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Design of a Subscription Based Community Solar Energy System for the Business Community of the "Back Gate", Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria

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Abstract: This study presents a model design of a subscription based community solar energy for the business community of the "Back gate", Alex Ekwueme Federal University Ndufu-Alike Ikwo. The business community is largely dependent on the use of fossil fuel generators due to the absence of connection to the Nigeria national electricity grid. The extensive use of the fossil fuel is not only associated with environmental pollution and global warming but its reserve is also finite, non-renewable and expensive. This study presents the use of solar energy to supply the electrical energy need of twenty (20) business premises at the study location. The design was carried out according to the daily electrical load profile of the community, taking into consideration the solar irradiation data of the location, the geographical location and the weather condition. The sizing of each of the system components and the economic analysis of the system in terms of the life cycle cost and electricity unit cost was also taken into consideration. The subscription based community solar with smart meter control gives energy access at reduce cost, the total unit of consumption, unit balance and other energy status per time. The unit cost of electricity using the model design was determined as #0.078/kWh which is cheaper with real time energy costing via a smart meter thereby encouraging the usage of the energy system as an efficient system with enhanced energy accessibility, real time energy services, climate change adaption by reduction of greenhouse gas emission, clean energy development plans/implementation within the community and an investment platform for would-be investors and philanthropist.

Key words: Community solar energy, charge controller, inverter, battery, Smart meter, Photovoltaic array

1.0. Introduction

Ndufu-Alike community in Ikwo local government area of Ebonyi state, Nigeria is largely dependent on fossil fuel generators for their electrical energy need due to unavailability or inadequacy of electric power supply within the community. Behind the Alex Ekwueme Federal University Ndufu-Alike (Figures.1 and 2) is a business community at the location popularly called the "back gate" which are largely involved in typesetting, printing, photocopying, binding, scanning and lamination of students assignments, projects and other documents. Their extensive use of fossil fuel is not only associated with environmental pollution and global warming but its reserve is also finite and non-renewable (Sagar, 2005; Fashina, 2019). The imbalance between energy demand and supply in electrical energy has necessitated the proliferation of these generators (especially "I better pass my neighbor generators" as used and called in Nigeria) which are dependent on fossil fuel, gasoline and diesel for operation. This alarming mass dependence on it exposes communities or persons around the location to the emission of greenhouse gases and air pollution.

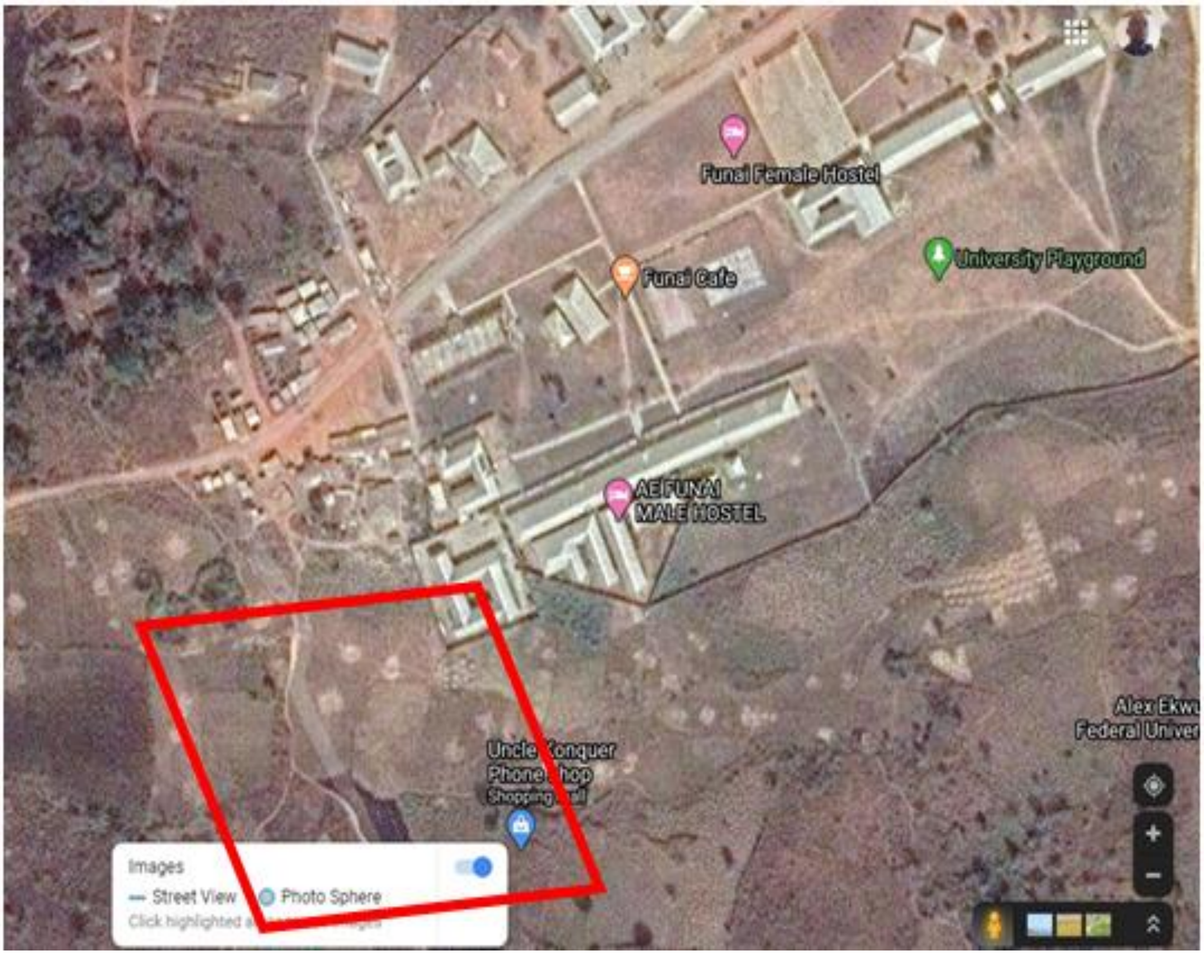

Figure 1: Google Map showing the study location described by the red polygon

Among the existing clean and renewable energy sources, solar energy is one of the most promising as the other sources are limited in their applications due to geographical conditioning, among other factors. The study location has evidently proven to be viable for solar energy installation as seen from the solar irradiation data of the location and the recent commissioning of a 2.8MW off grid solar hybrid power plant at Alex Ekwueme Federal University Ndufu-Alike Ikwo (FUNAI), Ebonyi State on August 2, 2019 by the Federal government of Nigeria (https://rea.gov.ng/osinbajo-inaugurates-2-8mw-solar-power-plant-funai/) which is only limited to the University campus. Solar energy technology also called the photovoltaic (PV) system has been characterized as eco-friendly, abundantly available with no geographical restrictions and is based on the photovoltaic phenomenon (Saleh *et al.*, 2015).

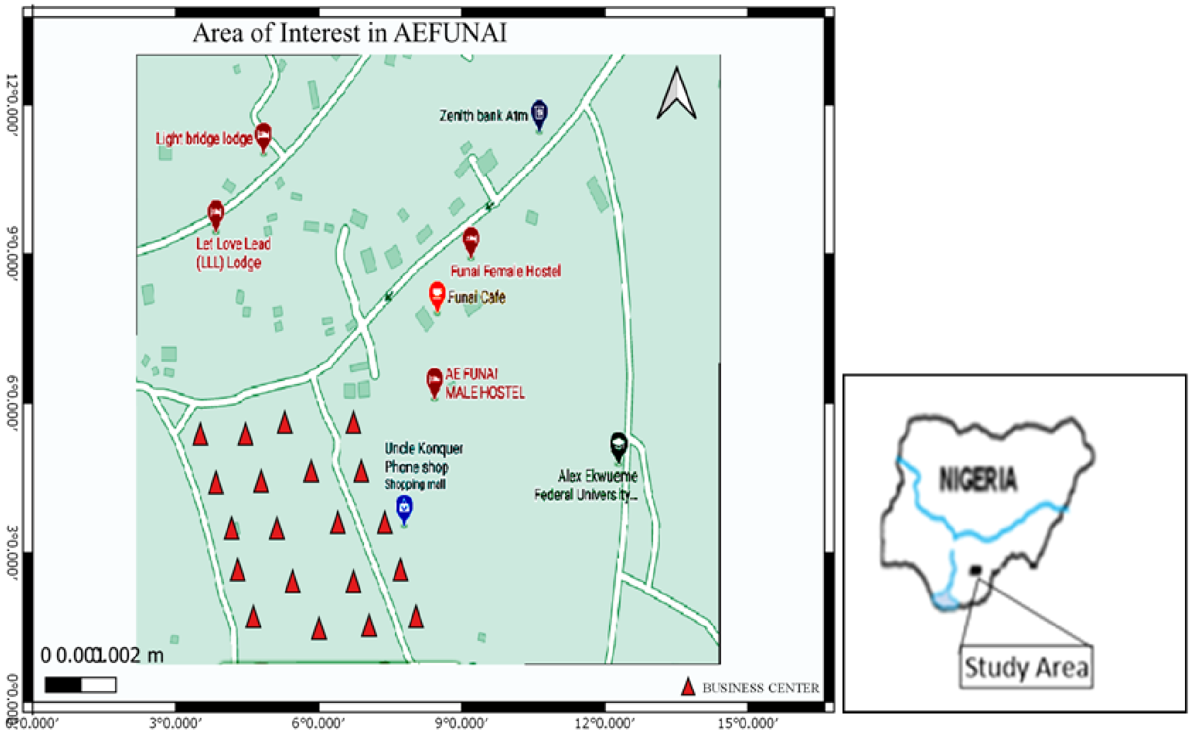

Figure 2: Location map of AEFUNAI showing 20 selected business centres at the "back gate"

The PV system consists of an arrangement of solar arrays which encompasses the ensemble of solar panel to absorb and convert sunlight into electricity, a solar inverter to change the electric current from direct current (DC) to alternating current (AC), installations cables, batteries for storage of surplus energy for use at night and the solar charge controller also called an integrated battery solution for providing regulated DC output as well as monitoring of battery voltage among other components of the systems (Guda and Aliyu, 2015).

PV system ranges from roof top mounted, ground mounted and wall mounted to building integrated system with capacities from a few to several thousand watts to large power stations megawatts generation. PV systems have no moving parts and such do not produce noise. It is highly module in nature, reliable, pollution free, requires little or no maintenance cost and can be easily installed at a choice location. Though the output from PV generator is zero at night, the incorporation of battery ensures that the PV generator charges the battery during the day while the battery serves as the power source at night so as to mitigate the issue of PV intermittency hence enhancing reliability (Hasan *et al*., 2016).

Many electricity end users are not able to implement individual solar energy installations due to financial or technical reasons. Although there are reports on PV system design, these reports are limited to standalone PV system for a single residential building (Abu-Jasser, 2010; Guda and Aliyu, 2015; Hasan *et al.*, 2016), local government offices (Johnson and Ogunseye, 2017), Laboratories (Saleh *et al.*, 2015; Mahmood, 2019) and Hybrid off-grid solar system (Chukwuemeka and Felix, 2018). The concept of community solar for energy accessibility is rarely reported. A community solar energy system is a mini solar plant whose electricity is shared by more than one property, building, shop or business premises. It is often ground mounted solar photovoltaic energy arrays which are smaller in installation size and power output than the utility scale solar PV systems but significantly larger than most individual roof top installations (Markvart *et al.,* 2006). The primary purpose of community solar is to allow members of a community the opportunity to share the benefits of solar power even if they cannot or prefer not to install solar panels on their property. Homes and businesses, even if shaded by trees, receive a bill credit as if the panels were on their own roof using "virtual net metering" or smart energy meter which cost less than they would ordinarily pay to their utility provider. The solar garden allows people to go solar even if they do not own property or roof top, thereby making it an attractive option for renters or those who live in shared building. The community solar has two modes of participation namely the ownership and the subscription mode/model of participation (Joshi and Yenneti, 2020).

The ownership model allows participants to own some of the panels or a share in the solar energy installation project such that they benefit from all the power produced by their share of the solar panels or in the installed solar energy system. In such a model, an individual can purchase enough share to meet the individual's annual or monthly energy requirement or electricity use such that a matching proportion of the installed system's actual output is credited through the individual's electricity bill or through some other form of arrangement with the solar energy system or project administrator.

The subscription model which is the model adopted in this study allows participants to become subscribers and pay a lower price for the electricity sourced from the community solar farm without owning the panels or paying for the installation. A third party or a utility company could develop and own the project and then extend an opportunity to the public to participate using smart meter so as to enhance real time energy consumption and costing (Chan *et al.*, 2017). A pictorial diagram of a typical solar garden and array concept is shown in figure 3, figure 4 shows an offsite shared solar while figure 5 shows how a solar garden works.

Figure 3: A solar garden array (https://www.sunshinecoast.evolutionsolar.com.au)

Figure 4: Community solar energy concept (https://www.energy.gov/eere/solar/community-and-shared-solar)

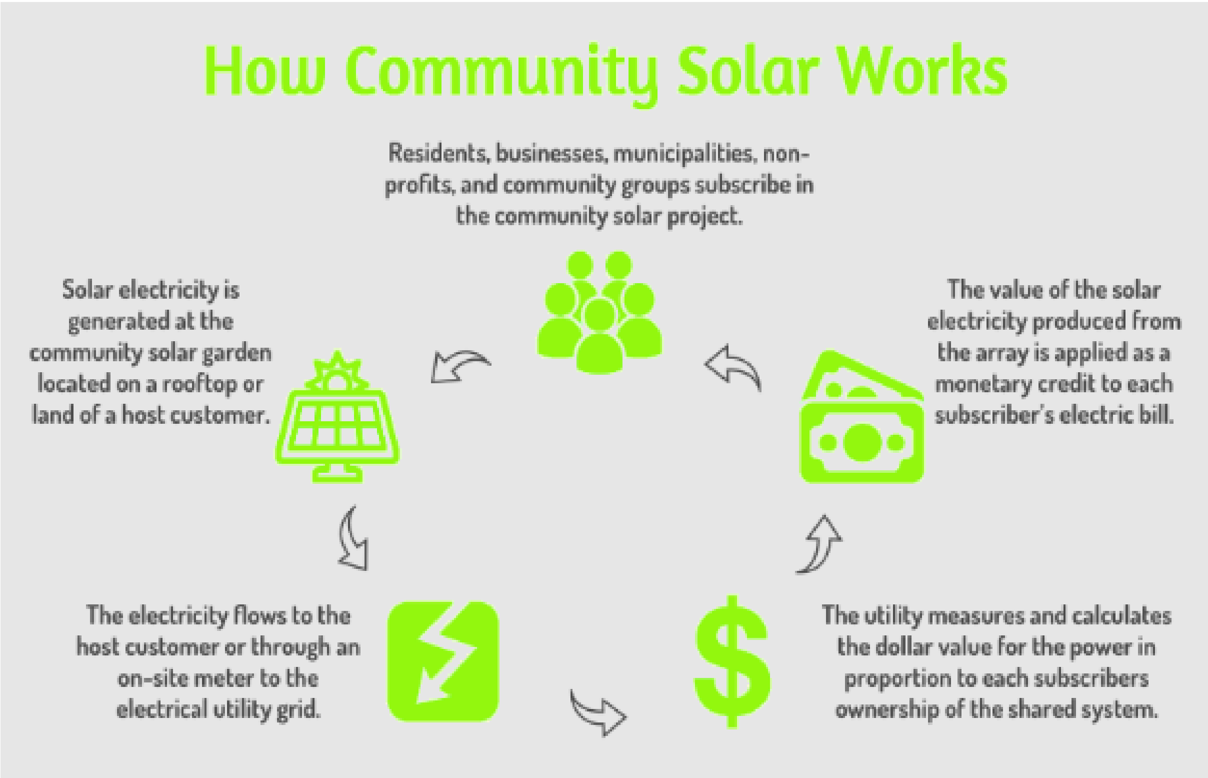

Figure 5: How solar garden works (https://www.sunshinecoast.evolutionsolar.com.au)

This study proposes a model which can be built upon for enhancing energy accessibility in a poor energy state of Nigeria, energy investment, renewable energy policy platform, climate change adaptation by adoption of renewable energy over fossil fuel generators and real time energy costing using a community solar concept with smart energy metering for the “back gate” small scale business community of Alex Ekwueme Federal University Ndufu-Alike, Ikwo-Ebonyi state as a prototype/model. The study also shows that although, the initial investment/installation cost of solar energy system might be high its long time gain is enormous as given by the economic analysis thereby encouraging the participation of individuals, cooperate bodies and possible integration of the solar energy system into the Nigeria National grid given its outlined potentials as a way out to the nation’s energy crisis.

2.0. Solar garden design Considerations/sizing

A basic block diagram of the solar energy generation is shown in figure 6 consisting of solar PV array, Charge controller, inverter, Battery and AC/DC loads.

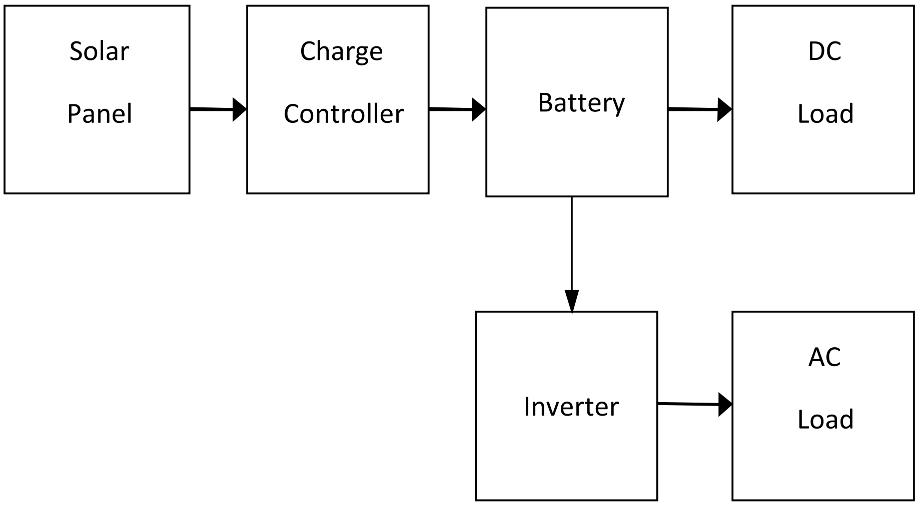

Figure 6: Basic block diagram for a solar system

The PV system design is essential for determining the voltage, current and power capacity of the system components for participating residential load profile balance/requirement. A local survey and energy auditing was carried out to determine the basic gadgets/appliances and their power consumption used by the business premises. It was discovered that the business premises largely use Photocopying machines, Laminating machines, Scanning machines, Laptops/Desktops, electric fans and phone charging points. A total of twenty shops (20) majorly involved in these appliances usage were selected. The basic power consumption of each of these appliances was selected after which the average of the range of power consumption by the appliances and average number of each of the items in a given shop was taken for the calculation of the energy profile and other system considerations. A usage period of 7:30am to 6:30 pm (11 hours) West African time was considered since it is the active period of the students’ availability on campus for academic activities by which the students also visit the business community. The average sun hours per day was estimated as five (5) hours. The loads are the power consuming units of the PV system which could be resistive or inductive loads. Each of the block items are discussed below taking into consideration energy demand, materials required/availability, cost consideration and efficiency factors.

2.1. Consumer energy demand (CED)/Residential load profile

The consumer energy demand (CED) which is the sum total of the energy demand by the chosen loads was calculated to determine the choice of other solar system design parameters taking into cognisance the duration of usage of loads, given the power requirement of the load as shown in table 1.The consumer energy demand for a given load which was used to obtain table 1 is expressed by equation 1 (Okwu *et al*., 2017):

$$CED = Q \times P \times T \quad (1)$$

Where Q= Quantity of the load, T= Duration of usage of the load per day in hour (H) and P= Power rating of the load.

Table 1: Consumer energy demand

S/N	Load	Quantity Q	Power rating per unit P (Watt)	Total power rating (W)	Usage/Duration T (H) per day	CED (WH)
1	Photocopier	20	725	14500	6	87000
2	Laminating Machine	20	30	600	3	1800
3	Scanner	20	12	240	3	720
4	Printer	20	523	10460	6	62760
5	Laptop	20	83	1660	11	18260
6	Desktop	60	310	18600	11	204600
7	Electric Fan	20	80	1600	11	17600
8	Lighting bulb (Compact fluorescent lamp)	20	10	200	1	200
9	Cell phone charging	80	2.5	200	11	2200
Total consumer energy demand (CED)						=395140WH

Source: Survey of selected equipment and energy demand/audit of case study location

2.2. The Solar panel

For the community solar comprising of twenty (20) business premises as a model, the panel requirement was based on the total consumer energy demand (CED) as calculated in table 1. Although different types of solar panels exist with varying efficiency, for design involving interconnections of solar panels, panels of the same make or type is of optimum importance for required efficiency. For the model design in this study a choice of monocrystalline solar panels with a rated efficiency of 80 % was made. The solar panel was selected taking into cognisance factors which affect the efficiency of solar panel such as resistance, reflection, recombination and non-usable energy since only 20% of the about 1000W, 1 $m^2$of solar energy radiated by the sun can be harnessed using solar panel which can be mounted on a roof top or a chosen site with provision for free movement in between the arrays for inspection.

A solar module: AE EXTREME 320P6-72 was selected for the design/ PV array sizing with specifications of: Rated voltage of one module $(V_{rm}) = V_{mp} = 36.75V$, rated current of one module$(I_{rm}) = I_{mp} = 8.71A$, Short circuit current $(I_{sc}\ ) = 9.28\ A$,
Power rating of module $= 320W$; dc voltage of the system/system voltage $(V_{dc}) = 96V$. Other parameters for the PV array sizing are: Average sun hours per day $(T_{sh}) = 5\ Hours$
Average daily energy demand $(E_d) = 395140\ watt - hours$

The required daily average energy demand (E_{rd}) is obtained by dividing the daily average energy demand by the product of the efficiency of all the basic system components which is given by equation 2 (El Shenwy et al., 2017):

$$E_{rd} = \frac{E_d}{ŋ_b ŋ_i ŋ_c} \tag{2}$$

Where $ŋ_b$=Battery efficiency=0.90;
$ŋ_i$=Inverter efficiency=0.97
$ŋ_c$=Charge controller efficiency=0.98

$$E_{rd} = \frac{395140}{0.90 \times 0.97 \times 0.98}$$

$$E_{rd} = 461860.35kWh/day$$

The average peak power $P_{av,peak} = \frac{E_{rd}}{T_{sh}} = \frac{461860.35}{5}$

$$= 92372.07w$$

The total dc current of the system is given by equation 3 (Chukwuemeka and Felix, 2018) while equation 4 and 5 (Mahmood, 2019) gives the number of modules to be connected in series and in parallel respectively.

$$I_{dc} = \frac{P_{av,peak}}{V_{dc}} \tag{3}$$

$$= \frac{92372.07}{96} = 962.21\ A$$

Number of modules in series $N_{sm} = \frac{V_{dc}}{V_{rm}}$ (4)

$$= \frac{96}{36.75} = 2.61$$

$$\cong 3 \text{ modules}$$

Number of modules in parallel $N_{pm} = \frac{I_{dc}}{I_{rm}}$ (5)

$$= \frac{962.21}{8.71} = 110.47$$

$$\cong 110$$

Approximately three (3) modules are needed in series while one hundred and ten (110) modules are needed in parallel. The total number of modules (N_{tm}) that forms the array was determine by multiplying the number of parallel modules by the series modules to give the total required number of modules as 330 using equation 6 (Btineth and Dalahal, 2012):

$$N_{tm} = N_{sm} \times N_{pm} \tag{6}$$
$$= 3 \times 110$$
$$=330 \text{ modules}$$

The distance (D) of separation between the panel and the battery was limited to 10 m in order to reduce the voltage drop along the cable from the solar panel since the solar panels are often mounted at some distance away from the battery in order to achieve maximum energy thus causing a distance of separation.

2.3. Solar charge controller

The standard practice of sizing the charge controller is to ensure that it is able to withstand the product of the total short circuit current of the solar array. The required charge controller current (I_{rcc}) is given by equation 7 (Btineth and Dalahal, 2012) :

$$I_{rcc} = I_{sc}^{m} \times N_{pm} \times F_{safe} \tag{7}$$

The safe factor (F_{safe}) has a value of 1.25, whileI_{sc}^{m} is the short circuit current of the selected module with a value of 9.28 A. Using the number of parallel modules (N_{pm}) as 110 as calculated in equation 6:

$$I_{rcc} = I_{sc}^{m} \times N_{pm} \times F_{safe} \tag{8}$$
$$= 9.28 \times 110 \times 1.25$$
$$= 1276\ A$$

Selecting a charge controller, I-Panda MPPT Solar converter (System voltage 96V/192V/216V/240V/384V automatic recognition, Rated current: 50A; 60A; 70A; 80A) with preferred $V_{cc} = 96V\ and\ \ I_{cc} = 80A$;

Number of charge controllers $N_{cc} = \frac{I_{rcc}}{I_{cc}} = \frac{1276}{80} = 15.95$

$$\cong 16$$

As such sixteen charge controllers of 80A each will be suitable and hence were preferred for the design.

2.4. Battery, Battery connection and battery capacity calculation/Sizing

A deep cycle battery was preferred which is also the most recommended battery for a solar PV design with an advantage of many times of recharging cycles after discharge. The estimated energy storage (E_{est}) is determined using equation 9 (Hasan *et al.*, 2016);

$$E_{est} = E_d \times D_{aut} \tag{9}$$

Where E_d is the average daily energy demand of the participating business premises which was calculated as 395140 watt-hours. D_{aut} is the number of autonomous days and was taken to be 3days. Substituting into equation 9:

$$E_{st} = 395140 \times 3 = 1185420Wh$$

Selecting a deep cycle VRLA/SMF Luminous battery with specification C_b (Capacity of a single battery in Ah) = 250 Ah, V_b (Rated dc voltage of one battery) =12V and D_{disch} (Maximum depth of discharge also called depth of discharge DOD) =80%. The safe energy storage (E_{safe}) by the battery was calculated using equation 10 while the total battery capacity (C_{tb}) calculated using equation 11 (Hasan *et al*., 2016):

$$E_{safe} = \frac{E_{est}}{D_{disch}} = \frac{1185420Wh}{0.8} = 1481775Wh \tag{10}$$

The total capacity of the battery bank in ampere hours (C_{tb}) is determined by dividing the safe energy storage by the rated dc voltage of one battery V_b as follows:

$$C_{tb} = \frac{E_{safe}}{V_b} = \frac{1481775Wh}{12} = 123481.25\ Ah \tag{11}$$

The total number of batteries (N_{tb}) is obtained by dividing the total capacity of the battery bank by the capacity of one of the selected batteries and is given by equation 12:

$$N_{tb} = \frac{C_{tb}}{C_b} = \frac{123481.25Ah}{250\ Ah} = 494 \tag{12}$$

The number of batteries in series (N_{Sb}) was determined using equation 13 (Pal *et al*., 2015):

$$N_{sb} = \frac{V_{dc}}{V_b} \tag{13}$$

$$= \frac{96}{12} = 8 \text{ Batteries}$$

Number of parallel battery strings was determined using equation 14 (Abu-Jasser, 2010):

$$N_{pb} = \frac{N_{tb}}{N_{Sb}} \tag{14}$$

$$= \frac{494}{8} = 61.75$$

$$\cong 62 \text{ Batteries}$$

The required total number of batteries (N_{rtb}) was determined using equation 15 after calculating the number of batteries in series and parallel.

$$N_{rtb} = N_{Sb} \times N_{pb} \tag{15}$$

$$N_{rtb} = 8 \times 62 = 496 \text{ Batteries}$$

Four hundred and ninety six, 12V batteries with capacities of 250 Ah each is preferred to give the total capacity of 123500 Ah. Battery of same capacitance of 250 Ah each were selected for connection in order to ensure optimum performance. Although the energy usage period is largely within the day time, 7:30am to 6:30pm there will still be need for energy storage for off-peak usage due to variation in solar irradiation with changing weather conditions.

2.5. Inverter rating

An inverter is rated by its output power (P_{kva}) and DC input voltage (V_{dc}). The inverter was designed to have a power rating that is equal to 125% of the sum of the power of all loads running simultaneously (inductive and non-inductive appliances) and 3.5 times the sum of the power of all inductive appliances. The total power consumed by the defined loads is expected to have same nominal voltage of the battery bank that is charged by the solar PV module. Thus the inverter power (P_{inv}) was determined using equation 16 (Saleh *et al*., 2015) :

$$P_{inv} = 1.25\ (P_{sum} + 3.5P_{ind}) \quad (16)$$

Where P_{inv} = Power of the inverter

P_{sum} =Power of all loads running simultaneously (Resistive loads +Inductive loads) =48060 W

P_{ind}= Power of all inductive loads with large surge current=27400W

$$P_{inv} = 1.25\ (48060 + 3.5 \times 27400)$$

$$P_{inv}=179950W = 179.95kW$$

The power rating of an inverter is related to the real power that is delivered by the output of the inverter and is given by the equation 17 (Saleh *et al.*, 2015):

$$Power\ factor\ (PF) = \frac{Deliverable\ real\ power}{Power\ rating\ of\ the\ inverter\ (P_{KVA})} \quad (17)$$

The real power is the power consumed for work on load while the PF is generally taken as 0.8.

$$0.8 = \frac{179.95kW}{P_{KVA}}$$

$$P_{KVA} = 143.96kVA$$

The standby mode power consumption which is the power consume by the system when it is not delivering power to the load was taken into consideration. It is usually 5VA per hour. Assuming the system runs for 24 hours, then the standby mode power consumption will be 120VA.Thus the rating of the inverter preferred for the design is 150 kVA.

2.6. Cable sizing

Two types of cables consisting of the inverter to distribution board (DB) system (AC current) of the individual residence and the PV array to battery bank (DC current) through charge controller was considered which is calculated thus: The PV array to battery bank through the charge controller' is obtained using the relation

$I_{cab} = I_{rcc} = I_{sc}^{m} \times N_{pm} \times F_{safe}$ Where each parameter has the same meaning and value. $I_{cab} = 9.28 \times 110 \times 1.25 = 1276A$

Hence a $3 \times 35\ mm^2$ insulated flexible copper cable was selected. For the inverter to distribution board system of each of the business premises/shop, the cable is based on the maximum continuous input current which is obtained from equation 17 (Saleh *et al.*, 2015) as:

$$I_{oi} = \frac{P_i}{V_{oi} \times PF} \quad (17)$$

Where V_{oi} = Output AC voltage of inverter, I_{oi} = Current at inverter output

$$= \frac{179950W}{240 \times 0.8} = 937.23\ A$$

For each residence, I_{oi} = 46.86 A. Hence a $3 \times 10\ mm^2$ insulated flexible copper cable was selected.

2.7. Smart metering

A smart meter was employed in the model design to provide a means of energy control and real time energy consumption costing using telecommunication for the automated transmission of data to facilitate energy costing and energy consumption evaluation. The smart meter will give information on energy unit consumed, energy unit remaining, and other energy status at a given point in time using the short message service (SMS). The smart meter design for the energy consumption by the participating business premises consists of a Global System for Mobile Communications (GSM) modem, a microcontroller, a liquid crystal display, a Relay, output load, Analogue to digital converter (ADC) and power supply. While an embedded "C" language program consisting of attention (AT) command string/set was selected for installation as the communication gate way for exchange of instructions/data after conversion of the source code to Hex file for interpretation or use by the microcontroller which is shown in form of a block diagram in figure 7.

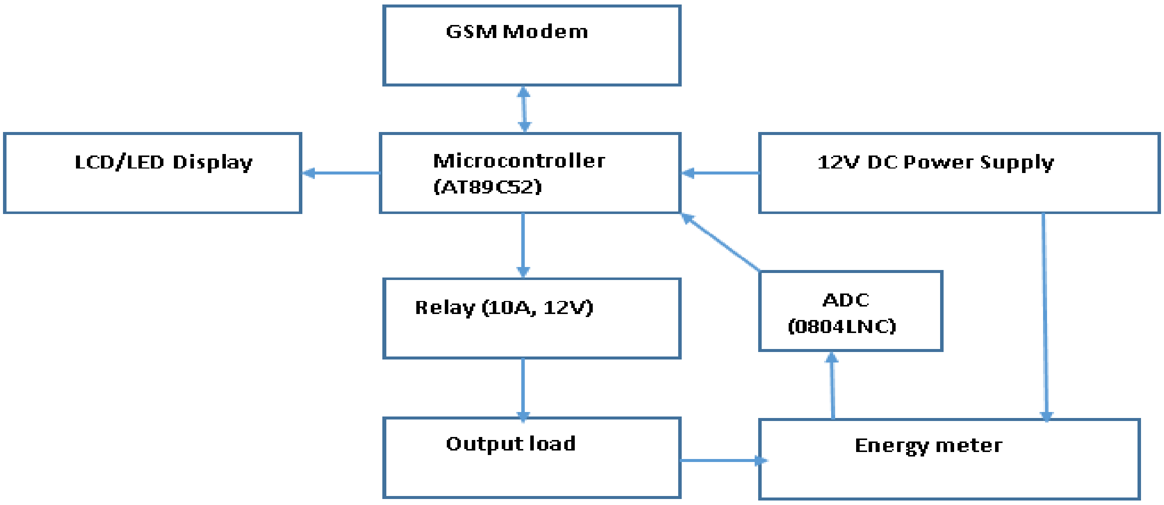

Figure 7: Block diagram of the smart energy meter

The entire system is powered by a 12V dc power supply unit. The microcontroller receives input from the GSM unit and sends it to trigger ON or OFF the relay. The relay receives the signal and either switches ON or OFF the energy supply to the participating shops or business premises. The microcontroller also receives signals from the phone and triggers the relay accordingly. At the interface between the smart energy meter and the microcontroller is the analogue to digital converter which receives analogue signals from the meter, converts to digital signal/equivalence in the form of unit of energy consumption, energy unit balance, low unit alert and other energy status as the case may be for processing by the microcontroller and further display by the liguid crystal display. A control centre will be in charge of the data base of each subscriber's data such as name, phone number, shop number, SIM ID and energy consumption records where amount of energy unit paid for, unit used and energy unit balance will be used to update the individual subscriber's data base for energy evaluation, planning, maintenance and management per time. As the energy is consumed by the loads in the individual participating residence, the smart meter sends units consumed to the prepared card which converts the unit consumed into expenditure (E) at every given instant after which it subtracts it from the recharged/subscribed unit amount (R_A) to obtain a balance (B) which is mathematically given by equation 18 (Joy, 2006) as:

$$R_A - E = B \tag{18}$$

The expenditure is calculated from the relation $E = N_A + C_C$, the current charge $C_C = E_C \times E_N \times M_F$ while the energy charged per kWh $E_C = L_R - P_R$. Where

L_R =Last system reading, E_C=Energy consumed, E_N=Energy charged per kWh

M_F=Multiplier factor, N_A=Net arrears, R_A=Recharged amount or subscribed unit amount

P_R=Present reading

2.8. Safety and protective devices

A fuse would be installed in series with each of the string to protect the modules and conduction from excess current and also to isolate faulty strings so as to enhance continuous energy supply. A lightning arrestor is recommended for installation to divert any surge which could be caused by lightning strike given the outdoor instalment. Selected earthly standards for the model design are BS6651, BS7430 and BS7671. DC disconnector at the DC side are also recommended as isolation devices to allow easy disconnection of the solar energy source in the event of system maintenance or fault.

2.9. Summary of PV model system components

A summary of the designed, selected or preferred components of the PV system comprising of the solar module, batteries, charge controller, cables, metering/control and safety/protection devices is shown in table 2 in terms of component model, power rating, voltage and current.

Table 2: Summary of PV model system components

S/N	Component	Quantity	Model	Power rating (W/Ah)	Voltage (V)	Current (A)
1	Solar module	330	AE EXTREME 320P6-72	320 W	36.75	8.71
2	Battery (Optional)	496	LUMINOUS VRLA/SMF Deep cycle Battery	250 Ah	12	-
3	Inverter	06	LUMINOUS 25kVA/240V	20000 W	360 Vdc/240Vac	66A dc/66A ac
4	Charge controller	16	I-Panda 240v/60A MPPT Solar controller	Not applicable	96	80
5	Cables	As required	Array to Battery Inverter to DB	3× 35 and 3× $10mm^2$	Insulated copper cable & flexible copper	
6	Smart energy meter	21	Not applicable	Not applicable	Not applicable	Not applicable
7	Protective/Safety devices	As required	Not applicable	Not applicable	Not applicable	Not applicable

Source: Theoretical analysis with the use of computational models/formulas and market/product survey for components specifications

3.0. Economic/investment cost analysis

A summary of the components cost of the modelled solar energy system is shown in table 3.

S/N	Component	Quantity	Unit cost (₦)	Total cost (₦)
1	PV Module	330	75000	24750000

2	Charge controller	16	240000	2640000
3	Battery	496	130000	64480000
4	Inverter	06	1500000	9000000
5	Cables (PV to battery & Inverter to Distribution board)	560 yards each	1000 per yard 1050 per yard	560000 588000
6	Smart meter	21	30000	630000
7	Design,Labour, installation/control cost	Not applicable		1500000
Total				(₦) 104148000.00K

Source: Theoretical analysis with the use of computational models/formulas and market/product survey for components specifications

The life cycle cost (LC_C) analysis is used to evaluate the behaviour of the proposed energy system. The life cycle cost analysis covers initial capital cost of components purchase and installation stage, operation and maintenance stage and the replacement stage. The operation and maintenance costs (OM_C) include annual periodic expenses for system management, site supervision and maintenance. The LC_C analysis takes into cognisance the longest life cycle of all system components. The storage batteries in the PV system are expected to be replaced every 5-10 years according to the battery type and operating conditions. The life cycle of the luminous battery proposed is 10 years while that of the PV modules is 25 years. The possible escalation trend in the overall costs of the system called inflation (i) and the possible decrease in the components cost with future mass production called the discounts (d) were considered for future estimation. The annual operation and maintenance cost is 2% of the PV initial cost (Shenawy, 2017) while the inflation rate (i) and the discount rate (d) was considered as 5 and 10% respectively. The annual OM_c cost was calculated using equation 14;

$$OM_c = 2\%\ PV_c \times \left(\frac{1+i}{1+d}\right)\left|\frac{1-\left(\frac{1+i}{1+d}\right)^{25}}{1-\left(\frac{1+i}{1+d}\right)}\right| \tag{14}$$

$$OM_c = 2/100 \times 24750000 \times \left(\frac{1+0.05}{1+0.1}\right)\left|\frac{1-\left(\frac{1+0.05}{1+0.1}\right)^{25}}{1-\left(\frac{1+0.05}{1+0.1}\right)}\right|$$

$$= ₦\ 6804000.00$$

The battery replacement costs are usually calculated for the first time after 10 years and for second replacement after 20 years since the battery life is considered as 10 years. This is calculated using equation 15 (Mahmood, 2019):

$$B_{C1} = BC\left[\frac{1+i}{1+d}\right]^{10} \tag{15a}$$

$$B_{C2} = BC\left[\frac{1+i}{1+d}\right]^{20} \tag{15b}$$

Where BC, the storage battery cost is ₦ 64480000.

$$B_{C1} = 64480000\left[\frac{1+0.05}{1+0.1}\right]^{10}$$

$$= ₦\ 38688000.00$$

$$B_{C1} = 38688000\left[\frac{1+0.05}{1+0.1}\right]^{20}$$

= ₦ 13927680.00

The system's life cycle cost was calculated using equation 16 (Shenawy *et al.*, 2017) by adding PV_c, B_{C1} (Battery cost), B_{C2} (Battery replacement), Inverter cost (Inv_c), Controller cost (C_C), Installation cost (I_C), Operation and maintenance cost (OM_c).

$$LC_C=PV_C+B_C+B_{C1}+B_{C2}+Inv_C+I_C+OM_C \quad (16)$$

= 24750000+64480000+38688000+13927680+9000000 +2640000+6804000

= ₦ 160289680

The annual life cycle cost (ALC_C) was estimated using equation 17 (Shenawy *et al.*, 2017).

$$ALC_C = LC_C\left[\frac{1-\left(\frac{1+i}{1+d}\right)}{1-\left(\frac{1+i}{1+d}\right)^{25}}\right]$$

$$ALC_C = 160289680\left[\frac{1-\left(\frac{1+0.05}{1+0.1}\right)}{1-\left(\frac{1+0.05}{1+0.1}\right)^{25}}\right]$$

= 11220277.60 K

The unit electrical cost (U_C) in ₦ /kWh can be estimated from the annual life cycle cost and the annual energy generation by the system using equation 18 (Mahmood, 2019);

$$U_C = \frac{ALC_C}{365\times E_L} \quad (18)$$

$$= \frac{11220277.60}{365\times 395140}$$

= ₦ 0.078/kWh

This is the unit cost of the installed system over 20 years of operation. A charge of ₦ 0.078/kWh is far cheaper than the present ₦ 30.93/kWh currently charged by the privatised Nigerian Power holding company called the Enugu Electricity Distribution Company (EEDC) in charge of Ebonyi state and is cheaper than the cost of using fossil fuel generator which is presently dispensed at ₦150.00k per litre in Nigeria.

3.0. Conclusion and recommendation

The community solar energy system which forms a mini electrical energy grid can be set up by a community/group of persons or an individual to open it up for subscribers with control using smart meter for energy pricing thereby reducing cost of an individual setting up the system especially for the low income earners, increasing energy accessibility/availability especially for low income earners even in cities, rural dwellers, small scale firms/industries and hence the enhancement of climate change adaptation through the reduction of carbon emission/greenhouse gases. Community solar concept has proven to be a fast growing approach to photovoltaic energy generation, transmission/utilisation. Given the pollution free nature, sustainability, reduced cost, reduction on fossil fuel reliance and other economic benefits of solar energy it becomes essential in contributing to the national energy mix and a promising alternative energy to households, firms and industries that depend on electrical energy for operation. Solar PV system with 330 modules have been estimated from the design to meet the energy demand of 20 selected small scale business/shops located at the “back gate” Alex Ekwueme Federal University Ndufu-Alike considered with a total appliances maximum daily energy demand of 48060W. Amidst the initial cost of installation of the system, its consistency, toughness, environmental friendliness and ease of maintenance makes the system worthy of consideration as it is beneficial for long-term energy investment since the payback period is less than 10 years while the life expectancy of the system is above 25 years. Also with the advent/improvement in technology for the production of PV component materials especially the solar module the initial cost of installation is expected to decrease, thereby reducing the payback period.

Having examined the potentials of solar energy using the community solar energy design concepts. It is recommended as a way of energy policy making that:

i. solar energy be integrated into the Nigerian national energy mix as a way out to the Nigeria energy poverty
ii. the establishment of local or indigenous industries for solar energy conversion technologies and application be encouraged by the government and other energy policy makers at all levels
iii. individuals and cooperate bodies be encouraged to generate solar power vai the community solar for onward integration to the national grid
iv. a national research and development fund on solar energy technology be created

Bibliography

1. A.A. Fashina. (2019). *Is there a possibility of Perovskites taking over the solar technology Market by 2030?* International journal of physical research, 7(1), 1-2.
2. A.M. Pal, S. Das and N.B. Raju. (2015). *Designing of a standalone photovoltaic system for a residential building in Grgaon, India*. Sustainable Energy, 2015, (3), 14-24.doi:10.1269.IIrse-3-1-3.
3. H.A. Guda and U.O. Aliyu. (2015). *Design of a standalone photovoltaic system for a residence in Bauch*i. International Journal of Engineering and Technology, 5(1), 34-44.
4. U.A. Saleh, Y.S. Haruna and F.I. Onuigbo. (2015). *Design and procedure for standalone photovoltaic power system for ozone monitor laboratory at Ayingba; North central Nigeria*. International Journal of Engineering science and innovative Technology (IJESIT), 4(6), 41-52.
5. D.O. Johnson and A.A. Ogunseye. (2017). *Grid connected photovoltaic system design for local government offices in Nigeria.* Nigeria Journal of Technology (NIJOTECH), 36(2), 571-581.
6. R. Hasan, S.Islam, A. Hossain, U. Sarjana and R. Hasan. (2016). *Design and development of a cost effective standalone PV system for a residential building in Pabna, Bngladesh*. International journal of scientific and engineering research, 7(9), 1664-1669.

7. A.L.Mahmood. (2019). *Design and simulation of standalone PV systems for Electronic and communications engineering department laboratories in Al-Nahrain University*. EAI endorsed Transactions on Energy web, 6(21), e9. Doi: 10.4108/eai.13-7-2018.156438.
8. S.Shaahid and M.Elhadidy. (2008). *Economic analysis of hybrid photovoltaic-diesel battery power systems for residential loads in hot regions-A step to clean future*. Renewable and sustainable energy reviews, 12: 488-503.
9. K. Btineth and D.Dalahal. (2012). "*Optimal configuration for design of stand-alone PV system".* Scientific Research, smart Grid and renewable energy, 3, 139-147.
10. A. Abu-Jasser. (2010). *A stand-alone photovoltaic system-case study: A residence in Gaza*. Journal of Applied sciences in Environmental sanitation, 5(1), 81-92.
11. T. Markvart, A. Fragaki and J.N. Ross. (2006). "*PV system sizing using observed time series of solar radiation*" *ELSVIER Solar energy*, 80, 46-50.
12. A.D. Sagar. (2012). "*Alleviating energy poverty for the world's poor*" Science Direct, Energy policy, 33(11), 1367-1372.
13. O. Chukwuemeka and A.A. Felix. (2018). *Design of a hybrid off-grid solar system for residential buildings in remote Benja Village*. International journal of Mechanical Engineering and Technology (IJMET), 9(8), 141-152.
14. C. Greacen, R. Engel and T. Quetchenbach, A. (2013) *Guidebook on Grid interconnection and Islanded operation of mini-Grid power systems up to 200Kw Lawrence Berkeley National laboratory*, April 2013.Retrieved from http://www.cleanenergyministerial.org/portals/2/pdfs/A Guidebook for Minigrids-SERC LBNL March 2013.pdf on 22nd June 2020.
15. N.K.Joy. (2006) *Electrical energy accounting methods*. Impressed publishers, Lagos, Nigeria.
16. E.T. El Shenawy, A.H. Hegazy and M.Abdellatef. (2017). *Design and optimisation of stand-alone PV system for Egyptian Rural Communities.* International journal of Applied Engineering Research, 12 (20), 10433-10446.
17. G. Joshi and K. Yenneti. (2020*). Community solar energy initiatives in India: A pathway for addressing energy poverty and sustainability?* Energy and Building, 210, 109736. https://doi.org/10.1016/j.enbuild.2019.109736
18. G.Chan, I. Evans, M. Grimley, B Ihde and P.Mauder. (2017). *Design choices and equity implications of community shared solar.* The Electricity Journal, *30* (9), 37-41. https://doi.org/10.1016/j.tej.2017.10.006
19. P.I. Okwu, C.C. Okolo, O. Okeke, D.O. Matthew and U. Ajuzie. (2017). *Details of photovoltaic solar system design calculations and the Accessories.* International journal of research in applied science and engineering technology (IJRASET), 5(6), 2933-2938.

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