Reliability Analysis of Switched Stand Alone Hybrid PV-Diesel Generation Power System for Rural electrification in Nigeria

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Abstract: There is a need for an action plan for achieving photovoltaic power generation capacity in Nigeria. The total irradiation of 5.5kW-hr/day/ m^2 (ECN-UNDP, 2005) of solar radiation in Nigeria is not utilized for PV generation. The integration of Solar PV grid technology into the Nigerian grid systems will provide an attractive environmentally sound technology options for the Nigerian Electricity industry, it could offset a significant proportion of the foreign exchange that is used annually for importing Power generators, and its associated accessories such as diesels, oil, spare parts, etc. In addition PV grid integration is well suited for meeting the recent directive by the federal government of Nigerian for Local government Sectors to generate its own electricity

The 5.5kW-hr/day/m^2 represents a huge prospect for solar energy generation if a total capacity can be developed for PV grid integration. This paper proposes using experimental models and control strategies, a large scale introduction of solar power (PV) into the Nigerian distribution grid. Counter measures for harmonics will be developed and demonstrated. The output from the PV systems and its associate problems such as Pulsating AC signal will be analyzed and demonstrated. We will evaluate the impact of a of PV penetration on the optimum economical design by using general purpose components for main circuits, switching elements and switches and selection of operating capacity that takes maximum advantage of the capacity of each element and solar irradiation capacity. The assessment of the best practice for program design and implementation will be observed.

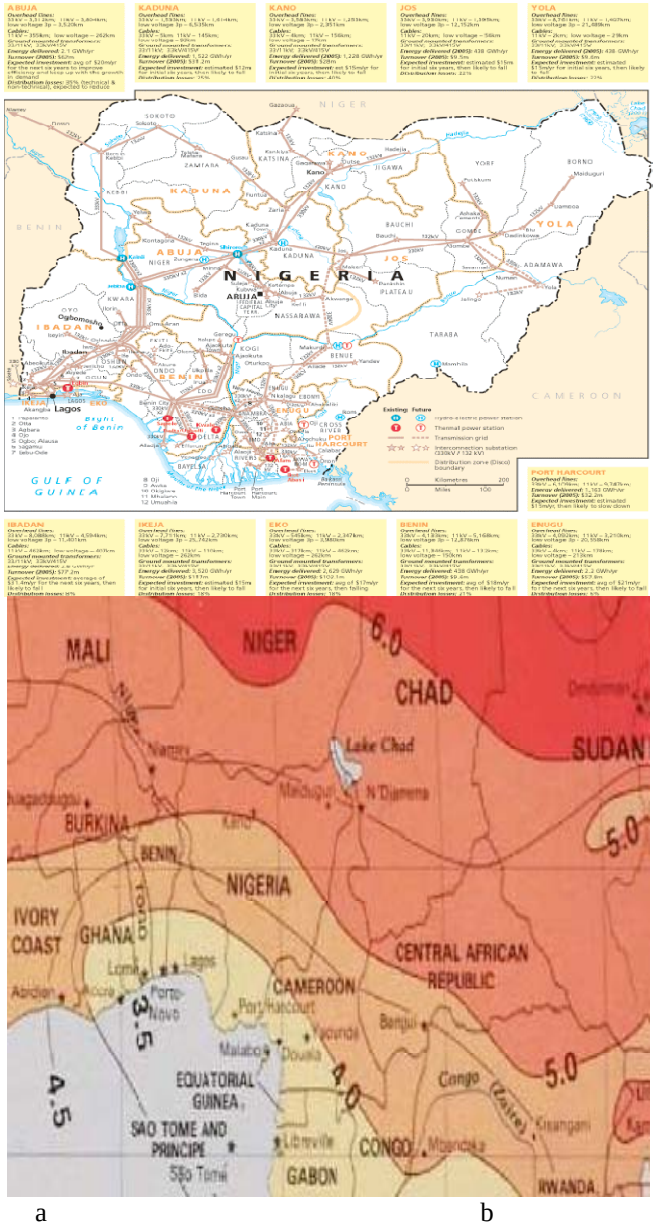
Keywords: Hybrid, Distributed generation, Stand alone, mini-grid, REB

1. Introduction

Rural electrification is a basic service required for development, and this has been carried out extensively both through grid extension and distributed generation through diesel operated Microgrids heavily subsidized by the federal government of Nigeria. The Nigerian rural electrification projects are in line with the government's goal of improving the quality of life of Nigerian rural dwellers and empowering them under the national Poverty Eradication Programme, the National Economic Empowerment Development Strategy and the Millennium Development Goals. The rural populace is currently groaning under acute shortage of electricity as over 80 million have no access to this basic necessity. Several rural communities in Nigeria, mainly in the Northern region of the country are located a considerable distance from the national grid systems, with scattered population and low electricity loads. The most common barrier for extension of electricity to this rural area is the high cost of grid extension making grid extension not feasible. Despite the provision of 23.3 billion Naira (about 0.18 billion dollars), for the year 2007, to the rural electrification agency for various project under its mandate, with the growing cost of transmission and distribution material and also the shortage of available generating capacity and low tariffs for rural area, there is little incentives for the Agency to champion an expansion programme. An immediate cost effective solution

Received: November 27th, 2012. Accepted: December 7th, 2012

to providing electricity supply to this community is through the installation of Distributed generation (off-grid supply) system, such option include decentralizes electricity generation using small autonomous power plant running renewable and non renewable options. Presently Electricity generation for such rural dwellers are generated using high speed, high quality small diesel generators. But with the advert of deregulation in the oil sector in Nigeria, diesel purchase (Figure 11) and transportation is now very expensive. This diesel operated power plants are now only often used for 5-7 hours daily. Furthermore most of the generating plants are oversized, therefore are underutilized, hence poor efficiency. The efficiency of diesel generators is proportional to the size of operating load. Manufactures recommends that diesel generators should be operated at between 80–90% of rated full load to produce Max-efficiency.



a b

Figure 1. (a) The Structure of the Electricity Grid In Nigeria and (b) Average low peak sun in Nigeria

Though the initial purchase coat of this generators is low, the running cost, fuel, maintenance cost, low usage and underutilization, translate to very high. With this draw backs, this option becomes less attractive, it no longer provides the adequate incentives to realize the benefit of this option. However, this rural areas has a high solar energy potential, where the average solar radiation intensity on horizontal surface is 6.5 kWh/sq M, while the total Sunshine hours amounts for a study area is indicated in Figure. 3c below. Therefore a hybrid system comprising of a PV Solar and Diesel generating power system is an excellent solution for electrification of these rural systems.

This paper will try to design and develop a hybrid –PV diesel power plant for distributed generation requiring no upgrade for transmission facility and greatly reducing transmission and distribution losses and the need for transmission lines to transverse long distances and sometimes difficult terrain it will identify the current economics of hybrid –PV diesel power plant for rural electrification in Nigeria and issues associated with achieving a large penetration of Hybrid-PV diesel power system in Nigeria. The goal of the study is not only to evaluate the feasibility of Hybrid PV penetration on the Nigerian rural electrification network, but to establish the cost target which will serve as incentives for solar PV energy generation in Nigeria.

2. The Existing REB Distributed Electricity supply System

A single line diagram of the REB Distributed Supply for Rural (Village) Power is shown in Figure 2 Below. These Villages ranges from a cluster of few houses up to a few hundreds, the electricity needs of these villages is usually solved with diesel generating sets and microgrid, comprising of have two Generators G1 and G2. The generators are operated alternately and a manual load transfer switch is used to change the load from one generator to the other. The Low Voltage from the generator is stepped –up to 11Kv via a 100KV step-up transformer for re-distribution through an 11Kv distribution Mini grid network to the communities via an 11/0.415Kv 100KVA distribution transformer for low voltage distribution the Generators operates between 17: 30 hrs to 24:00 hrs, the diesel generator operates usually for 6:30hrs daily. Daytime electricity supply is provided by individual consumers using Petrol generators. In the arrangement for the rural electrification project, the state government provides the complete town distribution network plus one generator while the local government council provides the second generation set, the generator house and the perimeter fencing of the power station. In the operation of the REB station, the state government provides the technical manpower to manage the stations, while the local government provides the operating materials, such as fuel, lubricants and other spare parts. However several factors affects the smooth operation of these REB stations, major constraints include, the high cost of Fuel, lubricants, spare parts leading to high operating cost. Secondly the non availability of access road during the raining season period from June to October period, when the local roads are flooded for several days hindering delivery of the necessary fuel and other materials necessary for the running of the generating station, so it is not usually possible to run these generators daily for electricity supply which leads to further limits its performance. But this has been accepted as the only option available and with the promise that grid extension electricity will someday get to this Villages. Though this system has a low initial investment cost, it has a high operating cost which leads to not operating the service.

This results to:

- the community spending large amount of their scarce financial resources for alternative energy sources including provision of Small stand-alone Petrol generators for individual houses, Kerosene lamps, candles and so fort
- Spending so much time collecting wood fuel

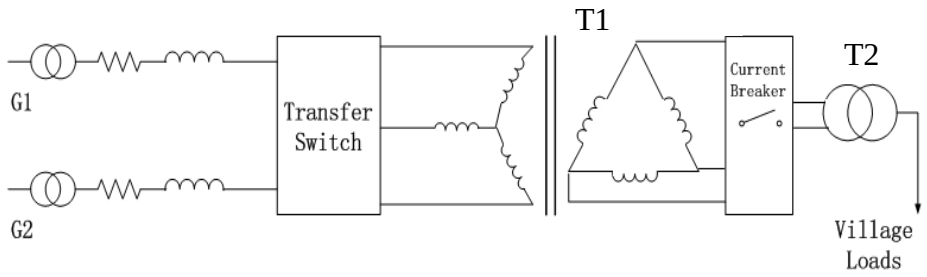


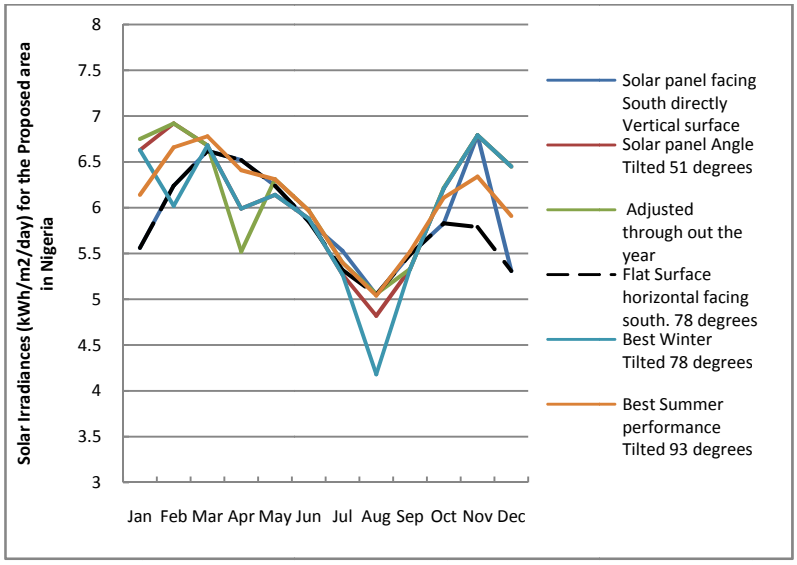
Figure 2. Single Diagram of the Exiting Diesel sets Mini- grid Power system

These communities have no proven deposit of crude oil, natural gas or large body of water. However they are blessed with abundant sunshine and solar radiation, (as shown in Figure 2 below) , thereby providing it with huge potential for both storage/non storage small autonomous solar power generation system for electricity supply with a complementary diesel Generator . The periods coincide with the daily solar irradiation period of this area.

The objective of this paper, is to explore the possibility of a Hybrid solar PV/Diesel Power system as an autonomous (stand alone) System for the REB electrification in Nigeria. It will focus on a Distributed system REB generation setup in several parts of rural communities in northern Nigeria, and presents feasibility to the accelerated use of hybrid solar /diesel generation System for electricity supply for these areas. It will present a Diesel/PV generation systems as a better alternative with considerable for cost reduction on the life time compared to the diesel operated REB Stations. Integrating the PV system into the Nigerian rural autonomous generation system is a suitable way to introduce renewable

3. Case Studies

Naturally it is difficult to design to design an energy system where solar power is the only source of energy, primarily because of the fluctuations of the solar radiation, which brings about the problem of intermittence and requirement of back-up (battery or fuel cells) which is very expensive. A combination of the solar system with other technologies such as diesel powered systems often called a hybrid system is a better option. It has the advantage of balance and stability, and the advantage of alternative source thus not minimizing output due to peak load demand or seasonal Changes. Although Nigeria lies usually within the tropical zone the climate condition of the study area is mainly of a short wet raining season and prolong dry season. With sunshine through the atmosphere and little cloud cover from the sky. The Proposed Village area is predominantly desert region with high wind speed, the average solar insulation over the area is about 6.5kwh/sqM/year. There are many clear sunny days in a year. Figure 2 below shows.



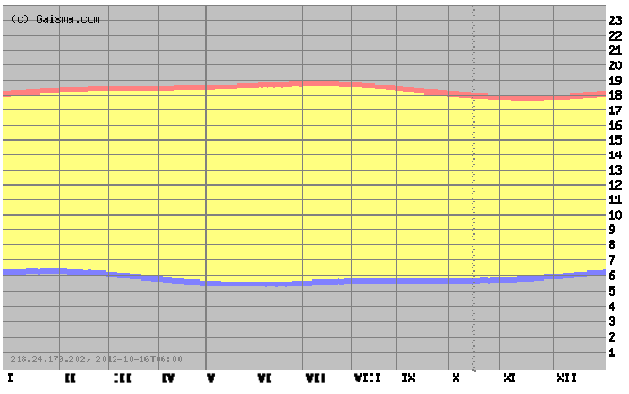
a.

Jan	5.56	6.63	0.00	5.56	6.63	6.14
Feb	6.24	6.92	6.92	6.24	6.02	6.66
March	6.62	6.68	6.68	6.62	6.68	6.78
April	6.52	5.99	5.52	6.52	5.99	6.41
May	6.24	6.14	6.31	6.24	6.14	6.31
June	5.85	5.88	5.97	5.85	5.88	5.97
July	5.53	5.27	5.40	5.32	5.27	5.40
August	5.05	4.82	5.06	5.05	4.18	5.04
September	5.49	5.33	5.33	5.49	5.33	5.52
October	5.83	6.21	6.22	5.83	6.21	6.11
November	6.79	6.79	6.79	5.79	6.79	6.34
December	5.31	6.45	6.45	5.31	6.45	5.91

b

*1 2 3 4 5 6

Figure 3a and 3b. Solar Irradiances (Measured in kWh/m2/day) measured for the Study area



c.

Annual Daily Sunshine hours for the Study Area

The study was carried in one areas of northern Nigeria as indicated in Figure.3 This community like many others is not connected to the Nigerian national Electric power grid, and transportation is mainly through rural feeder roads which are not well developed and un-motor able for several days during the rainy season. The only means of electricity supply is though the REB provided Diesel Generators supply through a micro- Grid as Shown in Figure. 2, and several other individual generators, Attempts was made to carry out a survey on the daily load demand study of the area is shown in Table 1, average load study carried is as indicated in Figure. 4. A survey of the solar energy potential the survey illustrated in Figure 3a and 3b illustrates the annual solar irradiation per meter square for 2011 of t area was acquired through Data acquisition recorded Nigeria metrological Agency (NIMET). The record proved it has a good solar energy production potential.

Based on the energy consumption Patten of the study area, the paper will try to optimize an innovative Switched hybrid system combining, Diesel fired and solar PV generators on the existing Mini-grid system.

A. Estimated Daily Load Demand of the Study Area

The estimated daily load demand and profile of the study area is indicated in Table 1 and Figure 4.

Table 1. Estimated Daily Load Demand Table

Load Type	Estimated No. of Customer	Estimated Connected Load(kW)	Total Load (kW)	Hours of Usage per Day	Estimated Daily kWh	Estimated Monthly (kWh)
High-demand Customer	20	0.7	14	8	140	4200
Medium-Demand Customer	32	0.35	11.2	8	89.6	2688
Retail Shops	3	0.5	4.5	6	27	810
Low-demand Customer	75	0.2	15	7	105	3150
Corn Mills	1	2.5	2.5	6	15	450
Tomatoes Mills	2	1	2	8	16	480
Shoe repair shop	1	0.4	0.4	6	2.4	72
Mosque	2	0.8	1.6	6	9.6	288
Primary School	1	2	2	6	12	360
Health Centre	1	3	3	8	24	720
Water Bore -hole	1	1.85	1.85	6	11.1	333
Workshop (Carpentry/Welding)	2	4	8	10	80	2400
Police Station	1	0.5	0.5	6	3	90
Black-smith Shop	1	0.2	0.2	10	2	60
Total	143	13.2	66.75	101	536.7	16101

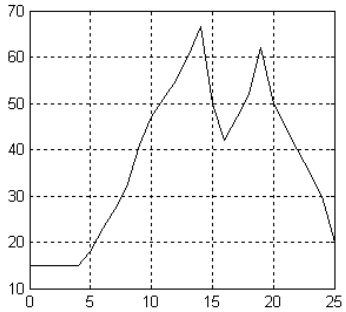


Figure 4. Estimated Daily load profile of The Study Area

4. Experiment Setup

In other to investigate the feasibility of Integrating the PV system into the Nigerian rural autonomous generation system, it is required to demonstrate the impact of the PV generator output on frequency, Voltage, current, power on solar Irradiance. A PV generation system was setup in The Dalian University of Technology Power System Lab.

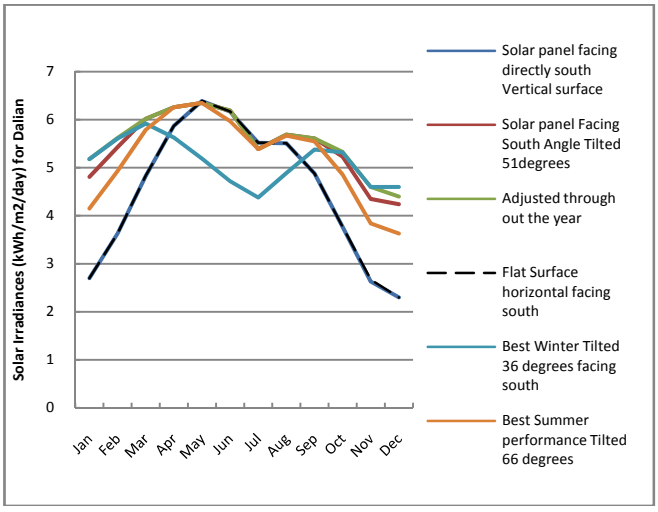
Figure 6 and Figure 7 below shows the schematic diagram of the experimental setup to Test PV generating Unit. The circuit diagram shows the physical arrangement o of the experiment. The test equipment consists of:

1. 4 Nos. 80 watts solar Panel
2. Nos. 24V 300 watts Inverter without harmonic filter and AC Voltage regulator
3. 1 Nos. 24 V 1000 watts Inverter with harmonic filter and AC Voltage regulator
4. 24VDc-DC Boast Converter
5. Solar Radiation Meter
6. Fluke 1735 Power Logger analyst
7. Laser Temperature Measuring meter
8. 4 Nos. Mismatch losses and blocking/Bypass Diodes
9. 100 Watts Load

Jan	2.70	4.81	5.18	2.70	5.18	4.15
Feb	3.63	5.43	5.62	3.63	5.61	4.93
March	4.83	6.02	6.02	4.83	5.92	5.79
April	5.87	6.26	6.26	5.87	5.63	6.26
May	6.39	6.35	6.35	6.39	5.19	6.35
June	6.17	6.19	6.19	6.17	4.72	5.97
July	5.52	5.39	5.39	5.52	4.38	5.39
August	5.51	5.69	5.69	5.51	4.89	5.67
September	4.88	5.61	5.61	4.88	5.38	5.55
October	3.77	5.23	5.33	3.77	5.32	4.86
November	2.63	4.35	4.60	2.67	4.60	3.84
December	2.30	4.24	4.40	2.30	4.60	3.63

* 1 2 3 4 5 6

a.



b.

Figure 5a and 5b. Annual Solar Irradiances (Measured in kWh/m2/day) for Dalian

The PV array has a power output of 320W, a rated voltage of 16 -23V and rated current 14A, Inverters input voltage are standardized at 12V, 24V, 48V, therefore a 24V boast converter is used to boost the voltage to the input voltage level of the 24V 300 W commercially available inverter, and the 24V 1000W Inverter specially built with Filters and Voltage Regulation circuit. Four (4) diodes were used as in Figure 6 and 7 for mismatch losses and locking/pass to avoid mismatch losses due to no uniform illumination of the array or because different modules in the array have different parameters. The connection is completed with a 100W load. In the experiment a Fluke 1735 Power Logger Analyst Instrument to measure Vpv, Ipv, Vac, Iac, PF, Freq, THD. A solar Irradiance meter and Laser Temperature measuring instrument were used to monitor and measure the solar irradiance and temperature respectively. Figure 5 is the Average annual solar irradiance table of Dalian. The experiment was setup in Dalian.

As shown in Figure 6 and Figure 7, the output voltage from the solar panel varies from 14v-22v DC due to function in solar radiation, low solar radiation results in low voltage while higher solar radiation increases the voltage output. While inverter inputs are standardized to 12, 24, 48 volts respectively, for this experiment a 24V boast converter and a thyristor based line commutated inverter (TLCI) was used in the experiment because of its modest cost, availability for higher power and familiarity with technology.
Used. Two experiments were carried with two different inverters.

The following Data were also observed , the solar irradiance in W/Msq, the DC voltage of the panels, the current (I) and the temperature in degrees centigrade (C) reading of the panels is as indicated in table 2 below :

Panel No.	Vdc	I	W/Msq	Temp(c)
1	15-20	0.23	606	21
2	15-19	0.33	553	22
3	15-21	0.40	643	27
4	15-22	0.28	673	20

Table 2. DC voltage, current and temperature of the Solar panels as a result of the Local Solar Insolation (Dalian China)

Several experiment were carried out Several Loads ranging from 25W, 50W, 60 W, 75W, 85 W. and 100W load were connected to the PV Generator. It was observed that beyond 100watt load with the solar irradiation level recorded in table 2. The Voltage profile of the System dropped significantly. The Maximum Solar Irradiation level recorded during the Experiment was 673w/Msq

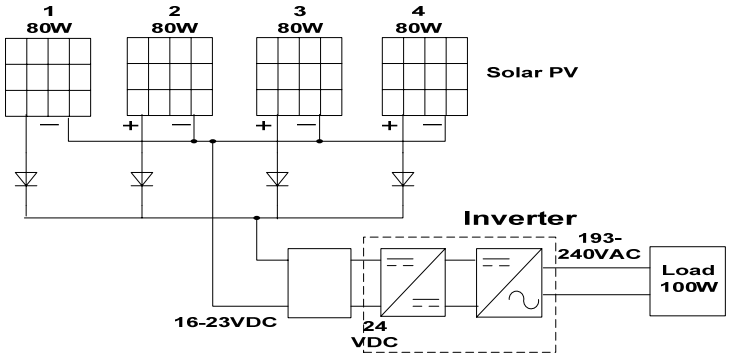


Figure 6. Single line Diagram of the PV generator without Harmonic filter and voltage regulation Unit

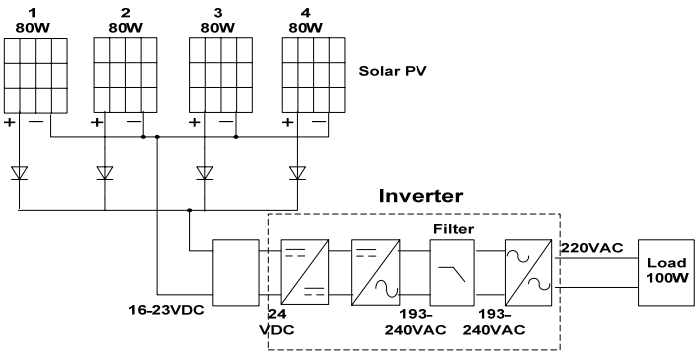
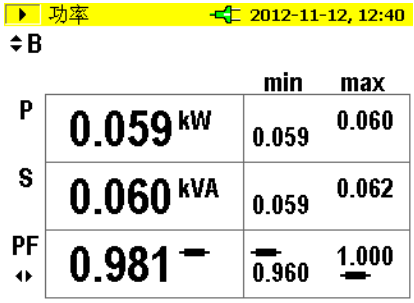


Figure 7. Single line diagram of the PV generator with Harmonic filter and voltage regulation Unit

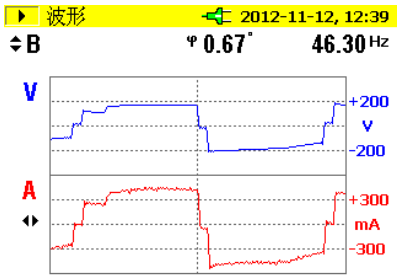
Figure 8 and 9 below shows the experimental result of PV generation. An essential part of the autonomous PV generator is the means of converting the dc from the solar array into ac power supply to the utility network. Inverters are used to perform this task

A. Experiment Results

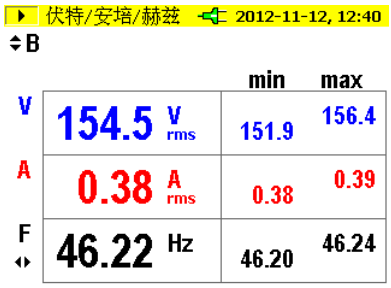
Case 1. PV Generator With no Harmonic filters and Voltage regulation circuit, the result is as indicated in Figure 8a, b, c and D below, The wave shape of the current flowing into the load and the voltage across it is distorted Figure 8b, it contains large amount of harmonics components and is a deviation from normal sine wave. The output signal is pulsating with a Minimum and Maximum values as shown in table 3.



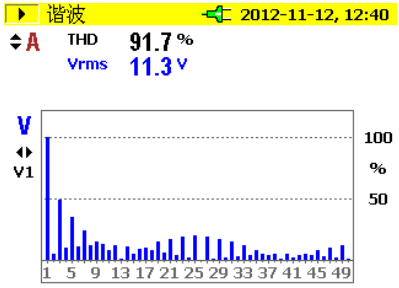
a. output power



b. output signal waveform



c . Output current and voltage



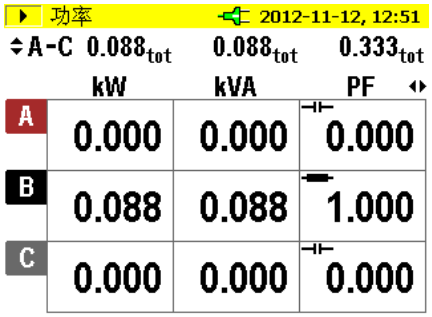
d. THD and Vrms

Figure 8. Ac Signal Output of PV Generator Without harmonic Filter and Voltage Regulation circuit

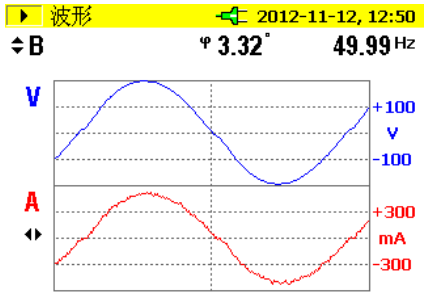
	Min.	Max.
Voltage (V)	151.9	154.5
Current (A)	0.38	0.39
Frequency (Hz)	46.20	46.24
Power factor	0.960	1.000
Power (Kw)	0.059	0.060
Power (Kva)	0.059	0.062
THD	97%	
Vrms	11.4	

Table 3. Ac signal of The PV generator without harmonic Filter and Voltage Regulation circuit

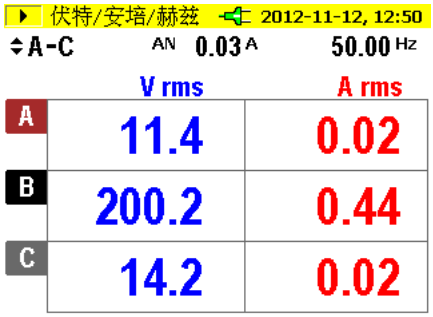
Case 2. An inverter with a harmonics filter and voltage regulation circuit is used, the result of the AC output signal across the load is indicated in Figure 9 below.



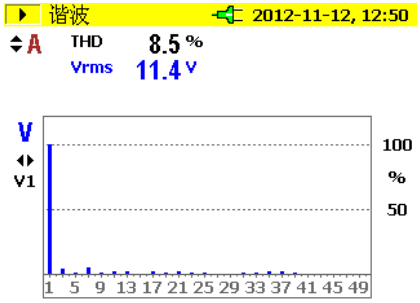
a. output Power



b. Output signal waveform



c. output current and voltage



d. THD and Vrms

Figure 9. AC signal Output of PV Generator With harmonic Filter Voltage Regulator

Voltage(v)	200.2
Current (A)	0.44
Frequency(Hz)	49.99
Power Factor(PF)	1.000
Power (Kw)	0.088
Power (Kva)	0.088
THD	8.5%
Vrms	11.4

Table 4. Ac signal of The PV generator with harmonic Filter and Voltage Regulation circuit

Using an improved version of the inverter with a filter and voltage regulator unit, the inverter current and voltage output is a sinusoid with frequency of 49.99 Hz which is approximately equal the utility frequency of 50Hz, the Harmonic is reduced to 8.5%, and the power factor is unity, while the Power has increase to 0.088 Kw.

5. Hybrid Systems Instead of Diesel Generators

Hybrid systems are basically a combination of two or more different but complementary energy supply system in the same site. A hybrid system will provide relatively constant electricity at an affordable cost even when one of the supply systems is unable to generate power. Typical hybrid system is Diesel/windmill, Diesel PV, Diesel/Windmill/ PV and so Forth

The expansion of photovoltaic systems and its integration on electricity network in most countries can be attributed to effort by Federal, states and local governments of these countries to promote both investment on solar PV generation for both stand-alone and grid connected PV technology, and public perception of PV technology improvement in the manufacturing process and considerable reduction in the cost of installation of these PV systems. Solar PV systems are more cost effective on a lifetime basis for Small Autonomous Power systems than diesel generators in situation where loads are low and very far from Transmission grid. However the threshold distances depends on the technology, power level, prevailing cost of equipment, fuel, operating and maintenance cost. The decentralized REB power stations in Northern Nigeria, it low power demand of the rural loads is adequately suited for the stand alone non-storage Solar PV Systems.

Integrating the PV system with the Diesel generator would not introduce too many changes into the general layout of the original system, the sizing of the PV system should be such that the diesel generators is turned on to meet the peak load demand period of the community and during cloudy days. The PV should supply power to the system during the off peak period. As the PV will operate during the Sunshine period Hours, the backup battery sizing could be minimized, reducing the investment on the battery considerable.

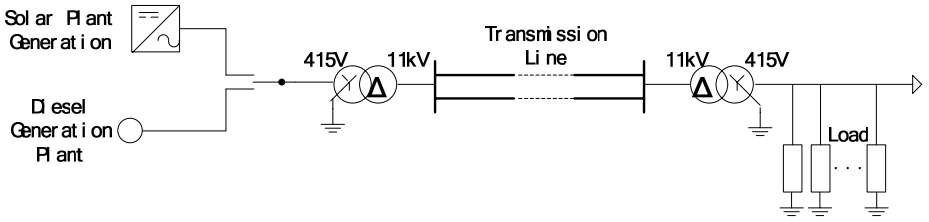


Figure 10. A Single line diagram of the Proposed Hybrid System

A. Solar PV system Sizing

It is important to properly size the solar power plant.if the system is too large, it will be to expensive and un-economical while if the system is too low. It will not be able to meet the load requirement of the Village.the size of the PV system can be determine from egn.1 wile the battery storage capacity in amperes hours is can be evealuated using eqn 2 below

$$P_{p_v} = \frac{\left[E_L + \left(D / C_R \times E_E \times 100\right)\right]}{X} \quad (1)$$

$$C_t = \frac{\left(E_L \times D\right)}{CD} \quad (2)$$

Where:

Ppv = array size in peak watt

EE = watt hour efficiency of the battery

CD = Watt-hour permissible depth of discharge (DOD)
CR = Charge Recovery of the battery efficiency (hours)
Ct = Total storage days
D = Number of Storage days
EL = Daily Energy requirement (Wh/day)
X = Annual average equivalent

B. Benefits due to Hybrid Generation

The replacement of one of the Generating sets with PV Solar Systems

- Reduction in noise and CO_2 emission from the environment, The PV generator is CO_2 emission and noise free.
- Greater fuel saving (No fuel consumption for the PV generator) translates to considerable in the cost of purchase of diesel. The cost of diesel fuel in Nigeria is about 150 Naira (1 USD) per liter of diesel. This price is difficult to justify going by the scarcity of diesel fuel and black marketeering. The more realistic cost of diesel will be about 200 Naira (1.33 USD) as shown in Figure 11.
- Significant Reduction in importation Generator and spare part. The price of diesel generator depends on diesel generator size, brand and technical characteristics such as speed (rpm), the cost of generators and imported spare parts for the Generators is converted into Naira at the current exchange rate of 150 Naira to 1 USD. This cost will be reduced considerable with the use of one generator.
- Reduction in Maintenance and running cost. The PV Generator requires minimal maintenance for 25 years. The each generator require routine maintenance for long –life service. The normal maintenance requires replacement of oil every 100 to 250 hours depending on dust conditions, oil filter usually to be changed every time oil filter, is changed and air filter required changing every 100 hours while fuel filter require changing normally every 200 to 250 hours depending
- Transfer of technology
- Improvement in the GDP of the Area
- Sustainable Energy
- Increase in tariff for the Utility board
- Job creation
- Use of barren land
- Increase in energy security
- Easy of integration with exiting system requiring little or modification
- Requires relatively simple supervision

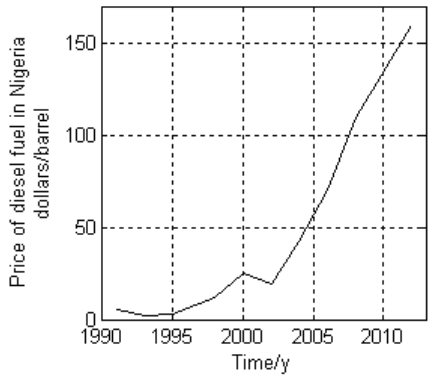


Figure 11. Comperative annalysis of trends in disel price in Nigeria

6. Management of Change in PV Generator Voltage

Changes in the sun radiation affects the voltage and power output of the solar generator, Low radiation results in low voltage output while high radiation from the sun increase the ouput voltage. Possibilities to overcome this is :

- limit the effective ouput of the PV system When overvolatage occurs, increase it when during low voltage by the use of diconect switchs to remove and reconnect panels.
- Management of supply with the use of battery storage system while fully benefiting from the power generated by the sun.
- Emply a load control management as an effective Strategy for mitigating low voltage such as moving high power demand load to a period of very low power demand period

7. Conclusions

The Result of the experiment setup shows the existence of favorable conditions based on the available solar radiation resources for isolated grid PV-Diesel application in Nigeria. The next step of the present research will be the validation of the experiment analysis with values measured at the study area in Nigeria. These values can be used to analyze the system hourly performance and then develop the PV Array size and system costs. A battery storage Facility can also be incorporated into the system to be used in Periods of no Solar Energy. The sizing process of both the PV modules and inverter should be based on the seasonal characteristics of the system Load, voltage, the total peak load should be available, and the total number of modules, storage capacity and other accessories can then be calculated. The system should be as simple as possible and easy to operate for the present operational crew. The PV system should provide electricity to the Microgrid independently via the distribution network, and a manual transfer switch should be implemented for the load transfer as in the present Structure; the diesel power system can be used as standby to assist in period of very high loads and or non availability of solar energy. Inverters with Harmonic filters and Voltage regulators -Case 2 - should be employed in the Design to avoid large presences of Harmonic distortion on the network. Provision of 24 hrs forecast (in hourly steps) to the network operators to ensure continuity in supply, and finally the utility company should implement appropriate operation and maintenance policy to ensure that the plant is optimized. Sustainable financial and technical solutions for operation, maintenance and management (O. M. M) are the key to the overall system success. A well maintained system can run for 25 years and this should be the target of the government.

Acknowledgment

This project was supported by the Doctoral Start Fund of Liaoning Province (20121023), China Postdoctoral Science foundation (2012024012) and the Fundamental Research Funds for the Central Universities (DUT11RC(3)09).

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