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The Design of A 3 Kw Solar Power Device for Class-Rooms and Offices in the Federal Polytechnic Mubi

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Abstract.

In this paper, the design of a 3kW solar power device is presented that can be used for illumination and meet the need of small power requirement for an office or an average classroom with a carrying capacity of 80 to 160 students in the Federal Polytechnic Mubi. This is done to meet the demand of energy required to sustain effective teaching and learning in an institution of this nature, since power from the main source is not constant. Also it is done with the aim to encourage clean energy initiative in the institution.

Introduction.

Energy is an integral part of the human life. Meaningful life without energy is a dream. Yet many of our most serious threats to clean air, clean water and healthy eco systems stem from human energy use of which electricity is one. Although we are generating electricity from hydro sources, however most of our energy is produced from coal, oil and natural gas in Nigeria, especially the on-going independent power plants. Most of the plants are powered by gas. For example, the issue of inadequate gas supplies to thermal stations had on several occasions resulted in the tripping of transmission lines thereby causing shortage of power to the national grid [1]. These energy sources mostly from fossil fuel pollute the air and water, damage the earth's climate, destroy fragile eco-system and endanger human health. A large amount of energy generated is wasted, raising energy costs and harming the environment. The fact is that we can meet our energy needs while protecting human health, our climate and other natural systems. The solution lies in the rapid transition to energy efficiency and use of clean, renewable energy such as the sun, hydro and wind [2]. Renewable energy sources are abundant and inexhaustible. They do not use fuel, so fuel costs and price fluctuations are not an issue. This paper highlights the design of a 3kW solar power device that can be used to meet energy demand in the office and illumination in the classrooms during lectures. The fact is that power supply fluctuations in the form of power outages (total blackout) or minor disruptions caused by incessant tripping of the line, has been a constant experience in our institution. This observation is a common experience in our country generally. According to Udoh [1], the issue of power supply in the Nigerian state is a heated discussion in various gatherings like the national assembly, academic workshops and conferences. The media (both print and electronic) is not left out in this outcry.

Using solar power to produce electricity is not the same as using it to produce heat. Photovoltaic principles are used. Photovoltaic (PV) is a solid-state, semiconductor based technology that converts light energy directly into electrical energy, without moving parts, noise and emissions. The most common form of photovoltaic device from 1950s to the early years of the new millennium was the crystalline silicon. By 2007, the Thin Film technology had overtaken the Crystalline because of its higher annual yield. There are number of other technologies, including amorphous silicon (a-Si), copper indium diselenide ($CuInSe_2$ or CIS), cadmium-telluride (CdTe), gallium arsenide (GaAs).

Solar panels are usually directed at the solar south in the northern hemisphere, while it is solar north in the southern hemisphere and they are directed at an angle dictated by the geographic location where they are to be installed. For solar panels to obtain maximum energy from the sun radiation, it must always be facing the sun. This could be achieved by the use of a tracking device which follows the sun. However, the use of a solar tracker is not practical in a one or two panel solar home system but is necessary in larger systems.

Load Estimation.

Estimating the electrical load in a solar power system is slightly different from direct power supply from AC generators and other non renewable energy sources like coal, gas and so on. Energy saving scheme must be employed to minimise cost. To do this, an energy audit usually in tabular form of all that the solar power system would supply must be made to justify what is allowed in the system. In this paper the energy audit for an average office is given. It is assumed that it will also meet the classroom power demand. The energy supplied will be used to meet the power demand for heating, cooling, lighting and other services requiring computers, television and so on.

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Before estimating the load demand for a standard office, the number of lighting points was determined. For a 15 by 10 (m^2) office space the number of luminaries are determined by using the method according to Udoh [3] as shown below:

Recommended illumination level = 300lux [4]

Height of luminary above the floor level (hm) = 2.5 m

$$\text{Room Index} = \frac{L \ x \ B}{hm(L+B)} = \frac{15 \ x \ 10}{2.2(15+10)} = 2.4$$

A closer value is 2.5, and this corresponds to a Utilization Factor (UF) of 0.57 for a ceiling reflectance (ρ_c) of 70 and wall reflectance (ρ_w) of 30 for a standard 40W fluorescent lamp of 1200mm with a lamp lumen of 2700 and a Maintenance Factor (MF) of 0.85 [3]. Accordingly, the number of lighting points is then calculated using,

$$\text{Number of points (N)} = \frac{Area \ x \ Illuminance \ \ (lux)}{UF \ x \ MF \ x \ LL} = \frac{15 \ x \ 10 \ x \ 300}{0.57 \ x \ 0.85 \ x \ 2700} = \frac{45000}{1.308.15}$$

$$= 34.4 \quad = \quad 34 \text{ lighting points.}$$

For the purpose of this paper, the number of lighting points (N) will be chosen as 30.

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Since there may likely be worse cases, the load in Table 1 will be used to determine the energy required from the system. The average daily energy usage is determined as follows:

1. Split unit A/C: 1000 x 8 hours per day gives, 8000 WH
2. Refrigerator: 150 x 8 hrs per day gives, 1264 WH
3. Ceiling Fan: 40 x 8 hrs per day, 320 WH
4. Standing Fan: 35 x 8 hrs per day, 280 WH
5. Electric Kettle: 1000 x 0.5 hrs per day, 500 WH
6. Lighting: 240 x 8 hrs per day, 1920 WH
7. Computer set: 18 x 8 hrs per day, 144 WH
8. Printer: 60 x 3 hrs per day, 180 WH
9. Projector: 240 x 3 hrs per day, 720 WH

Total energy usage per day is, **13,328 Watt-hours**

Solar System Components.

There are four primary components for producing electricity using solar power to provide a 120V AC namely; Solar modules (panels), Charge controller, Battery and Inverter. The process of producing alternating current with the system in question is that the solar panels charge the battery and the charge controller ensures adequate charging of the battery. The battery provides DC voltage to the inverter, which further converts the voltage to AC voltage. Where 240 volts is required, then a transformer or two identical inverters are series stacked to produce the 240 volts.

Determination of System Voltage.

System voltages are generally 12, 24 or 48 volts. The actual voltage is determined by the requirements of the system. If the batteries and the inverter are a long way from the energy source then, a higher voltage may be required to minimise power loss in the cables. To minimise losses in the system, it is advisable to keep the batteries and the solar panels close to their intended appliances. In combined array and battery bank systems, the recommended system voltage increases as the total load increases. For small daily loads, a 12 volt system can be used; while an intermediate daily loads may require 24 volts and larger loads 48 volts [5]. In this case, 24 volts is chosen as the system voltage.

Conversion of Watt-hours to Ampere-hour (A-hr).

Batteries are usually rated in ampere–hours (A-hr). It becomes necessary to convert the total energy requirement of the system in watt-hours to ampere-hours to enable appropriate sizing of the batteries. This is done by dividing the total energy in watt-hour by the battery system voltage (V_{dc}) to give the required ampere-hour demand. Hence,

$$\text{A-hr} = \frac{watt - hour}{system\ \ voltage} = \frac{E_t}{V_{dc}} = \frac{13328}{24} = 555.33 \text{ A-hrs}$$

Giving, 555 A-hrs.

Sizing of Battery for the Solar System.

In sizing the batteries the following are taken into consideration.

1. The ability for the battery to meet the energy demand of the system, known as 'days of autonomy', is defined as the maximum number of days that the batteries will supply the daily energy demand without input (charge) from the energy source. Typical figures range between 3 and 5 days [5].
2. Daily maximum depth of discharge. Battery manufacturers normally specify the maximum allowable depth of discharge for their batteries (DOD_{max}), typically ranging from 0.7 to 0.8 (70 – 80%).
3. Parameters relating to the discharge power (current) of the battery, which is specified as (a) Maximum power demand and (b) Surge demand.
4. Parameters relating to the charging of the battery, which is specified as the 'maximum charging current'.

Using the above considerations, 'days of autonomy' is chosen as 4; in view of the fact that this project is being carried out in Mubi which is a slightly sunny environment. Maximum depth of discharge (DOD) is chosen as 0.8 (80%). Therefore, the battery bank capacity is determined by,

$$\text{Battery capacity } (B_{cap}) = \frac{Daily\ \ energy\ \ demand\ \ (A{-}hr)\ x\ Days\ of\ autonomy}{Maximum\ \ depth\ of\ discharge}$$

$$= \frac{555\ x\ 4}{0.8} = 2{,}775 \text{ A-hrs}$$

From the global power map, the average sun hours for North African region, of which Mubi in the North-East zone of Nigeria belongs, is about 5 to 6 hours per day [6]. Since the battery will be powered by solar modules (panels), the above battery capacity in A-hrs will be divided by the sun hours per day to give the new battery capacity. Because of the location of Mubi the highest figure of 6 is chosen. New battery capacity is given by,

Battery capacity (B_{cap}) $= \frac{2775}{6} = 462.5 \approx 463$ A-hrs. From here the battery can be selected from the manufacturer's catalogue. For example a battery with the following parameters, voltage (12V) with

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305Ahr/120 hours, is selected. It should be noted that the number of batteries in series is determined by the system voltage divided by the voltage of the selected battery thus,

$N_{bs} = \frac{24}{12} =$ 2 batteries in series

It should also be noted that the number of parallel strings of batteries is determined by the overall battery capacity divided by the capacity of the selected battery thus,

Number of parallel strings = $\frac{463}{305} = 1.5 \approx$ 2 batteries in parallel

Total number of batteries required = 2 x 2 = 4

Sizing of inverter for the solar system.

Inverters are specified in continuous rating and surge rating. A continuous rating is the maximum power the inverter can support indefinitely, while a surge rating is the maximum power demand the inverter can support momentarily. According to SER [5], Australian Standard AS4509.2 allows the $^1/_2$ hour rating to be used when selecting an inverter to meet the maximum demand. But if the load profile is such that the maximum demand could last longer than $^1/_2$ hour duration, then the continuous rating should be used. From Table 1, the total power rating of the solar system is 2783W. To take care of surge and future load increase, the load is multiplied by a factor of 1.5 hence,

Maximum power demand becomes 2783 x 1.5 = 4175W.

Then for an inverter with the following parameters from the manufacturer's catalogue, V_{dc} input = 24V, continuous power of 2400W, with selector settings to give an output of 230V_{ac} at 50H then,

Number of inverters = $\frac{4175}{2400} = 1.74 =$ 2 inverters in parallel.

Sizing of Solar modules.

Modules (panels) are usually connected to form an array. Arrays are wired to match the load. Generally the load is a bank of batteries connected to store the dc power at 12V, 24V or higher voltage. This is known as the nominal system voltage. The modules are wired in series to suit the system voltage and also wired in parallel to provide sufficient charge to the battery bank. Most commercially available modules are configured to produce an open circuit voltage (V_{oc}) of around 20 volts and a nominal charging voltage of 14 volts to make them suitable for charging a 12V battery.

In this design, the system voltage is 24V. As stated previously the total energy requirement based on Table 1 is 13328W-hr. Then,

$$\text{A-hr} = \frac{Total\ energy\ requirement}{system\ voltage} = \frac{E_t}{V_{dc}} = \frac{13328}{24} = 555.33 \text{ A-hrs}$$

Giving, $I_{A\text{-}h}$ = 555 A-hrs. (Total energy requirement)

It could be recalled that the total average sun hours for Mubi is chosen as 6 hours per day. Then for a module with the following parameters: I_{mod} = 8.0A and power rating = 120W/module;

Number of modules in series = System voltage/ 12V = 2.

Number of modules in parallel = $\frac{I_{A-h}}{I_{mod}\ x\ Sun-hr} = \frac{555}{8\ x\ 6} = 11.56 \approx 12$

Therefore the total number of modules in the array is 2 x 12 = 24.

For this design the number of requirement for the solar system could be summarised as follows:

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Discussion.

The result of the design is presented in Table 3. The result shows that the solar modules (panels) are more in number than other components. This is based on the characteristics of the panels or modules. The panels come in different sizes and this affect the number in the array depending on the configuration adopted to either increase the current or the voltage of the system. In this design, the array is wired to sustain a dc voltage of 24 volts and current in multiples of the number of arrays in parallel. The batteries could be reduced if the rating is higher. The same applies to the inverter. All other factors that affect solar power design like issue of temperature factor, maximum power point tracker efficiency, battery and inverter efficiencies and the derating of the panels due to dirt are ignored because the system is a very simple one and moreover Mubi where the design is to be implemented has maximum sun radiation almost throughout the year. There has never been a cloudy period for more than two days and that could only happen during peak rainy season which cover about two months of the year that is, between August and September.

The cost of this project could be reduced by applying power management in its implementation. The fans and the air-conditioner cannot work at the same time. Even using the solar power for the A/C can even be abandoned for the fans only.

Conclusion.

In this paper the basic principles of the design of solar power system has been presented. The design so presented could be used for any size of load. Apart from the initial cost, the solar power system is a better alternative to electric power from fossil fuel sources because of its ability to preserve the environment from pollution. It is recommended that it be implemented despite its cost to serve the power needs of the institution in those basic areas that needs constant power supply.

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