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Research Paper

Performance Evaluation of 7kw$_p$ Solar Photovoltaic System for Rural Electrification

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ABSTRACT
Poor or lake of solar photovoltaic systems is one of the major problem affecting many rural communities and even some part of the city areas in Sokoto state. It is known fact that most of the rural communities in Sokoto state are not connected to national grid due to topographical constrains or other problems. Therefore, provision of standard solar photovoltaic systems to these communities is the lasting solution in order to improve their standard of living. Provision of standard solar photovoltaic system can only be achieved through design of the solar photovoltaic system, the essential part for design are: data (electrical load assessment), and analysis. It is through design that the specifications of all the components (solar panels, controllers, inverter cables and batteries) for the solar photovoltaic system can be identified. As usual designs are always accompanied by construction under normal condition, the construction should be in conformity with the design. For the installed solar photovoltaic system to be functional for the expected period of years, preventive maintenance should be taken into consideration at regular periodic interval. It is one of the preventive measures that the batteries should not be placed in an environment where temperature is beyond 25 ^{0}C, this is because high temperature affects batteries, as such their life span will be short, this will eventually render the system not functional.
KEYWORDS: *Solar; Photovoltaic; Radiation; Insufficient; Performance; Direct current.*

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I. INTRODUCTION

The Solar PV (photovoltaic) energy is a direct conversion technology that produces electricity directly from the sunlight without the use of a working fluid such as steam or gas and a mechanical cycle. Photovoltaic systems, therefore, the system appears simple, convenient and does not require moving part. In addition, they are modular, so that arrays of identical modules can be assembled and connected to meet various power demand ranging from small residential system installation to relatively large system. We call energy from the sun "renewable", not because it can be refreshed, or restored once burnt out, but because its supply is nearly endless. It has given us light on earth for more than 400 million years and will continue to brighten the lives of countless generations to come, though it is terribly far away, it is also incredibly powerful and is the bests of all forms of life or energy on earth. Solar energy refers to rays from the sun (radiation) that reach earth. This energy can be converted into heat and electricity using different technologies. Solar power is energy from the sun "Solar" is Latin and means "relating to the "sun" Without this powerful energy source there would be no life. Solar energy is considered renewable due to its plentiful supply.

Solar energy is virtually limitless and will not be exhausted in the lifetime of any human, the technology used to convert sunlight into electricity does not produce smoke (carbon dioxide and other air pollutants). Harnessing the sun's energy does not harm the environment.

An area of 2m^2 receives the double amount of solar power (W) on an area of 1 m^2 When radiation hits a surface, more and more energy builds up on the surface over time. We call this accumulated energy irradiation

The term solar radiation refers to energy emitted by the sun. It consists mostly of radioactive energy and light. Radiation that is not reflected or scattered but reaches the earth's surface directly as called direct radiation (Ga). Scattered radiation that reaches the earth's surface is called diffuse radiation (G_D). Reflected radiation (G_R) is the radiation reflected back into orbit on reaching the earth. Total global radiation (G) is the sum of three radiation.

Not all radiation from the sun is visible. Radiation can also come in the form of invisible infrared or ultraviolet radiation. Solar systems can even use parts of the invisible radiation to generate electricity. Solar radiation carries power and the unit for measuring power is watt (w), solar radiation power is called irradiance.

However, the amount of power depends on the strength of the radiation (how strong the sun shines) and on the size of the surface it shines on. A Large surface more power. Therefore irradiance is measured in watts per square metre (W/m^2)

In Nigeria at noon the irradiance on 1 m^2 can be as strong as 1000W. Therefore we say it is 1000 W/m^2. 1000 W is equal to 1kw. We can also say the irradiance is $1KW/m^2$. Irradiation is a measure of solar energy, energy is the impact of power for a period of time.

Energy is measured in Wh or KWh. (Watt hour or kilowatt hour). Solar energy is the product of solar power (irradiance) and time. Therefore, we measure it in Wh/m^2.

Solar technicians need to know how much solar energy can be used during a day. Therefore, we measure the solar energy in Wh/m^2 / day or KWh/m^2 day.

The supply of reliable electricity is prerequisite to cater certain fundamental services that should be provided to all communities to escalate out of poverty. The mandatory needs are: water supply, communication, transportation, health care and education. All these depend on electricity. Thus electricity has become the heart for the sustainable development of the nation's economy and is essential to every aspect of our daily life. With growing population and expanding economies, the need for electricity is increasing worldwide, despite of the abundant Renewable energy resources, it is a known fact that many communities in Nigeria, Sokoto State inclusive, still live with insufficient supply or even without access to electricity, the problem is more alarming in rural areas. Electrifying these remote areas by extending transmission lines from the utility grid to these rural communities is very labor and capital intensive. For efficient and reliable solar photovoltaic system to be installed, the data/result obtained in this research should be used.

Photovoltaic (PV) panels are designed to convert solar radiation into direct current (DC), only 5-20% of the incident energy is converted into electricity, depending on the PV cell technology used (Win et al. 2004) , Solar cell temperature is among one of the most critical factors that affects the efficiency of solar cells (Dincer and Meral, 2010).

Most significant change by temperature is voltage which decreases with increasing temperature, while output current slightly increase by temperature (Tobnaghi et al, 2013) However, the cumulative effect in reduction in power output.

Although Nigeria parades very rich energy resource endowment, yet the country is still greatly plagued with acute energy crisis clearly noticeable in all facet of the economy. Close to 100 million, Nigerians remain "in the dark" without access to electricity (NBS, 2006) and estimates of the new connections to the national utility grid system is well under 50,000 per year (ESMAP, 2005).

Most remote rural settlement are place at a very serious disadvantaged due to relatively high grid (generation, transmission and distribution) expansion cost. Obvious potentials of solar technology as readily deployable stand-alone facilities for provision of electricity, with long service life (about 30yrs) and low maintenance cost appropriate for rural areas are yet to be fully harnessed (Jerusleye 2010).

SIGINIFICANT OF THE STUDY

Electrical power supply plays important role in human life, therefore design of solar PV system which can be used for rural areas especially where grid system does not reach should be given more priority in order improve the living standard of the rural dwellers.

Provision of solar PV system in the rural areas will help in providing water supply, lightening, grinding of grains/vegetables, charging of cellular phones etc.This will no doubt improve the standard of living.

II. METHODOLOGY

The electric power is the product of voltage and current which are labeled on a solar panel can only be achieved at $1kW/m^2$ irradiance and at a solar cell temperature of 25^0c. Therefore, the rated power is often given as "Watt peak" (Wp). A module which is rated 85 Wp reaches its peak power output of 85 W only under these specific conditions. If the irradiance is less than 1 kW/m^2 or the temperature is above 25^0c, then the module generates less power.

$7KW_P$ is the peak power output of the solar panel array, having that the performance evaluation of the solar PV system is for Sahel savannah Sokoto state Nigeria inclusive, the peak sun hours (PSH) for Sahel savannah is $6KWh/m^2$ per day. Therefore the electrical load to be connected to $7KW_P$ serves as load assessment.

Load Assessment

Is the expected electrical load to be connected to the electrical supply system, this can be assessed through survey. For this research, $7KW_P$ serves as our basis upon which we can find the electrical load.

Electrical Load

Given that, 7KW$_P$ is the peak power output of the solar panel array, using the peak sun hours of Sokoto state which is 6KWh/m^2, therefore electrical load will be:

$KW_P \times KWh/m^2$ ……………………………………..…….Equation (1)

$7KW_P \times 6KWh/m^2 = 42KW$

Daily Energy Demand (E_{daily})

The daily energy demand is the load multiplied by the number of hours which the load will be connected to electrical supply.

Load ×Time (Hours) …......................…………………………. Equation (2)

42KW× 24hours = 1,008 KWh

Adequate size of Battery Bank

To adequately size the battery bank, the following must be considered: efficiency of the Inverter which is the ratio of useful output to the total input, efficiency of the inverter generally assume to be 90%, battery depth of discharge should not be more than 30% daily (always battery at least 70% charge) and system voltage must be selected in accordance with inverter input voltage.

Efficiency of the Inverter

The efficiency of the inverter is the ratio of daily energy requirement to the inverter efficiency.

$E_{daily}/90\%$ …………………….…………………………….. . Equation (3)

1,008 KWh/0.9 = 1,120 KWh

Depth of Discharge

For good battery life cycle, always leave the battery at least 70% charged. To use only 30% of the battery charge, we find the battery energy capacity (Wh) by dividing the energy demand by the expected quantity (30%) of the battery charge to be used.

$E_{daily}/30\%$……………….………………………………… ……. Equation (4)

Battery Energy Storage Capacity = 1,008 KWh/0.3 = 3,360,000Wh

30% of 3,360,000Wh = (3,360,000/100) × 30 = 1,008,000Wh

70% = 3,360,000Wh - 1,008,000Wh = 2,353,000Wh.

Battery Amperage Capacity (A/h)

Battery amperage capacity is the ratio of battery energy storage capacity to the selected system voltage.

To find the amperage capacity of battery for solar photovoltaic system, Inverter System Voltage and Maximum power voltage of the panel array must be selected.

Inverter System Voltage is 360Volt, meaning that there is going to be thirty (30) number 12Volt batteries connected in series to provide 360Volt 200Ampere.

Maximum power voltage of the panel array is 24Volt DC as usually indicated in the name plate of the panel.

Therefore, battery capacity in ampere per hour (A/h).

$$\text{Battery capacity} = \frac{\text{battery energy storage capacity}}{\text{Selected system voltage}} = \frac{3{,}360{,}000\text{Wh}}{360} = 9{,}333.3 \text{ Ah}$$

200Ah 12Volt batteries are to be used for the system, therefore the number of batteries required for the system will be:

9,333.3 Ah/200Ah = 46.66 ≈ 47 Batteries.

But having connected thirty (30) numbers 12Volt batteries in series in order to have the system voltage of 360Volt at 200Ah, to meet the battery amperage capacity of 9,333.3 Ah, 46 numbers 200Ah 12Volt batteries should be connected in parallel with 360Volt batteries. Therefore there are total number of 76 batteries. At this point the DC voltage and current of 360Volt at 9,333.3 A/h has been achieved.

Required size of solar panels array

The required size of photovoltaic array is the amount of solar energy which the panels should provide under normal condition.

In order to determine the size of the solar photovoltaic array, the following steps are followed:
1. Divide the daily energy demand by the performance ratio (0.65) of the solar system.
2. Divide the value obtained in 1 by the peak sun hours (6 hours) of Sokoto location/Sahel savanna.

E_{daily}/Performance ratio of the solar system

1,008KWh/0.65 = 1,550.8 KWh

1,550.8/6 = 258.46 KW_P = 258,461.5W_P

Quantity/number of solar panels

The quantity of solar panels to be used for the system are determine by considering the required size of the solar panel array and the capacity of the panel. Having that the required size of solar panel array is 258.5 W_P, for 450W_P panels to be used for the system, the quantity of solar panels will be:

258,461.5 W_P/450 = 574.3≈ 574 Solar panels.

Required size of charge controller

The charge controller regulates the power output from the solar panel array, which is used to charge the batteries. This is done by managing the voltage delivered by the solar panel array to the batteries. The charge controller is in between the solar panel and the load. It must manage the maximum current from the solar array because strong sunshine for short period can cause solar panels to produce 20% more output than their power rating. To determine the required size of charge controller for this system, use the following:

Required size of charge controller (W_p/Vmax) ×1.2…………………………….Equation (5)

Where W_p is the solar panel array and V_{max} is the Maximum voltage of the array.

Fifteen (15) panels should be connected in series; hence the maximum voltage will be

= 15 × 35 = 525V.

Size of the solar panel array (W_p) = 574 × 450W_p = 258,300W_p

Hence,

Required size of charge controller = (258,300 / 525) ×1.2 = 590.4 ≈ 600 A

Selection of inverter

An inverter is an electrical device that converts direct current (DC) into alternating current (AC). We need AC to supply power to most electric appliances. Selection of inverter can be achieved by using:

Inverter size = KW/P.F………………………………………….………..… Equation (6)

P.F. (Power Factor) = 0.8.

42KW/0.8 = 52.5KVA.

The same data/information obtained above using conventional method is also the same as that obtained using Microsoft excel as shown in table 1.

S/N	PARAMETERS/ITEMS	CAPACITY
1	Laod (KW)	42000
2	Daily energy requirement(Wh)	1008000
3	Efficiecy of the inverter 90%	1120000
5	Battery energy capacity (Wh)	3360000
6	Depth of disch.(DOD) of the battery 30%	1008000
7	Depth of disch.(DOD) of the battery 70%	2352000
8	Inverter System Voltage (V)	360
9	Battery capacity (Ah)	9333.333
10	Required size of soler panels array (Wp)	258461.5
11	Quantity of solar panel	574.359
12	Number of batteries connected in series	15
13	Mximum voltage of the panel array (V)	525
14	Charge controller in (A)	590.7692
15	Inverter (VA)	52500
16	Inverter (KVA)	52.5

Table 1. Data /result.

Figure 1: Solar photovoltaic panels array.

Figure 2: Battery Bank.

Figure 3: Charge Controller.

Figure 4: DC-A/C Inverter

III. CONCLUSION

It is necessary to evaluate the performance of solar photovoltaic systems to ensure that the system can perform the desired operation efficiently at all the time. Accurate load assessment must to be conducted in order to provide efficient and reliable solar photovoltaic systems. Load assessment serves as the basis for analysis and selection of all other component for the solar photovoltaic systems. Also during the installation there should be total compliance with electrical safety rules and regulations so as to safeguard the technicians installing the system, the system and the end users.

IV. RECOMMENDATION

Solar photovoltaic system design should be provided before the installation of any solar photovoltaic system, this will surely guarantee the efficiency of the system. Periodic checks/preventive maintenance is also necessary for efficient and reliable operation of the system.

Likewise the batteries should not be exposed to the temperature which is above 25 ^{0}C, this is because high temperature shorten the life cycle of batteries.

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