Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

TECHNICAL COMPARISON OF HYBRID RENEWABLE ENERGY SYSTEMS FOR INFORMATION TECHNOLOGY SERVICES

John ADEBISI,
University of Namibia, Namibia; adebisi_tunji@yahoo.com

Olumuyiwa AMUSAN,
University Lagos, Akoka, Nigeria; University of Johannesburg, South Africa

Ponmile OLAWOORE,
Alex Ekwueme Federal University, Ebonyi, Nigeria

Chukwebuka IGWE
Alex Ekwueme Federal University, Ebonyi, Nigeria

Abstract: In a bid to reduce the negative effect of atmospheric and environmental pollution and its consequent negative effect, a mix of renewable energy generation options is being considered across the globe. Hence, the technical comparison of an eco-friendly, cost-effective, and near zero carbon footprint for sustainable power solutions is still of core interest in the research space. Solar, wind and its hybrids can be further explored to meet the ever-increasing load demand of energy consumers, especially in high energy demand facilities including information technology (IT) services. Critical IT infrastructures represent a core backbone in research institutions, hence the need for hybrid energy solutions is pertinent for increased sustainability. This work compared hybrid energy sources of solar and wind against its independent sources using the IT laboratory in Alex Ekwueme Federal University, Ebonyi, Nigeria. An appropriate sizing of individual and a hybrid of wind, solar, and battery energy source was done, after which the input-output voltages across the set-ups was measured during peak and off-peak periods for a 300W laboratory IT load. The experimental result showed the input/output peak and off-peak DC voltages for solar, wind, and its hybrid energy are 12.67V/12.02V / 12.47V/11.61V, 12.53V / 11.90V / 12.48V / 11.87V, and 12.78V / 12.09V / 12.57 / 11.95V respectively signifying a significant increase from the on-load peak period while the on-load off-peak period is seen to be lower. The results also show that a hybrid solar-wind-battery system tested at 5 minutes time intervals gives a superior output voltage regulation and efficiency when compared to the solar or wind individual systems. It was concluded that the hybrid system of solar, wind, and battery energy source is an ideal standalone renewable energy power option for IT laboratory in the university.

Keywords*:* Solar PV system, Wind energy system, Solar-Wind-Battery hybrid system, Information technology

Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

1.0 Background

Human existence couldn't have been so interesting without reliable energy [1]. Additionally, human economy and fostered quality of life depend largely on energy for its reality [2]. Energy has the capability of machinery to result an external action [3]. To this view, various grades of energy are discriminated: the mechanical form which is of potential or kinetic energy, the thermal, nuclear, electric, chemical, and solar energies. For work to be done using the chemical, nuclear and solar energy there must be a form of transformation to its mechanical or thermal energy equivalence [4]. The quantity measure of the available energy is termed as energy basis [5]. The foundation of power is made of predominantly exhaustible assets and electricity from large part renewable sources. In respect to this, energy resources fossil and recent resources are distinguished: Fossil energy – a stock of energy that came into existence during the ancient geological age by biological or geological process. It has been further divided into bio-genous energy resources and fossil energy resources [6]. The hard coal, crude oil, and natural gas make up the biogenous resources [7]. Recent energy resources are those, which are currently generated by biological process. These are the biomass's energy content and the natural reservoir's potential energy. Energy sources necessitate a stream of energy to an extended period of time. In regards energy sources are termed inexhaustible [5].

However, the enormous variety of environmental impact significantly result during the affair of energy provision or more exactly of the related energy services all of which are heating living spaces, information, and mobility are less lived with by the society of the 21st century [6]. This is why energy problems, in conjunction with the underlying environmental problem will continue to be a major topic in energy engineering [8]. But the splendor of a surroundings now no longer mainly aggressive, plentiful, and value effective electricity sources have led growing range of industrialized nations to aid public financing of renewable electricity [9]. In Europe 2020, the European commission set a target of 20% of the share of renewable energy from renewable energy to foster obedience to an international agreement on greenhouse sending reduction and to make out a chance for employment and district growth [10].

Replacement of fossil gasoline with the aid of using exclusive sources of renewable power is one of the three concerned technological modifications in sustainable energy improvement strategy [10]. Renewable electricity is a sort of power made from self-renewing reassets along with solar light, wind, flowing water etc. In critical service organisations such as financial enterprise and information technology services such as video conferencing, telemedicine, e-government, e-leaning and several other services that has depended on IT especially in the post COVID era and those assets that require uninterrupted and economically viable electricity supply has informed the need for this research. Renewable strength technology in comparison with the traditional assets of strength bring about weightier merit. The electricity from the wind is generated from airflow via wind to automatically power generators for electricity. These turbines then convert the mechanical power brought on to electric power. Wind electricity, as an alternative to burning fossil fuels, is plentiful, renewable, broadly distributed, clean, produces no greenhouse gas emissions at some stage in operation, and uses little land. Generation of electrical electricity from sun energy can be executed with the aid of using the conversion of daylight into electricity, both directly using photovoltaics (PV) or not directly the usage of focused sun electricity (CSP) [11]. Invariably, technology promotes society's growth standard of existence, and combining solar, wind, and hybrid power systems will increase efficiency.

Consequently, improving energy efficiency will reduce the greenhouse effect, lower demand for energy, and cost on house and economy wide level. This can be obtained from renewable energy source [9]. To this extent this research is carried out on the basis of comparative technical analysis of the efficiency of solar, wind, and hybrid power system. It evaluates individual sizes of the energy mix and implements the mix with the most efficient power source through storage for maximum power supply.

Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

2.0 Review of Related Concepts

Energy will depend on solar and wind in the future because they are much available as a natural resource. The nature of energy generated will become more reliable to support the high demand for information technology services of the 21st century in all sectors [5]. Due to the pollution, high cost, and transmission power loss posed by the convectional power sources; future services will require clean energy, making the current energy source a difficult task. Constant power source and efficiency will be available when a combination of solar and wind plants are deployed as a single source with a battery as storage element [7]. Efficiency of energy will reduce its consumption and increase saves of consumer's money [2].

2.1 Solar energy Model

Sun provides the solar that reaches the earth's surface, and several amounts of it are absorbed in different places as a result of the geographical condition [8]. 1,367w of the power reaches each rectangular meter of the outer fringe of the earth's ecosystem. The environment as a result absorbs the power and reflects it. The radiation from the solar passes via the environment and because of the thickness of the environment, the sun electricity is reduced [13]. This sun power is renewable and unearths utility in water heaters, sun lamps etc. [8]. The Air mass 1 or AM1 radiation which is about 1000 W/meter square [3] is another concept during the noon time when the sky is clear there is an amount of radiation that reaches the earth sea level. Similarly, the sun's mild rays that reach a location as properly known as incident sun radiation is insolation. The daylight is erratically dispensed within-side the areas of the earth; equator areas get hold of greater radiation than some other part. Sunlight varies with the seasons because the rotational axis of the Earth shifts to prolong and shorten the darkish or mild days with the changing seasons. The amount of daylight attaining any location is likewise affected by the time of day, the climate (specifically the cloud cover, which scatters the sun's rays), and the air pollutants in that location. Likewise, those climatic elements all affect the quantity of sun power that is to be had to PV systems [13].

2.2 Types of solar power system

a. ***On-Grid solar:*** this consists of the sun panels, inverter, meter and software grid. Solar sources direct current. The inverter converts the DC from the sun to AC for maximum home equipment that don't use DC [14]. The alternating current flows via the meter this is connected to device. This is illustrated in Figure 2.1

Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

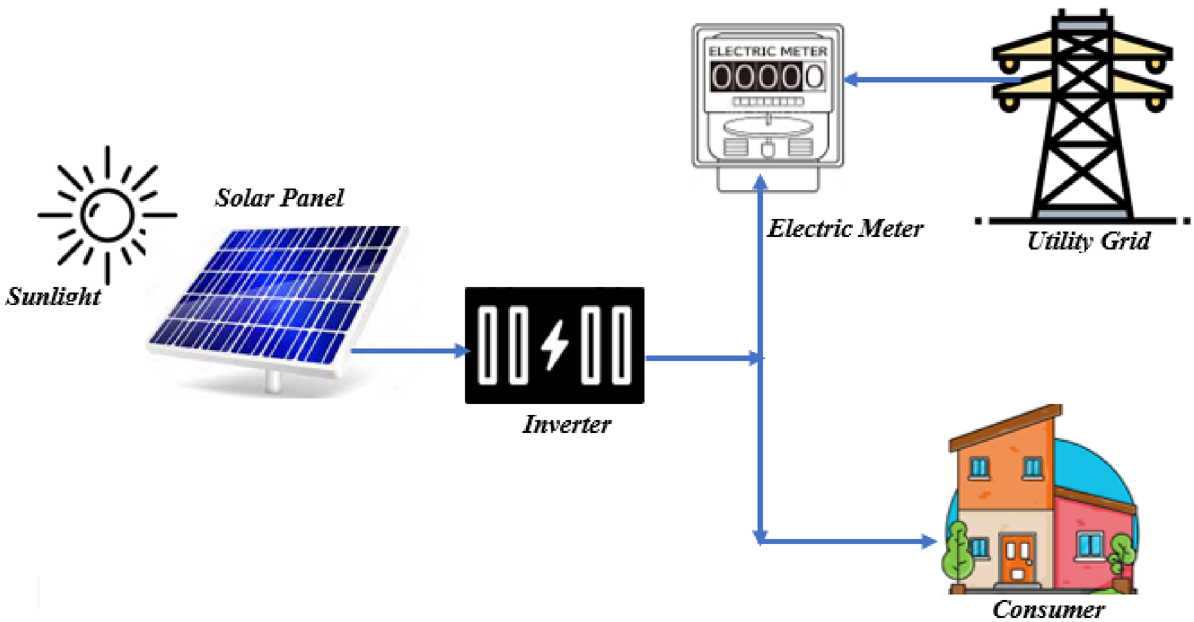

Figure 2.1: *On-grid solar illustration*

b. ***Off-Grid solar****:* this comprises of solar cells for conversion of solar light into direct current electricity, inverters are used for conversion of the direct current electricity from an alternating current [15], and battery bank for storage of the left energy [16]. A modified concept of 2.1 is as shown in figure 2.2.

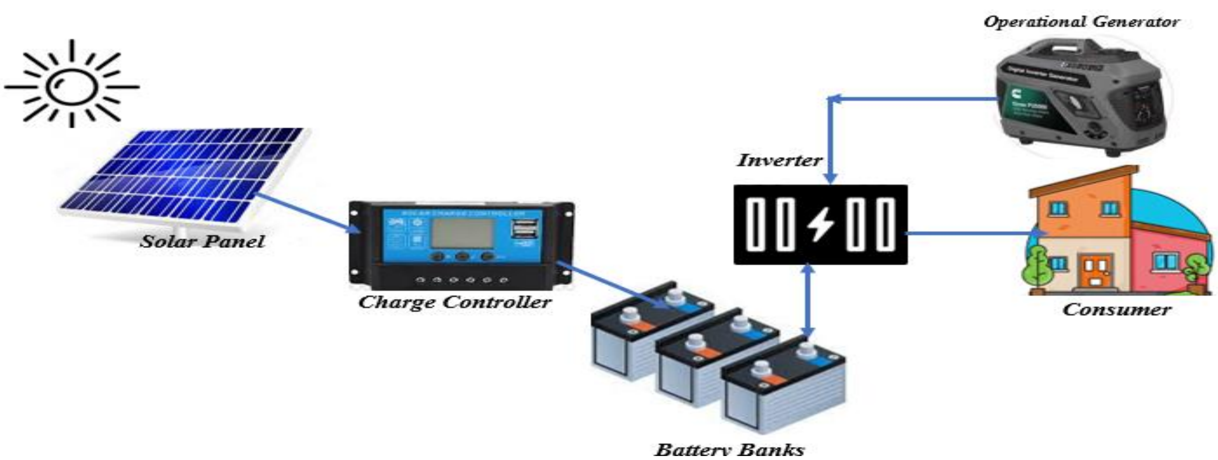

Figure 2.2*: Off-grid AC Solar Illustration*

© Centre for Cyber Physical Food, Energy & Water Systems

c. ***Hybrid Solar****:* The operation of hybrid solar integrates the working of On-Grid and Off-grid as indicated in figures 2.1 and 2.2 respectively. It stores energy through the batteries and is used when needed. At times when there's no support from both on and off grid solar causing no energy left in the storage battery. Uninterrupted electricity keeps it working and the battery could be charged [16]. System of this nature is required for high availability services such as information technology. Considering the various methods of harnessing the solar energy such as solar-thermal process which changes continuously for solar energy to obtain equivalent heat. This principle reflects concentrated solar light unto a load point. Heat form converted is applied to heat up water and dry crops [15].

Other methods include but are not limited to Solar-PV - that converts solar sunlight into its equivalent direct current electricity using photovoltaic cells [10]. Solar panel module - a module that is shaped while photo-voltaic cells are assembled together. The sun panel uses solar light to supply direct current electricity [14]. The panel works comparable precept just like the PN junction of a semiconductor. As photon fall at the panel, P-type and the N-type alternate their majority carriers constituting follow of current. As the technique continues, the battery connected to it gets charged. Solar cells are connected in series in order that it sums up the voltage [17]. Percentages of 15% to 22% of the strength from the sun are processed into usable strength. This relies upon on how the panel is placed, the climate condition, orientation and different comparable. Panel overall performance is decided through the quantity of daylight it may convert to electric powered contemporary indicating panel performance [9]. A general Test Condition this performance at an exact temperature of 25 ^{O} C and 1000W/meter square. This is the equal of a sunny day with the incident light hitting a solar-facing 37°-tilted floor. Under standard check conditions, a sun panel performance of 15% with a 1 m^2 floor location might produce 150 Watts [17]. Different types of solar panels are Mono-crystalline Solar Panel, Polycrystalline Solar Panel and the Thin film solar panels**.**

2.3 Panel efficiency at extreme condition

Nowadays, commonly used solar panels deliver an energy efficiency rating that ranges between 11% to 15%, this results to the proportion of solar energy that is actually converted into operational electricity. One of the extreme conditions is the Snow - the quantity of snow at the floor of a panel if far thicker than 5cm. might have a negative impact and decrease the performance of a solar panel by 100%. The inclined position of the panel permits the snow to slip off. It can be eliminated manually [18]. Another serious condition is wind - when there's massive boom in speed of the wind, the panel performance reduces. Wind causes principal harm to panels, making producer's behavior huge tunnel check to lessen the harm. Although wind impact cools panel. At 1^0 cool the panel will increase in efficiency of 0.05% [8]. Other conditions are Hail, Ice, Chemical Residue, UV Degradation and Damp heat testing.

2.4 Wind power and Conversion

Since this work compares different renewable energy sources, the place of wind power and its conversion is very important. In the 1980's the USA started the wind farm through the establishment of 10,000 turbines [19]. Each of the station produced 80-200Kw. Denmark pioneered wind energy in Europe [20]. Germany at the end of the 21st century took the lead in wind energy production until 2008[21]. 2020 was the best year for the global wind industry when 93GW of new capacity was installed and the development continues. Wind power provides natural energy. The flow of wind is from the higher pressure to the lower pressure level as a result of radiation falling unto the earth. The wind power is available day and night and is more in coastal regions. Moment past and location, wind varies and is unpredictable. The wind motion virtue gave rise to its kinetic energy. This kinetic energy of the wind is surrounded by wind Turbine, which extract the wind energy by conversion to Mechanical Power. The mechanical form of energy powers the electric power generator and causes it to turn. The amount of power generated is equivalent to the amount of wind available in the place.

2.5 Hybrid power

Based on the concept anchored upon by this work, the need for hybrid power cannot be overstressed because it is the future of energy generation for improved efficiency and sustainability of critical services such as Information technology [22]. The process of hybrid power generation, especially in renewable power systems, comprises of merging distinctive energy device correctly (in this case solar and wind) into a single system to enhance the overall gain compared to a single device with a single supply. It was initially designed as an aggregate of conventional, nonrenewable generation (e.g., diesel generators) with battery power storage structures (BESSs). Efficiency and cost of solar and wind energy depend on their parts, parameters, and topologies. Solar energy is extra efficient than wind. However, it isn't usually relevant as efficiency is predicated at the technological revolution of individual additives use in the PV or wind device [23]. Generally, wind turbine device is more expensive than the sun. Consideration of each value and performance normally imposes the consumer to compromise, which is more vital than the opposite. Increasing performance way making use of evolved strategies and putting in extra highly-priced device which bring about elevating the overall value of the device [24]. The method used for this technical comparison are detailed in the next section.

3.0 Methodology

Previous related works used incentive mechanisms [25], mathematical analysis methods[26], and other modelling software tools such as Advanced Interactive Multidimensional Modelling System (AIMMS)[27], Hybrid Optimization of Multiple Energy Resources (HOMER) [28-29]. In this work, different materials and methods through which the research is implemented is discussed using the following materials: A mono crystalline 12V 100W solar panel, Battery: 100A 12V DC Deep-cycle battery, Wind Generator: A 500W 12V wind generator, Inverter, 1000W 12V DC inverter with Output of 220-230V AC output, 20A 12V DC PWM Charge Controller, and a 300W IT laboratory load. The individual components areas described below.

3.1 Wind Generator: 500W, 12V

The effectiveness of independent wind solar hybrid energy systems is compared to that of solar panels and wind turbines working on their own as renewable energy sources in this study. There is a 500W wind turbine. The calculations for power (output/input) and efficiency of wind turbine and solar panel systems are made using historical data from the research region that was gathered by the institution's weather section. The energy provided by the wind is provided by [28];

$$P_w = \frac{1}{2}\rho A v^3 \tag{1}$$

3.2 Mono-crystalline Solar PV: 100W, 12V

In order to disperse the surface area across various orientations and receive more solar energy, the monocrystalline solar panels employed in this study have varying dimensions. The same amount of power is generated by smaller solar panels (16X24 cm) that have the same surface area as one large solar panel (35X62.5cm). Hence the dimension solar

Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

PV used is 60cm X 24cm. This does not include employing a solar tracking system to maximize the solar panels' exposure to sunlight. Efficiency is assessed using:

$$\eta_{solar} = \frac{P_{max}(Watt)}{I_r\left(\frac{W}{m^2}\right)A} \quad (2)$$

3.3 Hybrid Solar and Wind System

In order to build the hybrid renewable energy system under investigation, three-bladed wind turbine and the solar PV are employed to the same specifications. The overall power output of the hybrid is determined by equation 3 [29], where Nw and Ns represents the number of wind turbines and solar modules respectively.

$$P_{hybrid} = (N_w P_w) + (N_s P_s) \quad (3)$$

The power production is measured and tested for the wind turbine alone. The energy production from solar is evaluated first with a single large solar panel, then with six smaller solar panels with comparable characteristics. Each system's efficiency is calculated. The wind turbine is initially connected to the one giant solar PV and six smaller solar panels to test the hybrid system. The performance for each arrangement is again calculated for comparison. The integration of energy from two different renewable energy sources—solar panels and wind turbines—to produce a single output depends on the solar-wind hybrid controller. In order to store the energy, a rechargeable battery will be attached to the controller that mixes solar and wind energy. The controller's ability to prevent high or fluctuating voltage and guard against overcharging and prolong battery life is one of its additional functions. The renewable energy hybrid system's efficiency is determined by

$$P_{hybrid} = (\frac{1}{2} N_w \rho A_w v^3) + (N_s \eta_s I_r A_s) \quad (4)$$

3.4 Deep Cycle Battery: 100A, 12V DC

Battery is used to store the energy generated from the solar panel. They are connected in series such that the appropriate voltage is obtained. The battery used is the deep cycle.

$$\text{Battery capacity(Ah)} = \frac{\text{total watt−hour perday x days of autonomy}}{\text{0.85 x 0.6 x norminal voltage}} \quad (5)$$

Autonomy is the number of days the battery will work without using the solar panel. This is taken as 2days

3.5 PWM Charge Controller: 20A, 12V DC

This charge controller is used to ensure that the dc signal from the wind turbine and solar is connected directed to the battery. It also prevents overcharging of the battery, excess temperature on the battery and it prevents reverse-discharge from the battery [26].

Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

3.6 IT Services and the Hybrid System Layout

Various information technology services are available in the laboratory used as a case study of this research. Most of these services compete for high power supply with critical server infrastructures spanning application servers, network infrastructures, database servers, security architecture and management, virtualization solutions, automation and analytics, data center and Webhosting, remote infrastructure services, among others. Some of these services are out of reach, especially during power outages and occurrences of power interruptions. The hybrid system is such that a common DC bus connects all the energy sources of wind, solar, and battery together. The PV array is connected to the charge controller to limit the output for battery charging. The battery is a bidirectional power flow that can be charged from the DC line and supply power. The DC output from the wind turbine is connected to the general bus. The bidirectional inverter reverses the DC to AC for load use in the IT laboratory of the Alex Ekwueme Federal University, Ebonyi State, Nigeria.

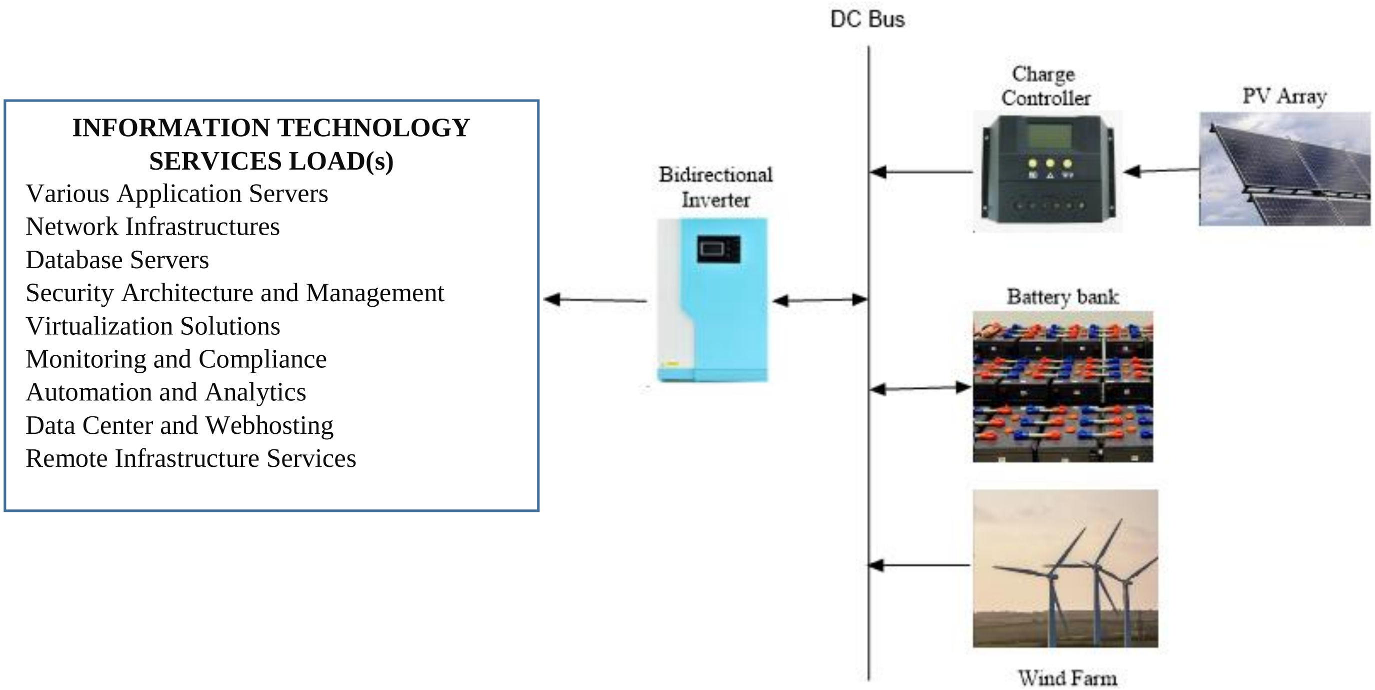

Figure 3.1: Overall Hybrid System for IT Services

Four (4) solar panels with individual outputs of 60W, 70W, 90W, and 90W making an overall output power of 310W was connected to power the 300W IT load. It is important to note that the combined area of small solar panels will produce the same output power if a single solar panel is used. However, for reduced cost, multiple solar units are connected in series. Because of this, it is necessary to connect the negative terminal of one solar panel to the positive terminal of the second solar panel. Since the voltage is cumulative in series connections, the ampere stays constant.

Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

The connections to the controller for the wind turbine and the negative and positive terminals for each group will remain the same as they were in the previous step. The solar panel size varies in each approach, despite the fact that the wind turbines in both cases have the same structure and dimensions. The associated components smoothed and decreased the voltage to a maximum output value of 14V, while the controller was designed to handle high input voltages from both sources. The components of the hybrid controller included a bridge rectifier to guarantee that all voltage was 100 percent direct current (DC), a capacitor to store energy in the form of an electrostatic field, similar to a small rechargeable battery, a resistor with an electrical resistance used in an electric circuit for operation, protection, or current control, and a diode to allow electric current to flow in only one direction.

4.0 Results and Discussion

The wind turbine and large solar panel each produce 24.9 W and 33 W of power, respectively. As was already established, the hybrid controller has every component from both systems in a single unit. The experimental setup is shown in Figure 4.1. The experiment took one day to complete for one run, and it was then performed four more times to gather five sets of data from which the average was calculated. This is being done to ensure that there aren't any significant changes in the data caused by changing weather and system changes. In order to measure the current and voltage, a multimeter is also used; it is linked to the battery in parallel for measuring the voltage and in series for measuring the current.

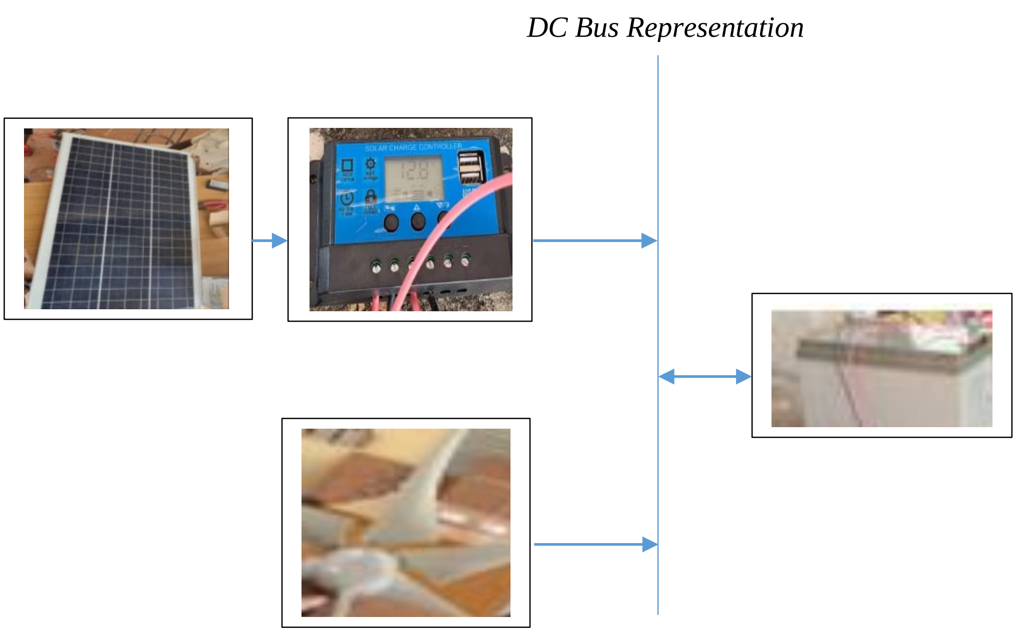

Figure 4.1: *Experimental Setup*

Averaging 30°C and 2.53 m/s of wind speed during the testing period. There are instances when there is no wind and the wind turbine cannot produce any power. But the solar panels kept their output power steady throughout the testing day. The output of the huge solar panel was 16.9 W at the least and 24.3 W at the highest. It was found from the testing

Journal of Digital Food, Energy & Water Systems, 3 (2): 1-12, 2022
ISSN 2709-4529
© Centre for Cyber Physical Food, Energy & Water Systems

of separate systems that the wind turbine did not consistently deliver an energy supply on testing days. When there is no wind, the wind turbine doesn't generate any power. In addition, the bigger solar panel generated more power than the smaller ones. This is due to the type of connection utilized to combine the tiny solar panels, which affects the voltage and current the solar panel generates following the first base-line analysis of the individual systems. Testing is done on the hybrid system. The initial hybrid system consisted of a wind turbine coupled with a sizable solar panel. Six miniature solar panels are coupled to a wind turbine in the second hybrid setup. Six days and five hours and a half, from 10:00 AM to 3:30 PM, are allotted for testing the separate systems. Each thirty minutes, the readings are recorded. After being tested separately, the hybrid system which combines solar panels and a wind turbine—has undergone additional testing. There are two main kinds of hybrid systems: one combines a wind turbine with a big solar panel (Hybrid System 1), and the other combines a wind turbine with six little solar panels wired in series (Hybrid System 2).

The testing window, which runs from 10:00 AM to 3:30 PM for each system, is the same as that window for the individual systems (five and a half hours). By doing so, the distinctions between hybrid and individual systems will be made clear. The wind turbine and huge solar panel were put to the test initially. The temperature was 31°C with an average wind speed of 4.89 m/s. The weather was sunny and clear. The hybrid system produced electricity from 19 W to 46 W, with an average of 39.11W. The comparison of the individual system against the hybrid experimental setup are depicted in tables 1, 2 and 3 showing the increment in output power. The hybrid system is compared to the separate systems with the most equivalent weather. It demonstrates that the power output significantly increased with a hybrid system. The large solar panel, however, produces more power than the little solar panel. In addition, the hybrid system's power output is continuous in contrast to the individual system, where the wind turbine's power is zero when there is no wind.

Table 4.1: *Solar Charge Measured Values*

S/N	SOLAR CHARGE	
1	PEAK PERIOD (Before Load)	12.67V
2	PEAK PERIOD (On-Load)	12.02V
3	OFF-PEAK PERIOD (Before Load)	12.47V
4	OFF-PEAK PERIOD (On-Load)	11.61V

Table 4.2: *Wind Charge Measured Values*

S/N	WIND CHARGE	
1	PEAK PERIOD (Before Load)	12.53V
2	PEAK PERIOD (On-Load)	11.90V
3	OFF-PEAK PERIOD (Before Load)	12.48V
4	OFF-PEAK PERIOD (On-Load)	11.87V

Table 4.3: *Hybrid Charge Measured Values*

S/N	HYBRID CHARGE	
1	PEAK PERIOD (Before Load)	12.78V
2	PEAK PERIOD (On-Load)	12.09V
3	OFF-PEAK PERIOD (Before Load)	12.57V
4	OFF-PEAK PERIOD (On-Load)	11.95V

5.0 Conclusion

The research investigated the performance implementation of an efficient hybrid solar-wind-battery energy system against independent solar and wind energy systems that can provide clean back-up power supply to information technology infrastructures in the IT laboratory of Alex Ekwueme Federal University, Ebonyi State, Nigeria. The result indicated that the developed system performs better than an independent solar or wind energy system in terms of voltage regulation and efficiency. The hybrid system's output produces more power than a single power installation system as it closes the energy supply gap due to insufficient solar irradiation or inadequate wind speeds. Summarily, this work revealed that; a hybrid energy system helps to ensure critical IT loads are kept on even during power outage during the hours when a single power source fails. This further enhances service reliability and environmentally friendly energy sources. Other key takeaways from the work are lower cost compared to the other power generation systems in use for same application, easier setup since no programming is required, and better efficiency as against independent solar PV or wind energy generator. Finally, it has been established that the uniqueness of this work is the application of hybrid solar and wind power system as an efficient standby power source for critical IT loads and infrastructure since the output power of the hybrid system is much higher in comparison with the individual solar and wind energy systems. Since the study considered the Load for 300W, in the future, the hybrid system capacity can be scaled up to power more IT Infrastructure, in addition, an algorithm that will automatically distribute energy across different IT services can be developed to priotize more critical servers for power supply stability and efficiency.

6.0 **ACKNOWLEDGMENT**

The authors wish to appreciate the Alex Ekueme Federal University, Ebonyi State Nigeria for their support during this research survey.

6.0 REFERENCES

[1] M. Kaltschmitt, W. Streicher, and A. Wiese, *Renewable energy: technology, economics and environment*. Springer Science \& Business Media, 2007.
[2] S. R. Bull, “Renewable energy today and tomorrow,” *Proc. IEEE*, vol. 89, no. 8, pp. 1216–1226, 2001.
[3] H. Lund, “Renewable energy strategies for sustainable development,” *energy*, vol. 32, no. 6, pp. 912–919, 2007.
[4] E. Shove, “What is wrong with energy efficiency?,” *Build. Res. \& Inf.*, vol. 46, no. 7, pp. 779–789, 2018.
[5] J. A. Adebisi, K. A. Abdulsalam, and I. O. Adams, “Multi-Power Source and Cloud-Backup Enabled Security Framework for Surveillance in Nigeria,” in *IOP Conference Series: Earth and Environmental Science*, 2021, vol. 730, no. 1, p. 12005.
[6] A. Shrestha, “3D MODEL OF PORTABLE POWER SYSTEM: A hybrid model of solar panels and wind turbine,” 2020.
[7] S. A. Gadkari, “A hybrid reconfigurable solar and wind energy system,” 2008.
[8] C. Bharatiraja, R. K. Pongiannan, M. T. Adedayo Yusuff, and T. Maddileti, “A simple switching on-time calculation revision in multilevel inverter-space vector modulation to achieving extended voltage boundary operation,” *Int J Pow Elec*

\& *Dri Syst*, vol. 10, no. 2, pp. 653–661, 2019.

[9] C. S. Kumar, P. Ramesh, G. Kasilingam, D. Ragul, and C. Bharatiraja, "The power quality measurements and real time monitoring in distribution feeders," *Mater. Today Proc.*, vol. 45, pp. 2987–2992, 2021.

[10] A. John A, B. Damilola E, and B. Olubayo M, "A multicriteria framework for selecting information communication technology alternatives for climate change adaptation," *Cogent Eng.*, vol. 9, no. 1, p. 2119537, 2022.

[11] M. Rajendran, M. Chinnasamy, S. Muthusamy, and M. K. Nair, "Introduction to Solar Energy Conversion," *Mater. Sol. Energy Convers. Mater. Methods Appl.*, pp. 1–31, 2021.

[12] M. Chandramouly and A. Raghuram, "Introduction to Solar Wind Hybrid Energy Systems," vol. 3, no. 12, pp. 1–6, 2017.

[13] V. Solar, "T 3.311 Course: Solar Thermal Energy Systems [T-MACH-106493]," *Modul. Handb. Mech. Eng. Exch. Students*, 2022.

[14] C. Brunet *et al.*, "Does solar energy reduce poverty or increase energy security? A comparative analysis of sustainability impacts of on-grid power plants in Burkina Faso, Madagascar, Morocco, Rwanda, Senegal and South Africa," *Energy Res. \& Soc. Sci.*, vol. 87, p. 102212, 2022.

[15] P. G. Munro and S. Samarakoon, "Off-Grid Electrical Urbanism: Emerging Solar Energy Geographies in Ordinary Cities," *J. Urban Technol.*, pp. 1–23, 2022.

[16] N. Ojong, "Off-Grid Solar Electrification on the Rise in Africa, but Where to?," in *Off-Grid Solar Electrification in Africa*, Springer, 2022, pp. 349–368.

[17] M. Alagu, P. Ponnusamy, S. Pandarinathan, and J. S. M. Ali, "Performance improvement of solar PV power conversion system through low duty cycle DC-DC converter," *Int. J. Circuit Theory Appl.*, vol. 49, no. 2, pp. 267–282, 2021.

[18] D. Akinyele, "Techno-economic and life-cycle impact analysis of solar photovoltaic microgrid systems for off-grid communities," 2016.

[19] E. Möllerström, P. Gipe, J. Beurskens, and F. Ottermo, "A historical review of vertical axis wind turbines rated 100 kW and above," *Renew. Sustain. Energy Rev.*, vol. 105, pp. 1–13, 2019.

[20] S. Krohn, "Danish wind turbines: an industrial success story," *Danish Wind Ind. Assoc.*, 2002.

[21] M. R. Patel and O. Beik, *Wind and solar power systems: design, analysis, and operation*. CRC press, 2021.

[22] J. Paska, P. Biczel, and M. Kłos, "Hybrid power systems--An effective way of utilising primary energy sources," *Renew. energy*, vol. 34, no. 11, pp. 2414–2421, 2009.

[23] W. M. Amutha and V. Rajini, "Techno-economic evaluation of various hybrid power systems for rural telecom," *Renew. Sustain. Energy Rev.*, vol. 43, pp. 553–561, 2015.

[24] A. S. Al-Buraiki and A. Al-Sharafi, "Hydrogen production via using excess electric energy of an off-grid hybrid solar/wind system based on a novel performance indicator," *Energy Convers. Manag.*, vol. 254, p. 115270, 2022.

[25] ICAT, "Initiative for Climate Action Transparency." 2022, [Online]. Available: https://climateactiontransparency.org/wp-content/uploads/2021/12/Renewable-Energy-Executive-Summary-Final.pdf.

[26] S. L. Gbadamosi, F. S. Ogunje, S. T. Wara, and N. I. Nwulu, "Techno-Economic Evaluation of a Hybrid Energy System for an Educational Institution: A Case Study," *Energies*, vol. 15, no. 15, p. 5606, 2022.

[27] S. L. Gbadamosi and N. I. Nwulu, "Optimal Configuration of Hybrid Energy System for Rural Electrification of Community Healthcare Facilities," *Appl. Sci.*, vol. 12, no. 9, p. 4262, 2022.

[28] S. L. Gbadamosi and N. I. Nwulu, "Optimal power dispatch and reliability analysis of hybrid CHP-PV-wind systems in farming applications," *Sustainability*, vol. 12, no. 19, p. 8199, 2020.

[29] D. T. Cotfas, P. A. Cotfas, S. Mahmoudinezhad, and M. Louzazni, "Critical factors and parameters for hybrid photovoltaic-thermoelectric systems; review," *Appl. Therm. Eng.*, p. 118977, 2022.