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Design Template for a Small Scale Solar Power Plant in Nigeria

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Abstract- This study presents the possibilities for power generation in Nigeria through the utilization of the sun's energy. It highlights the basic science for the design and selection of components for successfully harnessing solar power. The article introduces a concise, rational and practical method of designing a Stand-alone photovoltaic system.

Index Terms- Solar energy, Renewable energy, solar electric (photovoltaic) conversion,

I. Introduction

The changing lifestyle with rapid industrialization has made electricity an indispensable and essential commodity over the years. During the last few decades, increasing prices of electricity with increasing demand and decreasing fossil fuel reserves have raised many concerns for policy makers, investors, and customers. Moreover, existing supply chain also poses a challenge of carbon foot print due to its dependency on fossil fuels like coal and oil for electricity generation [1-3].

To alleviate the concern, policy makers across the world have been looking for some sustainable and feasible alternative input energy sources for electricity generation. They found many options like nuclear, wind, solar, hydro, biomass, tidal, geothermal, and so forth [3-4]. However, literature supports solar energy as it is the most ready and green option available across the world [5]. The report published by Indian Meteorological Department (IMD), Ministry of Earth Sciences, Government of India (GoI) [6] states that: The solar energy received by the earth is more than 15,000 times the world's commercial energy consumption and over 100 times the world's known coal, gas and oil reserves. And this energy is readily available during the day for anyone to tap and that too free and without any constraint. Even though most of the energy of the earth would not be present without the sun, only a few forms of power are considered to be solar power. In the context of renewable energy, solar power is associated with the harnessing of the sun's present emissions of heat or light. Solar power, besides providing heat and light, also causes the wind that we feel here on earth. Winds are created when various layers of the atmosphere absorb different amounts of heat and therefore expand differently. This creates regions of lower and higher pressure, resulting in masses of air that circulate both at ground level and at higher altitudes [7]. Initially used to supply electricity to satellites due to its high generation cost, solar technologies and its potential have improved enough to supply electricity not only to remote locations but also to supplement the national grid power at multi-megawatt levels [8]. Solar panels are made up of solar cells which are an array of photovoltaic cells (PV). Any type of equipment used to convert sunlight into energy is considered solar cell or panels. The technology behind Solar panels has varied widely throughout the five or six decades and while Sola cells were the true origin of modern solar panels, today researchers are shifting to new platform and approaches to gathering energy from sunlight which including crafting solar cells from silicon semiconductor configured to trap and convert sun energy which are coated in an antireflective coating and contained under a glass cover plate to protect the cell from the elements [9]. In the 1950s General Pearson, Calvin Fuller and Daryl Chaplain (of Bells Laboratories) discovered how well silicon worked as a semi-conductor. Silicon is what solar cells and panels are generally made up of today [10]. An ambiguous study has been made of using a solar satellite which is continuously in direct sunlight to collect the energy, convert into electricity and direct a microwave beam to a receiver on earth where it would be reconverted to electricity [2]. How-ever, the cost of such a scheme is likely to prohibit its realization.

Nigeria is blessed with both fossil fuels such as crude oil, natural gas, coal and renewable energy resources like solar, wind and biomass [11]. It has been estimated that Nigerian has about 3billionMWh/year of solar potential, crude oil reserve stands at 40billions barrels as at 2008[12] with a daily average output of 2 million barrels [13]. The one of natural gas represents 5 trillion cubic metres (cu m) of probable gas reserves or 120 trillion standard cubic feet (scf) of proven gas reserves, with 2 billion scf of associated gas produced daily, 1.75 billion scf of it flared and only 12.4% currently being used for commercial purposes, mainly power generation and rejection to enhance oil recovery [12, 13].

In Nigeria, wind and solar-based systems have been getting good response under the conducive environment created through different policy measures. In this paper, our focus is on the development of solar-based electricity supply systems.

II. Data Acquisition and Isolines' Representation

According to Ojosu [14], the LM 300/10 solar recorders and MR-5A pyranometers were used between 1982 and 1986, to measure and record the global solar radiation on a horizontal surface for a network of thirty (30) stations across the country.

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Based on this, average daily solar irradiation values for twenty five (25) city/centres were obtained.

By considering the geographical location of Nigeria and dividing latitudes 4^0N-15^0N and longitude's 2^0E-15^0E into 130 sections will give 1^0 x 1^0 of latitude by longitude as seen in figure 1. On the basis of this division, information on solar radiation data for each section were obtained from satellite – derived meteorological and solar energy parameter tables from NASA [15]. Using the spread sheet and drawing functions of the surfer-8 software.

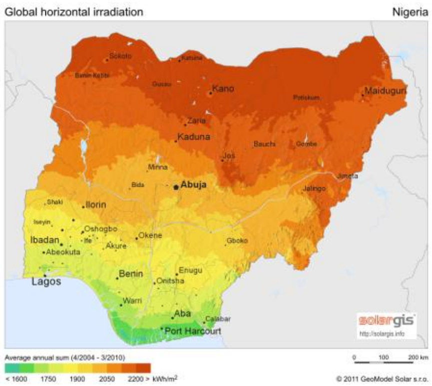

Fig 1 Solar irradiation map of Nigeria [20]

III. NIGERIA'S POTENTIAL FOR SOLAR ENERGY

The daily average solar radiation (KW .hr/m^2.day), for Nigeria which lies between 2^0 E-15^0E longitude and 4^0N-15^0N latitudes, enclosing Nigeria, geographically was determined using average solar radiation data from meteorological centres in Nigeria and satellite-derived metrology and solar energy parameters from National Aeronautics and Space Administration (NASA).

The deviations in results, when comparing solar radiation data from earth (ground) stations in Nigeria with those from NASA are very negligible, the average daily solar radiation on horizontal surface across the country is within the range of 4.5 KW.hr/m^2 in the southern parts to 6.6 kW.hr/m^2 northwards. Using the average daily solar radiation of the entire country, which is 6kW.hr/m^2, taking the efficiency of PVC panel to be 10% and for 1% of the country's surface area (1% of 923768 x 10^6 m^2), about 5545 x 10^3 MW.hr electric energy can be received from solar radiation on daily basis. [16]

The sunshine hours for which solar radiation can effectively be converted into electricity in Nigeria is between the ranges of four (4) hours in the south to about seven (7) hours in the northern parts of the country. With well over 60% of Nigerian rural communities without links to the national grid and those that are connected can hardly boast of six (6) hours of electricity daily, the use of solar radiation through PVC panels may likely alleviate the poor state of power supply and, at the same time, transmission and distribution losses from grid supply will be highly reduced. Employing other renewable energy resources such as biomass, biogas, wind power and so on will also reduce over dependency on firewood as source of heat and cooking, thereby preserving the trees and thus reducing desertification process, especially in the northern parts of the country.

IV. SOLAR ELECTRIC (PHOTOVOLTAIC) CONVERSION

Solar-electric (photovoltaic) conversion is the direct conversion of sunlight in to electricity through a photocell. This could be in a centralized or decentralized fashion. Solar-electric (Photovoltaic) technologies convert sunlight directly into electrical power. Photovoltaic system is made up of a balance of system (BOS), which consists of mounting structures for modules, power conditioning equipment, tracking structures, concentrator systems and storage devices. Photovoltaic conversion could be small scale for stand-alone systems or large scale connected to national grid. Solar cell also referred to as photovoltaic (PV) cells, which as the name implies (Photo meaning "light" and voltaic meaning "electricity"), convert sunlight directly into electricity. Panel stands for a group of modules connected mechanically and electrically. A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays. Photovoltaic cells are made of special materials called semiconductors such as silicon, which is most commonly used. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, al-lowing them to flow freely. PV cells also have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is the current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use say, to power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric fields), defines the power (or wattage) that the solar cell can produce [17]. PV modules are integrated into systems designed for specific applications. The components added to the module constitute the "balance of system" or BOS. Balance of sys-tem components can be classified into four categories [18].

4.1. Deep Cycle Battery store electricity to provide energy on demand at night or on overcast days. They are designed to be discharged and then re-charged hundreds or thousands of times. These batteries are rated in amp hours usually at 20 hours and 100 hours. Like solar panels, batteries are wired in series and/or parallel to increase voltage to the desired level and increase amp hours;

4.2. Inverters are required to convert the direct current (DC) power produced by the PV module into Alternating current (AC) power. Most solar power systems generate DC current which is stored in batteries while nearly all lighting, appliances, motors and so on, are designed to use AC power, so it takes an inverter to make the switch from battery-stored DC to standard power (240VAC, 60Hz);

4.3. Charge Controller A charge controller monitors the battery's state-of-charge to insure that when the battery needs charge current it gets it, and also insures the battery isn't over charged. Connecting a solar panel to a battery without a regulator seriously risks damaging the battery and potentially causing a safety concern. Some systems also require other components which are not strictly related to photo-voltaics[19].

V. Design Procedures

5.1. Energy Requirement: Sample List for DC and AC Load with Inverter Draw!

$$\text{Energy (Wh)} = \frac{\text{Total Power (W) x Usage (h)}}{\text{Efficiency (Decimal)}} \quad \ldots\ldots \quad (1)$$

Established based on your Total Energy Requirement the System Voltage

5.2. System Voltage: choose as a multiple of 12Volts (subject to System Size!)

$$\text{Max Current (A)} = \frac{\text{Total Power (W)}}{\text{System Voltage (V)}}$$

$$\text{Charge Required (Ah)} = \frac{\text{Energy Required (Wh)}}{\text{PV System Voltage (V)}} \quad \ldots\ldots \quad (2)$$

5.3. Select Battery:

Ideal C_{20} 12Volts (available Voltage 2, 6, 12 V_{dc})

C_{20} Battery 100(Ah) ≈=100Ah/20h = 5A for 20 hours

$$\text{Battery Capacity Required (Ah)} = \frac{\text{Charge Required(Wh) xAutonomy(d)}}{\text{Maximum DoD (decimal)}} \quad \ldots\ldots \quad (3)$$

$$\text{No batteries (series)} = \frac{\text{PV System Voltage (V)}}{\text{Nominal battery voltage (V)}} \quad \ldots\ldots \quad (4)$$

$$\text{No batteries (parallel)} = \frac{\text{Battery Capacity Required (Ah)}}{\text{Selected battery capacity (Ah)}} \quad \ldots\ldots \quad (5)$$

Total no battery required = No. of batteries (parallel) x No. of batteries (series) ………….. (6)

5.4. PV Array Sizing

$$\text{PV Array Output Need (Ah)} = \frac{\text{Charge Required (Ah)}}{\text{Battery Charging Efficiency (decimal)}} \quad \ldots\ldots \quad (7)$$

NOCT = 45^0C, G=920Whm^{-2}, T_{amb} = 35^0C, PSH =3.5hours, PV Panel Data: 80Wp, I_{mp} 4.54

Temp. Coefficient Crystalline: 0.5%/^{0}C Amorphous 0.25%/^{0}C

$$T_{cell} = T_{ambient} + \frac{(NOCT - 20)}{0.8} \times G = 35 + \frac{(45-20)}{0.8} \times 0.92kWm^{-2} \quad \ldots\ldots \quad (8)$$

$$T_{cell} = 35 + (25) \times (1.15) = 63.75^0C$$

$$P_{derated}\,(Wp) = f_{temp} \times P_{stc}\,(Wp) = [1-(\gamma_{vmp} \times (T_{cell} - T_{stc}))] \times P_{stc}\,(Wp) \quad \ldots\ldots \quad (9)$$

$$= [1-[\frac{0.5}{100} \times (63.75 - 25)]] \times 80\,Wp$$

$$= 0.806 \times 80\,Wp = 64.5\,Wp_{\,derated}$$

$$V_{derated}\,(V) = \frac{P_{derated}\,(Wp)}{I_{mp}} = \frac{64.5Wp}{4.54A} = 14.21V \quad \ldots\ldots \quad (10)$$

Short Form use: Tcell = T ambient +25C

$$\text{No module in series} = \frac{\text{PV System Voltage}}{V_{derated}} \quad \ldots\ldots \quad (11)$$

$$\text{No module in parallel} = \frac{\text{PV Output Required}}{\text{PV Daily Output}} \quad \ldots\ldots \quad (12)$$

$$\text{PV module daily output (Ah)} = I_{mp} x P_{sh} \quad \ldots\ldots \quad (13)$$

$$\text{Total No of modules required} = \text{No of modules in series X No of modules in parallel} \quad \ldots\ldots \quad (14)$$

$$P_{array\_stc}\ (Wp) = P_{mod\_stc}\ (Wp)\ X\ \text{Total no module required} \quad \ldots\ldots \quad (15)$$

VI. Conclusion

This paper focused on a step-by-step approach in designing a solar power plant that could be used in a variety of areas such as residence, industry, agriculture, schools and hospitals. Employing other renewable energy resources such as biomass, biogas, wind power and so on will also reduce over dependency on fossil fuel as a source of electricity generation which is the main policy backbone of the government.

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