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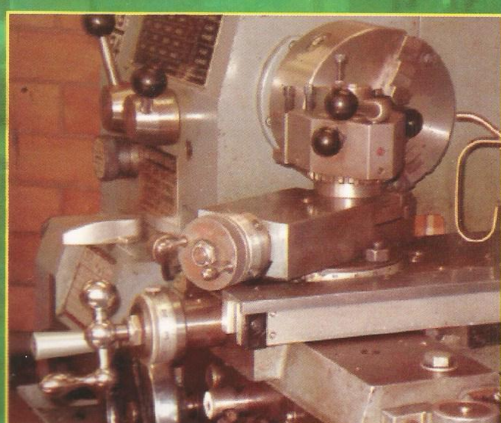

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THE DESIGN AND DEVELOPMENT OF SOLAR PHOTOVOLTAIC SYSTEMS IN MINNA, NIGERIA

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Abstract
The need to design and develop local photovoltaic systems in Minna, North-Central, Nigeria has been carried out. Though, the minimum value of energy from the developed Global radiation standard value was used alongside a suitable local Photovoltaic model to ascertain the extent to which solar radiation could be used to power certain loads in Minna. Of the three readily available solar modules with respect to manufacturing material, efficiency and technology, Monocrystalline and Polycrystalline are suitable for Minna. Thus, a developed and modeled local panel systems containing a 12V/12AH deep cycle battery, 300W pure sine-wave inverter, a mini solar controller, 80W monocrystalline local panel, demonstrates the said objectives with the aim of powering appliances like phones, mini-fans, laptops etc. Result is expected to increase baseline data required for design of local solar energy applications for use in Minna, North-Central, Nigeria as well as other locations on the same latitude as Minna.

Key words: Photovoltaic Systems, Global Solar Radiation, Monocrystalline, Local Panels.

INTRODUCTION

The efficiency of local photovoltaic (PV) panels is very important when it comes to installation at a particular location. The deep concern and increase to the growth of optional sources of energy to replace traditional fossil fuels is due to the increasing worldwide apprehension regarding environmental preservation, maintenance and the preservation of conventional natural earth deposits (ECN, 2005). The development of these new types of solar cells is promoted by the increasing public awareness that the earth's oil reserves will run out during this century (Michael, 2005). The fact that energy resources largely depend on firewood and fossil fuel, has led to the continuing deforestation and environmental pollution, at present, among majority of local users in Nigeria. Among other sources of renewable energy, solar power stands out as the only means having the tendency to provide the much more needed energy in use today. The quality of human life largely hinge on the availability of energy which is threatened unless renewable energy resources can be developed in the near future (Hagfeldt and Grätzel, 2000). Research results from Sambo, (1988) and Ojosu and Salawu (1990) show that energy from solar source is viable for homes and industries. The yearly solar energy per day reaching Nigeria is between 3.7kWhm^{-2}day^{-1} in the coast zones and 7.0kWhm^{-2}day^{-1} in the semi-desert regions with an estimation total of 5.08x10^{12} kWh of energy is received each day in the 923,768km^{2} area of Nigeria which means solar devices which are 5% efficient over a total land area of 1% in Nigeria, can generate electricity up to 2.541 x10^{6}MWh (Ojosu and Salawu, 1990). However, the common chart of excellent research-cell efficiencies always issued by the National Renewable Energy Laboratory explains research and engineering for decades, for solar cells designing with constant developing input-output results NREL (2017).

DEVELOPMENT OF PHOTOVOLTAIC SYSTEMS

The cells in all PV modules are made from semiconductors. The semiconductor materials are majorly crystalline and thin film, but only differ in the efficiency of light absorption, efficiency at which energy is converted, temperature coefficient, manufacturing process and production cost (Mah, 1998). The PV modules made from crystalline materials are Monocrystalline Silicon PV modules, Polycrystalline Sililcon PV modules and Gallium Arsenide (GaAs) PV modules; while those made from materials of thin-film are Cadmium Telluride (CdTe), Amorphous Silicon (a-Si) PV module, Copper Indium Diselenide (CuInSe2, or CIS). The V_{OC} (open circuit voltage), Isc (short circuit current), actual power (maximum) and efficiency were simulated for each PV module type (monocrystalline, polycrystalline and amorphous silicon), rated 80W each. Standard Test Conditions (STC) *i.e.* for the one Sun (AM1.5) illumination and a cell at a 25 °C is employed for efficiency rating. Zaid *et al* (2018) built a data collection system and an electrical system in order to measure and keep photovoltaic performance data. Test results from detailed analysis carried out every five days (Monday to Friday) of the month, for every of the panels, shows close ratings to the known recommended day for solar power engineering calculations (Kurpaska et al, 2018).

Photovoltaic system test for minna

The three readily available photovoltaic panels are polycrystalline, monocrystalline silicon and with semi-conductive layer made of copper (Cu), indium (In), gallium (Ga) and selenium (Se) (Kurpaska et al, 2018). Among the several known solar modules, only monocrystalline, polycrystalline and amorphous silicon PV modules are commercially available in Nigeria. As seen in table 1, results obtained from photovoltaic system test performance show that higher power outputs and short circuit current were recorded in Minna like most cities in the northern region, and during the peak dry season months than in the southern cities, and rainy season months. However, the reverse is the case for both open circuit voltage and conversion efficiency. Months with higher module temperature at the same or a little lower solar radiation, produces lower actual maximum power. However, this was not so for amorphous silicon module most times (Arinze, 2012). Unfortunately, STC are scarcely met in the field and majority of solar photovoltaic installations including Minna, are operating above 25 °C. More importantly, the efficiency of the vast majority of photovoltaic converters drops when temperature rise, with a rate commonly comprised between −0.1 and −0.5% K^{-1} (Dupré et al, 2017).

Modelled photovoltaic system for minna

Minna, just like most cities in Northern Nigeria, employs certain model to obtain a near relative specification that will enhance local PV system performance by:

1. Suitable global solar radiation data for standard test condition for Minna as shown in table 1 were obtained
2. These data were used to simulate the following: PV-module temperature at Minna city, the energy requirement from solar and

the minimum requirement to power a given load at a time.

3. The performance of the PV module type was analyzed based on the obtained results.

4. The PV module array requirement of a typical Nigerian home was estimated using the calculated PV module efficiencies.

Table I Processed Meteorological and Global Solar radiation Data (Awode et al, 2018)

MONTHS	*S*(hr)	*S*0(hr)	*S*0 *S*	*H* (MJm2day-1)	*H*0 (MJm-2day-1)	*H* 0 *H*	*T* max(oC)	*T* min(oC)	*T* av (oC)	*T* min/*T* max
JAN.	3.8727	11.4439	0.3384	21.8272	16.8255	1.2973	35.0399	20.5733	27.8066	1.7032
FEB.	4.2318	11.5387	0.3667	22.9727	15.9854	1.4371	37.0733	23.2684	30.1709	1.5933
MAR.	3.2500	11.7612	0.2763	23.1272	14.7126	1.5719	38.2657	25.3171	31.7914	1.5115
APR.	2.9273	12.0272	0.2434	21.7954	13.4101	1.6253	36.5664	25.2400	30.9032	1.4487
MAY	4.0864	12.0124	0.3402	19.7000	12.1293	1.6242	33.4588	23.7394	28.5991	1.4094
JUNE	3.4182	12.4873	0.2737	18.1818	12.4354	1.4621	31.0938	22.3752	26.7345	1.3897
JULY	2.6000	12.5573	0.2071	17.0181	12.9539	1.3137	29.3749	21.9953	25.6851	1.3355
AUG.	2.2727	12.4528	0.1825	16.9955	13.9107	1.2218	29.1567	21.8001	25.4784	1.3375
SEP.	3.2591	12.2346	0.2664	18.7181	15.1903	1.2322	30.0791	21.5226	25.8009	1.3976
OCT.	4.9273	11.9592	0.4120	19.6000	16.5412	1.1849	31.5659	21.6849	26.6254	1.4557
NOV.	4.6273	11.6999	0.3955	22.7500	17.3344	1.3124	35.0692	19.8918	27.4774	1.7627
DEC.	4.2182	11.5010	0.3668	22.3455	17.3736	1.2862	35.0592	19.2424	27.1508	1.8219

Solar radiation parameters makes it easier to select suitable PV system that fit Minna. As observed in Table I, the values of minimum sunshine hours for both measured (S) and calculated daily monthly mean (S_0). Likewise, the global radiation for measured (H) and calculated monthly mean daily (H_0) on a surface horizontally, for Minna are 2.2727 hours and 16.9955MJm-2day^{-1} respectively. These minimum values occur in the month of August. Two types of global solar radiation were observed from the result, as revealed in Table I. There were irradiation values at a high value in the dry season connected with sunshine hours of long duration (usually above 4 hours/day) and cloudy skies. Secondly, there were low irradiation values in the rainy season. At this time, the clouds bearing rain percolate the sky. Such periods are connected sunshine hour at lowest level (Awode *et al.* 2018). The afore-mentioned parameter align with efficiency and voltage capacity of Monocrystalline PV system.

Characteristics of the 3 commercially available PV modules types in Nigeria (Mah, 1998).

Monocrystalline Silicon-has uniform molecular structure and higher energy conversion efficiency (15-20%). It is also highly reliable for outdoor power application and does not degrade fast.

Polycrystalline Silicon-consists of small grains of single-crystal silicon and lower efficiency (12-18%). Also its efficiency does not degrade fast and it has outdoor reliability.

Amorphous Silicon-has high absorptivity of light, approximately 40 times greater than single-crystal silicon. It has low energy conversion efficiency, (5-10%). Covers more area at the same power rating with crystalline silicon modules. Also, it does not have outdoor reliability, since there is a decrease in efficiency over a few months due to sunlight, losing between 10 to 15%.

DEVELOPMENT OF LOCAL PHOTOVOLTAIC SYSTEM FOR MINNA

The solar panel manufacturing plant in Karshi, Abuja which is a branch of the National Agency for Science and Engineering Infrastructure (NASENI) is saddled with the sole responsibility of developing and producing local PV within the country under the supervision of its research and development team. Minna city benefits from this solar panel manufacturing plant in developing and producing solar panels that suits Minna Global solar radiation. Thus, panel development production involves stages and certain production line.

Typical local photovoltaic system plant production

The NASENI Solar Panel plant is running its first phase and part of the second phase meant for locally producing solar PV modules with most of the raw materials locally source except the solar cells and the glass. Currently, the company fully produces monocrystalline PV modules and it ranges in the following sizes and capacity: 80W, 175W, 180W, 190W, 200W; all these at commercial quantity. However, mini-sizes are produced at request and specification. It is worthy of note that this solar panel compete favourably with any solar panel imported into Nigeria; in fact its performance better than the imported once. Thus Energy Commission of Nigeria (ECN) has adopted it has one of the recommended solar panel in their bill of quantities in their ECN project, so has Millennium Development Goals (MDG). Also, this local panel has been used to execute several project e.g NITDA (National Information Development Agency), Nassarawa State Rural Area Electrification, Panda Rural Electrification Project sponsor by UNDP and many individual contractor's projects.

LOCAL PV PRODUCTION METHODOLOGY

Local PV production involves stages and line of production before a complete PV system is ready for dispatch or usage.

Panel production: stages of production and production line

The photovoltaic system operation as shown in figure 1 is explained by the following stages below:

Stage One- Solar cells testing and sorting: Here, the solar cells are tested, mostly in strings, to ascertain their electrical specification in terms of current, voltage, maximum power and efficiency. Each of them is sorted base on the above information i.e. the cells with same voltage, current, efficiency to avoid mis-match which can cause dark spot on the solar module. Dark spot occurs when solar cells of lower rating connect to other cells of higher ratings.

Stage Two- Single soldering: A solar cell has two surfaces i.e positive and negative. Connecting ribbon (silver plated ribbon) is soldered on the negative surface of the cells along the individual strips on the surfaces of the cells.

Stage Three- Stringing soldering: The single soldering cells are connected with the connecting ribbon in a string. The number of solar cells that makes a string depend on the size of the solar module to be produce e.g The 80W solar cells contain 32 cells which is 4strings ∗ 8cells. Also for 200W, it contain 80 cells = 8strings ∗ 10cells.

Stage Four- Laying and encapsulating of the string cells: At this stage the glass is washed using the glass washing machine to avoid any dirt in the surface of the glass, so as to receive as many sunlight available. It is layed on the laying table. The encapsulating material known as Ethlyn Vinyl Acetate (EVA) and Tedlar polyester Tedlar (TPT) are cut for the encapsulation of the cells. First, theEVA sheet is placed on the glass, then, the string solar cells will be arranged and connected in series on the EVA and another EVA

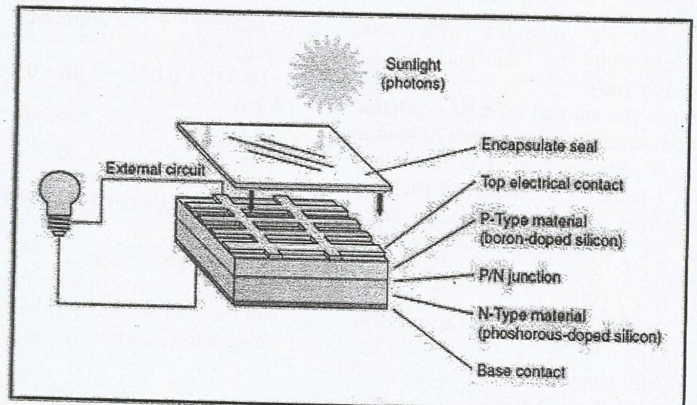

Figure 1 Schematic diagram showing PV cell and a powered load system Arinze (2012)

Sheet is used to cover the arranged string cells before the TPT back sheet is placed. Note, EVA serves as gum (adhesive) which melt during lamination. It binds the glass, the cells and the back sheet. The TPT protect the cells from being exposed to harsh weather condition and moisture.

Stage Five- Lamination: The encapsulating material, solar cells and glass are taking to the laminating machine where they are heated and pressurized to form one homogeneous item.

Stage Six- Trimming, framing and termination: The laminated PV module is trimmed and framed with aluminum frame using framing machine. After framing, the junction box is connected to the terminal of the modules to have the positive and negative terminals. ***Stage Seven- Final quality assurance***: Here, the sun is simulated in a dark room with the solar PV module connected to a micro-processor and other sensors. The micro-Processor is connected to a desk- top computer. The test is also operated from the computer. Once a button is pressed on the PC (computer), the simulated sun flash (incident) on the solar PV module and all the electrical output (maximum power, maximum voltage, efficiency, fill factor). Fill factor = imaginary power (I_{sc} * V_{oc})/ maximum power (I_{max} * V_{max}). At this stage the PV module is ready for package.

Stage Eight-Electricity generation: When all the holes are filled with electrons in the depletion zone, the p-type side of the depletion zone (where holes were initially present) now contains negatively charged ions, and the n-type side of the depletion zone (where electrons were present) now contains positively charged ions. The presence of these oppositely charged ions creates an internal electric field that prevents electrons in the n-type layer to fill holes in the p-type layer. When sunlight strikes a solar cell, electrons in the silicon are ejected, which results in the formation of "holes"—the vacancies left behind by the escaping electrons. If this happens in the electric field, the field will move electrons to the n-type layer and holes to the p-type layer. If you connect the n-type and p-type layers with a metallic wire, the electrons will travel from the n-type layer to the p-type layer by crossing the depletion zone (P/N junction) and then go through the external wire back of the n-type layer, creating a flow of electricity.

Standard test condition for local PV in minna and environs

PV systems are manufactured to have temperature of 25^{O}C i.e. Standard test

condition of PV modules with solar radiation of 1000W/m^2. Air mass of 1.5 wind speed of 1m/s.
For example, the amount of solar insolation required powering certain amount of load in a building or equipment set up is determined by the Area, A and Efficiency characterization of these parameters: Area, A of the PV Panel required to power the load, P i.e.
$P = A * \eta * I$ (Wh)
Most PV Panel have efficiency η, of 10%-20%
Thus for efficiency η of 15%; loads P, (15W, 25W, 60W AND 200W)
Sizing and Capacity

Insolation = 4.36 kWh/m2-day
Thus, A= $P / \eta * I$
$= (0.015 * 0.025 * 0.06 * 0.2) / (0.15 * 4.36)$
$= 4.5 \times 10^{-6} / 0.654$
Area, $A = 6.8807 \times 10^{-6}$

RESULTS AND DISCUSSION

The efficiency of every PV module varies owing to capacity in-built during production and the load attached. This is also known as sizing and capacity with respect to area.

Table II Sizing Equipment Capacity for a Sampled Home in Minna

S/N	Gadgets (Load)	Capacity
1	Powering of radio set	3.0 kWh
2	2 Units of water pumping	20.0 kWh
3	Gas Cooker	50.25kWh
4	Standing fan	0.125kWh
5	In house Electric Light bulbs	0.025kWh
6	Security Lightening	0.05kWh
7	Refrigerator	10kWh
8	Television	0.5kWh
	TOTAL	**6.455kWh**

SIZING OF PV AREAS USING GLOBAL SOLAR RADIATION STANDARD

Recall that $1kWh = 3.6\ MJ$. Therefore, $1kWh/m2/day = 3.6\ MJ/m2/day$. But, $1\ day = 24hrs. Hence, 1000W/m2/day = 3.6\ MJ/m2/day$; [11]
Thus, $6.455kwh * 1000 = 6455W/m2/24$
$= 23{,}238MJ/m2/day.$

$P = A * \eta * I$

Considering the fact that monocrystalline PV Panel have efficiency η, of 10%-20%
P= total load required to be powered
A= area
η= Efficiency of Panel and I= Solar Irradiance required
The regression Equation Constants for Minna lies between -1.0243 and 4.2538 as detailed in our companion paper (Awode *et al.*, 2018).
Both values are the root mean value for the regression constants to which positive values are employed. Thus, the value from this i.e. the positive (maximum value) required area:

$$A = P/(\eta * I)$$

$$= 6.455/(0.15 * 4.2538)$$

$$A = 10.1164m2$$

Result showing data sheet information of the three PV module types

Careful research and review for the three available solar module with standard test condition at the NASENI Solar plant along with the research and development team, present the following measured results.

Table III The Three PV Module Types Data Sheet Early Research Validation in NASENI

Characterization	Monocrystalline Silicon Module	Polycrystalline Silicon Module	Amorphous Silicon Module
P_{max}	80W	80W	80W
Efficiency	18%	17%	10%
V_{max}	19V	17.2V	77V
I_{max}	5.26 A	5.8A	1.293A
V_{oc}	22.8V	21.6V	99V
I_{sc}	5.68 A	6.46A	1.65A
Temp. Coefficient of P_{max}	-0.44%/°C	-(0.5±0.05) %/°C	-0.33%/°C
Temp. Coefficient of V_{oc}	-0.36%/ °C	-(80±10)mV	-0.2%/°C
Area	0.6465 m^2	0.77787m^2	1.5752 m^2

Local cost of production to foreign cost of production

The cost of local production of panel to foreign is cheaper owing to the fact, that indigenous panel materials are majorly source locally. Thus the cost is as follows:
Local panel cost per Watt= #200 while, Foreign panel= #230 per Watt from NASENI, Cost Value Sales in 2015.

Cost of local 80w PV component for phone and laptop range charging capacity

i. 80Watt PV Module = #15,000
ii. 12V-12AH battery= #5,500
iii. Solar regulator (12/24V 10A) = #5,500
iv. Inverter (300W, 12V DC, 220V AC) = #6,500
iv. Casing= #1, 500
v. Transport 1= # 3,000
vi. Transport 2= # 2,800
TOTAL= # 39,800

Power production per wattage

Result from Test on sampled loads show that:
For every 0.5A, and 3V
P= current * voltage i.e. P= I × V
P= 0.5A × 3V = 1.5W
Energy= Power × Time (t_i)
Energy= 1.5 × t_i, where; t_i varies for each load.
Minimum energy consumed by the load to attain full charge is 1.5t_i(Joules). Thus, the 80W Panel used during testing produced better efficiency of energy at a reasonable time, using systems like phones, electric

bulb and laptop. Thus, 3hrs range to charge a laptop fully.

Plate I A Well finished PV Cell

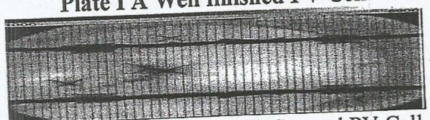

Plate II A Cracked and dark Spotted PV Cell

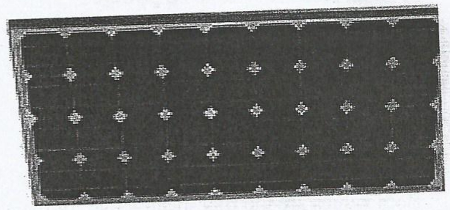

Plate III A well finished 80 Watts Monocrystalline Solar PV panel

CONCLUSION

(i) The cost of local PV modules is relatively low compared to the imported modules.

(ii) It is true that the area of module requires depend along with solar irradiance and efficiency of panel but varies with load input.

PV Module array requirement of a typical home in Minna was estimated using the calculated PV module efficiency and prove to be relatively visible, with positive standard test conditions.

Summarily, the work established that monocrystalline photovoltaic cell system is most suitable for Minna. Therefore, this work justifies and help to make suitable design for sustainable PV array system and also in making decision about PV module type and specifications for Minna. The optimum required value of 1000W/m^2 at 25% average minimum temperature for Minna photovoltaic systems is met which justifies and validates this work.

RECOMMENDATION

A lot of work have been done on solar energy, especially photovoltaic system but appreciable result and progress is still what our local communities especially Minna and its environs suffers, thus, to be able to mount both public and domestic photovoltaic systems that will be efficient and endure overtime, we need digitally calibrated equipments that will save time, generate high efficiency, reduce energy cost and minimize over-dependence on conventional energy source. The standard Test condition for all panels needs to be maintained. Mis-match of cells with different wattage and designed to be avoided to avoid dark spot. Modules should be handled with care to avoid cracks and destruction which lead to total malfunction of the entire set up system.

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