International Journal of Advances in Scientific Research and Engineering (ijasre)

E-ISSN : 2454-8006

DOI: 10.31695/IJASRE.2022.8.1.3

Volume 8, Issue 1
January - 2022

Planning and Installation of 3.5 Megawatts Off grid Solar Hybrid Power Plant: A Case Study of the Joseph Sarwuan Tarka University Makurdi, Nigeria

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ABSTRACT

This report highlights the processes involved in the planning and installation of a 3.5 Megawatts solar hybrid power plant situated at the campus of the Joseph Sarwuan Tarka, University Makurdi, Benue State Nigeria. These processes include Photovoltaic (PV) cells installations, Inverter Installations, transformer installations and the installation of string combiner boxes (SCBs) etc. The solar Hybrid Power plant installed is a hybrid power system that uses a combination of solar PV cells, batteries and diesel powered generators as energy sources to meet the energy need of the various load centers on the University campus. The solar PV cells array serves as the primary power source while the diesel powered generators serves as the power backup. Since the project is a hybrid installation, it becomes necessary to synchronize the power sources to increase efficiency of power supply and a reduced downtime. The back-ups are the three Diesel powered generators labeled (DG1, DG2, and DG3) and the Battery Banks labeled (BBR1, BBR2, BBR3). The secondary power source turns ON automatically when the primary power source fails. During the installation of the primary source, rigid flat framed PV modules made of Poly-Crystalline were used because of its temperature resistive advantage. Twenty (20) PV modules were wired together in series to form a table, two tables connected in parallel to form a String.The result shows that the power of each panel used was 330W while the output voltage varies between 37.5 to 40.5 Volts. The total voltage per table was between 736 to 823 volts during the day. The total number of PV modules installed at the site was 12,140. Three sets of diesel Generators, comprising of two 1 MVA capacity and a 1.5 MVA capacity, all terminated at their respective transformers. Their output voltage is 0.415 kV each, terminating at the Low Voltage (LV) side of their respective transformers. The transformer steps it up to 11kV to supply the High Tension (HT) panel.The Minimum and Maximum PV power and load demand data obtained by the plant Supervisory Control and Data Acquisition System (SCADA) within one year period after installation shows the Maximum and Minimum power at 2.5 MW and 1.75 MW, while the maximum and minimum load demand stood at 850 kW and 350 kW. The average daily power consumption stood highest at 900kW during weekdays and lowest at 200 kW during weekend.

Keywords: *Solar Plant, String Combine Boxes, PV Strings, PV Inverter, Battery bank.*

1. INTRODUCTION

The availability of electricity is the driving force behind industrialization of any nation [1]. However, according to the world energy council, almost half of the world's population has no access to electricity, with majority of these people living in Africa and many part of Asia [2]. The case is not totally different in Nigeria.

In Nigeria, the on-grid energy comes majorly from natural gas which accounts for about 80 percent of the total energy mix. However, due to continuing challenges with grid infrastructure and the environment, a large proportion of the economy is not connected to the grid, while a good population depend on off-grid fossil-based sources such as diesel and petrol.

The aforementioned sources of power generation present many challenges to humanity and the environment such as pollution of harmful gases and green house affect which causes climate change. Therefore, the need for clean, reliable, and renewable source of power supply cannot be over emphasized.

Nigeria is blessed with abundant renewable power resources that are not sufficiently exploited. These renewable energy resources have the capability to change the power landscape of the nation and position the country on the path of industrialization. The availability of renewable power resources in all parts of the country has been demonstrated in many studies. Therefore, it becomes imperative to consider the inclusion of renewable power supply in the energy mix to reach energy sufficiency and reduce the negative effects on the environment while at the same time drive industrialization and economic growth.

Solar energy resource is available in all parts of Nigeria with the average irradiance of 5.535 $kWh/m^2/day$ [3]. The vast expanse of Sahel Savannah in the northern region of Nigeria is a sufficient land space to produce the power that meets the need of the country. With this huge solar energy resource, it becomes possible to generate solar energy sufficient to meet the electricity need of the University community.

This project is the Federal Government initiative to provide alternative source of power supply to the University to create good atmosphere for effective teaching and research.

2.0 PHOTOVOLTAIC CELLS INSTALLATIONS

2.1 Construction of Solar Module Mounting Structure

Solar PV modules are not to be installed on the ground directly, since they are delicate materials. Before installing the modules, tables are constructed with Aluminum materials called the module mounting structures (MMS). The MMS are surfaces that give a perfect angle of inclination for solar PV modules during installation.

The base metal of the MMS stood vertically at an angle of 90 degrees to the ground and the adjacent metal made 12 degrees with the base metal. Before attaching the inclined metal, the base metal was driven into the ground a depth of one meter, and a mixture of concrete and cement solidified the foundation. Figure 1 show the installation of module mounting structure.

Fig 1: Installation of module mounting structure (MMS)

2.2 Installation of Solar PV Module

The heart of a photovoltaic system is the solar module. Many photovoltaic cells are pre-wired together by the manufacturer to produce a solar module. During installation at the site, solar modules were wired together in series to form table. Two tables connected in parallel to form a string. Rigid flat framed modules made of Poly-Crystalline PV were used because of its temperature resistive advantage. The Poly-Crystalline PV cells were thereafter mounted at the different tables of the MMS. The various tables were given unique codes as identifiers to indicate which inverter the tables are supplying. Figure 2 is the project site showing PV installation on MMS while figure 3 is the full view of installed table. Table 1 gives the PV module information

DOI: 10.31695/IJASRE.2022.8.1.3

Figure 2: Project site showing PV installation on the MMS

Figure 3: full view of an installed table

Table 1: PV module information

Module made	Trina Solar
Module Type	Poly-crystalline
No of table at site	607
No of ModulePer table	20
Total No. Of Module at site	12,140
Maximum power	330W
Max. Power Voltage	37.4
Max. Power Current	8.83A
Open circuit Voltage	45.8V

2.3 Installation of String Combiner Box

String combiner box (SCB) is an electric device used for combining strings of solar modules. It consists of a positive and negative bus and an isolator which engages and disengages contacts between the input bus and the output bus. The site was design to contain 32 SCBs. Each SCB carries about tenstrings of solar modules. The output of the SCBs gives 823V which goes into the main control room and terminates at the PV inverter. The output of the inverter is fed to the transformers which steps up the power and sends it to the various load centers. The outgoing cables of the SCBs are single core, 165mm^2 copper insulated armored cables. Figure 4 show the installation and termination of cables at the SCB.

Fig 4: Installation and termination of cables at the SCB

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3.0 INVERTER SECTION

Inverters convert AC current to DC. However, with advances in technology, a great deal of inverters now has the capability of bi-directional energy conversion from AC to DC and vice versa. Industrial inverters with bi-directional power conversion system (PCS) such as the type used for this project incorporate in-built charge controllers with the Maximum Power Point Tracking (MPPT) capability, making it more suitable for our application. The rating among other key factors is put into consideration when selecting the right solar inverter for a power system. For the system under discuss, the inverters were selected such that their combined power rating was not less than 25% higher than the total load requirement of the power system. This is to take care of the power loses during operation.

3.1 Termination of Inverter Transformers Incomers

Two inverter step-up transformers of 2500 kVA capacity respectively were used to step up the voltage from the solar PV modules inverters. Their input is supplied through the Low Voltage side (LV) of 0.415 kV and the output taken through the high Voltage side (HV) of 11kV. The step-up voltage is sent to the Ring Main Unit (RMU) and part of it sent to the PCS for onward charging of the batteries.

4.0 DIESEL POWERED GENERATORS AND STEP-UP TRANSFORMERS

The Diesel powered generators were used at the site for backup purposes. Three sets of diesel generators, comprising of two 1 MVA capacity and a 1.5 MVA capacity, all terminated at the diesel powered generators (DG) transformers. Their output is 0.415 kV and is terminated to the LV side of the DG transformers. The transformer steps it up to 11kV to supply the HT panel through a 3 core, 180 mm^2 cable.

5.0 BATTERY BANK SECTION

The battery converts chemical energy contained within its active materials directly into electric energy and vice versa. This project utilized Valve regulated lead-Acid batteries (VRLA) of 2 V each. The battery bank contains cells connected to form a string. A string has a total of 1098 batteries. A set of three batteries were racked and connected in parallel, giving a total of 336 racks per string. The series connection of all the racks gives each string a total voltage of 732 V. The float voltage for a string is 830V, and we had eight (8) strings in total. The strings were terminated in parallel at the power conversion system (PSC) in the main control room using a single core 300mm^2 armored cables. Figure 5 show sets of three batteries racked, while figure 6 show the batteries arranged in strings. Table 2 gives battery bank information while table 3 gives battery bank information per string.

Fig 5: Sets of three (3) Batteries racked.

Fig 6: batteries connected in strings

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Table 2: Details ofbattery banks information

Battery Bank	*No.of Cell*	*Voltage/string*	*String No.*	*Cell Capacity*	*NO.of String*
BBR1	3,294	732v	1, 2, 3	4100Ah	3
BBR2	3.294	732v	4, 5, 6	4100Ah	3
BBR3	2, 196	732v	7, 8	4100Ah	2

Table 3: details of battery bank information per string

Nominal voltage per cell	2 V
System Voltage	732V
Capacity @C_{10} at 27^0C	4100Ah
Cell/ module Type	2V-4100Ah
No of Cells	366
Float Voltage	816.18V
Boost Voltage	841.80V
Max. Charging Current	1230A

6.0 CONTROL SECTION

The control section contains High Tension (HT) switchboard and the Energy Management System (EMS) that uses Supervisory Control and Data Acquisition (SCADA) System, which is a control system architecture comprising of computer networks, data communication, and graphical user interface for high level process supervisory management. This was installed at the site to monitor energy flow and fault detection. Figure 7 show the installation of the Supervisory Control and Data Acquisition system

Figure 7: Installation of the SCADA system

7.0 LOAD DEMAND AND PV POWER GENERATION

Figure 8 is the graph of power generated from the PV module and the load demand of the University within a period of one year. The result shows the maximum and minimum power at 2.5 MW and 1.75 MW, while the maximum and minimum load demand stood at 850 kW and 350 kW respectively. The daily power consumption stood highest at 900 kW during weekdays and lowest at 200 kW during weekend as shown in figure 9. With these results, the plant can sustain future load demands. Figure 10 is the schematic of the power flow in the system.

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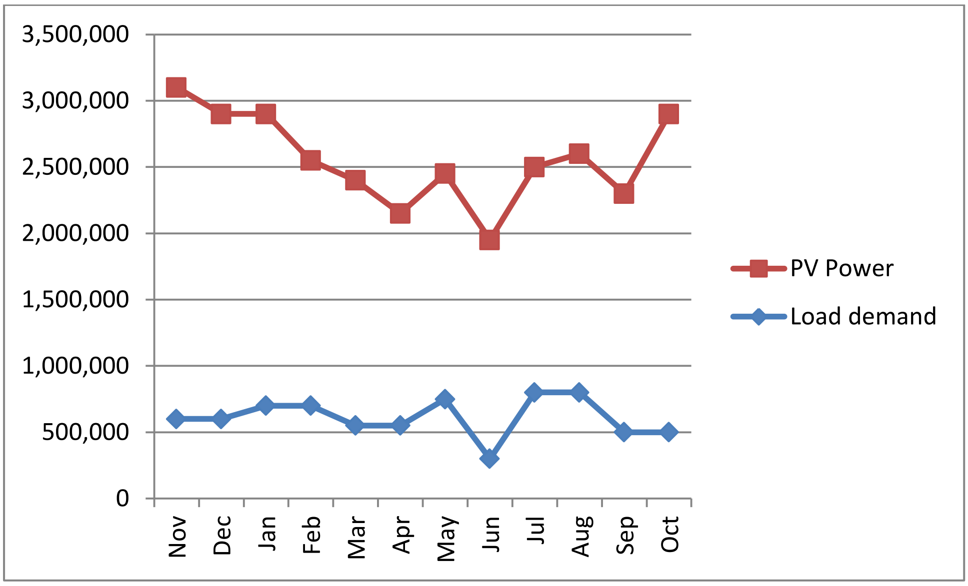

Figure 8: Power from PV module and load demand of the University Over a period of 12 months from November 2020 to October 2021

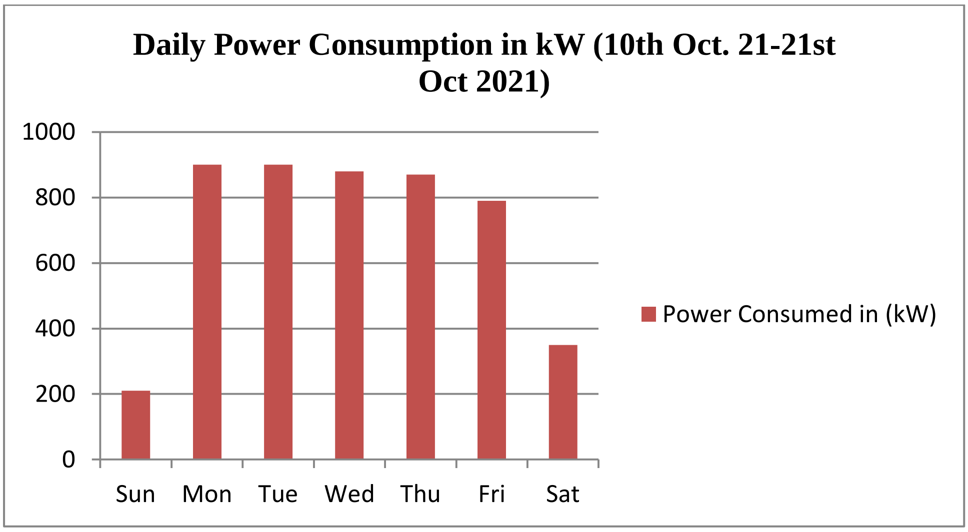

Figure 9: Power consumption of the university recorded between 10th of Oct. 2021 to 21st Oct 2021

DOI: 10.31695/IJASRE.2022.8.1.3

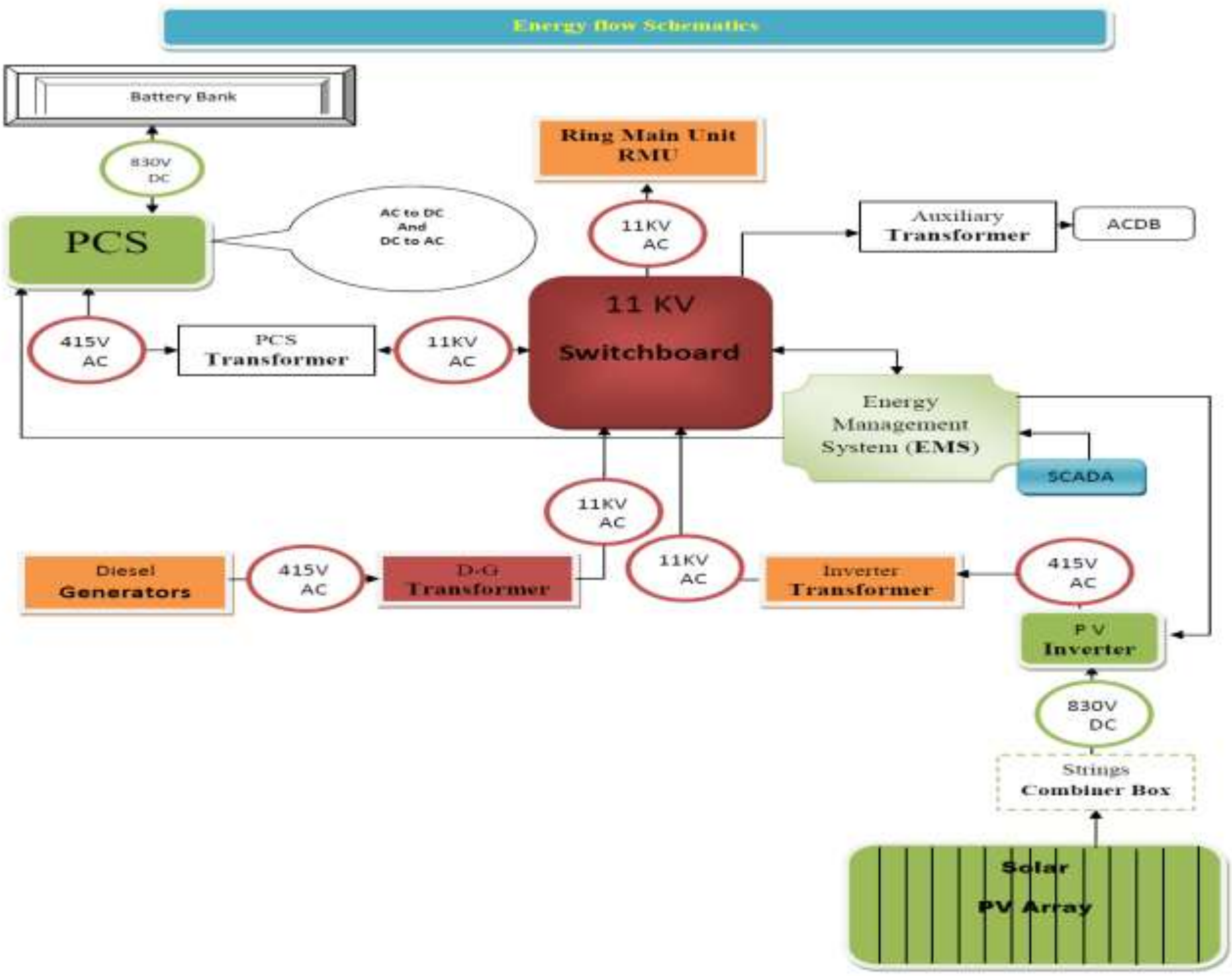

Figure 10: Schematic of Power Flow in the system

8. CONCLUSION

Energy sufficiency is a viable approach in addressing the socioeconomic problems of any nation, particularly in developing countries such as Nigeria. Utilization of renewable energy sources is very key in achieving energy sufficiency particularly where there are abundant renewable energy resources such as solar irradiance. This paper discussed the processes involved in the Planning and Installation of 3.5 Megawatts Off-grid Solar Hybrid Power Plant in Joseph Sarwuan Tarka University Makurdi, Benue State Nigeria to solve the energy need of the University community. The data of the energy generated and load demand over a period of one-year show that the plant can sustain future load demands.

ACKNOWLEDGMENT

I must acknowledge the efforts of Nigeria Rural Electrification Agency (REA), an Agency under the federal ministry of power, works and housing, whose mandate is to increase electricity access to un-served and under-served rural communities. I wish to acknowledge also the Energizing Education Programme (EEP) initiative of the federal Government under (REA) to develop Off-grid captive power plant projects for the generation, and distribution of electric power to federal universities and teaching hospitals for which Joseph Sarwuan Tarka, University Makurdi, Benue State Nigeria is one among the few pilot universities. I wish to acknowledge also the University management under the leadership of the Vice Chancellor Prof Richard Anande Kimbir for providing leadership that enabled the successful implementation of this project.

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DOI: 10.31695/IJASRE.2022.8.1.3