

SOLAR PHOTOVOLTAIC (PV) DESIGN FOR EMBEDDED POWER GENERATION SYSTEM

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Abstract

The recent de-regulation of the Power Utility industry in Nigeria has led to the licensing of Independent Power Producers (IPPs) to attract investment into the sector. The eleven Distribution Network Operator (DNO) Companies are to purchase Electricity as a commodity from the IPPs and Distributed (Embedded) Generation Systems where available. Recent Global Energy Issues are de-emphasizing conventional methods of Power generation to reduce Global warming, now seen as the earth's greatest enemy. A feasibility study of 20KW and 10MW solar photovoltaic (pv) energy supply systems are presented. The bulk power energy supply system keys into the Global trend to reduce the burning of fossil fuels for bulk power generation. The study brings to the fore the equipment, technical and real estate requirements for such clean energy plants for Distributed Power Generation in Nigeria

Keywords. *Embedded Generation, SolarPhotovoltaic, Distribution Network Operators, and Independent Power Producers.*

1.0 Introduction

The next phase of the privatization programme of PHCN would see the eleven distribution companies being owned and managed by independent Distribution Network operations (DNO). Such operators would buy and market electricity as a commodity. It would then be necessary to consider renewable energy options as embedded generation at the local distribution levels.

The PHCN has been brought to a state of collapse by a plethora of problems [3, 4] despite the efforts of the Federal Government to share up the dearth of generation capacity. The problems of inadequate gas supply to the thermal stations, the seasonal drop of water level at the hydro-station and poor transmission and distribution infrastructure has continued to plague the company. Besides, the establishment is heavily dependent on imported technology, a handicap capable of grounding the system in the event of critical component failures. Also, the slow pace of implementation of the on-going privatization programme is introducing an era of lack of drive and absence of clear

ownership structure amongst its workforce. On the other hand as Nigeria attains rapid economic growth and the population increases, the energy needs will soar. The current target of 10,000MW should be far below the energy needs of the country. In consideration of global environmental issues Nigeria should wake up to the utilization of renewable energy resources and solar energy will become feasible options for embedded generation. This paper presents a feasibility study for design and technical issues to be considered in adoption of a 20KW solar pv supply connected to the distribution networks. The system, if developed, should provide a launch-pad for adoption of clean energy plants for distributed generation connected to the National Grid.

2.0 Global Energy Issues

Today's modern societies are maintained by a high consumption of fossil fuels to drive the technology infrastructures. Associated with the depletion of the energy sources are the problems of energy security for the future and global environmental issues.

There is now anxiety in the scientific world over the effect of release of greenhouse gases into the atmosphere. One of these gases is carbon dioxide from combustion of fossil fuel (coal, oil, gas) in conventional power plants. The other are Nitrous oxide, methane, a number of Hydrochlorofluoro carbons and sulphur hexafluoride from petro-chemical reactions. Their effect on the environment include

- (i) Increase in atmospheric temperature
- (ii) Sea level rise
- (iii) Ozone layer depletion

Ozone exists in the stratosphere and is useful for absorbing harmful ultra-violet radiation to protect living beings on the earth. It is depleted by chlorofluorocarbons (CFC) and Halous-chemicals used in refrigerants, aerosol propellants and foam blowing. Ozone depletion results in induction of skin cancer, cataracts, reduction of agricultural yields and exacerbation of urban smog.

High industrialization also leads to high concentration of gases such as carbon dioxide sulphur dioxide, nitrogen oxides, which form acids by reaction with moisture in the atmosphere. They are produced by fossil fuel power generation and Internal Combustion engines. The substances can move beyond boundaries and become regional issues. Nigeria, with a high level of over-used cars and diesel generators, should monitor the effect of these effluents in the atmosphere.

3.0 Sustainability of the National Power Utility

At the inception of the present administration, it was generally agreed that there was need to introduce private sector input to the National Power Utility to the ensure improved efficiency and stable supply of electricity. Privatisation would introduce necessary capital investment which should manifest in power generation and distribution companies marketing electricity as a commodity. However, a number of stakeholders raised the question as to whether private investors would be interested in investing in a comatose power utility and pointed out a number of obstacles to its

effective operation [3,4,5]. These obstacles included:

- Poor standards in Power Distribution Networks
- Dearth of Generation Capacity and inadequate spinning Reserve Capability
- Lack of back-up Technology to support the industry
- Poor Management and high level of instability

The slow pace of the privatization exercise in the last eight years has justified the fears of the skeptics at the inception of the exercise. The present effort of the Federal Government to increase massively the available generation capacity is also addressing the problems identified by the stakeholders. In 2001, two new power plants Afam V and Delta II provided 426MW and an Independent Power Producer, the AES Barge provided 270MW. Also Agip oil IPP in Delta State. The government is funding Chinese Contractors to build power stations at Omotosho and Papalanto in Ondo state, Gereggu in Niger State, Alaoji in Abia State and Delta III to produce a total of 1600MW. The most ambitious programme in boosting the available generation capacity is the on-going construction of seven new power plants in the Niger Delta through the National Integrated Power Project (NIPP) to provide additional 2,744MW to the grid. Three of the projects have been flagged off whilst the rest are billed to take off soon. Newspaper reports say that the NIPP plants might be ready in three years [6].

The Mandibilla pump storage hydro station expected to deliver 2000MW to the system, has reached advanced planning stage. If more companies operating in Nigeria can be made to invest in Power Generation, Nigerians will begin to witness a secure and stable power utility.

These notwithstanding, a number of questions are still being asked about the privatization programme. If PHCN is being privatized, why is the nation putting in so much funds in building new Power Station? Are national interests in the areas of technology development and acquisition

being protected in the arrangements for privatization? As Distribution Network Operators emerge for the distribution networks, it is crucial that Nigerian Engineers are empowered to become players in the development of the sector.

4.0 Considerations for Embedded Generation

Most countries of Europe now have energy policies that seek to reduce carbon dioxide emission from conventional power generating plants in line with the Kyoto agreement. In the UK, the policy seeks to provide 20% of her electricity needs from renewable energy sources by the year 2020 and 50% by the middle of the century. The implication of this is that the landscape of Europe is cluttered by renewable energy plants (winds, solar) mostly connected to the grid systems as embedded distributed generation at the power distribution level.

In contrast, Nigeria with natural endowments of these clean energy has no renewable energy supply system connected to the grid. The prospects of having Distribution Network Operators marketing electricity as a commodity should drive the development of renewable energy systems for embedded generation applications. The basic safety and technical requirements for interface between Public Electricity Supply (PES) Systems and embedded generating plant are specified in Engineering Recommendations G59/1. the embedded generator may be connected in parallel with the distribution network as shown in fig 1. The energy source may also be used as an alternative supply that cannot operate in parallel with the DNO's network.

Other safeguards to be put in place include:-

- (i) The means of synchronization of the embedded generating equipment to the PES system
- (ii) Breakers for connection and disconnection between PES and embedded Generator-System.

If the reactances of the network equipment are specified, the equivalent circuits of Fig 2 are easily obtained. The fault level at 11 KV busbar with the contributions from the

network and the embedded generator installation are determined.

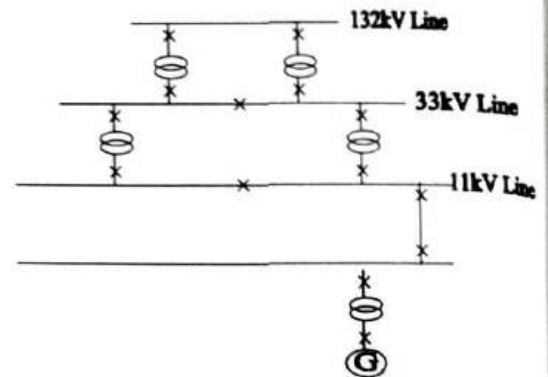
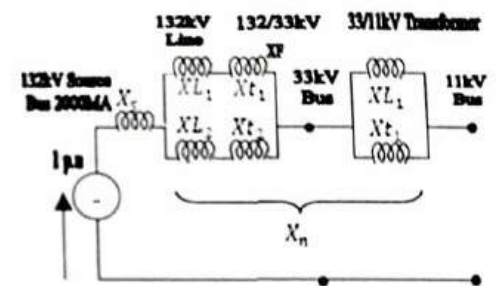
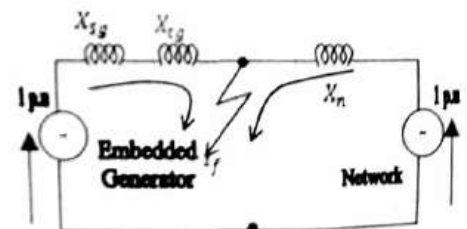


Fig 1: Connection of Embedded Generation to Distribution Networks



(a) Network between 132kV and 11kV busbars



(b) Embedded Generator connected to 11kV busbar

Fig 2: Equivalent Circuits for Fault level calculations

If the figure is above the level specified for planning 11KV systems (ie 95% of 250MVA ie 237.5MVA), then reactances would have to be added to reduce the fault level. If more than one embedded generator is connected to the 11KV busbar, the contribution of each generator should be added to obtain the fault level.

5.0 Current Utilization of Solar Photovoltaic Power Supply Systems

One of the most attractive options of the community adopted Renewable Energy sources is the photovoltaic power technology. It is widely accepted as the clean energy of the future given the global environmental energy issues and is being developed on a large scale for network integration. Energy experts have demonstrated the feasibility of very large scale photovoltaic-system [8] and it has great potential for application in Nigeria.

- Nigeria has an average solar radiation on an average solar radiation on a horizontal surface of about $7.0 \text{ KWhm}^{-2}\text{day}^{-1}$ along the semi-arid areas to the North of the country [12].
- Real Estate problems are easy to overcome in semi-arid regions for large scale solar photovoltaic power plants.
- Step by step development using modularity of photovoltaic-systems make expansion from small to medium scale installations.
- Large scale installations are now necessary given the dearth of generation capacity in the current.

Utilisation of solar-photovoltaic systems worldwide are increasing and cover the small scale, medium scale and large scale groups shown below.

1. Stand alone systems used in solar home applications and lower power applications
 - 4 – 1 KW photovoltaic systems for private dwellings
 - 2 – 10KW systems on roofs of dwellings
 - 10 – 100KW systems in office buildings and schools.
2. About a dozen sites in the world provide 100KW – 1MW from photovoltaic systems, usually established in unused land on the outskirts of urban areas.
3. Solar photovoltaic plants greater than 10MW are established on vast barren unused land with extensive exposure to sunlight. This can become one of

solutions to future energy and environmental problems across the globe.

6.0 Need for a Pilot Large Scale Solar-PV Scheme for Embedded Generation Applications

This paper presents a feasible study including the analysis for a 20KW solar photovoltaic plant for embedded generation at the Federal University Technology Owerri. The energy can be connected to the Engineering Faculty 11KV busbars to supplement the electrical power available in the faculty. The University has over the years suffered from the incessant power supply failures prevalent in the country. When outages occur the available standby of the load demand on the campus research and academic activities are adversely affected in the faculty of engineering. The faculty should take up the challenge of developing the alternative energy not only to augment its power needs but also to serve as a launch-pad for clean energy plants for distributed generation connected to the National Grid in various parts of the country.

On the other hand, Nigeria's leadership role in Africa requires her to lead the way in development of renewable energy, capabilities in developing economies. Such a project at the FUTO will provide a hands-on faculty for teaching and research, which can enhance industrial development.

The University is endowed with a waterfront spanning about 5km which is attractive for sighting renewable energy plants. The project has aesthetic values and is being proposed for other reasons such as

- It can enhance University –Industry collaboration which needs to be encouraged.
- It can reaffirm the position of the University as a source of ideas which lead to development of nations.
- It is a good platform for the consultancy programme of Centre. For Energy and Power System Research CEPSR of the University.

7.0 Design of the 20KW Solar PV Plant

The photovoltaic power supply system is shown in fig. 3 to consist of array of solar panels and an inverter to provide the a.c supply to the network

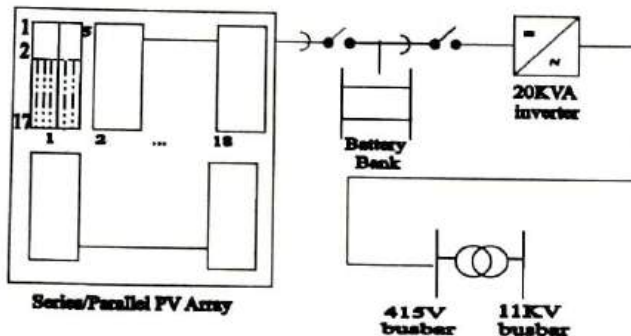


Fig 3: PV Power plant for Embedded Generation Systems

For embedded generation applications, the battery bank and assorted charger regulator will not be required.

Solar radiation in coasted Nigeria = $3.7 \text{ KWhm}^{-2} \text{ day}^{-1}$

Assuming daily load demand of 20KW is weeded during working hours i.e 8 hours a day

System output =

$$\frac{\text{Daily load in watts} + 20\% \text{ system loss}}{\text{Peak sunshine hours}}$$

$$= \frac{20 \times 103 \times 8 + 0.2 \times 20 \times 103 \times 8}{3.7} = 52 \text{ KW}$$

If the inverter output voltage is at 415V

$$\text{Current} = \frac{52 \times 10^3}{415} = 126 \text{ A}$$

Specifying a solar panel that delivers 15V across its length and 1.5A with dimensions of 100cm x 10cm.

Total no of panels required = 2520

The panels are inter-connected in series-parallel arrays of 14 modules and five strings to provide 7 amperes. These arrays are further inter-connected to provide 420V and 126A at the terminals.

8.0 Battery System for 20KW Plant

$$\text{Daily load in watt-hours} = 20 \times 8 \times 1.2 = 192 \text{ KWhrs}$$

For a 50 per cent discharge of rated capacity, the battery size should be based on twice the daily load, giving :

$$\text{Effective daily load} = 2 \times 192 \text{ KWhrs}$$

$$\text{Required output voltage of Battery} = 8 \times 12 = 408 \text{ V}$$

$$\text{Load in Amp-hours} = 384 \times 103 / 408 = 941 \text{ Ah}$$

Dividing by battery charge Capacity of 0.5 gives 1882 Ah

Choosing a low maintenance battery type SP250, 12V and 250Ah,

$$\text{No of batteries required} = 1882 / 250 = 8 \text{ batteries}$$

9.0 Costing for 20 KW Solar-PV System

Although the maintenance and operating costs of solar-photovoltaic supply systems are minimal, the capital outlay for acquiring such systems has been prohibitive and hindered the adoption and popularization of these abundant and free energy sources for power generation. It was shown by Okoro et al [2] that a 480W solar photovoltaic system which only powers a few household items, would cost the same amount of money as a 5-10KVA conventional diesel generator which not only powers all fittings and equipment in a house but also provides power for as long as required. However, the cost of solar panels is dropping rapidly as a result of the efforts being made by the National Agency for Science and Engineering Infrastructure to produce electronic devices e.g solar cells from organic materials. With technological advances and large increase of volume of solar cells being manufactured, the cost of solar systems can be significantly reduced from the present \$4/W to below \$2/W.

The cost of the proposed 20KW, 415V solar photovoltaic supply system for laboratory demonstration of embedded generation include a total cost of ₦6,280,000 is very high when compared with funds available for groups of researchers in the Nigerian University system. It is often necessary for prototypes of equipment and engineering

systems to be developed and tested by researchers in a University laboratory.

Table 1: Cost of the Proposed 20KW 415V Solar Photovoltaic Supply System

S/N	Item	Quantity	Unit Price (₦)	Price (₦)
1.	Solar Panels (50watts panel)	2520	5,000	113,400
2.	Batteries	5	40,000	200,000
3.	Diodes	-	-	-
4.	Battery Charge Controllers	-	-	200,000
5.	20KW, 415V Inverter	-	-	4,000,000
6.	Solar panel connectors	-	-	-
7.	Panel combiners/Junction boxes	-	-	-
8.	Steel L and T bars to support solar panels	300 lengths	-	300,000
9.	140A cables for inverter output	100m	-	-
10.	Digital Oscilloscope	2	-	1,000,000
11.	Laboratory Computers	2	-	500,000
12.	Software packages for power system analysis	-	-	780,000
13.	415V/11KV Power Transformer	1	-	4,000,000
14.	Total			6,280,000

The facility professionals who would go to install the systems at identified locations. Such projects can be easily funded if it is accepted by policy makers as national priority objective.

10.0 Design of Very Large Scale 10MW Solar-Photovoltaic Plant for Bulk Power Production

A design for 10MW solar-photovoltaic plant is captured by the diagram of Fig 4. The total number of solar panels required would be $5 \times 17 \times 6400 \times 2$. If the low maintenance battery type SP250, 12V and 250Ah is to be

used, a total no of 3768 batteries would be needed. The total cost of the panels alone run into billions of naira. Such a large plant can be developed in 100KW modules which are easily connected in series-parallel to achieve the 10MW plant.

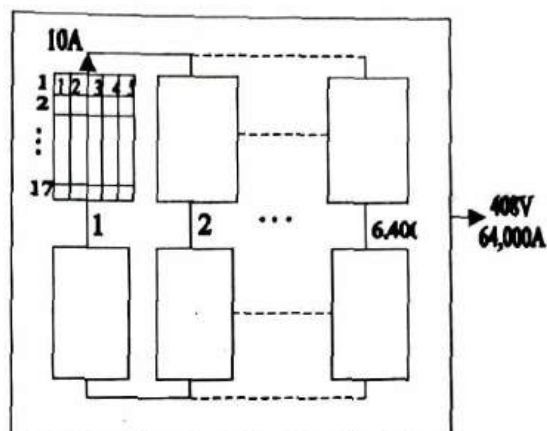


Fig 4 Series- Parallel PV Array for a 10MW Plant

11.0 Conclusions

An evaluation of requirements for development of solar-photovoltaic supply system has been presented for a 20KW, and 10MW plants. The cost remains prohibitive but there is some possibility that the cost will reduce significantly as the volume of solar panels being manufactured increase. The cost of any project can also be brought down if some of the technology and system development are done using local capability. With the present attention on Global Energy Issues, the cost of solar panels will crash to affordable levels for developing economies. Technology Development Centers such as the Nation's Schools and Faculties of Engineering should be given the challenge to supplement their power supply systems using our abundant solar energy.

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