and high level of poverty and unemployment and in addition, many potential entrepreneurs are discouraged from starting up small and medium enterprises (SMEs) due to the unfavorable condition. Government policies on the promotion of small scale business are not effective due to the poor electricity supply in Nigeria.

1.3 Aim of the study

The aim of the research is to model a hierarchical power scheduling algorithm and energy management in a smart solar micro grid.

1.4 The Specific objectives for the research are as follows:

1. To develop a mathematical model for comprehensive load analysis of the test bed
2. To develop energy management model for solar microgrid in both island and grid connected modes
3. To determine the number of batteries controllers and PhV array sizing for varying load using developed mathematical model.
4. To develop power scheduling algorithm that improves the load discrepancy in the microgrid while boosting user fulfillment and steadiness of the power system
5. To create an ideal technique that gives coverage in both grids connected and off grid connected modes using multi cluster box.

1.5 Significance of the Study

Though apparatuses of the MGs are understood moderately, the system as a whole seems not. When numerous sources are coupled to structure a MG, the system performance likely becomes unpredictable. In other to avoid catastrophic failures as a result of uncertainties, modeling the system and simulating it, in order to develop an appropriate management system, is the sole purpose of this micro-grid research. Exploring the viability and advantages that the MGs may offer, some challenges are confronted comprising of the unbalanced loads and harmonics linked with the system. This study is apprehensive with the modeling of the MG for Energy management. Furthermore MGs is bound to decrease environmental pollution and global warming by employing low-carbon technology. The research work drives at being of incredible benefit to both users and energy providers. Besides full-duplex information flows, designing of the grid devices can be adapted for timely response to the grid status. For instance, energy storage systems can collaborate with distributed renewable energy resources (DRERs) to bring equality in supply and demand, and users can modify their energy consumption according to the market price fluctuations.

2. REVIEW OF RELATED LITERATURE

According to Luo, Ranzi, Wang and Dong, 2019 Due to the spread of distributed energy resources, sensing infrastructure, and automation facilities, modern homes are becoming “home microgrids.” Their work intended to support this trend and proposed a two-stage hierarchical energy management system for smart homes by considering both day-ahead and actual operation stages. In the day-ahead stage, an efficient scenario analysis approach was developed to account for residential photovoltaic solar power uncertainty. Their approach performed solar power scenario generation and reduction based on the Wasserstein distance metric and K-methods, respectively. This was then followed by the use of a stochastic day-ahead residential energy resource scheduling model. In their actual operation stage, a semi-scenario based rolling horizon ‘optimization mechanism was proposed, based on which an actual operation model was established. Simulations were conducted and the effectiveness of the proposed system was validated.

Ndwali, Njiri, & Wanjiru, 2020 experimented the exponentially increasing demand of electrical energy in developing countries and the struggle to provide electricity to the end-users. Therefore, their paper proposed a constrained optimal operation control strategy of microgrid connected photovoltaic with diesel generator backup system related to commercial and industrial (C&I) setups in Kenya. Particularly, their objective function simultaneously amid at reducing energy purchased from utility grid and the fuel consumption cost of the conventional diesel generator. The constraints related to control variables were taken in the context of C&I in Kenya. The optimal operation control was carried out using FMINCON interior-point algorithm. A case study was done based on the daily load profile of the Engineering workshops at Jomo Kenyatta University of Agriculture and Technology (JKUAT) located at −−1.099∘∘ latitude and 37.014∘∘ longitude. The optimal operation control showed great benefits in terms of energy saving, cost saving as well as daily revenue. The daily energy saving was increased to 52.1%, the daily cost saving was 20%, and daily energy sold was found to be 142.4 kWh which could generate daily income of $17.

Eva Chinedu Umeozor 2015 presented a multi-parametric programming (MPP) based approach for energy management in microgrids. The algorithm created operational strategies for efficient and tractable coordination of distributed energy sources in a residential level microgrid. The hybrid energy system comprises of renewable (solar photovoltaic and wind turbine), conventional systems (microturbine and utility grid connection), and battery energy storage system. The overall problem is formulated using multi-parametric mixed-integer linear programming (mp-MILP) via parameterizations of the uncertain coordinates of the wind and solar resources. This resulted in a bi-level optimization problem, where choice of the parameterization scheme was made at the upper level while system operation decisions were made at the lower level. The mp-MILP formulation leads to significant improvements in uncertainty management, solution quality and computational burden; by easing dependency on meteorological information and avoiding the multiple computational cycles of the traditional online optimization techniques. Results evidence the feasibility and effectiveness of MPP.

MahmoudElkazaza et al 2020 their paper presented a hierarchical two-layer home energy management system to reduce daily household energy costs and maximize photovoltaic self-consumption. In their study the upper layer comprised of a model predictive controller which optimizes household energy usage using a mixed-integer linear programming optimization; the lower layer comprised of a rule-based real-time controller, to determine the optimal power settings of the home battery storage system. The optimization process also included load shifting and battery degradation costs. The upper layer determines the operating schedule for shiftable domestic appliances and the profile for energy storage for the next 24 h. This profile is then passed to the lower energy management layer, which compensates for the effects of forecast uncertainties and sample time resolution. The effectiveness of the proposed home energy management system was demonstrated by comparing its performance with a single-layer management system. For the same battery size, using the hierarchical two-layer home energy management system can achieve annual household energy payment reduction of 27.8% and photovoltaic self-consumption of 91.1% compared to using a single layer home energy management system. The results show the capability of the hierarchical home energy management system to reduce household utility bills and maximize photovoltaic self-consumption. Experimental studies on a laboratory-based house emulation rig demonstrate the feasibility of the proposed home energy management system.

According to F. Luo et al 2018 Home energy management system (HEMS) provided an effective solution to assist residential users in dealing with the complexity of dynamic electricity prices. The study proposed a new HEM in contexts of real-time electricity tariff and high residential photovoltaic penetrations. First, the HEMS accept user-specified residential energy resource operation restrictions as inputs. Then, based on the forecasted solar power outputs and electricity prices, an optimal scheduling model is proposed to support the decision making of the residential energy resource (RES) operations. For the scheduling of heating, ventilating, and air conditioning system, an advanced adaptive thermal comfort model was employed to estimate the user's indoor thermal comfort degree. For the controllable appliances, the `user disturbance value' metric was proposed to estimate the psychological disturbances of an appliance schedule on the user's preference. The proposed scheduling model was aimed to minimize the future day energy costs and disturbances to the user.

In the paper presented by F. Luo, G. Ranzi, X. Wang and Z. Y. Dong 2016 Driven by the energy crisis and global warming problem, smart grid was proposed in the early 21th century as a solution for the sustainable development of human society. With the two-way communication infrastructure available in smart grids, a current challenge is to interpret and gain knowledge from the collected grid big data to optimize grid operations. Service recommendation techniques provide promising tools to discover knowledge from the grid data, and recommend energy-aware products/services/suggestions to the smart grid participators. Their paper was among the first to investigate the prospective of introducing service recommendation techniques into the smart grid demand side management (DSM).

According to F. Luo, G. Ranzi, X. Wang and Z. Y. Dong 2019 Rapid growth of data in smart grids provides great potentials for the utility to discover knowledge of demand side and design proper demand side management schemes to optimize the grid operation. The overloaded data also impose challenges on the data analytics and decision making. Their study introduced the service computing technique into the smart grid, and proposes a personalized electricity retail plan recommender system for residential users. The proposed personalized recommender system (PRS) is based on the collaborative filtering technique. The energy consumption data of users are firstly collected from the smart meter, and then key energy consumption features of the users are extracted and stored into a user knowledge database (UKD), together with the information of their chosen electricity retail plans. For a target user, the recommender system analyzes his/her energy consumption pattern, find users having similar energy consumption patterns with him/her from the UKD, and then recommend most suitable pricing plan to the target user. Experiments were conducted based on actual smart meter data and retail plan data to verify the effectiveness of the proposed PRS.

S. Squartini, M. Boaro, F. De Angelis, D. Fuselli and F. Piazza, 2013 Smart Home Energy Management has been a very hot topic for the scientific community and some interesting solutions have also recently appeared on the market. One key issue is represented by the capability of planning the usage of energy resources in order to reduce the overall energy costs. This means that, considering the dynamic electricity price and the availability of adequately sized storage system, the expert system is supposed to automatically decide the more convenient policy for energy management from and towards the grid. In thier work a comparison among different linear and nonlinear methods for home energy resource scheduling was proposed, taking into consideration the presence of data uncertainty. Indeed, whereas the employment of advanced optimization frameworks took advantage by their inherent offline approach, the need to forecast the energy price and the amount of self-generated power. A residential scenario, in which system storage and renewable resources were available and exploitable to match the user load demand.

D. Oliveira, et al 2015 The theoretical potential for renewable energy resources (RES) to meet the global demands of energy is generally high and the ambitions for introducing RES into energy systems are growing worldwide, which also can contribute to global climate change mitigation if it is produced in a sustainable manner. To address these issues, more and more governments are implementing various programs and energy policies to accelerate the deployment of RES. The aforementioned two reasons lead to an urgent need to add new generating capacity or reduce consumption during peak periods, or both. The first option for power generation is to use RES which can inject electric energy to the grid while avoiding greenhouse gas emissions. However, the capacities of RES are not enough to supply all the required power from the side of the load. Facts that are leading to the proposal of original ways to reduce the use of energy in many sectors, namely in commercial, residential, and industrial sectors, in order to reduce the total energy costs of the consumer, to reduce the energy demand specially during on-peak hours and the greenhouse gas emissions while safeguarding end-user preferences. The aim of this paper was to determine the impact of model predictive control (MPC) on energy savings of residential households. Furthermore, the value and impact of generated power by local power sources, such as roof-top-solar, will be determined during off-peak, mid-peak, and on-peak, providing simulations during 24 hours in a house.

Y. Zheng, K. Meng, F. Luo, J. Qiu and J. Zhao, 2017 The net demand of distribution systems of renewable energy shows strong daily and seasonal patterns that may cause a loss of operation and constriction. Battery energy storage systems (BESS) allow peak load shaving and are used to enhance the reliability of distribution systems. In addition to the problem of an unbalanced net demand, there can be significant net demand fluctuation for different times and locations. To address this, mobile BESS (MBESS) can offer advantages over static BESS (SBESS) in operation flexibility, though may require higher engineering costs. In this study, an operation model was proposed to coordinate static and MBESS to improve overall system economic efficiency and reliability. On the basis of this model, a framework was proposed to optimally allocate MBESS/SBESS in a distribution system based on cost-benefit analysis. Using this approach, the optimal operation schedules for MBESS and SBESS can be simultaneously obtained. The proposed optimization problem uses a new evolution algorithm, a natural aggregation algorithm. A case study on the IEEE test system successfully verified the effectiveness of the proposed approach for the optimal allocation of MBESS/SBESS in distribution systems.

Gholamreza Aghajani, Noradin Ghadimi 2018 In recent years, the management and operation of micro-grids are considered by many advanced societies with regard to the development of scattered energy resources. The main goals that are paid attention in micro-grid management are the operation cost and pollution rate, which the aggregation of such contradictory goals in an optimization problem can provide an appropriate response to the management of the micro-grid. In their paper, the MOPSO method has been used for management and optimal distribution of energy resources in proposed micro-grid. On the other hand, the problem was analyzedbwith the NSGA-II algorithm to demonstrate the efficiency of the proposed method.

J. von Geibler et al 2018 Combined heat and power (CHP) production in buildings is one of the mitigation options available for achieving a considerable decrease in GHG emissions. Micro-CHP (mCHP) fuel cells are capable of cogenerating electricity and heat very efficiently on a decentralized basis. Although they offer clear environmental benefits and have the potential to create a systemic change in energy provision, the diffusion of mCHP fuel cells is rather slow. There are numerous potential drivers for the successful diffusion of fuel cell cogeneration units, but key economic actors are often unaware of them. This paper presents the results of a comprehensive analysis of barriers, drivers and business opportunities surrounding micro-CHP fuel-cell units (up to 5 kWel) in the German building market. Business opportunities have been identified based not only on quantitative data for drivers and barriers, but also on discussions with relevant stakeholders such as housing associations, which are key institutional demand-side actors. These business opportunities include fuel cell contracting as well as the development of a large lighthouse project to demonstrate the climate-neutral, efficient use of fuel cells in the residential building sector. The next step could involve the examination and development of more detailed options and business models. The approach and methods used in the survey may be applied on a larger scale and in other sectors.

Subhash Chandra, Sanjay Agrawal, D.S. Chauhan 2018 Energy is the key factor for the growth of any country. Per capita energy consumption is the significance of the progress of any nation. With the increasing environmental impacts, word community is searching the way to shift towards sustainable energy sources. Recently the penetration of photovoltaic systems has increased to generate the electricity at grid or local level. Although this technology has improved a lot however the performance of these systems is site dependent. The experiment is conducted in laboratory of GLA University, Mathura, UP, India (hot and dry climate zone of India). Two PV modules of same electrical and mechanical specifications are taken for experiment. To analyze actual performance; different months of a year from various seasons are chosen including artificial wind. It has been observed that increased module temperature reduces performance but the cooling mechanism provided, bring down the module temperature due to which a net energy gain is 5.07% in considered time. Performance measure indices i.e. PR is improved by 3.4%. Experimental and Simulated energy is 431.28wh and 434.98wh for cooled module while for not cooled module experimental and simulated energy is 410.44wh and 439.7wh. Simulated values of energy are closer to experimental values for cooled module hence ANN avoids the underestimation of performance and overestimation of size, average simulated PR is also same as that of experimental PR i.e. 98.6%.

Irfan Ahmad Ganie 2020 This project proposes ameliorated hybrid solar and wind accompanied by a battery management system with specialized and accurate controllers developed using the PID controller. The main apprehension of the project was to design an intelligent system which would work in synchronization with all other components of the microgrid. The algorithm is developed in such a contrivance that all sources should cooperate according to the variable load conditions. We have proposed an algorithm which is efficient in terms of making system reliable and stable, we have involved renewable resources as solar and wind energy for generation thus saving fuel consumption ultimately it affects the economy of the country. Simulation has been done which demonstrates the whole scenario of operation of all components of the microgrid. The simulation model comprises of a model of renewable sources and battery with its controller grid and Load. To test the persuasiveness of the system, it is simulated on MATLAB. The competence of the system at different conditions namely as step changes in irradiance and several load condition.

Microgrid

Microgrid is a collection of distributed generators or micro-resources, energy storage devices and loads which operate as a single and independent controllable system capable of providing power to the area of service (Roozbehani, Dahleh & Mitter, 2017). **The micro-resources that are incorporated in micro-grids comprise of small units, less than 100 kW provided with power electronics (PE) interface.** Most common resources are Solar Photovoltaic (PhV), Diesel Generators or Micro turbines which are located close to the load centers and integrated together to produce power at the distribution voltage level. The Power Electronics (PE) interface and controls of the micro resources ensure that desired power quality and energy output is maintained independently during operation. Hence, from the utility grid perspective, the Microgrid is viewed as a single controllable unit capable of meeting local energy needs helping in reliability and security of the system.

Microgrid is another emerging paradigm in Smart Grid (SG), which is a small power grid, composed of localized medium or low level power generation, energy storage, and loads. **Because of flexible DGs, MG is considered as one of the most important feature application in SG**. In the connected mode, the MG is connected to the macrogrid, which is a main power grid with a large amount of centralized generation and loads; the connection is through the point of common coupling (PCC), which can also be disconnected for an islanded operation, when the MG operates as a small but independent power system, supporting the local load with its own local power generation.

According to S. Ashok (2014) Solar energy, radiation from the Sun capable of producing heat, causing chemical reactions, or generating electricity. The total amount of solar energy incident on Earth is vastly in excess of the world's current and anticipated energy requirements. If suitably harnessed, this highly diffused source has the potential to satisfy all future energy needs. The Sun is an extremely powerful energy source, and sunlight is by far the largest source of energy received by Earth, but its intensity at Earth's surface is actually quite low. This is essentially because of the enormous radial spreading of radiation from the distant Sun. A relatively minor additional loss is due to Earth's atmosphere and clouds, which absorb or scatter as much as 54 percent of the incoming sunlight. The sunlight that reaches the ground consists of nearly 50 percent visible light, 45 percent infrared radiation, and smaller amounts of ultraviolet and other forms of electromagnetic radiation.

3. METHODOLOGY

This is a careful step by step detail of the actualization of the research study

3.1 Data Collection

Hourly Solar Resource Data is required to determine Solar PV production during 24-hours Load Cycle. Awka which is 6.210528 and the longitude is 7.072277. The study choice software is Hybrid Optimization of Multiple Electric Renewable (HOMER). HOMER is a performance and financial model designed to facilitate decision making for researchers Involved in Renewable Energy Industry. For the study, Weather Data File for Awka is obtained through its co-ordinates (Longitude and Latitude) using HOMER Platform. Hour-by-Hour Solar Resources is used to calculate solar PV power output consisting of hourly Values of Solar Resources for some time. Monthly Solar Resource Data are selected randomly from 1985--2012 to reduce errors due to climatic uncertainty of a year.

3.2 System Sizing

Three main steps must be followed to calculate the proper size of a photovoltaic system

(i) Estimation of the required electrical energy (the load demand)

(ii) Determining the available solar energy (the resource)

(iii) Combination of energy demand and solar energy offer (the matching)

3.2.1 Estimate the required electrical energy (the demand)

Develop a load profile by recording the power consumption of the equipment as well as the estimated usage time. Then calculate the electrical energy required on a monthly basis. Consider the expected usage fluctuations due to variations between the rainy and dry season, school and vacation periods, etc. The result will be 12 energy demand values, one for each month of the year. The power consumption must include the inverter efficiency in the case of DC-AC conversion.

3.2.2: Determine the available solar energy (the resource)

Based on statistical data of solar irradiation available from meteorological institutes or websites, determine the solar energy available while paying attention to the orientation and optimal inclination of the solar panels. Solar energy data is usually stated in monthly intervals, reducing the statistical data to 12 values. This estimation is a good compromise between precision and simplicity.

3.2.3: Combine energy demand and energy offer (the matching)

The so-called "worst month" is the month with the least favorable relationship between the energy demand and the available solar energy. To determine that ratio the research will divide the energy demand by the energy resource (peak sun hours). The month with the highest resulting figure is the month with the least favorable relation between energy demand and availability. Solar energy and energy demand data from that month are what is used to size the photovoltaic system. For the table below, solar irradiation data for the Abba Town Ngikoka LGA in Awka Capital City Anambra state in Nigeria was used. Using solar energy data and energy demand data for that particular month then calculate:

(i) Necessary energy storage capacity of the battery bank

(ii) Energy generation capacity of the solar array

(iii) Size, number and type of solar panels

(iv) Required electrical characteristics of the regulator

(v) Length and diameter of cables required for electrical connections

SOC Control Algorithm Scenario.

Check the battery SOS

Check the main supply EEDC

Check the solar irradiance

Check the diesel in the generator

If the EEDC is on them shut down, the diesel generator charge the battery and supply the load.

If the battery is fully charged 100%, switch off the charging system, and then if EEDC goes off, check the state of charge of the battery.

If the battery state of charge is 100%, then switch the load to the battery.

Check the solar irradiance if the battery is charging, switch load to the solar PhV and charge battery.

If there is no solar irradiance, check the battery state of charge if charging. If it is below 30%, switch to the generator if the generator is on ensure that the battery is charging.

If the battery is full then switch off the generator and switch to battery. Ensure that the battery state of charge don't decrease below 30% if the time is 4:00pm switch off all the major load

The algorithm is designed based on the SOC and variations between the solar panel generation and the load. The system can operate to charge or discharge the batteries and the algorithm's objective is to keep the SOC consistently in the 30% to 80% charge range to ensure that the batteries do not reach extremely high or low ranges. The algorithm will monitor the SOC. If the SOC passes either the upper or lower limit, the power supplied by the main grid will be adjusted to ensure that SOC stays within the established ranges. The logic of the algorithm is to check the SOC every two hours and adjust the system accordingly. The following actions of adjustments are taken based on the detected conditions:

Decrease the power grid by 30% if: SOC is between 80% - 90%; and the power grid is greater than 200 w.

Decrease the power grid by 30% and shift it down by 2,000 if: of SOC is between 80% - 90%; and the power grid is less than 200 w.

Decrease the power grid by 20% if: SOC is between 80% - 90%. Leave the power grid as it is if:

SOC is between 30% - 80%.

Increase the power grid by 20% if: of SOC is between 20% - 30%

Increase the power grid by 30% if: of SOC is between 20%- 30%; and the power grid is greater than 200 w.

5Increase the power grid by 30% and shift it up by 2,000 if: SOC is between 15% - 25; and

The power grid is less than 200 w.

Decrease the power grid 40% and shift it down by 2,000 if: SOC is greater than 90%.

Increase the power grid by 30% and shift it up by 2,000 if: SOC is less than 20%.

MICROGRID SPECIFICATIONS

The microgrid under consideration is a 3-phase Alternating Current (AC) microgrid. This means that the generated power is distributed in the AC form. The distribution voltage level is 220v-240v while the frequency is 50Hz. The microgrid can operate in both isolated and utility grid-connected mode.

3.3.1 SIZING THE BATTERY BANK

When sizing a battery bank in Nigeria, the following should be taken into account, Batteries should discharge no more than 50% of their rated capacity each discharge. Depth of Discharge (D.O.D = 50%), assuming a deep cycle or "solar" battery is used.

Total number of days of autonomy should be at least one day and can increase depending on the application and the holdover time required. The more the days of autonomy the more the number of batteries needed.

The total energy required to be stored in the battery bank can be calculated using,

$$E_{battery} = \frac{E_{load} \times DA}{DOD \times EF_{battery}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.1$$

$$E_{battery} = Energy\ of\ the\ Batter \dots\dots\dots\dots\dots\dots\dots\dots 3.2$$

E_{load} = Load Energy Demand

DA = Days of autonomy

DOD = Depth of Discharge

$$EF_{battery} = Efficency\ of\ the\ battery$$

The total Battery capacity in Ampere-Hour (AH) of the battery Bank can be calculated using

$B_{capacity} = \frac{E_{battery}}{System\ Voltage} \dots\dots\dots\dots\dots\dots\dots\dots .3.3$

$B_{capacity}$

3.3.2 Sizing the Inverter the Grid and Battery Manager

When choosing an inverter, noting that the inverter performance varies according to the quantity of power requested. Over sizing an inverter not only leads to inefficient operation but also adds unnecessary costs and damages. Correct inverter sizing is important for optimal system performance. In addition, the size (or nominal output) of an inverter cannot be raised or upgraded once purchased. In the point, the inverter differs from modules and batteries, which can be added at a later time in case the system design or sizing proves to be insufficient.

The central component of the micro grid is the battery inverter. In its role as grid former and manager, it maintains the stability of the AC network and ensures that voltage and frequency remain within permissible limits. The bidirectional battery inverter and is often referred to as a combined inverter/battery charger. It takes care of storing excess energy in the battery and supplying the micro grid with power from the battery. These devices are particularly cost-effective because they perform both functions via the same power semi-conductors.

The battery inverter is equipped with both grid management and with a highly developed battery management function, which includes monitoring. Thus it is continuously updated on the exact battery charge and as system manager makes necessary ongoing decisions. When the batteries are empty and there is little generation capacity, it activates a permanently available backup energy source (diesel generator) alternatively can even switch off certain consumer loads. It also determines the optimum strategy for charging the batteries, and in so doing, increases their lifespan.

Extreme overload capability

When certain loads are switched on, high start-up currents are frequently encountered which can be well in excess of the normal operating current. In addition, some loads may require a lot of energy just for a short while creating short peaks on the load profile. As a result, when sizing a micro-grid system it is extremely important to use battery inverters with a high overload capability. This will ensure that load peaks are dealt with ease. For the design Sunny Island inverter was used.

Inverter Power = Peak or Total Power Demand X safety factor

3.3.3 SIZING THE PV ARRAYS: YIELD CALCULATIONS

The size of the solar array depends on the energy demand of all electrical consumers, the available solar irradiation at the site of installation and the performance ratio of the solar system. Whenever energy demand varies throughout the year, we choose the data from the *worst month,* determined as described above; the same applies for the available solar energy.

To calculate the solar energy availability the study used *peak sun hours*. The performance ratio for a stand-alone photovoltaic system is between (60-95) percent depending on the system efficiency being considered. The size (required power) of the solar panel array can be calculated as follows:

Divide the daily energy demand (kWh) by the performance ratio in order to get the theoretical daily energy output of the solar array (energy generated if there were no losses).

Divide the Total energy output (kWh) over the peak sun hours, as these hours indicate the length of exposure of our solar array to full sunlight (1,000 W/m²).

The result is the array size in KWP.

Total Energy output of PV array = $\frac{daily\ energy\ demand}{System\ Efficiency\ or\ performance\ ratio}$ 3.4

Required Power of Solar Array = $\frac{\text{Theoretical Energy output of PV array}}{P.S.H\ of\ worse\ Month}$ 3.5

Case I: Block A

Loads	Power (watt)	Quantity	Hours	Total Power (watt)	Energy (watt.h)	Power of Loads (watt)	Total Energy (watt.h)
Standing Fan	**150**	**12**	**9**	**1800**	**16200**		
Ceiling Fan	**65**	**39**	**9**	**2535**	**22815**		
Table Fan	**45**	**22**	**9**	**990**	**8910**		
Split Unit Air-Conditioner	**1250**	**23**	**5**	**28750**	**143750**		
Box Unit Air-Conditioner	**830**	**4**	**6**	**3320**	**19920**		
LED Television	**40**	**13**	**9**	**520**	**4680**		
CRT Television	**200**	**5**	**9**	**1000**	**9000**		
Security Light	**12**	**15**	**12**	**180**	**2160**		
Refrigerator	**220**	**11**	**4**	**2420**	**9680**		
Printers	**850**	**13**	**3**	**11050**	**33150**		
Desktop Printers	**250**	**5**	**3**	**1250**	**3750**		
Scanners	**35**	**4**	**1**	**140**	**140**		
Photocopier	**850**	**7**	**3**	**5950**	**17850**	72070	363060
Desktop PC	**120**	**22**	**9**	**2640**	**23760**		
Laptop PC	**80**	**47**	**4**	**3760**	**15040**		
Ceiling Rose	**5**	**63**	**9**	**315**	**2835**		
Bulb Testing Table	**150**	**4**	**9**	**600**	**5400**		
Variac	**400**	**1**	**1**	**400**	**400**		
Soldering Iron	**100**	**17**	**8**	**1700**	**13600**		
Radio/CD player	**75**	**4**	**8**	**300**	**2400**		
Projector	**270**	**2**	**4**	**540**	**2160**		
Shredder	**230**	**2**	**1**	**460**	**460**		
Blower	**250**	**3**	**2**	**750**	**1500**		
Water Dispenser	**100**	**7**	**5**	**700**	**3500**		

3.4.1 Size the battery Bank for block A

Total Power -------------------------------------72070W

Load Energy Demand-------------------------363060Wh

System Voltage --------------------------------48V

Days of autonomy ------------------------------1-day

Depth of Discharge-----------------------------50%

Efficiency of Battery---------------------------90%

Parameters	batteries
$V_{battery}$	**2**
AD	**1**
DOD	**0.5**
V_{bus}	**48**
Efficiency	**0.9**
Total AH	**16808**
battery AH	**3500**
N.(parallel branches)	**5**
N.(batteries/ branches)	**24**
N.(batteries)	**120**

$$E_{battery} = \frac{E_{load} \times DA}{DOD \times Ebatt} = \frac{363060\ Wh \times 1}{0.5 \times 0.9} = 806800Wh$$

$$B_{capacity} = \frac{Ebattery}{System\ Voltage} = \frac{806800Wh}{48V} = 16808Ah$$

Chosen Battery: 3500Ah/2V Hoppecke OPZV Solar Power

$$Number\ of\ banks = \frac{16808Ah}{3500Ah} = 4.8 = 5 - banks$$

Since the system voltage is 48V, the required number of batteries per bank is:

Total number of Batteries in the Bank = 24 * 5 = 120 Batteries

3.6.1 Size the Inverter for Block A

Parameters	Inverter
safety factor	**1.2**
power factor	**1**
rated power	**86484**

Inverter Power = $\frac{\text{Total Power Demand} * \text{Safety Factor}}{Inverter\ Efficiency} = \frac{72070 \times 1.20}{0.958} = 90276W$

Chosen Inverter: SMA Sunny Island 8.0H >6Kw

5-Clusters of 15-Sunny Island

Size the PV Array for Block A

Solar Power = $\frac{\text{Load Energy Demand}}{P.S.H * Performance\ Ratio} = \frac{363KWh}{4.3 * 0.826} = 102.202$

Chosen solar panel: Canadian Solar 325Wp Poly crystalline

Number of 325Wp modules = $\frac{102.202KW}{0.325Wp} = 315$

Recommended Number of Panels based on the design is 324 panels.

Parameters	Panels
power	**325**
$T_{ambient}$	**40**
solar irradiation (G)	**800**
NOCT	**45**
TCP	**0.41**
T_{cell}	**65**
Number	**314**
Losses	**8.2**

Chosen String Inverter: SMA Sunny Tri-Power 20000TL> 20kW

Number of SMA Sunny Tri-Power = 6

324 – Panels to 6 – 20000TL

54 – Panels to 1 – 20000TL

18 – Panels to 1 – String

3 – Strings to 1 – 20000TL

18 – Strings to 6 – 20000TL in Total

Daily Energy Requirement (Load analysis) for block B

Case II: Block B

Total Power -------------------------------------28674W

Load Energy Demand--------------------------129966Wh

System Voltage ---------------------------------48V

Days of autonomy -------------------------------1-day

Depth of Discharge-----------------------------50%

Efficiency of Battery---------------------------90%

Loads	Power (watt)	Quantity	Hours	Total Power (watt)	Energy (watt.h)	Power of Loads (watt)	Total Energy (watt.h)
Standing Fan	**150**	**4**	**9**	**600**	**5400**		
Ceiling Fan	**65**	**7**	**9**	**455**	**4095**		
Radio/CD Player	**75**	**2**	**8**	**150**	**1200**		
Split Unit Air-Conditioner	**1250**	**3**	**5**	**3750**	**18750**		
Box Unit Air-Conditioner	**830**	**4**	**6**	**3320**	**19920**		
LED Television	**60**	**1**	**9**	**60**	**540**		
CRT Television	**145**	**2**	**9**	**290**	**2610**		
Security Light	**12**	**6**	**13**	**72**	**936**		
Refrigerator	**220**	**2**	**4**	**440**	**1760**		
Printers	**850**	**3**	**3**	**2550**	**7650**		
Desktop Printers	**250**	**1**	**3**	**250**	**750**		
Scanners	**35**	**1**	**1**	**35**	**35**		
Photocopier	**850**	**1**	**3**	**850**	**2550**	28647	129966
Desktop PC	**120**	**3**	**9**	**360**	**3240**		
Laptop PC	**80**	**14**	**4**	**1120**	**4480**		
Ceiling Rose	**5**	**19**	**10**	**95**	**950**		
Blower	**250**	**1**	**2**	**250**	**500**		
Water Dispenser	**100**	**1**	**5**	**100**	**500**		
Soldering Iron	**100**	**4**	**9**	**400**	**3600**		
Electric Welding Machine	**2500**	**2**	**5**	**5000**	**25000**		
CNC Machine	**3000**	**1**	**3**	**3000**	**9000**		
Lathe Machine	**2500**	**1**	**3**	**2500**	**7500**		
Drilling Machine	**1000**	**2**	**3**	**2000**	**6000**		
Electric Milling Machine	**1000**	**1**	**3**	**1000**	**3000**		

Size the battery Bank for block B

Parameters	Batteries
$V_{battery}$	**2**
AD	**1**
DOD	**0.5**
V_{bus}	**48**
Efficiency	**0.9**
Total AH	**6016**
battery AH	**3500**
N.(parallel branches)	**2**
N.(batteries/ branches)	**24**
N.(batteries)	**48**

$E_{battery} = \frac{Eload \times Taut}{DOD \times Ebatt} = \frac{129966Wh \times 1}{0.5 \times 0.9} = 288813\text{Wh}$

$B_{capacity} = \frac{Ebattery}{System\ Voltage} = \frac{288813Wh}{48V} = 6017\text{Ah}$

Chosen Battery: 3500Ah/2V Hoppecke OPZV Solar Power

Number of Banks = $\frac{6017Ah}{3500Ah} = 1.7 = 2\ bank$

Since the system voltage is 48V, the required number of batteries per bank is:

$\frac{48V}{2V}$ = 24 batteries

Total number of Batteries in the Bank = 24 * 2 = 48 Batteries

Size the Inverter and Controller for Block B

Parameters	Inverter
safety factor	**1.2**
power factor	**1**
rated power	**34376.4**

Inverter Power = $\frac{\text{Total Power Demand} * \text{Safety Factor}}{Inverter\ Efficiency}$

$= \frac{28674\text{W}*1.20}{0.958}$ = 35917W ≈36kW

Chosen Inverter: SMA Sunny Island 8.0H >6kW

2-Clusters of 6-Sunny Island

Solar Power = $\frac{\text{Load Energy Demand}}{P.S.H*Performance\ Ratio} = \frac{130kwh}{4.3\times0.826} = 36.601KW$

Size the PV Array for Block B

Parameters	panels
power	**325**
$T_{ambient}$	**40**
solar irradiation (G)	**800**
NOCT	**45**
TCP	**0.41**
T_{cell}	**65**
Number	**112**
Losses	**8.2**

Chosen solar panel: Canadian Solar 325Wp Poly crystalline

Number of 325Wp modules = $\frac{36.601KW}{0.325Wp} = 113 \approx 114$

Recommended Number of Panels based on the design is 114 panels.

Chosen String Inverter: SMA Sunny Tri-Power 15000TL> 15kW

Number of SMA Sunny Tri-Power = 3

114 – Panels to 3 – 15000TL

38 – Panels to 1 – 15000TL

19 – Panels to 1 – String

2 – Strings to 1 – 15000TL

6 – Strings to 3 – 15000TL in Total

Case III: Block C

Loads	Power (watt)	Quantity	Hours	Total Power (watt)	Energy (watt.h)	Power of Loads (watt)	Total Energy (watt.h)
Standing Fan	**150**	**3**	**9**	**450**	**4050**	23730	132290
Ceiling Fan	**65**	**16**	**8**	**1040**	**8320**		
Radio/CD Player	**75**	**4**	**8**	**300**	**2400**		
Split Unit Air-Conditioner	**830**	**12**	**5**	**9960**	**49800**		
LED Television	**40**	**2**	**4**	**80**	**320**		
Security Light	**12**	**10**	**12**	**120**	**1440**		
Refrigerator	**220**	**3**	**5**	**660**	**3300**		
Printers	**850**	**4**	**5**	**3400**	**17000**		
Desktop Printers	**250**	**2**	**3**	**500**	**1500**		
Scanners	**35**	**2**	**1**	**70**	**70**		
Photocopier	**850**	**1**	**3**	**850**	**2550**		
Desktop PC	**120**	**30**	**8**	**3600**	**28800**		
Laptop PC	**80**	**23**	**4**	**1840**	**7360**		
Ceiling Rose	**5**	**22**	**8**	**110**	**880**		
Blower	**250**	**1**	**2**	**250**	**500**		
Soldering Iron	**100**	**5**	**8**	**500**	**4000**		

Total Power -------------------------------------23730W

Load Energy Demand-------------------------132290Wh

System Voltage --------------------------------48V

Days of autonomy ------------------------------1-day

Depth of Discharge-----------------------------50%

Efficiency of Battery---------------------------90%

Parameters	Batteries
$V_{battery}$	**2**
AD	**1**
DOD	**0.5u**
V_{bus}	**48**
Efficiency	**0.9**
Total AH	**6124**
battery AH	**3500**

N.(parallel branches)	**2**
N.(batteries/ branches)	**24**
N.(batteries)	**48**

$E_{battery} = \frac{Eload \times Taut}{DOD \times Ebatt} = \frac{132290Wh \times 1}{0.5 \times 0.9}$ = 293978Wh

$B_{capacity} = \frac{Ebattery}{System\ Voltage} = \frac{293978Wh}{48V}$ =6125Ah

Chosen Battery: 3500Ah/2V Hoppecke OPZV Solar Power

Number of Banks = $\frac{6125Ah}{3500Ah}$ = 1.75 = 2-Banks

Since the system voltage is 48V, the required number of batteries per bank is:

$\frac{48V}{2V}$ = 24 batteries

Total number of Batteries in the Bank = 24 * 2 = 48 Batteries

Parameters	Inverter
safety factor	**1.2**
power factor	**1**
rated power	**28476**

Inverter Power = $\frac{\text{Total Power Demand} * \text{Safety Factor}}{Inverter\ Efficiency}$

= $\frac{23730W * 1.20}{0.958}$ = 29724W ≈30kW

Chosen Inverter: SMA Sunny Island 6.0H >5kW

2-Clusters of 6-Sunny Island

Solar Power = $\frac{\text{Load Energy Demand}}{P.S.H * Performance\ Ratio}$

= $\frac{133KWh}{4.3 * 0.826}$ = 37.446KW

Parameters	Panels
power	**325**
$T_{ambient}$	**40**
solar irradiation (G)	**800**
NOCT	**45**
TCP	**0.41**
T_{cell}	**65**
Number	**114**
Losses	**8.2**

Chosen solar panel: Canadian Solar 325Wp Poly crystalline

Number of 325Wp modules = $\frac{37.446KW}{0.325Wp}$ =115 ≈ 114 Panels

Recommended Number of Panels based on the design is 114.

Chosen String Inverter: SMA Sunny Tri-Power 15000TL> 15kW

Number of SMA Sunny Tri-Power = 3

114 – Panels to 3 – 15000TL

38 – Panels to 1 – 15000TL

19 – Panels to 1 – String

2 – Strings to 1 – 15000TL

6 – Strings to 3 – 15000TL in Total

General PV Structure Designing Steps

1. Getting the Location Coordinate

- Latitude = Φ
- Longitude

2. Getting the tilt angle (β)

- Declination Angle (δ)

$\Delta=23.5\sin\left(\frac{360}{365}(284+d)\right)$

- Elevation Angle (α)

A = 90 – Φ + δ

- Module Tilted Angle (β)

B = 90 – α

3. Getting Peak Sun Hours value (S_M)

- For each month
- S_H is the Global Solar Irradiation from NASA database
- β is constant throughout the entire month
- δ at 21-day of each month
- α depends on the declination angle
- S_m depends on the beta, S_H and alpha

1. Getting the Location Coordinate

- Latitude = 45
- Longitude = -75

2. Getting the tilt angle (β)

The worst month: 21 Dec d=355

- Declination Angle (δ)

$\Delta=23.5\sin\left(\frac{360}{365}(284+d)\right)$

$=23.5\sin\left(\frac{360}{365}(284+355)\right)$

=-23.499 =-23.5

- Elevation Angle (α)

A = 90 – Φ + δ

= 90 – 45 – 23.5

= 21.5

- Module Tilted Angle (β)

B = 90 – α = 90 – 21. = 68.5

3. Getting Peak Sun Hours value (S_M)

- for each month

S_H (45N-75W)	1.60	2.57	3.70	4.54	5.18	5.65	5.65	4.92	3.75	2.42	1.50	1.30

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
S_H	1.60	2.57	3.70	4.54	5.18	5.65	5.65	4.92	3.75	2.42	1.50	1.30
B		←					75					→
Δ	-20.1	-11.3	-0.40	11.6	20.2	23.5	20.5	11.8	-0.20	-11.8	-20.5	-23.5

A	24.9	33.7	44.6	56.6	65.2	68.5	65.5	56.8	44.8	33.2	24.5	21.5
S_M	3.74	4.39	4.58	4.07	3.65	3.61	3.95	4.38	4.62	4.20	3.57	3.52
$S_{M(min)}$	3.52											
$S_{M(max)}$	4.62											
P.S.H	4.023											

Dimensions Formula

Panels Spacing = $\frac{\text{Sin}\,(180-\delta+\beta)*PW}{Sin\;\delta}$

Where;

δ = Declination Angle at 21 December

β = Isolation Angle or Tilted Angle

PW = Panel Width

T-Cell Formula

$T_{cell} = T_{air} + \frac{\text{NOCT}-20}{80}\text{S}$

Or

$T_{cell} = T_{ambient} + G\,\frac{\text{NOCT}-20}{800}$

Where;

T_{cell} = Temperature of the Cell

$T_{ambient}$= Ambient temperation of the Cell

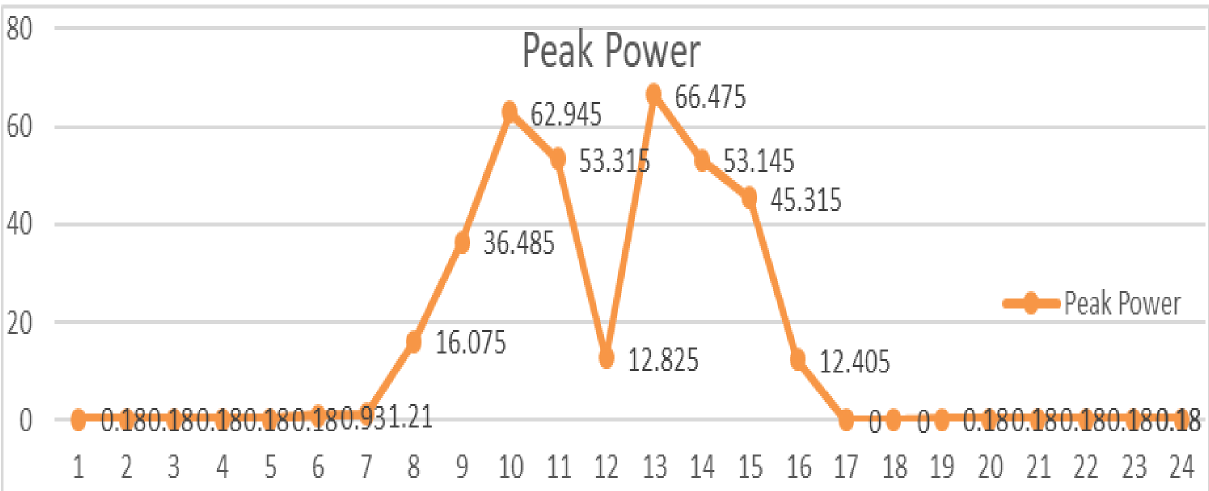
NOCT = Nominal Operating Cell Temperature

G = Solar Irradiance

4. RESULTS AND ANALYSIS

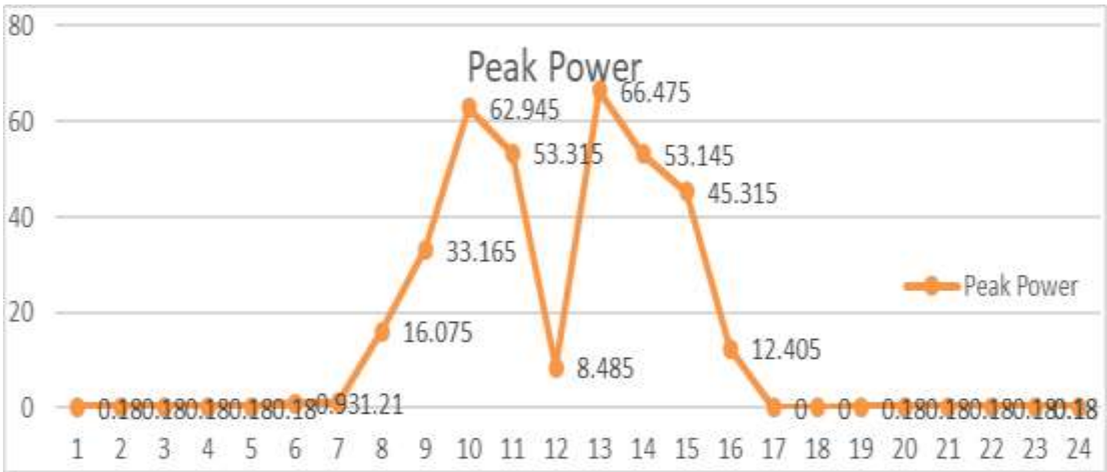
It could be deduced from the developed algorithm result, it was observed that the load was constantly being served from the DERs in the system. The load consumption of the various buildings in ELDI where plotted for a period of twenty four hours and twenty eight days of the month. The average daily power consumption for each month was taken into consideration and the daily power consumption was plotted. The various changes in weather as regards to west Africa was taken into consideration.

January load analysis for block A



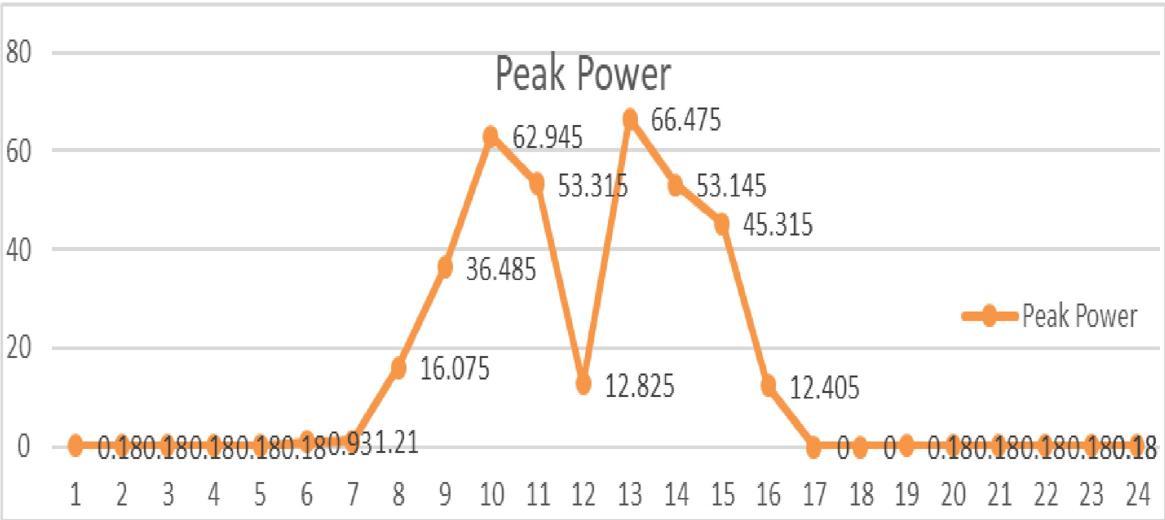
The average peak power consumption of block A for the month of January 66.475watts.

February load analysis for block A



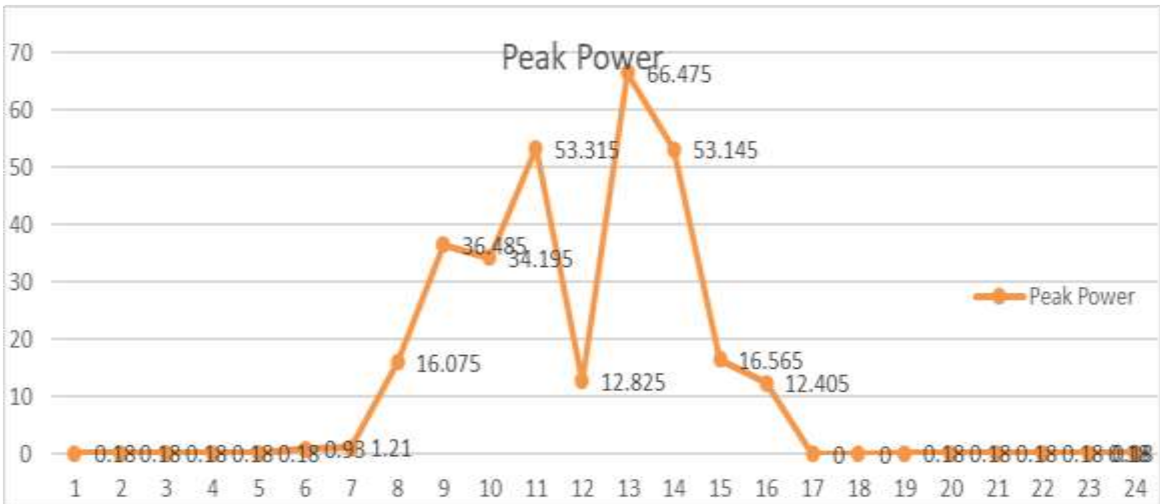
The average peak power consumption of block A for the month of February 66.475watts.

March load analysis for block A



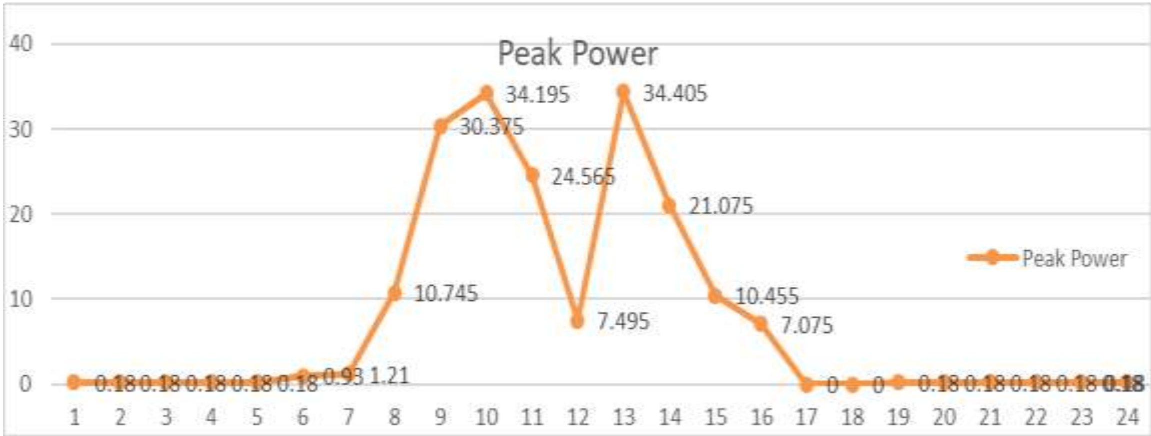
The average peak power consumption of block A for the month of March 66.475watts.

April load analysis for block A



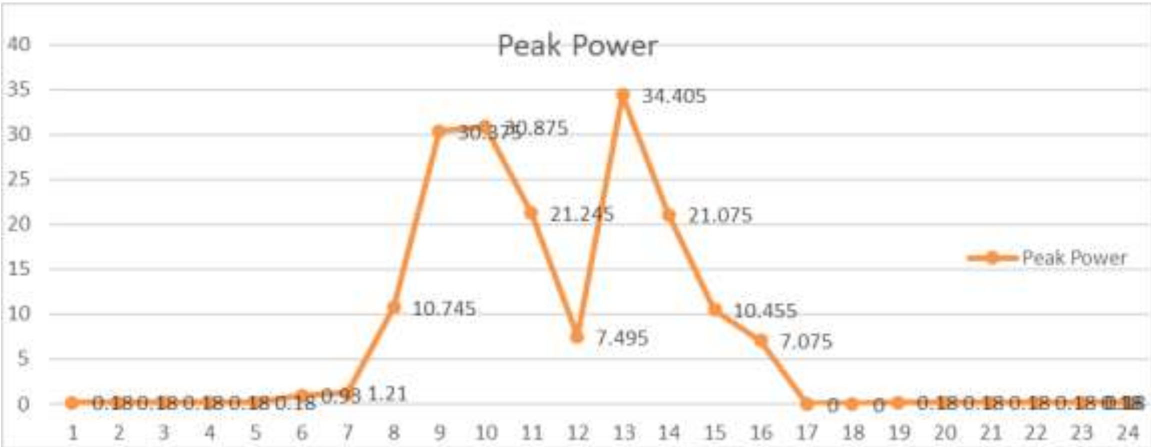
The average peak power consumption of block A for the month of April is 66.475watts

May load analysis for block A



The average peak power consumption of block A for the month May 34.195watts.

June load analysis for block A

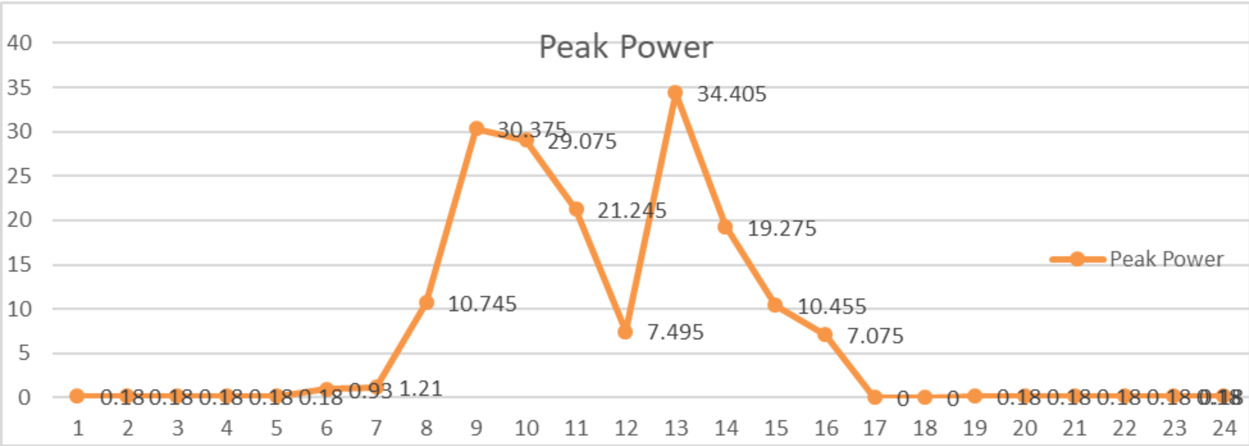


The average peak power consumption of block A for the month of June 34.405watts.

July load analysis for block A

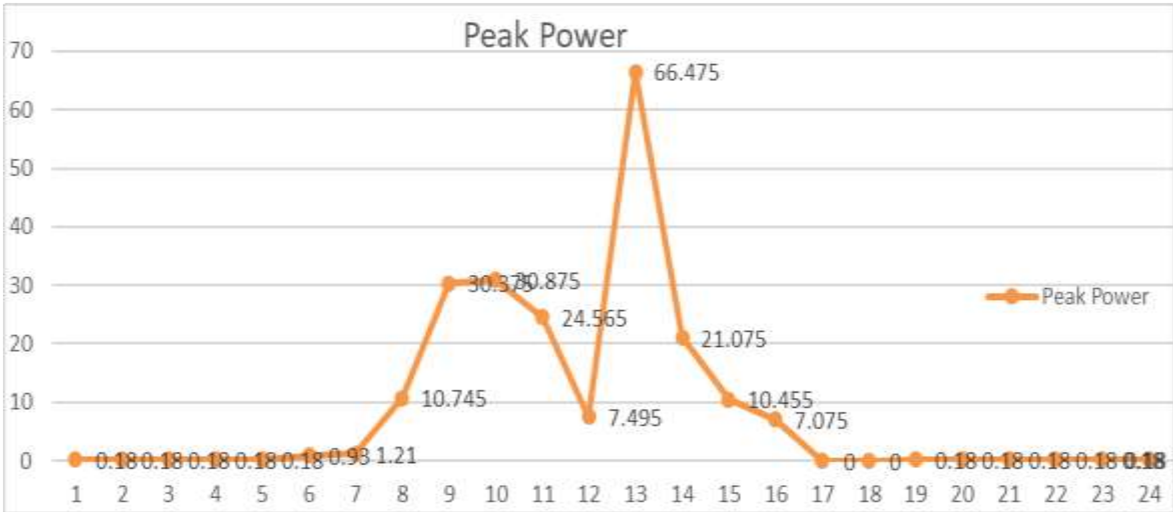
The average peak power consumption of block A for the month of July 34.405watts.

August load analysis for block A



The average peak power consumption of block A for the month of January 34.405watts.

September load analysis for block A

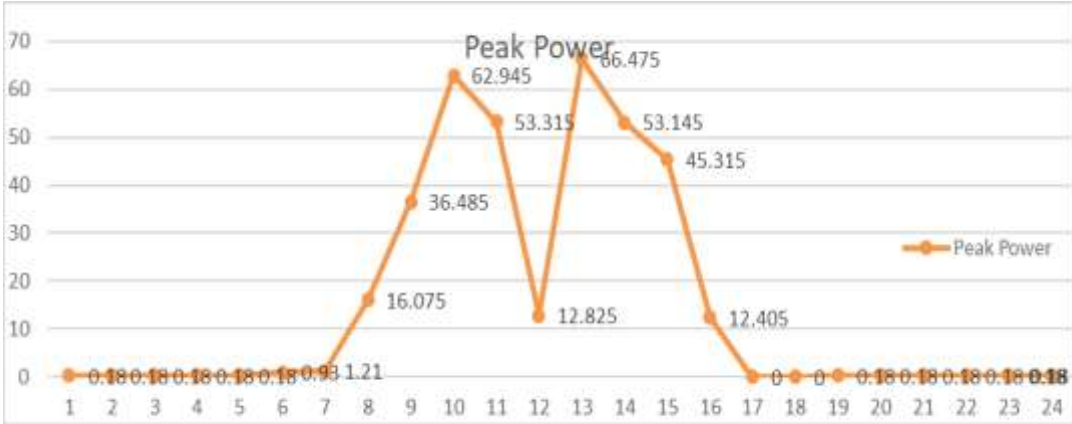


The average peak power consumption of block A for the month of September 66.475watts.

October load analysis for block A

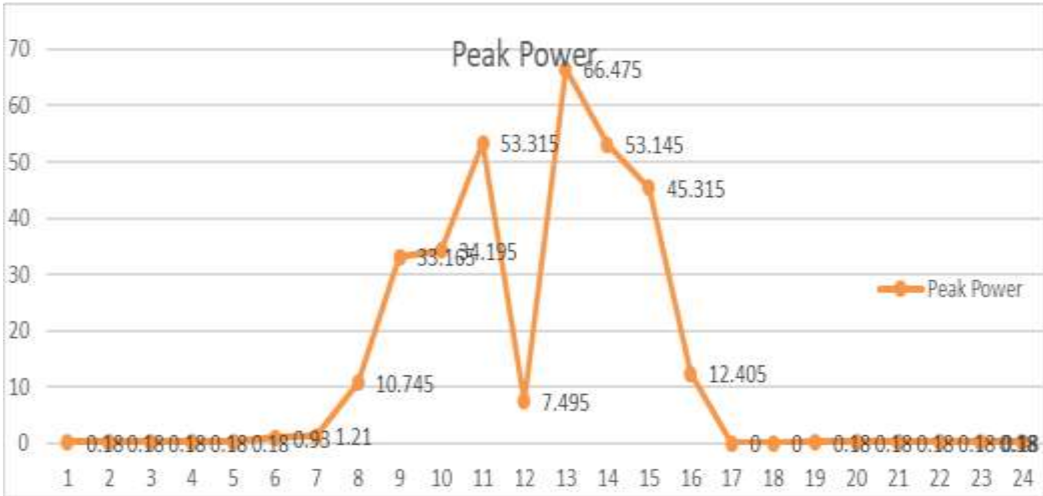
The average peak power consumption of block A for the month of October 66.475watts.

November load analysis for block A



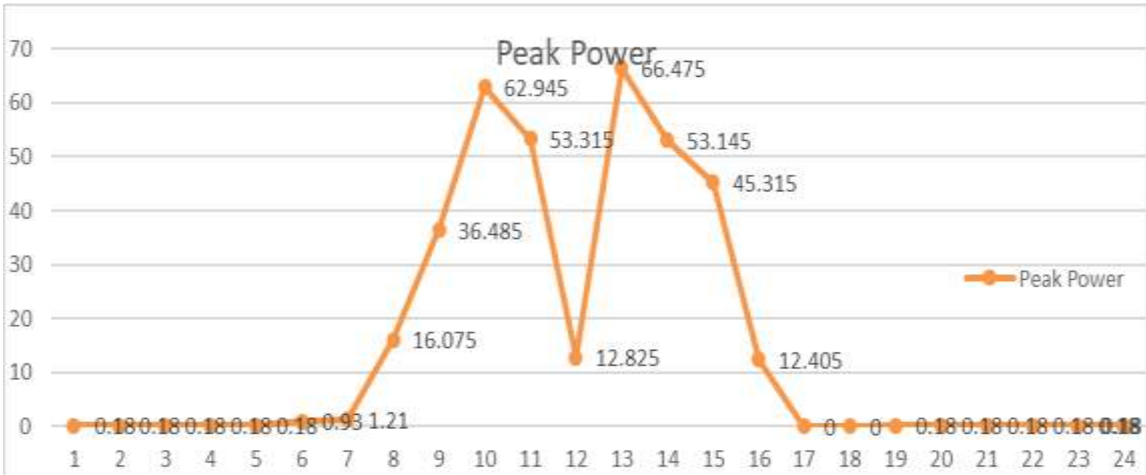
The average peak power consumption of block A for the month of November 66.475watts.

December load analysis for block A



The average peak power consumption of block A for the month of December is 66.475watts.

Block A Load profile during Dry Season



The average peak power consumption of block A for the Dry Season is 66.475watts.

Block A Load profile during Raining Season

The average peak power consumption of block A for the Rainy Season is 66.475watts.

5. CONCLUSION AND RECOMMENDATION

5.1 Contribution to the Body of Knowledge

This work made the following contribution to the body of knowledge.

a) A detailed load analysis was developed and integrated proactive detailed calculation in solar analysis and design also made.

5.2 Problems Encountered

a) Economy. The problem of poverty has dealt incisively in solar power systems. There seems to be an argument that it is quite cheaper to run generators than to install solar systems

b) Orientation. People lack or are inadequately informed about solar systems especially as regards to sizing load analysis. Somebody wants to install a solar system with just two batteries of 200amps and inverter of 05kva. He then expects it to power his full duplex with five air conditioners

c) Expertise. There is a lot of unemployment in Nigeria. Expertise training of the youth scan help reduce unemployment there creating a formidable knowledge and expertise in solar system.

d) Government Policy. Nigeria must include solar microgrid as part of rural electrification. Nigeria central grid must be decentralized this would also help more people to go into solar power generation which would in turn be injected into the gird hereby boasting power generation.

5.3 Recommendations

a) Solar installation in Nigeria must be done by solar experts. In solar systems we have a lot of quacks who are only knowledgeable in buying and selling.

b) b) Nigeria must make plans for companies to start manufacturing of solar panels here in the country. Companies with such plans must be given tax incentive

c) Nigeria must ban the importation of fairly used solar panels and inveretrs into the country.

d) COREN, NSE, SON and other relevant bodies like NAFDAC must ensure the quality of materials. Solar panels Inverters charge controllers must be subjected to extensive testing in other to ensure the quality and durability of the electronic items. Stamp and Seal should be developed for certified solar instructors.

e) Nigeria Government must make flexible polices as regards Electronic circuits and devices. Local content must be passionately encouraged in other that it can be harnessed.

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