Design Of A Hybrid Solar/Diesel Ups Supply For Low Power Applications

T. C Madueme[1] and R. U. Abonyi[2]
[1]Professor in Electrical Engineering department, University of Nigeria, Nsukka, Nigeria.
[2]Master of Engineering Student in Electrical Engineering Department. University of Nigeria, Nsukka,

ABSTRACT

Over the years, it has been really difficult for governments in developing nations like Nigeria to provide constant power supply to her citizens. The reasons for lack of constant power supply to the people especially those in the rural areas range from inability of government and utility companies to generate enough power, their failure to connect the people to the national grid, the land topography which sometimes makes it really difficult to access and connect people who live on islands, creeks and other inaccessible terrains to the national grid, cost of extension of the national grid, return on investment on power generation and distribution equipment, technical manpower amongst others. However, it has been discovered that a combination of different power generating systems known as hybrid power systems can be used to solve the problem of provision of uninterruptable power supply especially for the running of critical equipment such as lifesaving instruments in hospitals, offices, small scale businesses and for the supply of distributed power to rural dwellers and islanders.The load list, load profile, power demand, energy profile and components of the hybrid system were designed and specified. The design showed that the effective performance of the solar panel in charging the battery bank depended on the level of insolation available in the area where the solar panel was installed; the Inverter changed the 12 V direct current source from the batterybank to 230 V alternating voltage output. It also performed the automatic system change over functionfrom inversion mode to conversion mode changing the 230 V AC from the diesel generator to 12 V DC for charging the battery bank.The inverter output voltage decreased with increase in the connected load on the inverter. The uninterruptible power supply function of the system is achieved through the automatic change over system in the inverter. The results obtained during the implementation of the design showed that it's possibleto provide constant electricity for low power applications through hybrid power system thereby solving the problems of irregular or non-existent power supply.

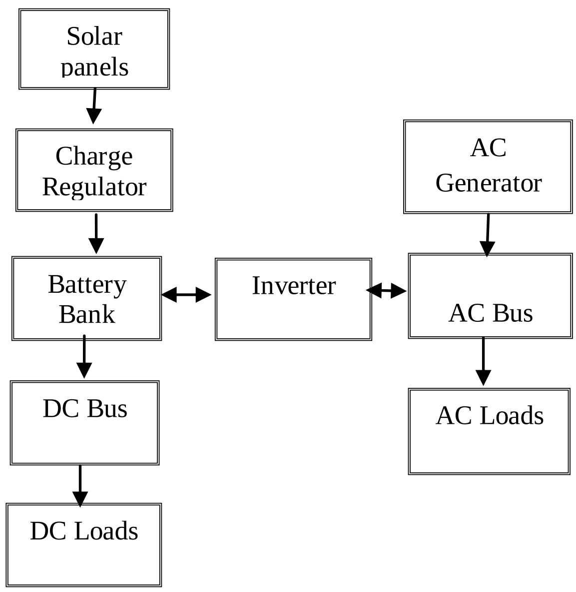
Keywords: *Solar panel, Photovoltaic, Diesel Generator, Batteries, Charge controller, Inverter*

1. INTRODUCTION

Modern civilization depends almost on electricity because electricity is responsible for the survival of critical small scale businesses, operations of critical equipment in the health sector, industries and other offices. It ensures the reliability and availability of electrical and instrument equipment for critical operations amongst others. In short, electricity is the driver of our modern economy because our life is increasingly dependent on it. Its importance cannot be over emphasized. It helps us to improve in all aspects of our standard of living. So, as population continues to grow, there is an ever-increasing demand for electricity placed on the world's power generation and distribution facilities resulting in inadequacies in power generation and distribution due to overload conditions on the existing infrastructures. Although significant measures are taken to ensure a reliable supply of electric power, the demand for power increases the likelihood that power outages and other electrical disruptions such as blackouts, brownouts or under voltages will occur. Energy is essential to our society because it is used to generate electricity and the increasing costs and environmental concerns involved in generation of electricity through conventional (non-renewable) energy sources have increased our interest in researches into renewable energy sources. Of course, if the world's power consumption demand is to be met, then our electricity generating capacity must increase proportionately. Presently, almost all the electricity generation takes place at central power stations and these power stations utilize coal, oil, gas, water or fissile nuclear materials as the primary fuel source [1].The fact is that the world is facing a major threat of fast depletion of the fossil fuel reserves because most of the present energy demand is met by the use of fossil and nuclear power plants. A very small part is recently being met using renewable energy technologies such as the wind, solar, biomass, geothermal amongst others. There is ever increasing demand on the use of the fossil fuel which is a non-renewable energy source for power generation and there will soon be a time when we will face a severe fossil fuel shortage and this will result in increase in cost of petroleum and its by-products or other fossil fuels. Most of the research now is about how to conserve the available energy and a better way of utilizing them. This trend has created the need for researches into alternative energy sources. There are a lot of researches on the development of reliable and robust systems to harness energy from renewable energy resources. Among them, wind and solar energy resources have experienced rapid growth in the past decade. Both are pollution free sources of abundant power [2].Renewable energy sources are alternatives to the fossil fuels but they are still developing and for now, their efficiency is poor due to the intermittent nature of these resources. Utilization of renewable energy sources is limited by their availability and efficiency [3], hence the need for hybridization which is a means of using more than one renewable source of energy so that the best of two or more of these sources of energy can be harnessed to fill the growing energy demand for generation of electricity. Again, the rapidly increasing costs of power line extensions, cost of running a central power station system and the cost of fossil fuel, combined with the desire to reduce carbon dioxide emissions which cause air pollution necessitated the development of hybrid power system. Hybrid power systems are independent of a large, centralized electricity grid and incorporate more than one type of energy source. In general, a hybrid system might contain alternating current diesel generators, an alternating current distribution system, a direct current distribution system, electrical loads, renewable power sources, energy storage system, power converters, dump loads, load management options or a supervisory control system [4]. They may range in size from relatively large island grids to individual household power supplies [5]. The combination of different energy sources brings improvement on the energy efficiency and reduces the energy storage requirements compared to systems with single renewable energy source [6]. Research has shown that small off-grid stand-alone hybrid power system offers an imperative choice for decreasing the electricity gap in remote areas of developing and developed world where progress in grid extension stays slower than population growth [7]. A study of a PV/Diesel hybrid power system with battery backup for a village being fed with diesel generated electricity to displace part of the diesel by solar generated electricity showed that it became more economical with the hybrid system than the diesel only system [8]. A design and analysis of a PV-wind-diesel hybrid system for a family house in Palestine showed that it costs more to generate electricity through renewable energy systems but the cost of electricity can be compensated in the cost of renewable energy equipment, maintenance and pollution free electricity [9]. Distributed hybrid power generations, even though, they generate relatively little power, the power generated from them can considerably enhance quality of life in remote areas [10]. When fossil fuels are burnt, they produce the gas carbon dioxide which is known as greenhouse gas because it traps heat from the sun much like the glass in a green house, prevents it from escaping out of the Earth's atmosphere into the space. Greenhouse gases are found naturally in the atmosphere and they are essential for keeping the earth warm. Hence to avoid this type of problems, the renewable energy resource is utilized to provide energy for uninterruptible power [11], [12]. In many countries, hybrid power systems are used to supply electricity to people who cannot be connected to the national grid such as islanders [13], [14].The use of solar energy for the production of electricity reduces the price/unit [15]. The use of renewable energy sources in electricity generation reduces maintenance cost and ultimately produces safe and affordable power [16]The environmentally friendly nature of the hybrid system with the integration of isolated loads or homes will lead to near off-grid homes without depending on grid power. It can be an excellent, cost effective & also a reliable solution to mitigate the existing power crisis[17].

II. Components of a solar-diesel hybrid power system

The components of a solar-diesel hybrid power system are shown in Figure 1.



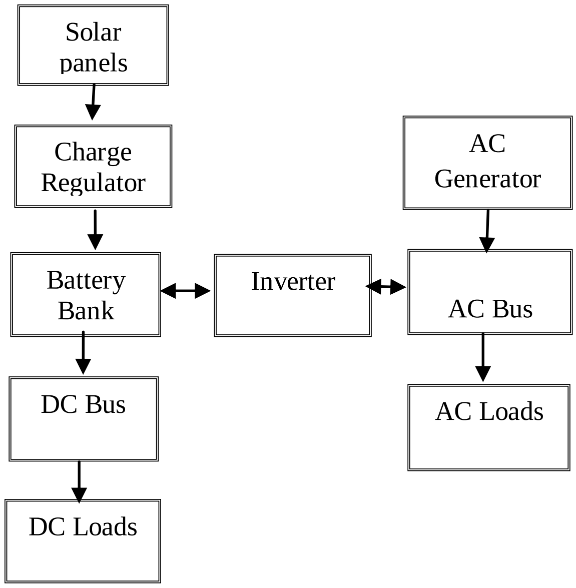


Figure 1, Components of a Solar-Diesel Hybrid power system.

A. Solar Energy and Solar Panels

Solar energy, radiant light and heat from the sun are harnessed using a range of ever evolving technologies such as solar heating, photovoltaic, concentrated solar power, solar architecture and artificial photosynthesis. All of these are referred to as solar energies. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties and designing spaces that naturally circulate air. Active solar technologies encompass solar thermal energy, using solar collectors for heating and solar power, converting sunlight into electricity either directly using photovoltaic or indirectly using concentrated solar power.A photovoltaic system component known as solar panel converts solar energy into direct current (DC) electricity by taking advantage of the photoelectric effect. Photovoltaic system has turned into multi-billion dollars fast-growing industry, it is cost-effective and it has the highest potential among all renewable energy technologies. Concentrated solar power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Commercial concentrated solar power plants were first developed in the 1980s.

B. Batteries

One disadvantage of electricity is that it cannot be easily stored on a large scale. Almost all the electrical energy used today is consumed as it is generated. This poses no hardship in conventional power plants where the fuel consumption is varied with the load requirements. The solar radiation and wind, being intermittent sources of power, cannot meet the load demand at all times, 24 hours a day. For this reason, energy storage systems are incorporated in renewable power units especially in stand-alone plants. Energy storage systems significantly improve the system availability and as such increase the system reliability. At present, electrochemical batteries are the most convenient energy storage technology that is considered for stand-alone photovoltaic and wind power systems and as such it is likely going to be both the present and future energy storage technology.

There are two basic types of electrochemical batteries; the primary battery which converts the chemical energy into the electrical energy and the secondary battery which is also known as the rechargeable battery. The batteries as energy storage systems contribute to the stability of the hybrid system. They are intended to support the power generation output by maintaining a stable power output from the system despite fluctuations in the main renewable energy sources intraday and the constant changing electrical load in the system.

C. Power Converter, Control Units and Inverters

An essential component of the hybrid system is the power converter which is needed to perform AC/DC, and DC/AC power conversions. The control units are the brain of the system. The objective of the control systems in the hybrid units is to manage the components of the hybrid system in the best way possible so that constant and stable power output can be achieved. The control units are sophisticated and oftentimes operated by computers. The inverter is an electrical circuit that performs power conversions. It is also used to provide backup power to sustain electronics equipment during power outage or for the provision of power where there is none. There are three main types of inverters known as standard inverters and they are (i) The square wave inverter (ii) The modified sine wave inverter or quasi sine wave inverter, and(iii) The pure sine wave inverter.

D. Alternating Current Generators

The inclusion of alternating current (diesel) generator in the hybrid system increases the availability and reliability of the system. The factors that determine the process of selecting a generator include initial cost, power requirements, fuel availability and maintenance requirements.

III. Design of a solar-diesel hybrid system

The design procedures for the hybrid system include preparation of the load list, construction of the load profile, and calculation of the design load and energy demand. Materials and components required for the design of Solar-Diesel hybrid system include A/C Generator, Inverter, Battery Bank, Charge Regulator, Solar panel, electrical conductors, electrical panel, power and control cables.As shown in Figure 1 the hybrid system contains a battery based inverter unit. The battery based inverter hybrid system supports the system in the night and during cloudy days unlike a battery-less based inverter system where the system shall switch over to the diesel generator immediately it detects low insolation which is unable to generate the needed power to run the system.Table 1 shows a typical load estimate for a low power application hybrid system

Table 1, Load Estimate

Code Number	Appliance Description	Quantity	Rated power (W)	Total power (Watt)	Autonomy hour (Hr)	Energy consumption (Wh)
1	Electric Bulbs	4	20	80	12	960
2	Standing fans	2	20	40	6	240
3	Television	1	60	60	4	240
4	Printer	1	50	50	2	100
5	DVD player	1	30	30	4	120
6	Laptop	1	50	50	6	300
7	Electric Clipper	1	30	30	7	210
	Total			340		2,170

IV. Inverter and Inverter sizing

The inverter is used in the hybrid system to provide AC power output from a DC power source and the power rating of the inverter must not be lower than the total load to be connected to it. In short, for a stand-alone system, the inverter must be large enough to handle the amount of power needed from it. So, for the above reason, the inverter size should be 25% to 30% higher than the total load to be connected to it and in case of motor and compressor appliances, the inverter size should be minimum of three (3) times the capacity of the total load to be connected to it so that it can handle the surge current during the start up of the motors and compressors. Inverter circuit design incorporates several major circuits which may include transformer, pulse width modulators, automatic change over circuits and supervisory systems such as low/full battery charge indicator, inversion and mains supply indicators and the collective specification of the inverter should be properly defined to show its Power rating, Frequency, number of phases and Input/output voltage.

To achieve an efficient inverter design requires that a near unity power factor be used. High power factor values from 0.80 to 0.98 produces better power values than low power factor values at less than 0.80

Equation (1) can be used to determine the capacity of the inverter.

Let apparent power (S) $=\frac{A_P}{P_f}$ (1)

Where S = Apparent power, A_P= active power, P_f= power factor

Assume power factor of 0.95 for all the loads. The total connected load as shown in Table 1 is 340 watts. However, for safety reasons, the inverter should be rated 30% above the total load to be connected to it. So, the inverter capacity becomes = 340 + (0.3×340) = 442 watts.

From equation (1), apparent power (S) = $\frac{442}{0.95}$= 465 VA. So, the inverter power rating = 465 VA.

Total number of the inverters needed to supply the required power

$N_{inverter} = \frac{P_{Load}}{P_{Inverter}}$ (2)

Where $N_{inverter}$ = Number of Inverters, P_{Load} = Total Inverter connected load, $P_{Inverter}$ = Inverter designed load capacity. So, from equation (2), $N_{inver\ ter} = \frac{340}{442}$= 0.77 ≈ 1.0, so, one unit of inverter is needed to supply the needed power.

The specification of the inverter: Power (VA) = 465, Frequency (Hz) = 50, AC Single Phase, Power factor = 0.97, DC Input Voltage = 12 V.

Output Voltage = 230 V.

A. Operations of the Inverter

The Inverter has the capacity to invert its primaryinput DC voltage to AC voltage output, and again it can convert its AC Voltage output to DC Voltage. So, a single phase inverterchanges its input 12 V direct current source from the battery bank to 230 V alternating voltage output.It also performs automatic change over function from inversion mode to conversion mode thereby changing the 230 V ACoutput (from it) or input to it from the diesel generator or utility supply to 12 V DC for charging the battery bank. So, on detecting low level voltage input from the battery, it automatically switches over from the battery supply to the utility or generator supply, and when the battery is fully charged or there is power outage from the generator or utility supply, it switches over to the inversion mode taking itsinput/supply from the battery bank and by this operational sequence, itensures uninterruptible power supply to the end user.

V. Battery and battery sizing

Today the most suitable storage technology for hybrid systems is lead acid batteries with tubular plates in the form of vented lead acid (VLA) flooded batteries with liquid electrolyte to be regularly refilled or valve-regulated lead acid (VRLA) maintenance-free batteries. The battery recommended for use in hybrid power system is the VRLA deep cycle battery. Deep cycle battery is specifically designed to be discharged to low level and to recharge rapidly. It is also cycle charged day after day for many years. The battery should be large enough to store sufficient energy to operate the appliances at night and during cloudy days.

Battery Capacity: This is the maximum amount of energy that can be extracted from the battery under certain specified conditions and it is measured in ampere hour. Every cell in the battery has the potential for producing a certain amount of energywhen it's fully charged. If the stored energy in a battery C_{25} =100 Amp-hr, then it can provide a current of 4 Amps for 25 hours under specified conditions.

The energy stored in a battery in Kilowatt Hours (kWh) $=\frac{Ah \times V}{1000}$ (3)

Where V = the battery voltage, Ah = the amount of the electrical charges stored in a battery.

Battery Charging Rate: This is specified by battery manufacturers and it depends on the battery capacity and state of charge. To determine the capacity of the battery that can supply the needed energy to run the connected load requires the following procedure (i) calculate the total watt-hour per day to be used by the appliances. (ii) Divide the total watt-hour per day used by the appliances by 0.85 where 0.85 is a factor for losses in the battery system. (iii) Divide the result obtained in step (ii) by 0.6 where 0.6 is for the depth of discharge of the battery. (iv) Divide the result of step (iii) by the battery nominal voltage (in most cases, the battery voltage is 12V). (v) Multiply the result of step (IV) with the number of the autonomy days. (Autonomy days are the number of days the system will run on battery only without being recharged either from the solar panel or the utility supply). Most systems are designed for two (2) autonomy days.

Battery Capacity $(B_C)=\frac{T_{Whpd}}{0.85 \times 0.6 \times 12} \times 2$ (4)

Where T_{WHPD} = Total watt-hour per day, Autonomy days = 2.From Table 1, T_{WHPD} = 2170 Wh

from equation (4) $B_C = \frac{2170}{0.85 \times 0.6 \times 12} \times 2$ = 710Ah

The batteries can be connected in Parallel, Series or Series-Parallel to supply the energy to run the load. Batteries are connected in parallel to increase the current keeping its voltage constant. Again, they are connected in series to increase the voltage keeping the current constant. A battery bank can also be connected in a series-parallel topology to increase in both current and voltage values of the battery. In order to get the required system's energy for this design, the batteries shall be connected in parallel.

Where $B_P=\frac{B_R}{B_C}$ (5)

B_P= Numbers of batteries to be connected in parallel, B_R= required battery bank capacity.

B_C= Capacity of the selected battery inAh. Assuming that a battery capacity (B_C) of 200 Ahis procured for this design.From equation (5), $B_P=\frac{710}{200}$= 3.55 ≈ 4, so four (4) batteries rated 200 Ahconnected in parallel can supply the needed electrical charges to run the system for two autonomy days.

Number of Batteries tobeconnectedinSeries, $B_S=\frac{V_N}{V_B}$ (6)

Where V_N= System DC voltage, V_B= Battery Voltage, B_S= Numbers of batteries to be connected in series. From equation (6), $V_N = V_B$=12 V DC. Therefore, $B_S=\frac{12}{12}$=1. So, one battery rated 710 Ah shall be connected in series to supply the electrical energy to run the system for two autonomy days.

Total number of batteries needed to run the system $B_N=B_S \times B_P$ (7)

Where B_N= Total number of batteries,

B_S= Batteries connected in series, B_P= Batteries connected in parallel. Using equation (7), the total number of batteries needed to run the system B_N=1× 4 = 4 batteries.

VI. Solar panels and Solar Panels Sizing

The solar panel is to provide power to charge the batteries and also supports the battery during inverter operation. The procedures for solar panel sizing are; (i) calculate the total power consumption of the system connected load. By calculation, it is the sum of appliances' power ratings multiplied by the number of each of the appliances connected in the system (bearing in mind the appliance rated power factor and efficiency where they are specified).

$AP_{rating} \times AP_{number}$ (8)

Where AP_{rating} =Appliance power rating, AP_{number} = Number of appliances.

From Table 1, the total connected power is 340 Watts.

(ii) Calculate the daily energy consumption of the connected load; this is also the sum of the energy consumed by each connected load or appliance. By calculation, this is the sum of each connected appliance power rating multiplied by the appliance total run hours per day. So, daily energy consumption of the connected loads is obtained as shown in equation (9)

$$P_{D\,E} = L_{SUM} \times AP_{rating} \times AP_{RH} \qquad (9)$$

Where $P_{D\,E}$ = Daily energy consumption of the connected load, L_{SUM} = Sum of connected load

AP_{rating} = Appliance rating power rating, AP_{RH} = Appliance run hours per day.

From Table 1, the total connected power is 2170 Watts.

(iii) Calculate the total watt-hours per day or daily energy needed from the PV panels (modules): this is done by multiplying the daily energy required by the connected load by a factor of 1.3 and this is given in equation (10)

$$WH_{TPD} = P_{D\,E} \times 1.3 \qquad (10)$$

Where WH_{TPD} = Total watt-hours per day. The factor of 1.3 accounts for energy lost in the system.

Using equation (2), WH_{TPD} = 2170 × 1.3 = 2821Wh.

(iv) Calculate the total watt-peak rating needed from the PV modules; here we divide the daily energy (Watt-hours per day) needed from the PV panels by a factor known as the solar panel generation factor. The solar panels generation factor for Nigeria is 3.41.

So, the total watt-peak rating needed from the PV panels $W_{T\,PR} = \frac{WH_{TPD}}{SP_{GF}}$ (11)

Where W_{TPR} = Total watt-peak rating needed from the PV modules, SP_{GF} = Solar panels generation factor (v) Calculate the number of the PV modules needed to generate the total watt-peak rating required from the PV modules to run the system. The procedure requires that we divide the total watt-peak rating needed from the PV panels by the rated power capacity of the chosen solar panel to be installed to generate the needed power

Hence $N_{SP} = \frac{W_{TPR}}{SP_{PR}}$ (12)

Where N_{SP} = Number of solar panels, W_{TPR} = Total watt-peak rating needed from the PV panels, SP_{PR} = Solar panel power rating. In order to maximize space for the installation of the PV panels, a solar panel with higher power rating can be chosen. The solar panel is to provide power to charge the batteries. Using equation (11), $W_{T\,PR} = \frac{2821}{3.41} = 827Wh$. Assuming that solar panels rated 100 W are to be installed to generate the power, then the numbers of the solar panels needed to generate the above energy can be obtained using equation (12). Where SP_{PR} = 100 W, then $N_{SP} = \frac{W_{TPR}}{SP_{PR}} = \frac{827}{100} = 8.27 = 8.3$.

So, nine (9) solar panels rated 100 Watts shall be installed to generate the power to charge the batteries. However, it is necessary to maximize the space where the solar panels shall be installed and in such cases, solar panels with higher power rating can be used.

The specification for the solar panel: PV Panel Make = Renogy, Monocrystalline Solar Panel, Module Type; 100D, Maximum Power (P_m) = 100 W, Optimum operating voltage (V_m) = 18.9 V. DC, Optimum operating current (I_m) = 5.29A, Open circuit voltage (V_m) = 22.5 V. DC, Short Circuit Current (I_{SC}) = 5.75A.

VII. Solar charge regulator and the solar charge regulator sizing

The charge regulator is to regulate the charge current from the PV panel to the battery. The short circuit current (I_{SC}) of the PV panel is used in sizing the solar charge controller. Multiply the value of the short circuit current of the PV module by 1.3, where the factor of 1.3 accounts for energy lost in the system $S_{CCR} = PV_{SCC}$ x 1.3 (13)

Where S_{CCR} = Solar charge controller rating, PV_{SCC} = Total short circuit current of PV array. From section 6, the short circuit current rating of the100 W solar panel used in the design is 5.75A.

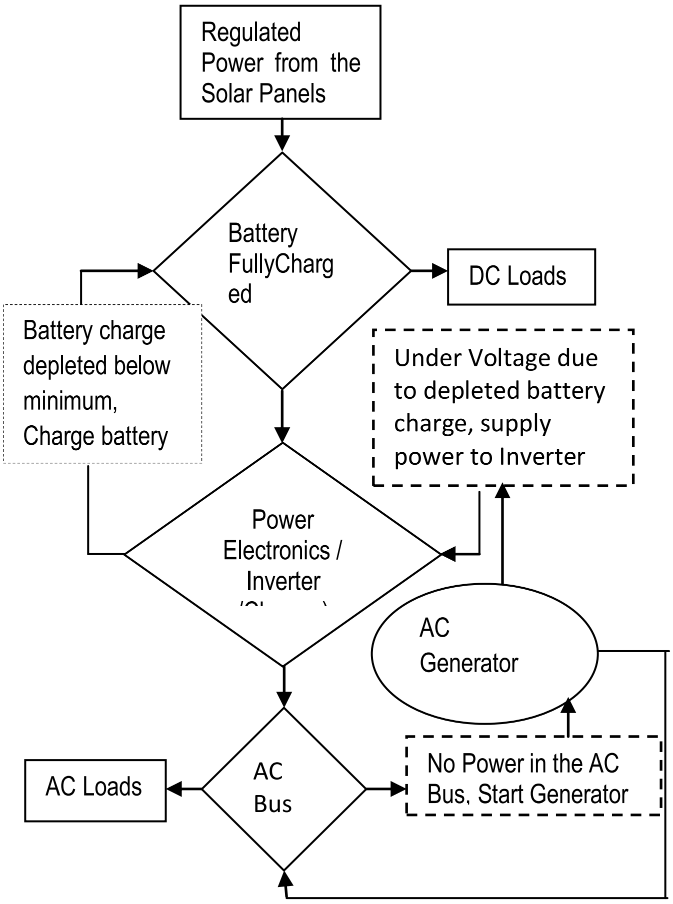
So, Solar Charge Controller rating for each of the solar panel = 1 x 5.75 x 1.3 = 7.5A. Hence the Solar Charge Controller rating for the hybrid system = 9 x 5.75 x 1.3 = 67.3A

VIII. Diesel Generator

The inclusion of diesel generators in the hybrid system increases the availability and reliability of the system. Most of the small alternating current generators use gasoline engines as their mechanical prime mover, however, methane, propane and petroleum powered engines can also be used. A number of factors affect the generator selection process and these include cost, power requirements, fuel availability and maintenance requirements. According to the reliability level desired from the use of the hybrid system, one can decide to install one or more generators in order to provide full services even during maintenance periods. The generator set in the hybrid system provides power mainly for the peak periods of energy demand during early mornings and evenings. The power from the generator is also used for charging the battery bank.Load shedding technique can be used to maximize the system's output power during peak demands. This is done by isolating some of the loads based on priority. It can also be applied when the battery charge has depleted so that when the battery is fully charged, the isolated loads can then be connected back.The total connected load as shown in Table 1 is 340 Watt, while the designed capacity of the inverter was 465 VA. So, the generator shall be sized to generate power for peak demand and for possible future expansion.

The specifications of the generator used include for the design; Make = Honda, Model EP 1000,Rated Output (VA) =700 VA, Maximum Output (VA) = 800, Frequency (Hz) = 50 Hz, AC Single phase, Output Voltage = 230 V, StartingSystem = Recoil Starter, Fuel = Petrol, Speed = 3000 RPM

The operational procedure of the designed solar-diesel UPS system is shown in Figure 2.



IX. Test Results of the hybrid system

The test results of the hybrid system are shown in Figures 3 and 4.

Figure 3. The graph of the daily power profile of the Hybrid system

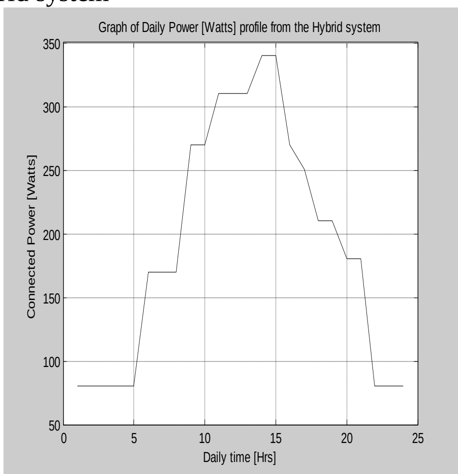
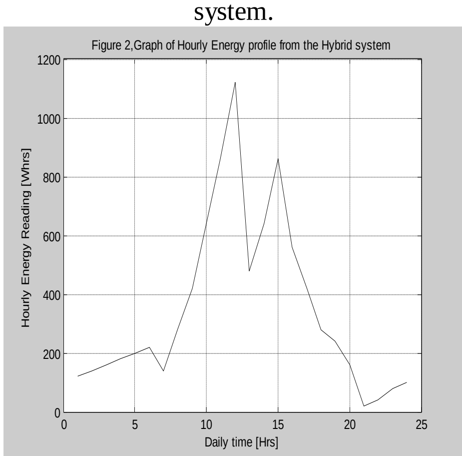


Figure 4 Hourly energy profile of the hybrid system.



X. Conclusion

This model of solar-diesel hybrid system with a battery based inverter provides uninterruptable, fast response and reasonable pollution free power for low power application. It is effective, reliable, cost effective and durable. It can provide power to critical equipments thereby reducing the over dependence on conventional power generation and distribution system which oftentimes does not guarantee power supply to the end users when power is critically needed.

References

[1] U.S. Energy Information Administration, "Total Energy", Monthly Energy Report, Nov. 2015 http://www.eia.gov/totalenergy/data/monthly/#electricity

[2] Z. M. Nyo, '' Evaluation of PV, Wind, Diesel Hybrid Energy Potential for GSM Tower in Myanmar'' International Journal of Electrical and Computer Engineering, (IJECE), Vol. 5, No. 6, pp. 1245-1251, December, 2015.

[3] I. B. Gould, "Hybrid Systems Architecture and Control," Handbook on Hybrid Power Systems. Golden, Colorado: National Renewable Energy Laboratory, March, 1998.

[4] M.M Mahmoud, I.H Ibrik, "Techno-economic feasibility of energy supply of remote villages in Palestine by PV-systems, diesel generators and electric grid." Renewable and Sustainable Energy Reviews, Vol. 10, Issue 2, pp. 128-138, 2006

[5] G. Deb, R. Paul, S Das. "Hybrid Power Generation System" International Journal of Computer and Electrical Engineering, Vol.4, No.2, pp. 141-144, April 2012.

[6] Energy Storage Association, ESA. "Energy Storage Technologies", 2014 [Online] Available: https://energystorage.org/energy-storage [Accessed 25 March, 2016]

[7] O. Ellabban, H. Abu-Rub, F. Blaabjerg, "Renewable energy resources: Current status, future prospects and their enabling technology", Renewable and Sustainable Energy Reviews, Vol. 39, No. 10, pp. 748-764, 2014

[8] A.M. Makbul Ramli, A. Hiendro, H.R.E.H. Bouchekara "Performance Analysis of Hybrid PV/Diesel Energy System in Western Region of Saudi Arabia", Hindawi Publishing Corporation, International Journal of Photo energy, Vol. 2014, No. 626251, pp. 1-10, May, 2014http://dx.doi.org/10.1155/2014/626251

[9] A. K. Daud, M. S. Ismail, "Design of Isolated Hybrid Systems Minimizing Costs and Pollutant Emissions," Renewable Energy, Vol. 44, No. 2, pp. 215-224, 2012

[10] A.N Celik., "A simplified model for estimating yearly wind fraction" Renewable Energy, Vol. 31, issue 1, pp. 105-118, 2006 http://dx.doi.org/10.1016/j.renene.2005.03.006

[11] L.A.S Ribeiro, O.R Saavedra, S.L Lima, J.G Matos; ''Isolated Micro Grids with Renewable Hybrid Generation: The case of Lencois Island'', IEEE Transactions on Sustainable Energy, Vol.2, No.1, pp. 1-11, Jan, 2011

[12] L. Xu, X. Ruan, C. Mao, B. Zhang, Y. Luo, "An improved optimal sizing method for wind-solar-battery hybrid power system," IEEE Transactions on Sustainable Energy, Vol. 4, No. 3, pp. 774–785, 2013.

[13] BB. Blackwell, R. Sheldahl, LV. Feltz; '' Wind Tunnel Performance Data for Two and Three Bucket Savonius Rotor'', Journal of Energy, Vol.2, pp. 160-164, 1978

[14] A.N Celik, ''Optimization and Techno-economic Analysis of Autonomous Photovoltaic-Wind Hybrid Energy Systems in Comparison to single Photovoltaic and Wind Systems'', Energy Conversion and Management, Vol. 43, pp. 2453-2468, 2002 http://www.leonics.com/support/article2_12j/articles2_12j_en.php

[15] S. M Rompicherla."Solar Energy: The Future". International Journal of Engineering Trends and Technology (IJETT). V4(6):2513-2517, Jun 2013. ISSN:2231-5381. www.ijettjournal.org. published by seventh sense research group.

[16] N.Sivaramakrishna, Ch.Kasi Ramakrishna Reddy "Hybrid Power Generation through combined solar – wind power and modified solar panel ". International Journal of Engineering Trends and Technology (IJETT). V4(5):1414-1417 May 2013. ISSN:2231-5381. www.ijettjournal.org. published by seventh sense research group.

[17] Karuna Nikum, Rakesh Saxena, Abhay Wagh"Performance Analysis of Battery Banks with PV-Wind Connected Hybrid Distributed Power System", International Journal of Engineering Trends and Technology (IJETT), V29(4),177-182 November 2015. ISSN:2231-5381. www.ijettjournal.org. published by seventh sense research group