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DESIGN SPECIFICATIONS OF A 5.56 MW SOLAR PHOTOVOLTAIC POWER PLANT IN FEDERAL POLYTECHNIC NEKEDE, OWERRI NIGERIA.

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Abstract

As an indispensable and essential commodity for industrialization, electricity in Nigeria is unavailable, inaccessible, and of poor quality. This paper extensively discussed installing a solar photovoltaic power plant (SPPP) that would meet the energy requirement of Federal Polytechnic Nekede, Owerri Imo State, Nigeria. To alleviate inefficiencies posed by the electricity challenge, a 5.56 MW SPPP design was proposed with regard to the energy demand of the Institution estimated to be 4.275 MW. The project is estimated to require 6.27 Ha (15.49acres) of land area. Again, considering the available land mass of the Institution, this design recommends that the SPPP be sited in Special Use allocation because it is a unique project and the estimated maximum solar field required for the PV is 6.27 Ha (which is 23.8% of the lot for Special Use and 4.52% of the total land mass).

Introduction

Electricity is an indispensable and essential commodity for industrialization. Electricity poverty occurs when supply of electric power falls below demand or expectations (Iwuamadi, Dike and Iwuchukwu, 2014). No doubt the poverty performance of the Nigerian power sector, in terms of matching supply with demand expectations, has led to an exponential decline in the living standard of the population and cramped sustainable development in the country.

In spite the poverty, there is also epileptic technical performance due to many critical shutdowns and fluctuations that occur in power networks affecting many industrial sectors. The education sector is no exception, but the impact of power outages (planned and unplanned) on critical infrastructures like databases, research processes, etc., is somewhat neglected. Institutions now incur very high cost to provide daily alternative source of electricity.

The Federal Polytechnic Nekede, Owerri as an example is currently operating on two major modes of power supply namely utility and local generators. The frequent failures and unavailability of supply from the utility source has made the institution depend mostly on local generators for electricity supply to most of its facilities (Anyaehie and Iwuamadi, 2020). This development has led to the institution running different generators for different facilities and as a result, there are over 27 different generating sets with varying capacities running simultaneously almost daily. The high cost of fuelling and maintenance of these generators can be imagined. The generators have a very high operation cost and are not clean source of energy either. Therefore, there is great need for a sustainable and clean source of energy; solar energy is the largest existing renewable energy source which can meet the energy demand of the Institution.

In this project, a 4.5 MW onsite solar photovoltaic power plant was designed along with the space requirement and economic analysis for the Institution. The Federal Polytechnic Nekede, Owerri is considered as a case study for the design.

Problem Statement

In all sectors of Nigerian economy, it has become evident that there is electricity poverty and technical inefficiency in the power sector. In education, most tertiary institutions with FPNO as a case study, have several generators which are running simultaneously per working day thereby stressing the available financial resources on fuelling and maintenance. The current hike in cost of diesel has advertently reduced the operating hours of generators and this affects performance efficiency of staff and students.

Objective

The main objective of this paper is to analyze and design a 4.5 MW Solar Photovoltaic Power Plant (SPPP) in Federal Polytechnic Nekede, Owerri. This will drastically mitigate the dependency on Utility and existing alternative to cut recurrent cost.

Study Area

The study was carried out in Federal Polytechnic Nekede, situated a little distance off the Aba - Owerri Road, in Owerri North, Imo, 460242, Nigeria which is located at 5° 26' 0.0672'' N, 7° 2' 2.238''E (5.433352°N, 7.033955°E). The Institution has 32 generators with a total installed capacity of *5059.5 kVA* while the functional/available capacity is 3657.5kVA or 3.6575MVA (Anyaehie and Iwuamadi, 2020). The estimated peak load demand capacity of the Institution is 3.42 MW with a projection of sequential increment of 0.855 MW over a period of 5 years at 5% growth rate per annum. The SPPP was designed to accommodate the projected load demand of 4.275 MW.

Design of Solar Photovoltaic Power Plant

The daily average solar radiation $(KW.hr/m^2\ per\ day)$, for Nigeria which lies between $2°E - 15°E\ longitudes\ and\ 4°N - 15°N\ latitudes$, enclosing Nigeria, geographically was determined using average solar radiation data from meteorological centers in Nigeria and satellite-derived metrology and solar energy parameters from National Aeronautics and Space Administration (NASA, 2006).

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 $6\ KW.hr/m^2$ about $5545 \times 10^3\ MW.hr$ electric energy can be received from solar radiation on daily basis (Boyi, Jibril, and Mu'azu, 2006).

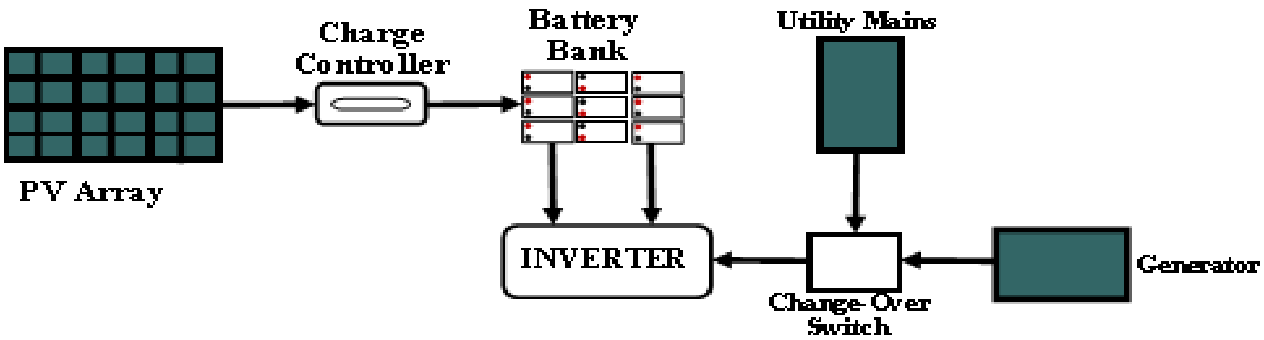

Fig 1: Cascade of an on-site Solar Photovoltaic Power Plant

Energy requirement

The standard efficiency of an inverter ranges from $0.95 - 0.98$ (Chul-Young Park, *et al.*, 2020) and the annual average daily number of hours of bright sunshine is 4.72hrs (4hrs 44mins) while the annual average daily number of hours of possible sunshine is 11.97hrs (11hrs 58mins) (Ekwe, Joshua, and Igwe, 2013). The design used the minimum efficiency for total power and the annual average daily number of hours of bright sunshine

$$Peak\ energy\ consumption/day = \frac{Total\ power \times Usage\ hours}{Efficiency} = \frac{4275kW \times 4.72}{0.98} = 20589.8kWh/day$$

Energy lost in the solar PV system is 30% of its energy (Khelif, *et al.*, 2012), hence, the energy required from PV modules can be calculated by multiplying peak energy consumption in $kW\ h/day$ by 1.3 (the energy lost in the system) to get the total energy requirement which must be provided by the panels.

$$Energy\ required\ from\ PV\ modules\ =\ 20589.8kWh/day \times 1.3\ =\ 26766.74\ KWh/day$$

The value of panel generation factor determined analytically can be obtained using (Onwuzuruike, and Aminu, 2019):

$$Panel\ generation\ factor, \qquad PGF = \frac{f_{PV} G_T}{G_{T,STC}} \qquad (1)$$

where f_{PV} is the derating factor of the PV, G_T is the solar radiation incident on the PV array in $(KW.hr/m^2\ per\ day)$ and $G_{T,STC}$ is the incident radiation at standard test conditions $(1kW/m^2)$. Derating factor comprises of temperatures above 25°C (15%), sunlight not striking the panel directly (5%), not using maximum power point tracking (10%), dirt (5%), and the solar panel being below specification and ageing (10%) (Herb, 2008).

$$f_{PV} = 0.85 \times 0.95 \times 0.9 \times 0.95 = 0.69 \qquad (2)$$

The global horizontal irradiance for the Federal Polytechnic Nekede is $(4.584\ kWh/m^2\ per\ day)$ (Global Solar Atlas, 2022).

$$\therefore PGF = \frac{0.69 \times 4.584}{1} = 3.163$$

Total watt peak rating for modules is calculated using the energy required to be produced from the solar PV modules and the panel generation factor (Khelif, *et al.*, 2012).

$$Total\ watt\ peak\ rating\ for\ modules, P_{PV} = \frac{Energy\ required\ from\ PV\ modules}{Panel\ generation\ factor} = \frac{26766.74}{3.163}$$

$$P_{PV} = 8462.45kW$$

In this design, a polycrystalline PV module with the following specifications is selected for this SPPP: $Model\ type: CS6K - 315MS\ (IEC\ 1000)$

$$Nominal\ Maximum\ Power, P_{max}\ :\ 315W$$

$$Power\ tolerance: 0 + 5W$$

$$Optimum\ operating\ voltage, V_{MP}: 33.1\ V$$

$$Optimum\ operating\ current, I_{MP}: 9.52\ A$$

$$Open\ circuit\ voltage, V_{OC}: 40.3\ V$$

$$Short\ Circuit\ Current, I_{SC}: 10.07\ A$$

$$Maximum\ System\ Voltage: 1000\ V$$

$$Dimension: 1.623m \times 1.048m \times 0.04m$$

$$At\ STC: air\ mass\ 1.5, irradiance = 1000W/m^2$$

$$Cell\ temperature = 25℃$$

$$Maximum\ series\ fuse\ rating: 15A$$

Total numbers of PV modules required in the power plant is calculated using the total watt peak rating required and the PV module nominal maximum power (Khelif, 2012).

$$Number\ of\ PV\ modules\ required = \frac{P_{PV}}{P_{max}} = \frac{8462.45 \times 1000}{315} = 26864.9 \approx 26865\ modules$$

$$Number\ of\ modules\ to\ be\ connected\ in\ series = \frac{1000}{40.3} = 24.8 \cong 25$$

$$Maximum\ power\ voltage\ at\ inverter\ input = 25 \times 33.1 = 827.5\ V$$

$$Total\ number\ of\ PV\ arrays\ in\ series\ for\ 827.5\ V = \frac{26865}{25} \cong 1075\ arrays$$

The size of inverter used in SPPP depends on the total peak watts requirement. The projected total energy required was *4.275 MW*, so the inverter must be large so as to handle the total peak watt requirement of the campus at any time. The inverter size should be 25% - 30% bigger than the total energy requirement of the Institution.

$$Inverter\ size = 4.275\ MW \times 1.3 = 5.56\ MW.$$

$600KVA/380V - 415V/3phase\ PSC\ Solar\ UK\ (KR33600)$ Xantra Online Inverter/Charger Technical Specs is selected for this SPPP. The input dc voltage and output power factor of selected inverter is rated 480V and 0.9 respectively with a frequency of $50H_z$. Also recommended for this SPPP are 12V/220Ah Luminous tubular batteries with MPPT controller of *6MW* capacity.

$$\therefore rated\ output\ power/inverter = 0.9 \times 600KVA = 540KW$$

$$Number\ of\ inverters\ required\ = \frac{Inverter\ size}{rating\ of\ an\ inverter} = \frac{5.56 \times 10^3}{540} = 10.3 \cong 11$$

$$Total\ battery\ watt\ hours\ used\ per\ day\ =\ 26766.74\ KWh/day$$

$$Battery\ loss\ =\ 15\% = 0.15$$

$$\therefore Battery\ remnant, B_R = 1 - 0.15 = 0.85$$

$$Depth\ of\ discharge\ for\ battery\ (DoD) =\ 40\% = 0.4$$

$$Nominal\ battery\ voltage, V_N\ =\ 480V_{dc}$$

$$Total\ battery\ Capacity\ (Ah) = \frac{Total\ battery\ watt\ hours\ used\ per\ day \times Days\ of\ autonomy}{(1 - DoD) \times B_R \times V_N}$$

$$\therefore Total\ battery\ Capacity\ (Ah) = \frac{26766.74 \times 10^3 \times 1}{0.6 \times 0.85 \times 480} = 109341.26\ Ah$$

$$Number\ of\ parallel\ arrays\ of\ battery, N_{PB} = \frac{Total\ battery\ Capacity\ (Ah)}{Battery\ capacity\ (Ah)} = \frac{109341.26}{220} \cong 497$$

$$Number\ of\ batteries\ in\ a\ series\ array, N_{BS} = \frac{V_N}{Battery\ voltage} = \frac{480}{12} = 40$$

$$Total\ number\ of\ batteries = N_{PB} \times\ N_{BS} = 497 \times 40 = 19880$$

Solar field

The land mass required for this SPPP can thus be determined with recommendation that the battery bank will be housed under the PV arrays. The pitch between arrays was designed to be at 60cm.

$$PV\ module\ Dimension = 1.623m\ \times\ 1.048m\ \times\ 0.04m$$

$$Total\ length\ of\ module, L_{Tm} = 1075 \times 1.623m = 1744.725m$$

$$Total\ pitch\ distance\ between\ arrays, L_{Tp} = 1074 \times 0.6m = 644.4m$$

$$Length\ of\ solar\ field, L_{sf} = L_{Tm} + L_{Tp} = 1744.725 + 644.4 = 2389.125m$$

$$Width\ of\ solar\ field, W_{sf}\ =\ total\ width\ of\ module\ in\ series = 25 \times 1.048m = 26.2m$$

$$Solar\ field\ required\ for\ PV = L_{sf} \times W_{sf} = 2389.125m \times 26.2m = 62595.075m^2 = 15.49acres$$
$$= 6.27\ Ha$$

Land Allocation in the Institution

The Federal Polytechnic Nekede Owerri covers a total land mass of 138.78 Ha of which Physical Planning Unit judiciously allocated accordingly to accommodate future growth. Central administration has 4.47%, academic area has 30.75%, and communal use has 12.6% while central use is allocated 1.16% of the total land mass. Furthermore, 14.6% is given for recreation, 8.37% given for housing while Special use and circulation is left with 18.98% and 9.06% respectively.

Conclusion

The feasibility study carried out to install a $5.56MW$ solar photovoltaic power plant that would meet the electricity demand by the Federal Polytechnic Nekede Owerri, considering onsite option reveal that for this power generation, a total of $26865\ PV\ modules$ are required with $25\ modules$ in each row. Also, eleven $600KVA/380V - 415V/3phase\ PSC\ Solar\ UK\ (KR33600)$ inverters and battery bank of $109341.26\ Ah$ containing a total of $19880\ batteries$ are required to supply the power. The solar field required to accommodate these is $6.27\ Ha$ ($15.49\ acres$).

For solar photovoltaic panels it is important to avoid any shading that would reduce energy output. Again, considering the available land mass of the Institution, this design recommends that the SPPP be sited in special use allocation which is $26.34\ Ha$ because it is a special project and the estimated maximum solar field required for the PV is $6.27\ Ha$ (which 23.8% of the lot for special use and 4.52% of the total land mass).

The PV arrays will be arranged high enough as roof shed to surpass any shadings on site in height and to house the battery bank during the pre-planning process. Other factors that affect energy output from PV panels are orientation and the tilt angle of PV.

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