International Journal of Applied Research

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2015; 1(11): 447-452
www.allresearchjournal.com
Received: 12-08-2015
Accepted: 15-09-2015

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Hybrid Solar Power System: Campus Model Solution

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Abstract
Power supply from the national grid is inefficient and unreliable, hence the need to provide alternative source of power. It is imperative that if the country is to be self-sufficient in power generation, transmission and distribution, it must be based largely on indigenous engineering initiative and researches to design, adapt, develop and manufacture local based renewable energy. This research work was carried out at Federal College of Agriculture Moor Plantation Ibadan Nigeria and focus on a design and development of campus reliable power system. Materials includes the power main, 5KVA generator, solar energy panels, charge controller, power inverter, automatic voltage regulator and 12V 200Ah dry cell batteries. Four approaches were adopted to achieved the aim of the research work. This includes the audit with stakeholders interview, solution design, stage proof of concept, implementation and testing. Load analysis was carried out for the whole campus, which was used to design energy requirement for the institution.

Keywords: Hybrid, Solar Power, Campus Model, renewable energy

1. Introduction

Nigeria is endowed with abundant renewable energy resources, like biomass, wind, small and large scale hydro with potential for hydrogen fuel, geothermal and ocean energies. Except for the large scale hydropower generating station which serves as a major source of electricity, the current state of exploitation and utilization of renewable energy resources in the country is very low [8].

[3] cited in [4] has stated that power generation, transmission and distribution has been an indispensable factor in the progress of an economy, ranging from manufacturing, banking, media, health care, aviation, etc. Environmental pollution which leads to degradation or depletion of ozone layer is one of the major problems caused by the use of generator with fossil fuels. Increase in the cost of fossil fuel which has been one of the major prime movers in the internal combustion engine (ICE) has been noticed. This can be accounted for based on the rapid decrease in the level of oil well. [2] has observed that significant worldwide interests and efforts are currently being directed at the development and production of improved forms of renewable energy and new fuel sources of which biofuels are crucial.

[3] discovered that solar energy is fast becoming an alternative source of energy due to the high rate of depletion of the conventional energy sources. It is non-polluting, can be tapped at a relatively low cost has no danger of fire or other hazards. Due to the depletion and high cost of fossil fuel, there is need to search for alternative source of energy. More than 1.3 billion people are compelled to live on less than one dollar a day; more than 800 million people go hungry and the number may exceed one billion by the year 2020, with high concentration on the developing countries of which Nigeria is one [10]. Therefore, it is imperative that if the country is to be self-sufficient in power generation, transmission and distribution, it must be based largely on indigenous engineering initiative and researches to design, adapt, develop and manufacture local based renewable energy.

This brings up the idea of this research work which was fully funded by National Information Technology Development Agency (NITDA) Abuja.

[5] has mentioned [1] described inverter has a special type of power inverters that convert direct current (DC) electricity into alternating current (AC) and feeds it into an existing electrical grid. GTIs are often used to convert direct current produced by many renewable energy sources, such as solar panel or small wind turbines, into the alternating current used

to power homes and businesses. The technical name for a grid- tie inverter is "grid – interactive inverter". Grid – interactive inverters typically cannot be used in standalone application where utility power is not available.

Methodology

The hybrid solution components will include the following

1. The Power mains/ Generator
2. Solar Energy Solution (Solar panels, charge controllers)
3. Power Inverters
4. Batteries
5. Automatic Voltage Regulator (15KVA)

The Power inverters will utilize the batteries to provide power supply to the laboratories in the event of power outages and during downtimes (when the generator is off). The batteries are charged in a ratio using power supply from both the AC mains and the solar energy solution. At every point in time, approximately 80% of the battery charging voltage is provided by the AC mains while the remaining 20% will be provided by the solar energy solution.

To ensure a very robust Hybrid-Power solution design, which will fit into the needs of the College, the following approaches were adopted;

1. Audit and Stakeholders Interview
2. Solution Design
3. Staging and Proof of concept
4. Implementation and Testing

Audit and Stakeholders Interview

This represents the entry phase of the research work and it involves a detailed assessment of each of the departments/ units and their components. Interview was also conducted with the stakeholders within each of the units. At the end of this exercise, load estimate was determined which includes the frequency of usage and also the timing of usage.

A successful design involves accurate knowledge of daily electrical load calculation and accounts for all worst case scenarios which might possibly occur during operation. A good design must be pragmatic and keep the costs down by cutting on unnecessary over sizing the system.

Table 1: Load Estimate of the College Cybercafé

S/N	Appliance	Quantity	Power Rating(W)	Hourly Use(Hr)	Total Power(W)	Total Energy(W)
1	Fan	1	75	6	75	450
2	Computer	16	360	6	5760	34560
3	Bulb	4	30	6	120	720
4	Photocopier	1	183	6	183	1098
5	Printer	2	100	6	200	1200
Total					6338	38028

Solution Design

By leveraging the results from the initial site survey and the detailed audit/ assessment, design of the hybrid power system now comes up to fit into the College need. The design covers the solar-powered solution design. The specific approach for the design includes the following;

(i) High-Level Design - this stage considered all the parameters and the needs of the units as obtained in the surveys, and develop a technical concept that meets the needs of the units. With the high level design I ensured that we capture all the components of the proposed solution and at a glance one can have a true picture of the solution architecture.

(ii) Low-Level Design – each of the components of the high-level design was designed in detail. This stage involves designing the details associated with the solution such as cabling and power phase design, power distribution design, the expected design and configuration of each component. At the end of this stage, we have developed the full design.

Sizing the PV Modules (Wp)

Besides solar panels which generate photocurrent, a solar PV system is made up of many components – charge controller, inverter, batteries – all connected by wires. None of these are 100 percent efficient. For instance, every 100 amp-hour drawn from the battery requires putting in about 115-120 amp-hours of charge into it. Inverters are typically only 85 percent efficient and likewise for charge controller. Cables offer electrical resistance to the flow of current which is substantial because of rather low DC voltages involved.

Assumptions made in the design stage

80% efficiency for the inverter/charge controller

85% for the battery bank and 3% wire losses.

Thus, we over size the requirement from the modules by $1/(0.80 \times 0.85 \times 0.97) = 1.51$

Plate 1: 185W Solar Panel

Inverter Sizing

An inverter is used in the PV system when 220V-AC power output is needed. Its rating should never be lower than the total watt of appliances and input DC voltage (12V) must match the voltage of the battery bank. [6] has stated that the inverter size should be generally 25-30% bigger than total watts (W) of appliances. If the load includes an appliance such as motor or compressor then inverter size should be minimum 3 times the capacity of these appliances so that it can handle the starting surge current for few seconds.

Assumption made: 25% of the total connected wattage was added;

From the Load estimation worksheet, the total connected wattage = 7,190W
Inverter Sizing = 30% (Total connected wattage) + Total Connected wattage
= (0.30 * 8010+1900) + 9910
= 2973 + 9910
Inverter Sizing = 12,883W

Plate 2: Power Inverter System

Battery Sizing
Sandia (2004) has discovered that the battery bank should be large enough to provide the desired backup. Battery capacity calculation involves accounting for battery losses (typically 15%), maximum allowable depth of discharge (DoD) and days of autonomy. Although the deep cycle batteries can be occasionally discharged up to 80 percent, but for longer life it is better to keep the routine discharge limit to only 50 percent. Given the unpredictable nature of PV systems, once in a while batteries pay visit to the 80 percent limit of DoD

Plate 3: Set of Batteries inside rack

Design for Energy Stored in the battery
Battery capacity is measured in Amp Hours (200AH).
X (Battery size in AH) x Y (Battery Voltage) = Z (Power available in watt hours
For a 200AH, 12V battery the Watt Hours;
200(X) x 12(Y) = 2400 WH (Z)
This means the battery could supply 2400W for 1 hour, 1200W for 2 hours, the more energy you take, the faster the battery discharges. However we cannot be able to take all the power from a battery as once the voltage drops below equipment's requirements it will no longer be able to power it.

Fig 4: Dry Cell Batteries

Design for Solar Energy Generated from the panel

The final part to sizing your solar system is the solar panels. The power generation rating of a Solar panel is also given in Watts. 28 pieces of 185W solar panel was donated to the College by NITDA (National Information Technology Development Agency, Abuja).

In Theory, to calculate the energy it can supply to the battery, Energy supply by panel = Watts (of the solar panel) x hours exposed to sunshine.

An average FCA Ibadan Nigeria peak sunshine average gives 6.6 hours of sunshine, while lowest sunshine average gives 2.5 hours.

From the equation above;

Energy supplied by the solar panel at peak period = 185W x 6.6Hr = 1221wh

Energy supplied by the solar panel at low period = 185W x 2.5Hr = 462.5

Using the above calculation takes into consideration any losses in the system from the regulator, cables and battery you may be using 15% according to [9].

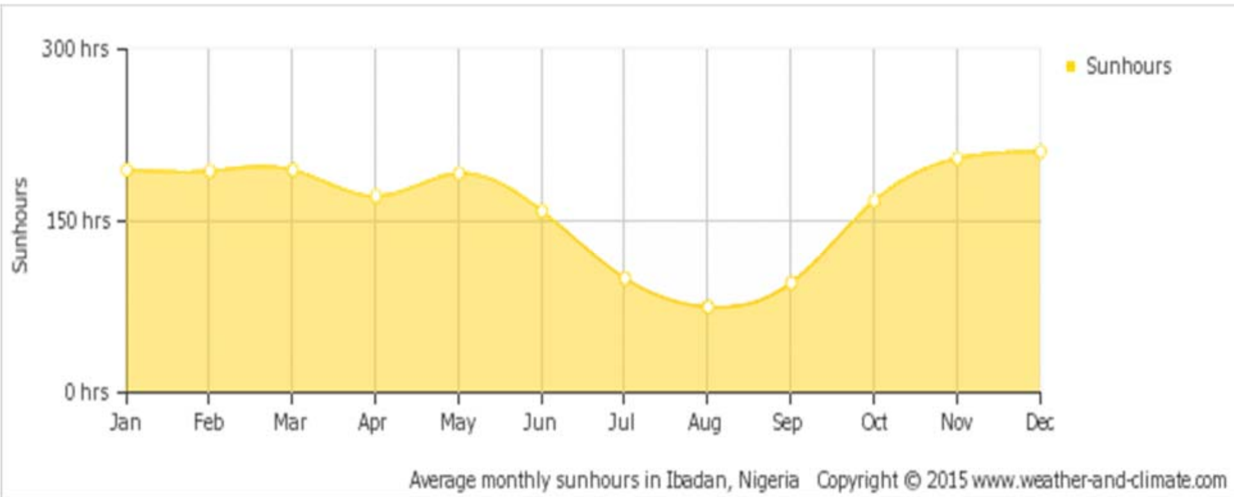

Fig 1: Average monthly sunshine hours in Ibadan Nigeria

Cabling

The length of cable between the panel and the charge controller is 20m. A typical cable with 1.5 sq mm cross section has resistance of about 0.012 ohms per meter of wire length.

Resistance for 20m long = 0.012 x 20 = 0.24 ohm

Voltage drop across the wire;

Applying Ohms law, V = IR

Where V = Voltage drop across the wire (V)

I = Current (A) = 10A

R = Resistance (Ω) = 0.24Ω

V = 10 x 0.24 = 2.4V

Temperature

Solar cells perform better in cold rather than in hot climate and as things stand, panels are rated at 25 °C which can be significantly different from the real outdoor situation. For each degree rise in temperature above 25 °C the panel output decays by about 0.25% for amorphous cells and about 0.4-0.5% for crystalline cells. What it means is that the panels will put out up to 25% less power compared to what they are rated for at 25 °C. Thus a 185W panel will produce only 138.75W in February and December in South West area of Ibadan Oyo State Nigeria where temperatures reach 34 °C.

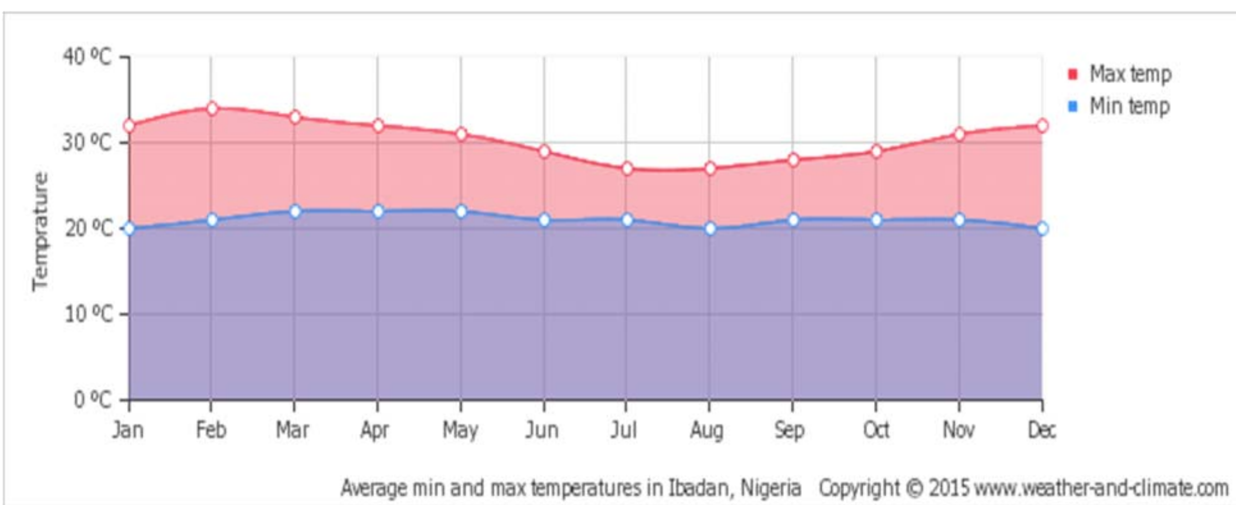

Fig 2: The monthly mean minimum and maximum daily temperature

Solar panels are tested under laboratory conditions, called STC (Standard Test Conditions): at an Irradiance (light) level of $1000W/m^2$ with a temperature of 25 °C. But in the real world these conditions are constantly changing so the panel output is different from the lab conditions. So, another specifications are reported, called NOCT (Nominal Operating Cell Temperature). It is the temperature reached by open circuit cells in a module under the following conditions:

Irradiance (light) falling on the solar panel at $800W/m^2$; Air temperature of 20 ºC; Wind speed at 1m/s; and the panel is mounted with an open back (air can circulate behind panel).

Most good quality panels available today in India have NOCT values of 47±2 °C. Lower the NOCT the better it is expected to perform in hotter climates.

Temperature coefficient of the rated watt power, P_{max}, is another important parameter.

Example: EMMVEE solar panels have NOCT of 48±2 °C and temperature coefficient of rated power -0.43% per K. Moser Baer panels have NOCT of 47±2 °C and temperature coefficient of rated power -0.43% per K for panels up to $125W_p$; their higher power panels have NOCT of 45±2 °C and temperature coefficient of rated power -0.45% per K.

MPPT (Maximum Power Point Tracker) Controller

MPPT controller was used for the research work because besides performing the function of a basic controller, an MPPT controller also includes a DC to DC voltage converter, converting the voltage of the panels to that required by the batteries, with very little loss of power. In other words, it attempts to keep the panel voltage near its Maximum Power Point, while supplying the varying voltage requirements of the battery. Thus, it essentially decouples the panel and battery voltages so that there can be a 24 volt system on one side of the MPPT charge controller and panels wired in series to produce 48 volts on the other. Thus, offering the ability to provide some charging current even in dull conditions when a simple controller would not help much.

The standards specified for charge controllers and power conditioning units by [6] was used (IEC 60068-2 (1,2,14,30) / Equivalent BIS Std.,)

Battery Efficiency

Whenever backup is required batteries are needed for charge storage. Lead acid batteries are most commonly used. All batteries discharge less than what go into them; the efficiency depends on the battery design and quality of construction; some are certainly more efficient than others.

The energy input in a battery during charging E_{in} can be given as

$E_{in} = I_C V_C \Delta T_C$

where I_C = constant charge current

V_C = voltage

ΔT_C = time duration

Likewise after it is discharged at a constant current I_D, at a voltage V_D during a time ΔT_D; the delivered energy is

$E_{out} = I_D V_D \Delta T_D$

Now writing the energy efficiency as $E_{in}/E_{out} = I_C V_C \Delta T_C / I_D V_D \Delta T_D$

$$Energy\ Efficiency = \frac{\mathrm{ICVC}\ \Delta\mathrm{TC}}{\mathrm{IDVD}\ \Delta\mathrm{TD}}$$

There are two types of efficiencies: voltage efficiency (V_D / V_C) and coulomb efficiency ($I_D \Delta T_D / I_C \Delta T_C$)

Since lead acid batteries are usually charged at the float voltage of about 13.5 V and the discharge voltage is about 12 V, the voltage efficiency is about 0.88. In average the coulomb efficiency is about 0.92. Hence, the net energy efficiency is around 0.80

A lead-acid battery has an efficiency of only 75-85% (this includes both the charging loss and the discharging loss). From zero State of Charge (SOC) to 85% SOC the average overall battery charging efficiency is 91%- the balance is losses during discharge. The energy lost appears as heat which warms the battery. It can be minimized by keeping the charge and discharge rates low. It helps keep the battery cool and improves its life.

Solar Panel Tilt Angle

A solar collector or photovoltaic module collects the maximum solar radiation when the Sun's rays strike it at right angles. As the solar collector or module is tilted away from perpendicular alignment to the Sun, less solar energy is received. However, small deviations away from the ideal tilt will not affect energy output much, and may be preferable from an appearance (as along the roof slope) or stability standpoint [7].

The installation of the College hybrid solar system makes use of the stability stand point. The optimal tilt angle for a solar energy system depends on both the latitude of the location and on nature of the application. Angle of 45^0 was used on N-W location with the help of compass on GPS (Global Positioning System).

Staging and Proof of concept

This phase involves the initial actualization of the expert system and design. The hybrid solution design was implemented in a small scale. This involves a simple deployment scenario, to serve as a proof of concept. One of the main benefits of this phase is that it enable us discern the likely challenges associated with the model, enables better trouble shooting, enable us to implement in a controlled scenario before the large-scale deployment.

Implementation and Testing

Having conquered some of the challenges associated with design and staging, the real solution was deployed to the College, whereby the technicians follow the design details for installation and testing. This involves implementing the solution as contained in the low-level design, and as amended based on the outcome of the staging. The installation was also tested in this phase to ensure that it will work as expected.

Table 2: Bill of Engineering Materials and Evaluation

S/N	Description	Specification/ Unit	Quantity	Unit Cost (N)	Total Cost (N)
1	inverters System	15 KVA	2	310,000.00	620,000.00
2	Deep Cycle Batteries	200AH	16	47,500.00	760,000.00
3	Solar Panels	185W	28	120,000.00	3,360,000.00
4	Dc Fuse for Solar system		4	2,000.00	8,000.00
5	Cable for Battery Interconnection (Red & Black)	25mm	6	26,000.00	156,000.00
6	AC cable	2.5MM 3-core	4	5,000.00	20,000.00
7	Solar Regulator	MPPT	2	70,000.00	140,000.00
8	Battery Rack suitable for	8, 12V/200Ah Batteries	3	35,000.00	105,000.00
9	Motorised Single Phase Automatic Voltage Regulator (AVR)	10KVA	4	70,000.00	280,000.00
10	Change Over Switch		2	10,000.00	20,000.00
11	Distribution Fuse board		1	15,000.00	15,000.00
12	Galvanised Solar Frame Structure		1	150,000.00	150,000.00
13	Foundation for Solar Frame		1	35,000.00	35,000.00
14	Grounding System		1	5,000.00	5,000.00
15	Transportation		1	22,000.00	22,000.00
16	Service Charge		1	60,000.00	60,000.00
				Sub-Total	5,756,000.00
				5% VAT	287,800.00
				Total	6,043,800.00

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