

Solar Hybrid for Power Generation in a Rural Area: Its Technology and Application

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Abstract— One of the primary needs for socio economic development in any nation in the world is the provision of reliable electricity supply systems. This paper develops an indigenous technology hybrid solar /Wind/ Diesel Power system that harnesses the renewable energies in Sun and Wind to generate electricity. Renewable energy resources are a favourable alternative for rural energy supply. In order to handle the fluctuating nature, hybrid systems can be applied. The 2007-2016, nine years solar radiation data, and the 2007–2016 data for wind speed for Potiskum in Yobe State of Nigeria, were collected. The two parameter Weibull distribution was used to simulate power in watts per meter square densities for the nine years period. Load estimates of a typical rural community and for rural ICT infrastructures were estimated. The step by step design of a 15kW solar power supply system and a 10kW wind power was done as a sample case. The results showed the average exploitable wind power density of 54.5W/m² average mean speed of 8.04m/s. It was found that with the exception of monsoon months, August and September, solar energy can be utilized throughout the year for North-Eastern region of Nigeria. Therefore, the development of hybrid wind-solar system for off grid communities will go a long way to improve socio economy lives of people in that community.

Index Terms- diesel, hybrid power system, photovoltaic, renewable energy, wind

I. INTRODUCTION

Energy is essential to our society to ensure quality life and to underpin all other elements of our economy. The availability and consumption of energy is an index of prosperity in any nation. It is a known fact that the high rate of industrial growth of any country is a function of the amount of energy available in that country and the extent to which it is utilized [1]. This interest has been stimulated by the relative ease with which electricity can be generated, distributed, and utilized, and variety of its applications. It is arguable whether the consumption of electricity should be allowed to grow unchecked, but the fact is that there is an ever-increasing demand for this energy form [1].

The objective of the energy system is to provide energy services. Energy services are the desired and useful products, that results from the use of energy, such as for

lighting, provision of air-conditioned indoor climate, refrigerated storage, transportation, appropriate temperatures for cooking, etc. The energy chain to deliver these services begins with the collection or extraction of primary energy, which is then converted into energy carriers suitable for various end-uses [2, 3]. The case of Nigeria is not so different from other African countries. Nigeria's energy is supplied from different hydro-power and thermal power stations. The country, located between longitude 8°E and latitude 10°N, and has two major seasons, wet and dry. The seasonality makes the extent of water availability at the different hydro power stations variable, leading to intermittent supply at times of low water levels during the dry season [4].

Also, the thermal power stations have been bedeviled by lack of adequate supplies of natural gas from the various Niger Delta gas wells, thereby making continuous energy production from these installations difficult. This has left Nigerians at the mercy of private alternative power generation through the use of diesel and petrol generators. A national projection based on 13% Gross Domestic Product growth rate revealed that energy demand will increase from 5746 MW in 2005 to 297900 MW in 2030 while supply should increase from 6440 MW to above 300,000 MW within the same period of years [5]. To accomplish this, requires an additional 11,686 MW every year to meet demand and costing for the period about \$US484.62 billion. However, current energy production within the country is less than 4000 MW due to fluctuations in the availability and poor maintenance of generating equipments. Thus, Nigeria still has a long way to go in achieving energy sufficiency [6].

II. POWER GENERATION IN NIGERIA AT A GLANCE

Under colonial rule, Nigeria started electricity generation and supply in 1896. In 1929, it set up the Nigeria Electricity Supply Company (NESCO) as an electricity utility company operating a hydroelectric power station near Jos, Plateau state. In 1951, the Electricity Corporation of Nigeria (ECN) was established. The first 132kV line was built in 1962, to link Ijora power station in Lagos to Ibadan power station [4, 6]. Since then, there has been increase in electricity infrastructure and changes both in the nomenclature and operations of the regulating agencies. The Niger Dams Authority (NDA) was established in 1962 with a mandate to develop the hydro-power sub-sector. It was merged with the ECN in 1972. It was followed by the coming of the National Electric Power Authority (NEPA) then National Electricity Regulatory Commission (NERC) and Power Holding Company of Nigeria (PHCN) as the search for stable power supply in the country continues [5].

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Electricity production in Nigeria over the last 45 years has varied from gas-fired [6], oil fired, hydroelectric power stations to coal fired stations with hydroelectric power systems and gas fired systems taking precedence. Before now there are a total of 16 power plants in Nigeria 10 owned by Power Holding Company of Nigeria and another six plants belonging to independent power producers. This is expected to generate 6,426 MW of electricity in order to achieve the presidential target of 6,000 MW of electricity by December 2009. The Nigerian Power Generation sector can be detailed into the following subsectors [7] as shown in Tables I and II respectively:

- (a) Existing Federal Government of Nigeria (FGN) Power Generation facilities.
- (b) National Integrated Power Projects (NIPP).

TABLE I
EXISTING FGN HYDRO POWER STATION

S/N	Name of generation company	Year of construction	Location	Installed capacity (MW)	Available capacity (MW)
1	Kainji/Jebba Hydroelectric PLC-kainji power station	1968	Kainji, Niger state	760	480
2	Kainji/Jebba Hydroelectric PLC Jebba power station	1985	Jebba, Niger state	540	450
3	Shiroro Hydroelectric PLC	1989	Shiroro, Niger state	600	450
TOTAL				1,900	1,380

TABLE II
INDEPENDENT POWER PROJECT

S/N	Name of power plant	Location	Installed capacity (MW)	Available capacity (MW)
1	AES Power Station	Egbim, Logos State	224	224
2	SHELL-Afam VI Power Station	Afam, Rivers State	650	650
3	AGIP- Okpai Power Station	Okpai, Delta State	480	480
4	ASG-Ibom Power Station	Akwa-Ibom State	155	76
5	RSG-TRANS AMADI Power Station	Port Harcourt, Rivers State	100	24
6	RSG-Omoku Power Station	Omoku, Rivers State	150	30
TOTAL			1,759	1,484

A. Technologies for rural energy supply

Generally, power supply in developing countries for rural areas takes place in three different ways:

1. Locally, by supplying single consumers and load groups;
2. Decentralize, by erecting or extending stand-alone regional mini-grids;
3. Centrally, by expansion of interconnected grids.

The approaches of local and decentralized electrification are obviously closely related and can be met by similar technologies [8].

B. Decentralized electrification

At certain distances from the grid, the decentralized approaches of regional mini-grid systems or local supply of single consumers can become competitive due to lower investments and maintenance costs compared to large scale electrification by expanding interconnected grids. Different technological options are in practice, most commonly diesel generating sets and renewable energies [8].

- Diesel Generating Sets

In this cases security of supply is not of major importance, single diesel gensets are applied for electrification, due to repair or maintenance [9]. This problem can be met by using a group of diesel gensets, with the other gensets providing backup. The voltage of the generator is often adjusted to be higher than the required 220 Volt for the household because of high losses within the local distribution lines. Diesel gensets have problems with short durability. Moreover, frequent start-up and shut-down procedures decrease their lifetime as well [10]. Diesel gensets are typically just operated for around 4 hours in the evenings, and very often old motors from cars are used for the purpose of electrification [11]. Many, especially, rural areas are far away or isolated (that is islands) from higher developed regions so that the regular supply with diesel fuel becomes a logistical problem and an important financial burden even in countries, where fuel is heavily subsidized [8, 12].

- Renewable Energy Technologies

The use of renewable energy technologies is a very promising approach towards meeting environmental, social as well as economic goals associated with small town electrification [6, 7, 13]. Renewable energy resources are of various forms with varying potentials, some of which are: Biomass energy; solar energy; Wind energy; geothermal energy; Hydrogen and fuel cells; Ocean energy and Hydro-power.

C. Prospect for solar energy in Nigeria

It is estimated that there is solar radiation of 3.5 to 7.0 kWh/m²/Day across Nigeria daily, 3.5kWh/m²/day at coastal areas like Rivers and Bayelsa state and about 7.0KWh/m²/day at the extreme northern part of Nigeria. This amount to about, 5.53 kWh/m²/Day, for the average global and solar radiations unutilized. This average amount represents a huge prospect for Solar energy generation if a total capacity can be developed for solar PV generation. The northern areas have an average daily sunrise time of 06:15 hours and sunset time of 18:38 hours [14, 15]. The mirage of problems encountered by Power Holding Company of Nigeria (PHCN) resulting in her inability to supply the required electricity to the Nigerian nation, due to lower generation capacity, out dated equipment, and other similar factors inclusive, makes the future of alternative (solar) energy very bright [16].

D. Concept of solar energy

Solar energy is energy from the Sun. It is renewable, inexhaustible and environmental pollution free. Nigeria, like most other countries is blessed with large amount of sunshine with an average sun power of 490W/m²/day [7]. Solar charged battery systems provide power supply for complete 24hours a day irrespective of bad weather.

There are two basic categories of technologies that convert sunlight into useful forms of energy. Firstly, solar photovoltaic (PV) modules convert sunlight directly into electricity. Secondly, solar thermal power systems use focused solar radiation to produce steam, which is then used to turn a turbine producing electricity [9, 10]. The advantage of using solar energy is that beyond initial installation and maintenance, solar energy is free on like oil or coal, and requires significantly lower operational labour than conventional power production. Life expectancy ranges between manufacturers, but many panels produced today carry a 25-30 year warranty – with a life expectancy of up to 40 years [10].

- Decentralization of power

Solar energy offers decentralization in most (sunny) locations, meaning self-reliant societies [11].

- Solar avoidance of politics and price volatility

Solar energy has the ability to avoid the politics and price volatility that is increasingly characterizing fossil fuel markets. Solar energy production is set to become even cheaper in the near future as better technology and economies of scale take effect [10].

E. Hybrid system technology

Hybrid systems are another approach towards decentralized electrification, basically by combining the technologies presented above. They can be designed as stand-alone mini-grids or in smaller scale as household systems. Hybrid power system combines two or more modes of electricity generation together, usually, renewable energy technologies, such as Solar Photovoltaic (PV) and Wind turbines [11-14]. Hybrid systems allow for all productive uses of electricity (domestic, public and income-generating uses), permitting the scaling up of productive applications and rural development [10]. A case study is as shown in table III.

**TABLE III
 APPLICATION OF HYBRID SYSTEM TECHNOLOGY**

Energy services	Application	Benefits
Lighting	Household, public and community lighting	Improvement of health care,
Communication	Internet/ telephone TV broadcast/cinema	Facilitation of security/safety and
Refrigeration	Refrigeration of medicine Cold storage, ice making	emergency assistance, Reduction of
Water supply	Drinking water, irrigation, Purification	marginalization, Increase of employment,
Motive power	Drying and food preservation, textile and dyeing	Enhancement of social life, Generation of added value product and increase of productivity.
Health services	Sterilization of medical equipment, electric diagnosis.	

F. Solar resource assessment of the site

The state lies mainly in the dry Savannah agro-ecological region and it is dry and hot for most part of the year, except in the southern part which has a milder climate. The state is predominantly rural with few towns like Nguru, Damaturu, Fika, and Potiskum. Rural communities are well spaced out on the plain to allow each community enough land to support agriculture as the economic activity. The energy needs by household in the state are mainly for cooking, where about 97.7% is gotten from fuel wood, for lighting, where kerosene lamp is the major source; and agricultural activities which is usually done manually. Machines and equipments used in micro-scale enterprises like tailoring, weaving etc. are powered manually [11]. The average monthly solar irradiation level for the site, Potiskum, is as shown in Table IV.

**TABLE IV
 SOLAR IRRADIATION LEVEL FOR POTISKUM IN (kWh/m²/day)
 FOR 2007-2016**

Month	Sunshine hours, S	Day length, S _{MAX}	sunshine hours % S/S _{MAX}	Hg (MJ/m ² /day)	H ₀ (MJ/m ² /day)	KT
January	6.9	11.51	0.59	16.3	32.32	0.50
February	8.8	11.76	0.75	22.4	34.71	0.64
March	8.0	12.09	0.66	28.1	36.99	0.76
April	6.8	12.28	0.55	26.1	37.91	0.69
May	8.3	12.61	0.66	27.9	37.37	0.75
June	8.8	12.55	0.70	26.0	36.74	0.71
July	6.6	12.51	0.53	24.8	36.89	0.65
August	6.5	12.21	0.53	21.9	37.46	0.58
September	7.1	11.89	0.51	22.8	37.15	0.61
October	7.8	11.48	0.68	27.9	35.35	0.79
November	9.4	11.41	0.82	21.4	32.79	0.65
December	10.1	11.37	0.89	17.4	31.42	0.56

Where: Hg =the monthly average daily global solar radiation falling on a horizontal surface at a particular location,

H₀ = the monthly mean daily radiation on a horizontal surface in the absence of atmosphere,

S = the monthly mean daily number of observed sunshine hours,

S_{max} = the monthly mean value of day length and

KT = the clearness index at a particular location.

From this it can be deduce that the average sunshine hours is approximately 8hours for an average day length of 12 hours. From the observation of clearness index, the presence of clouds is very rare even in monsoon months. This is the favorable condition for solar energy utilization. Atmospheric clearness is indicated by fraction of extraterrestrial radiation that reaches the earth surface as global solar radiation, KT. From the estimated value of the global radiation, Hg, the clearness index, KT, is calculated. With the above results and considerations, the maximum values of global solar radiation appear in March, April and May respectively during dry season while minimum values were observed in August and September, respectively during wet season.

G. Wind resource assessment

The wind speed data were obtained from Nigeria meteorological Agency Oshodi. The wind speed data obtained are for twenty years (1997-2016) at a height of

10m from the ground surface. The probability distribution functions of the wind speed and the duration function were calculated. Mean monthly values of wind speed were used for the calculation of Weibull distribution parameter C, D and K. Mean monthly values of wind speed were used to calculate wind energy and power densities [12] as shown in table V.

TABLE V
 WIND DATA FOR POTISKUM FOR SIXTEEN YEARS (1997-2012)

Month	V (m/s)	Σ (m/s)	C (m/s)	K	Power density (W/m ²)	Energy density (kWh/m ²)
January	8.57	2.28	9.57	4.23	55.52	43.11
February	9.07	2.46	10.14	4.20	60.01	42.58
March	9.07	2.25	10.09	4.57	73.34	72.59
April	8.94	1.74	9.81	5.95	69.73	68.85
May	8.32	1.57	9.11	6.16	68.35	55.39
June	8.30	2.16	9.26	4.34	65.27	50.89
July	7.71	2.02	8.60	4.31	63.59	48.72
August	6.58	2.19	7.43	3.32	49.85	37.92
September	6.29	1.70	7.03	4.16	25.09	15.87
October	6.41	1.54	7.12	4.73	39.92	30.25
November	8.54	2.25	9.53	4.28	43.89	28.79
December	8.69	2.52	9.76	3.80	39.32	23.32

Where, V = the average wind speed

Σ = the standard deviation,

C = the average scale factor,

K = the shape factor

From the Table V, it is deduce that the average mean speed is 8.04m/s with an average power density of 54.5W/m². This site corresponds to the wind power class of 1 and therefore, this particular site is ideal for non grid connected applications.

III. METHODOLOGY OF THE DESIGN TECHNOLOGY

With most forms of electricity production, the primary fuel is “dispatchables”, which can be converted to electrical energy at a rate which is controlled by the operator. The combination of solar and wind with diesel generator(s) and a bank of batteries, is included for backup purposes. Power conditioning units, such as converters, are also a part of the supply system. In order to ensure the continuity of supply, maximize the lifetime of components by reducing the stress on the system (especially the battery), and since solar and wind are dependent on seasons, diesel/gasoline/LPG generators are commonly used as complementary sources/backup. Basic operation of the hybrid system components are as follows.

A. PV module

To obtain high power, numerous cells are connected in series and parallel circuits on a panel (module), to generate the required current and voltage. By wiring modules in series the available voltage is increased and by wiring in parallel, the available current is increased. To determine the size of PV modules, the required energy consumption must be estimated. Therefore, the PV module size (Ms) in Watt Power is calculated as:

$$Ms = \frac{Ec}{Is \times \eta} \quad (1)$$

Where, Ms= module size in watt power

Ec= Daily energy consumption in watts or kilowatts

Is= Insulation in kWh/m²/day

η = efficiency

The PV modules mounting can be a ground mount that works either on rooftops or the ground, or pole mount for getting them up in the air. If the rooftop has a good angle to the sun, the modules could be mounted solidly to the roof without an adjustable rack. Trackers are another PV mounting option, which are pole mounts that automatically adjust themselves so that the PV faces the sun throughout the day.

B. Small wind turbine

Most turbines have either two or three blades. These three-bladed wind turbines are operated “upwind”, with the blades facing the wind. The other common wind turbine type is the two bladed, downwind turbines. Utility scale turbines range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping. The design principles of smaller wind turbines are somewhat different to the larger ones in that the small wind turbines produces power frequently over short periods, like for battery charging. It is important that small turbines generate in weak winds and respond quickly when harnessable winds occur.

Various mathematical models have been developed to assist in the predictions of the output power production of wind turbine generators (WTG). A statistical function known as Weibull distribution function has been found to be more appropriate for this purpose [10]. The function is used to determine the wind distribution in the selected site of the case study and the annual/monthly mean wind speed of the site.

The two parameter Weibull distribution function is expressed mathematically in equation (2) as:

$$F(v) = \frac{k}{c} \left[\frac{v}{c} \right]^{k-1} \exp \left[- \left[\frac{v}{c} \right]^k \right] \quad (2)$$

It has a cumulative distribution function as expressed in the equation (3):

$$M(v) = 1 - \exp \left[- \left(\frac{v}{c} \right)^k \right] \quad (3)$$

Where v is the wind speed, K (dimensionless) is the shape parameter and C (m/s), the scale parameter of the distribution.

To determine K and C, the approximations widely accepted are given in equations

$$k = \left[\frac{\sigma}{v'} \right]^{-1.09} \quad (4)$$

$$C = v' x \frac{k^{2.664}}{0.184 + 0.186k^{2.735}} \quad (5)$$

Where: C = standard deviation of the wind speed for the site (m/s)

v' = mean speed (m/s)

• Power Content of the Wind

The amount of power transferred to a wind turbine is directly proportional to the area swept out by the rotor, to the density of the air, and the cube of the wind speed.

The power, P, in the wind is given by:

$$P = \frac{1}{2} C_p \cdot \rho \cdot A \cdot v^3 \quad (6)$$

Where: C_p = turbine power coefficient.

A = rotor swept area (m^2), proposed theoretical maximum value of 0.593 for C_p

ρ = air density (kg/m^3)

$$A = \frac{\pi D^2}{4} \quad (7)$$

Where D = rotor blade diameter (m) and

v = mean wind speed (m/s)

• Wind speed variation with height

Wind speed near the ground changes with height. The most common expression for the variation of wind speed with height is the power law expressed as follows:

$$\frac{v_2}{v_1} = \left[\frac{h_2}{h_1} \right]^\alpha \quad (8)$$

Where v_1 and v_2 are the mean wind speed at height h_2 and h_1 respectively. The exponent factor depends on factors such as surface roughness and atmospheric stability.

The power available in the wind is proportional to the cube of its speed. This means that if wind speed doubles, the power available to the wind turbine increases by a factor of eight, (2^3). To make wind energy feasible in a given area, it requires minimum wind speeds of 3m/s for small wind turbine and 6m/s for large turbines.

C. Diesel gensets

A diesel generator is simply a normal electric generator driven by a diesel engine (prime mover). According to the reliability level desired in this paper, one can decide to install one or more generators in order to be able to provide full service, even during maintenance periods. Regarding the diesel generator, major maintenance operations should be considered with respect to the cost and unavailability of the equipment. Gensets in the range of 30 kVA to 200 kVA would typically need a major maintenance operation after 15,000 to 25,000 running hours. The decrease in efficiency is 1% for every 100 m above sea level, and another 1% for every 5.5°C above a temperature of 20°C.

D. Batteries of the hybrid system

The case study uses lead acid batteries with tubular plates, either vented lead acid (VLA: flooded batteries with liquid electrolyte to be regularly refilled) or valve-regulated lead acid (VRLA: maintenance free batteries). The chosen battery should be specifically designed for solar applications. Because of the strong impact of temperature on battery service (life a temperature increase of 5°C decreases the service life by 15%-20%), design of the battery room should ensure that batteries are kept at the lowest temperature possible. The battery to be used must:

- be able to withstand several charge and discharge cycle
- be at low self-discharge rate
- be able to operate with the specified limits.

The battery lifespan (measured in number of cycles) depends on the depth of discharge reached at every cycle. The smaller the battery capacity, the cheaper the initial battery costs; however a smaller battery would be more

deeply discharged and its lifetime reduced with its replacement cost increased. Because the battery recharge process ends with a very low power load (constant voltage, diminishing current) it is preferable to have this end-of-cycle charged by the genset rather than by the PV array, and at a time when the genset operates at a good load factor. This operating mode allows for maximizing the usage of solar energy.

A battery's total capacity (the total amount of current it can deliver multiplied by the duration of that supply) is reduced when discharged with a high current. This has to be taken into account when considering locations with significant demand growth.

E. Inverter

A multifunctional inverter system is a device that inverts DC current into AC and rectifies the AC current into DC to charge the battery. It also controls the charging of the battery to extend its lifespan. These functionalities can be split between several distinct units or combined in a central piece of equipment. Seasonal variations of the load and its yearly growth should be taken into account when specifying its rated capacity. Improper settings for the various thresholds that control the shift between sources may affect the lifespan of the battery or the efficiency of solar energy use.

For PV Solar Systems, the inverters are incorporated with some inbuilt protective devices such as:

- Overload protections
- Miniature Circuit Breaker Trip Indicator (MCB)
- Low - battery protection
- Constant and trickle charging system
- Load status indicator.

The charging system (charge controller) should be able to manage the various charge steps, including regular equalization and float charge to maximize battery lifespan. It should have these features:

- Prevent feedback from the batteries to PV modules
- Have a connector for DC loads
- Have a work mode indicator.

For hybrid systems, there are two distinguish scenarios: firstly, if the hybrid systems relies on renewable energy technologies for power supply alone (like PV/Wind hybrid systems), the control of charge and discharge will work as it does in systems with just one renewable energy resource. The main objective of applying charge control is to maximize the battery's lifetime. Secondly, the situation is different for hybrid systems using diesel gensets as a backup.

F. Configuration for hybrid systems technology

- Electricity generation coupled at DC bus line

All electricity generating components are connected to a DC bus line from which the battery is charged. AC generating components need a DC/AC inverter. The battery, controlled and protected from overcharge and discharge by a charge controller, then supplies power to the DC loads in response to the demand. AC loads can be optionally supplied by an inverter.

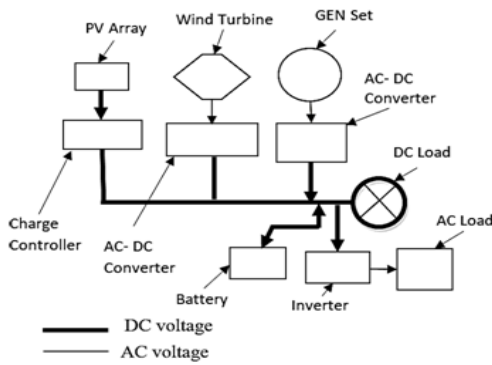


Fig. 1: Electricity generation coupled at DC bus line for charging the battery.

(b) Electricity generation coupled at AC bus line

All electricity generating components are connected to an AC bus line. AC generating components may be directly connected to the AC bus line or may need an AC/AC converter to enable stable coupling of the components. In both options, a bidirectional master inverter controls the energy supply for the AC loads and the battery charging. DC loads can be optionally supplied by the battery.

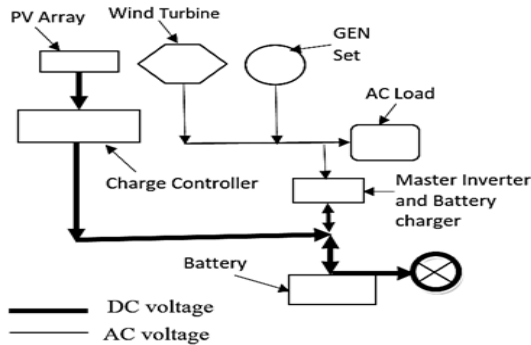


Fig. 2: Electricity generation coupled at AC bus line to enable a bidirectional master inverter control of energy supply to the AC loads and the battery charging.

G. Load estimate of a typical community including information communication technology (ICT) services

The base load is generally present in the morning, and in some cases extends to night hours. Small hybrid systems are suitable for supplying the power needs of a small rural village where the energy consumption is quite limited; for instance a Potiskum village with none or very few, productive or commercial activities.

Assuming there are twenty families resident here, two health centers, two schools and an ICT centre. With the generation of electricity to this village, it is assumed that the 20 household's resident there will own electrical appliances. The load specification for the next three years is used in this analysis.

i. Lighting Circuit Assessment

Assume that each household will use 6, 40 W bulbs, therefore power demand for lighting is for 8 hours in a day for a week, P_w , will be:

$$P_w = 6 \times 40 \times 20 \times 8 = 38.4kWh \quad (9)$$

ii. Power Circuit Assessment

Assume also that each household has 1 television set, T_s ; 1 radio set, R_s ; and 1 refrigerator, R_{ref} , at power ratings of 120W, 20W and 250W respectively.

Therefore, Power for the Television sets:

$$P_{Ts} = 1 \times 120 \times 20 \times 8 = 19.2kWh \quad (10)$$

Power for radio set:

$$P_{Rs} = 1 \times 20 \times 20 \times 8 = 3.2kWh \quad (11)$$

Power for refrigerator:

$$P_{Ref} = 1 \times 250 \times 20 \times 18 = 90kWh \quad (12)$$

iii. Power demand for water pumping

Assume that the entire village will use two 1.5hp pumping machine, pm.

Power demand:

$$P_{pm} = 2 \times 1.5 \times 0.746 \times 2 = 4.476kWh \quad (13)$$

Total power demand, P_{Td} :

$$P_{Td} = P_w + P_{Ts} + P_{Rs} + P_{pm} + P_{Ref}$$

$$P_{Td} = 38.4 + 19.2 + 3.2 + 4.476 + 90 \quad (14)$$

$$P_{Td} = 155.276kW$$

iv. The energy needed for a typical ICT center, Hospital center and School in rural/remote environment are as shown in Tables VI, VII and VIII.

All items use AC current. The total daily electricity demand is 185.496kWh; the annual demand is 67.487MWh; the maximum load for the system is 12.5kW; and the study assumes a peak of 15kW.

TABLE VI
 ENERGY NEEDED FOR A TYPICAL ICT CENTER IN RURAL ENVIRONMENT

Qty	Description of Item	Load (Watts per unit)	Total Load (Watts)	Daily Hour of Actual Utilization (hours)	Weekly Watts Hours (Wh)
1	Router	25	25	8	1,200
1	Port fast Switch	15	15	8	720
2	Wireless Access Point	12	24	8	1,152
1	Server (plus accessories)	150	150	8	7,200
1	RF (Radio Communication)	40	150	8	1,920
10	Laptops (with security cables)	40	400	8	18,200
2	VOIP Phones	20	40	6	640
2	HP desk jet 5943	44	88	8	704
1	Laser Printer	100	100	7	700
4	Lighting	15	60	8	2,880
4	Ceiling fans	60	240	8	11,520
	Total			10,156	46,836Wh

TABLE VII
 ENERGY NEEDED FOR A TYPICAL HOSPITAL SERVICE IN RURAL ENVIRONMENT

Description of Item	Qty	Load (Watts per unit)	Total Load (Watts)	Daily Hour of Actual Utilization (hours)	Weekly Watts Hours (Wh)
Cold Chain Storage (fridge)	1	60W	60W	8	2,400
Lighting for the operating Theatre	3	15W	45W	8	2160
Lighting for Ward	6	15W	90W	8	4320
Premises Lighting/Street Light	2	40W	80W	10	960
Television Color	1	150W	150W	6	900
Fans	6	15W	90W	12	1920
Total				4340	12660Wh

TABLE VIII
ENERGY NEEDED FOR A TYPICAL SCHOOL IN RURAL ENVIRONMENT

Description of item	Qty	Load (Watts per unit)	Load (Watts) Total	Daily Hour of Actual Utilization	Weekly hour of Actual Utilization (Watts).
Fans	8	60	480	8	19200
Lightning for street	6	15	30	9	1890
Lightning for classroom	12	15	300	8	12000
laser printer	2	100	200	5	5000
HP desk jet 5943	2	44	88	4	704
Total				7862	
2 school				15724	

H. Design Results

The capacity ratio of solar to wind power units is 60:40. The plant is required to produce 200kWh/day, which means that solar power plant should generate up to 120kWh/day and the wind plant should generate 80kWh/day. Thus the annual generation should be up to 73MWh. The choice of components for the hybrid plant is as follows:

- a. The solar plant is expected to operate for 8 hours,
- b. The wind plant is expected to operate for 24 hours
- c. The battery system is used during night hours.

The choice of 15kW is a sample case and this can be extended to any required capacity. To achieve a solar power capacity of 15kW the capacities of Solar panel, Charging Controller, bank of battery and Inverter are determined. For this design 8 hours was assumed for the duration of the operation and the calculations is done as indicated below:

1) Solar Panel

Total load = 15kW

Period of operation or duration = 8 Hours

Then, Total Watt-Hour = 15x8= 120kW-hr

The period of the solar panel exposed to the sun = 8 Hours (Averagely between 8am and 5pm)

Therefore solar panel wattage = 120kWh/8h=15kW.

Hence solar panel of 15kW will be needed for this design.

Since the highest power produced is 242.11kWh/m², so for 8 hours of average sunshine, we have 40.34kW/m². This is much for this design, considering a 15kW system is needed.

For this design, the Sun module SW 275 mono, Maximum power P_{max} 275 Wp, Open circuit voltage V_{oc} 39.4 V, Maximum power point voltage V_{mpp} 31.0 V, Short circuit current I_{sc} 9.58 A, Maximum power point current I_{mpp} 8.94A, Cells per module 60, Cell type Mono crystalline, Cell dimensions (65.94cm x 39.41cm), weight 46.7 lbs (21.2kg) with an efficiency of 16.4%. The study assumes that a maximum point tracker control method will be used and uses the minimum number of PV modules that will deliver 100% electricity to the load.

Therefore, No of panel =15000W/275W= 56

This shows 56 of 275 Watt solar panel will be required for this design

2) Charging Controllers

For this design of 15kW solar power supply,

$$P = IV \tag{15}$$

Where:

I = the expected charging current and

V = the voltage of the battery (12 V)

P = the power supply rating (15kW)

Hence,

$$I = \frac{P}{V} = \frac{15000}{12} = 1250 \text{ Amps} \tag{16}$$

A Charging controller of 625 Amp will be used for this study.

3) Battery capacity

The battery will supply 30% of the total load for 10hrs during the night hours, that is, 3.75kW

Operational period = 10 Hours

Watt-hour capacity = 37.5kW/h

To make the chosen battery to last long it is assumed that only a quarter (¼) of the battery capacity will be made used of, so that it will not be over discharged therefore the required battery capacity will be 37.5 x 4 = 150kW/h

Now the choice of battery hour depends on A-H rating of the storage battery. For example, for 1000AH, 12V battery the number of batteries that will be needed is 150000/1000=150 batteries. Hence, for this design and to avoid too much weight and occupying unnecessary space, a 2490AH 12V, with size as 40 by 13.5 by 33 and weight of 1690lb, a product of Solar-One technology battery is used. Therefore the total number of storage battery required for 150kW solar power supply system = 60. The batteries are connected in parallel to increase the A-H rating, and the voltage is increased using an inverter with a step up transformer to increase it to utility voltage of 240V.

Since the total load is 12.5kW it is advisable to size the required inverter to be 15kW as designed for solar panel ratings. Hence 15kW pure sign wave inverter is recommended with 90% efficiency, in other to prolong the lifespan of the inverter.

4) Wind turbine

The wind turbine is estimated to produce 10kW, in order to estimate the power extracted from the wind by the turbine, using the formula:

$$W = \frac{1}{2} \rho A V_1^3 \times 0.59 \tag{17}$$

$$\text{Where, } A = \frac{\pi D^2}{4} \tag{18}$$

Using equations (17) and (18), an average power output of 10kW at a blade diameter of 8.2m can be obtained from the study site, where mean wind speed, V=8.04m/s.

For this study the 2 Amp air AWT wind turbine rated at 6kW, with a cut in wind speed of 3m/s and a rated wind speed of 11m/s and a rotor diameter of 5.5m is recommended as it can deliver optimal power generation in low and moderate wind speed. This turbine was chosen because the total power generated was approximately 10kW.

5) Diesel genset

With the diesel generating set being used intermittently to supply the peak load for at least 10 hours, the recommended rating of the gen set should be 15KW.

6) Control system for power management and Optimization of operational strategy

Operating strategy for the hybrid PV/Wind/Diesel system with battery implies when the renewable sources produce less energy than what is demanded (that is, the wind speed, the solar radiation are low), the deficit power should be supplied by the battery bank. A good operation of a hybrid system can be achieved only by a suitable control of the interaction in the operation of the different devices. Hybrid controller switches the batteries into charging mode whenever excess power is available from the renewable sources, and switch to discharging mode whenever there was a short over from sources. The block diagram is as shown in Figure 3.

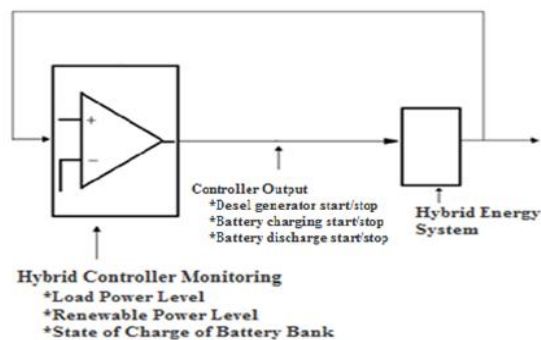


Fig. 3: Hybrid System Controller Block diagram for switching the batteries into charging mode or discharging mode.

That is the battery power indicates operating strategy for the hybrid system will show charging (power positive) or discharging (power negative), indicating that the hybrid controller utilizes the battery bank effectively.

IV. DATA ANALYSIS ON STUDY LOCATION

The proposed site for the project is Potiskum, Yobe State, located in the North-East geopolitical zone of Nigeria. The area is located at 11.42°N, 11.02°E with an altitude of 414.8m, its hottest month are March, April and May with temperature ranging from 30° to 42° and has an average annual solar irradiation of 6.12kWh/m²/day as shown in Table 1. The state is predominantly rural with few towns like Nguru, Damaturu, Fika, and Potiskum. The energy needs by household in the state are mainly for cooking, where about 97.7% is gotten from fuel wood, for lighting, where kerosene lamp is the major source; and agricultural activities which is usually done manually. Machines and equipments used in micro-scale enterprises like tailoring, weaving etc. are powered manually.

V. CONCLUSION AND RECOMMENDATION

With decreasing PV prices, PV /wind/diesel hybrid mini grids attract significant attention from institutions in charge of rural electrification and donor agencies to mitigate fuel price increases, deliver operating cost reductions, and offer higher service quality than traditional single source generation systems. The combining of technologies provides interesting opportunities to overcome certain technical limitations. The future deployment of hybrid technology in developing countries will be driven by different factors

according to the type of application addressed. Capacity building and access to concessional financing will be the key enablers for the development of this segment. Medium size distributed hybrid systems need political momentum to foster the involvement of the private sector. The result obtained from the analysis indicates that the solar energy utilization has bright prospects in Potiskum. The estimated values of global radiation can efficiently be used to compensate for energy deficits. From the studies it has been found that with the exception of monsoon months, August and September, solar energy can be utilized throughout the year for North-Eastern region of Nigeria. The site corresponding to the wind power class of 1 is also ideal for non grid connected applications.

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