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Performance Investigation of Wind/Photovoltaic/Fuel cell Hybrid Energy System for Stand-alone Power Supply

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Abstract **Original Research Article**

Large numbers of households in isolated areas in Nigeria were reported to have lacking access to national grid. Their basic electricity demand is served through fossil fuel generators which are costly and environmentally unfriendly. The fact that extension of national grid lines to those areas becomes difficult, renewable energy resources exploitation is the best alternatives. Wind and solar energy as clean abundantly available resources could be harnessed in a hybrids form with long-term storage devices for enhancing energy optimization and power stability. This paper investigated the performance of Wind-PV-Fuel cell Hybrid Energy Systems for stand-alone application. The performances of Wind-Battery-Fuel cell and PV-Battery-Fuel cell Hybrid Energy Systems were investigated by using Hybrid Optimization Models for Energy Renewable (HOMER), through cycle charging controls. The techno-economic Figure of merits for the optimal configurations from these systems was compared. The results revealed that Wind-Battery-Fuel cell Hybrid had been the best system for serving4.37kWh/day (1595kWh/yr) residential load demand. The system was reported with 321 kWh/yr excess electricity, 8.59 kWh/y unmet load and 10.5 kWh/yr capacity shortage. While, the Net Present Cost (NPC), Operation and Maintenance Cost (O&MC) and Cost of Energy (COE) were $25,951, $185 /yr and $1.229/kWh respectively. The result of sensitivity analysis, predicted the unmet load and capacity shortage to be declined by 0.0% each, with system autonomy of 7.9 days. Meanwhile, the NPC, O&MC and COE have decreased by 24.6 %, 8.1 % and 25.06 % respectively. This analysis confirmed that Wind-Battery-Fuel cell-Hybrid Energy System could be an economically viable and technically feasible for stand-alone power supply for isolated areas.

Keywords: Renewable Energy, Wind Turbine, Excess Electricity, Stand-alone, Fuel cell, Battery, Electrolyzer.

1.1 INTRODUCTION

The electrical energy supply system is a major challenge for socio-economic development in Nigeria. Increase in energy demand in Nigeria caused by the rapid growth of population resulting in 40%, 37% and 44% energy deficits due to power generation, transmission and distribution respectively (Akpan and Ishak, 2011). This leads Nigerians (about 160 million people) to be served with only 60% of their consumption requirement leaving about 50.5% of households lacking access to electricity (Akpan and Ishak, 2011). The isolated areas in Nigeria needed electricity basically for lightning, domestic cooling, water pumping and communication services such as powering television and charging cell phones. The connection of those villages to the power grid lines could be an enormous challenge, in terms of meeting the energy demand and providing robust infrastructure, without adversely impacting the environment (Xiangium 2010). The total dependency of these areas on fossil fuel generators would be very much costly and could lead to environmental degradation due to climate changes. However, the rising consumption of energy and the cost of electricity due to the industrial developments cause greenhouse gases to effect the natural ecosystem and renewable energy to receive more attention (Mehmed, 2011).

Renewable energy technology has attracted attention of many nations, because fossil fuels are depletable, unfriendly and contribute immensely to global warming and climatic changes. Wind and solar energy, as most abundant renewable energy sources, are periodically and seasonally intermittent. Roberto and Lorana (2011), Pointed out intermittency in renewable energy sources as essential feature which conflicts reliability of electricity supply. Thus renewable energy systems based on intermittent sources exhibit strong short-term and seasonal variations in their energy outputs Sakya *et al.*, (2005). Stand-alone system is the most preferred wind energy systems in remote locations, because extending the national grid involved high price and logistics. Wind power driven stand-alone systems have becomes one of the most promising way for solving problems of electricity demand of various off-grid consumers worldwide Erkan *et. al,* (2012).

However, as the renewable energy such as wind is intermittent in nature, energy storage devices are required to provide balance between the supply and the load demand. Storage devices in stand-alone wind energy system improve system reliability and guarantee energy supply during times when there is no wind or when it is available but not at the required intensity. Batteries are most commonly used storage devices but are associated with problems of short term storage, self discharge and short life time and waste contents which comprise significant and dangerous pollutants. Researchers proposed the used of devices such as Ultra-Capacitor, Pump hydro, fly wheel and Fuel cell and or their combination with storage batteries. Furthermore, hydrogen is considered as well suited fuel for use in fuel cells that efficiently generate electricity IEA, (2015). Hydrogen has also been considered as an energy carrier that can enable new linkages between energy supply and demand with potentially enhancing overall energy system reliability.

In comparison to commonly used storage systems, fuel cell is well suited for seasonal storage, because of its inbuilt high mass energy density and longevity of energy storage. In such a hybrid system, electricity production in excess of demand is converted to hydrogen, using an electrolyzer and electricity requirement in excess of production is met by converting the stored hydrogen back to electricity using a fuel cell. Hydrogen remains the only valid source for energy storage and its production can be achieved in large quantities from water electrolysis knowing that water is a clean resource available in large quantities everywhere Mohamed *et al.,* (2016). Hybrid Renewable Energy Systems (HRES) are popular alternative energy sources for the stand-alone power generation in remote areas. The system combines the use of two or more renewable power generation technologies, making the best use of their operating characteristics, obtain efficiencies that are higher than could be obtained from each individual power source Pao *et al.,* (2013). The seasonal and periodic climatic variations hinder neither a solar nor wind energy stand-alone system from fully satisfying load consumption. Therefore, it is more reliable and efficient to install a hybrid energy system with storage Stish and Jagadish, (2014). The hybrid energy system by integration of renewable energy sources is considered as an excellent option for power generation with more stable time Beatriz *et al.,* (2013).

The capacity of energy storage is a principal issue for increasing the conversion efficiency of renewable energies (RE) and with the production of hydrogen from water electrolysis, the storage capacity with it the efficiency of renewable energies may be increased Calderon *et al.,* (2009). The storage of excess renewable energy is a high-potential alternative, therefore, the advances in hydrogen technology and equipment such as electrolyzers, fuel cells, and hydrogen storage techniques will increase the possibility of making the remote areas and isolated community self-sufficient Karri *et al.,* (2008).. In addition to energy efficiency increase, the autonomy of the system is also determined by the capacity of the storage facilities. The system autonomy is measured in hours and it is an indicator of how many hours a system works during period of low or absent of wind speed. An efficient, stable and reliable stand-alone system should have better autonomy, therefore, integrating hydrogen energy facilities with storage batteries forming wind-battery-fuel cell hybrid system, enable enhancing high autonomy. Computer modeling had been used in various literatures to help in determining the suitable configuration and parameters of the system Karri *et al.,* (2008). The techno-economic feasibility of wind/fuel cell /battery /diesel hybrid system for Gambel village in Alaska, was investigated by Sayed and mohammed (2011), using Homer software and found renewable energy resources as feasible solution for distributed generation of electric power for stand-alone application in remote locations.

A wind hydrogen hybrid system should consist of a wind turbine, AC/DC converter, charge controller, storage batteries, DC/AC converter, AC/DC converter, electrolyzer, hydrogen storage tank, compressor and fuel cell being interconnected to serve a desired electrical load. The wind turbine generates AC electric energy which would be converted to DC through AC/DC converter or a charge controller which controls the charging of the batteries. The DC/AC converter or inverter converts the energy stored in batteries into AC and serves the load. The main aim in a Wind/PV/ Fuel cell Hybrid System is to use the excess electrical energy, which would otherwise be wasted, to decompose water in an electrolyser to produce and store that energy as hydrogen. Basically, a complete system would include the wind turbine, Solar PV modules, Battery bank, an electrolyser, hydrogen storage and a fuel cell. The electricity generated by either wind turbine or PV module delivers idle power supply to the load and the excess electricity is controlled and directed to the electrolyser unit which generates and stores hydrogen. When the wind turbine shuts off due to low or high wind speed or PV due to absence of solar radiation, the hydrogen can be channeled to a fuel cell generating the constant supply of electricity needed for a set duration. The wind/PV/fuel cell hybrid system would have huge benefits to local and distributed power Carton and Olabi (2010). Figure 1.1 shows block diagram of Wind-PV-Battery-Fuel cell Hybrid System.

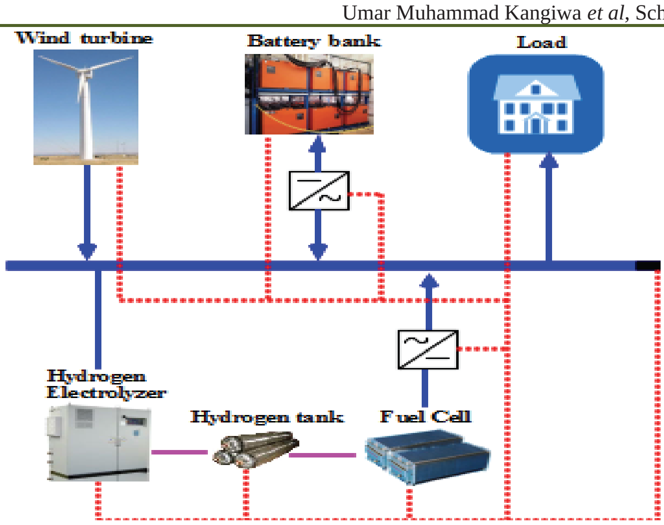

Figure 1.1: Schematic of Wind-Hydrogen-Fuel cell Hybrid System: Zachariah, *et al.*, (2013)

2. MATERIALS AND METHODS

Wind energy is abundantly available in Nigeria, especially in B/Kebbi, northwestern region. This area is located on (13° 01'N and 04°15'E), at 287m above sea level and with 32,000 km^2 land mass, it has about 4.27 million people according to 2006 census. Akpan and Ishak (2011), reported B/Kebbi with 69.5 % of household lacking access to national grid, especially those in remote areas. It has also been reported to have mean wind speed of about 5 m/s Sodunke *et al.*, (2011). But according to Adaramola and Olewa (2011), B/Kebbi has 7.8 m/s mean wind speed at 20m which results about 2.56 MWh/m^2/yr wind energy available and by considering 1m^2 diameter turbines, about 1516.06kWh/yr at Beltz limit efficiency (59.3%) will be extracted.

2.1 Techno-Economic Analysis of Wind-PV-Fuel cell Hybrid energy Systems

Techno-economics performance of Wind-PV-fuel cell hybrid, Wind-Fuel cell Hybrid and PV-Fuel cell hybrid energy systems were investigated by using HOMER tools. Each of these systems comprised four or more of these components: wind turbine, PV modules converters, batteries, electrolyzer, hydrogen tank, fuel cell and load. The significance parameters used as input variables for HOMER software simulation includes: renewable energy resources, load demand, components sizes and the technical and economic constraints. The average monthly wind speed, sun radiation data, load profile and technical and economics specifications of wind turbine, PV modules, converter and storage battery and electrolyzer, fuel cell and hydrogen tank were inputted into HOMER data base. Simulation and optimization were conducted for optimal techno-economic configurations for 25years project life cycle through circle charging controls.

2.2 Load Demand

Load demand profile determines the number of electrical components desired to be powered by electrical power system in a particular household. The electrical energy consumption in kWh/day from a typical household in a study area is necessary for adequate component sizing and efficient power supply from the source to the load. The typical load demands of two bed rooms flat in B/Kebbi was based on what is reported by (Dabai *et al.*, (2012) and Umar *et al.*, (2020) as two bed rooms flat with energy consumption of 4.37kWh/day and 960W peak. Table 2.1 presents the demand profile of a typical two bedrooms flat.

Table 2.1: Load demand profiles of a typical house hold in B/Kebbi

Locations	Equipments	No. of Units	Power Rating (W)	Daily use (Hours)	Power (W)	Daily Energy Use (Wh/Day)
Outside	Compact fluorescent	2	40	12	80	960
Bedrooms	Compact Fluorescent Ceiling Fan	2 2	20 50	6 8	40 100	240 800
Sitting Room	Compact Fluorescent Ceiling Fan TV Colour 19 Satelite Dish Refrigerator	2 1 1 1 1	20 50 70 30 85	6 8 12 12 6	40 50 70 30 85	240 400 840 360 510
Comfort	Lighting	1	10	2	10	20
Total P_{ed} 505 E_{ed} 4370						

Source: (Dabai *et al.*, (2012) and Umar *et al.*, (2020)

2.3 Energy Resources

Wind and solar energy recourses are basically needed input variables. Averages wind speed from National Metrological Agency of Nigeria (NIMET) and solar radiation were used for this research.

Table 2.2: Monthly Averages Wind Speed and solar radiation of B/Kebbi

Month	Monthly Average Wind speed (m/s)	Average mean sun radiation (kWh/m^2/day
January	6.190	5.417
February	6.000	6.038
March	6.020	6.248
April	4.860	6.266
May	5.100	6.321
June	5.000	6.169
July	4.690	5.743
August	4.190	5.026
September	3.580	5.799
October	3.830	6.205
November	5.140	6.004
December	5.310	5.772

2.4 System Components Sizing and Economics

Wind turbine converts wind energy into electricity and it greatly depends on wind variations to generate available energy. The capacity of wind turbine is generally much high than the electrical load Kham and Iqbal, (2005). Bergey Wind Power, BWC XL1 model 1kW and 24V rating was considered in this research, due its greater capacity factor for harnessing the available wind power. The cost price of 1kW Bergey is $4500, while its replacement and maintenance costs were taken to be $4200 and $15/year respectively with life cycle of 25years. For optimization, the sizes 0.5kW, 1kW, 2kW and 3kW respectively at 25 m hub height were considered.

Solar PV module sharp 250 silver polycrystalline, WD250QCS, 250 W at $289 per unit was considered; the flow of energy between the AC and DC components is being controlled by power electronic converter. The cost of 1unit is considered at $280 with replacement cost of $250, and the sizes 0, 0.5, 1.0, and 1.5.0kW were considered with 15years life cycle at 90% efficiency. The cost and efficiency of elctrolyzers depend on the types and technology; however, Kham and Iqbal, (2005) described the cost of 1kW electrolyzer as $1500-$3000 and suggested $2000/kW for this research and $1500 and $20/yr for replacement and maintenance cost respectively.

Hydrogen tank is essential in renewable energy storage system where electrolyzer is used for hydrogen production. The cost of tank with capacity of 1kg is assumed to be $ 800. The replacement and maintenance cost was taken as $600 and $10/year respectively. The sizes 0, 0.5, 1.0 and 2 kg were considered to widen the search space for a cost effective configuration. However**,** conventional batteries are the primary energy storage facility in hybrid renewable energy systems, in this research 12V, 200Ah, and 6FM200D model was considered and 2, 4, 6, 8, 10 and 12 pieces/unit of batteries was taken with life cycle of 10 years at cost of $250 per unit.

Fuel cell converts hydrogen energy into electricity. The stored hydrogen from the tank and the atmospheric oxygen will be utilized to generate backup power when load demand exceeds turbine generation. The cost of fuel cell was taken as $3000/kW with replacement and maintenance costs of $2500 and $20/yr respectively. Fuel cells sizes 0.0, 0.5, 1.0, 1.5 and 2 kW with operational hours of 15000hr at 90% efficiency were considered.

A project lifetime of 25years is being considered for simulation of the two configurations of wind-PV-fuel cell hybrid stand-alone system with annual interest of 6% over the lifetime of the project. The capital cost, operating and maintenance cost were included as same system components detailed. The maximum capacity shortage restricted to 2%, renewable energy fraction of 100%, wind energy efficiency of 50% and PV module efficiency of 18% were considered in this study.

These set of variables were inputted into HOMER and simulation was conducted for techno-economic feasibility investigation. Figure 2.2 present schematic diagrams of the simulated systems. The system simulation calculated the total electrical energy output (kWh/yr), total load served (kWh/yr), excess electricity delivered (kWh/yr) and unmet load (kWh/yr), capacity shortage (kWh/yr) and total energy loss (kWh/yr) and total system autonomy (hours) as a technical parameters. The total capital of the project ($), total Net Present Cost NPC ($), total annualized cost ($/yr) and total operation and maintenance cost (O&MC) ($), Levelized Energy Cost COE ($/kWh) and replacement cost ($) were calculated and the NPC, O&MC and COE were considered as economic Figures of merit.

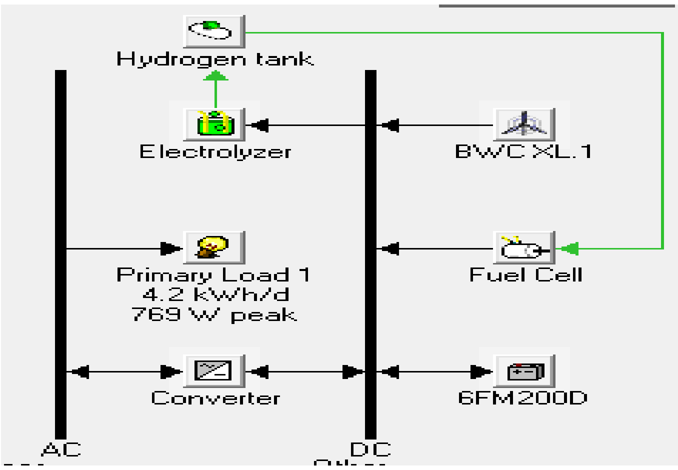

Figure 2.2: Schematic Diagram of Wind- Battery-Fuel cell hybrid System

2.5 Sensitivity Analysis Variables

The sensitivity analysis for the optimal configuration was conducted by using the heights of the turbine, wind speed, electrolyzer and fuel cell as sensitivity variables. The height ranges from 15 to 25 m are used. Due to the fact that average monthly wind speed varies from minimum of 3.58m/s to the maximum of 6.19m/s, the wind speed ranges (4.5, 5.0 5.5 and 6.0 m/s) were used as sensitivity variables. The electrolyzer efficiency ranges from 85% to 87% are considered Kham and Iqbal (2005). The sensitivity analysis was conducted base on percentage reduction of fuel cell cost for stationary application. The cost multiplier factor of fuel cell was assumed to be 100% and 60%, Grath, (2011). The lifetimes of fuel cell range are taken to be 10, 000 15,000 and 25,000 hours and efficiency of 30%, 60% and 90% were used for sensitivity analysis.

2.6 Control Strategy of the System

The cycle charging strategy at 80% set point state of charge was used in this work, such that whenever a wind generator operates to serve the primary load, it operates at full output power and the excess electricity goes to battery bank. When the battery was 80% charged then the surplus energy goes to electrolyzer where it is converted and stored in a form of hydrogen energy. However, when there is an energy deficit due to shortage of wind power, the stored hydrogen is converted into electricity through a fuel cell and feeds the load.

3. RESULTS AND DISCUSSIONS

3.1 Wind-PV-Battery-Fuel cell Hybrid Energy System

This system comprised of Wind turbine, PV modules, Battery bank, Electrolyzer and Fuel cell as major components. The result of the simulation conducted showed those 6kW PV module and 1kW wind turbines were integrated to serve the load demand. Wind turbine operates in 7,213hours/year to generate 2,803kWh/year, while, the PV array operates in 4,376kWh/year to generate 10,660kWh/year. This shows a contribution of 21% and 79% by the wind and PV given a total production of 13,462 kWh /year. As the total energy consumes by the AC primary load and electrolyzer was 1,627 kWh /year, the system releases an excess electricity of 11,620 kWh /year that was 86 % of the total energy generated. The system generates 2kg of hydrogen with autonomy of 378hours. Moreover, considering the economics constraints, the NPC, O$M cost, and cost of energy were reported as $34,743, $ 689/ year and $1.760 kWh respectively.

3.2 PV-Battery-Fuel cell-Hybrid Energy System

This configuration is an interconnection of solar PV module-Battery-Electrolyzer-Fuel cell. The simulation result shows that PV array operates for 4,384 hour/year and generated 3,570 kWh/year to serve 1,544 kWh/ year AC primary and 418 kWh/year electrolyzer loads with an excess electricity of 1,321kWh/year which is 36.7 % total load of the system. Moreover, the system generates 9 kg/year of hydrogen with NPC, O&MC and COE have values $39,849, $571 /year and $2.619 /kWh respectively.

3.4 Wind-Battery-Fuel cell-Hybrid Energy System

The schematic diagram for the Wind-Battery-Electrolyzer -Fuel cell Hybrid System simulation is shown from Figure 2.2. The optimal configuration showed that 3BWC XL.1 model wind turbine integrates with 8unit vision 6FM200D batteries, 1kW electrolyzer, 1kg hydrogen tank and 1kW converter and 1kW fuel cell is feasible. From the Homer data base, the turbine with 22.3% capacity factor operates in 6,657 hours/yr and generates 5,865kWh/yr with 0.67kW mean output. As 1,534 kWh/yr AC primary load and 321kWh/yr electrolyzer load were been served, the excess electricity, unmet load and capacity shortage of 3,740 kWh/yr, 8.59kWh/yr and 10.5kWh/yr were observed. From simulation output, batteries with 19.2kWh nominal capacity, 576kWh/yr annual throughput and autonomy of 65.8 hours have 129 kWh/yr energy losses. A converter with 17.4% capacity factor operates in 87261 hours/yr with 0.17kW mean output and losses 169kWh/yr. Electrolyzer consumes 321kWh/yr and produced 6.92kg/yr at 46.38 kWh/kg specific energy consumption. The hydrogen tank stored about 6.02 kg hydrogen and supply a fuel cell with autonomy of 190 hours. A fuel cell consumed 6.02kg hydrogen and produced 18kWh/yr electricity with mean output of 0.948kW at specific fuel consumption of 0.334kg/kWh. The NPC, O&MC and COE for running this project in 25years at 6% annual interest were estimated as $23,951, $185/yr and $1.229/kWh respectively.

Wind-Battery-Fuel cell Hybrid system has been confirmed as best configuration due to its lower values technical and economic Figure of merits. Therefore, it has been recommended as a feasible system for stand-alone application compared with Wind-PV-Battery-Fuel cell and PV-Battery-Fuel cell hybrid energy systems. Nevertheless, sensitivity analysis for the optimal configuration was necessarily been observed in order to further reduce the unmet load, capacity shortage and the cost of energy with improving energy production for enhancing better efficiency.

3.3 Sensitivity Analysis for Wind-Battery-Fuel cell Hybrid Energy System

The results of sensitivity analysis of the optimal configuration of wind-battery-fuel cell hybrid system are presented in Table 3.1.

Table 3.2: Summary of Results of Sensivity Analysis for Wind-Battery-Fuel cell hybrid system

WS	HH	WTP	EE	UL	CS	NPC	COE	O&MC	TC	AUT	HP
4.5	15	4,958	57.1	1.7	2.0	22,751	1.181	185	3	255.8	6.89
	20	5,463	60.4	0.9	1.0	22,754	1.171	186	3	255.8	7.50
	25	5,861	63.5	0.6	0.7	22,751	1.168	185	3	255.8	6.92
5.0	15	4,270	51.6	1.3	1.5	20,056	1.073	249	2	288.7	5.48
	20	4,660	55.2	0.9	1.1	18,057	0.930	170	2	255.8	5.96
	25	4,964	57.7	0.6	0.7	18,057	0.927	170	2	255.8	6.27
5.5	15	5,262	60.1	0.4	0.5	18,057	0.925	170	2	255.8	6.24
	20	5,690	63.9	0.2	0.2	18,054	0.923	170	2	255.8	5.31
	25	6,020	66.0	0.0	0.0	18,054	0.922	170	2	255.8	5.25
6.0	15	6,244	67.5	0.0	0.0	18,053	0.921	170	2	255.8	4.93
	20	3,345	40.3	1.4	1.8	15,369	0.795	234	1	288.7	4.25
	25	3,414	42.9	1.4	1.8	13,361	0.692	155	1	255.8	4.56

Key: WS= Wind speed (m/s), HH = Hub height (m), WTP = Wind Turbine Production (kWh/yr) EE = Excess Electricity (%), UL = Unmet Load (%), CS = Capacity Shortage (%), TIC = Total Initial Cost, NPC = Net Present Cost ($), COE = Cost of Energy ($/kWh), O&MC = Operation and Maintenance Cost ($/yr), TC = Turbine Capacity (kW), AUT = Autonomy (hours), HP = Hydrogen production kg/yr

Considering the results presented from Table 3.1, extrapolation of hub height from 15 to 25 m with 4.5 m/s average wind speed, caused the energy production by 2kW turbine to increase by 18.2 % and the excess electricity increases by 11.2%. The unmet load and the capacity shortage have decreased by 64.7% and 65% respectively. Also, by hub height extrapolation from 15 m to 25 m with average wind speed of 5 m/s, the wind turbine production has increased by 16.25%, and excess electricity by 11.82%, while, the unmet load and capacity shortage have decreased by 53.8 % and 53.3 % respectively. However, the net present cost, the operation cost and the cost of energy have decreased by 9.9%, 31.7% and 13.6% respectively, while the hydrogen production increases by 7.8%. Furthermore, observing hub height ranges from (15 to 25) m, with 5.5 m/s average wind speed, the wind turbine production has increased by 14.4 %, the excess electricity by 9.8 % and then the unmet load and capacity shortage have decreased by 100 % each. However, the net present cost increases by 0%, cost of energy by 0.32%, and the hydrogen production decreased by 15.86%.

Moreover, regarding the effect of wind speed optimization at the same hub height for the 2kW wind turbine capacity, results shows that with increase in wind speed from 5 m/s to 6 m/s at 15m hub, the power production has increased by 46.2%, the excess electricity by 30.8% and the unmet load and the capacity shortage have decreased by 100% each. Also, the net present cost, the operation cost and the cost of energy have reduced by 9.98 %, 31.7 % and 14.16 % respectively. This revealed that wind speed has greater influence on wind energy system optimization than the hub height. The optimum configuration is considered as 2kW turbine with 6.0 m/s, at 15 m hub which generates 6,244kWh/yr, and results 67.5% excess electricity, 0% unmet load and 0% capacity shortage. While the NPC, O &MC and COE values have finally reduced to $18,053, $170/yr and $0.921/kWh respectively. This indicated the influence of sensitivity analysis on for optimizing Wind-Battery-Fuel cell hybrids system towards enhancing efficiently designed for an economic viable system.

3.4 Controls Strategy for Wind-Battery-Fuel cell Hybrid Energy System

The energy system controls strategy is an essential feature for determining the operational mode of the designed system. Figure 3.1 presents how circle charging principles is used for controlling operations of the turbine output, excess electricity, load served and energy stored in batteries. The wind turbine output drift below the load served from 12:00 pm to12:00 am due to the shortage of wind speed, which caused excess electricity to zero and the batteries to discharges power for the load. However, as the turbine output peak-up from 12:00 am to 6:00 pm, the battery state of charge rose and the excess electricity has increased.

Moreover, the illustration of the effects of wind turbine output on electrolyzer and hydrogen stored with respect to load served and excess electricity is shown in Figure 3.2. As the wind speed is at lower level, there is little excess energy serving the electrolyzer and therefore little amount of hydrogen is generated. Considering the load served from 3:00 am to 11:00 am, with greater value than the turbine output, has caused the excess electricity and electrolyzer energy consumption to zero and the hydrogen tank to discharge. Furthermore, at around 11:00pm, when the turbine output peak-up, the electrolyzer consumption has increased, which raised the level of hydrogen in a storage tank.The energy deficits are shown in Figure 3.3 with wind speed below 2 m/s which is less than the cut-in wind speed of the turbine and results zero production from the wind turbine. In this regards, the load receives power from the discharging storage batteries, until when wind speed peak-up to 4.5 m/s, from 4:30 to 9:30 am, then the wind turbine generates power which helps the battery serving the load and makes discharging power becomes less than the load served. From 2:30 to 4:30 pm, the wind speed has further drift, as the battery continues discharging, therefore, the fuel cell starts to generate back-up power for the load. The fuel cell output is greater than the load served, therefore, excess power is stored in battery which keeps the system operating from 4:30 pm to 8: 30 pm although the wind speed and the respective wind turbine production are lower.

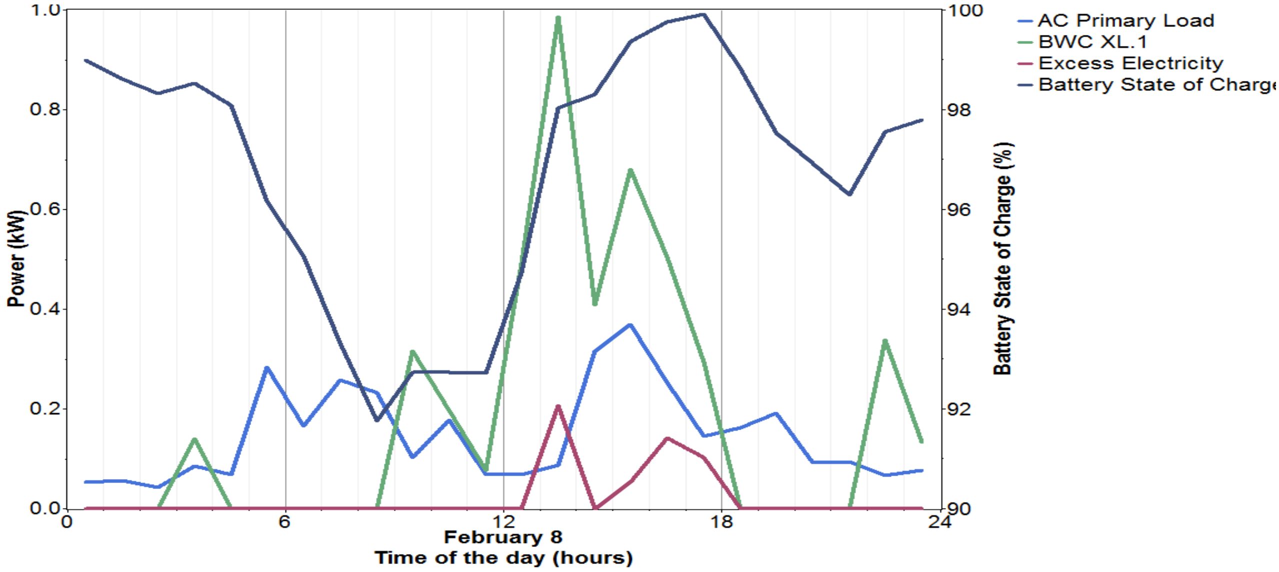

Figure 3.1: Control of Power outputs with Respect to Storage Batteries

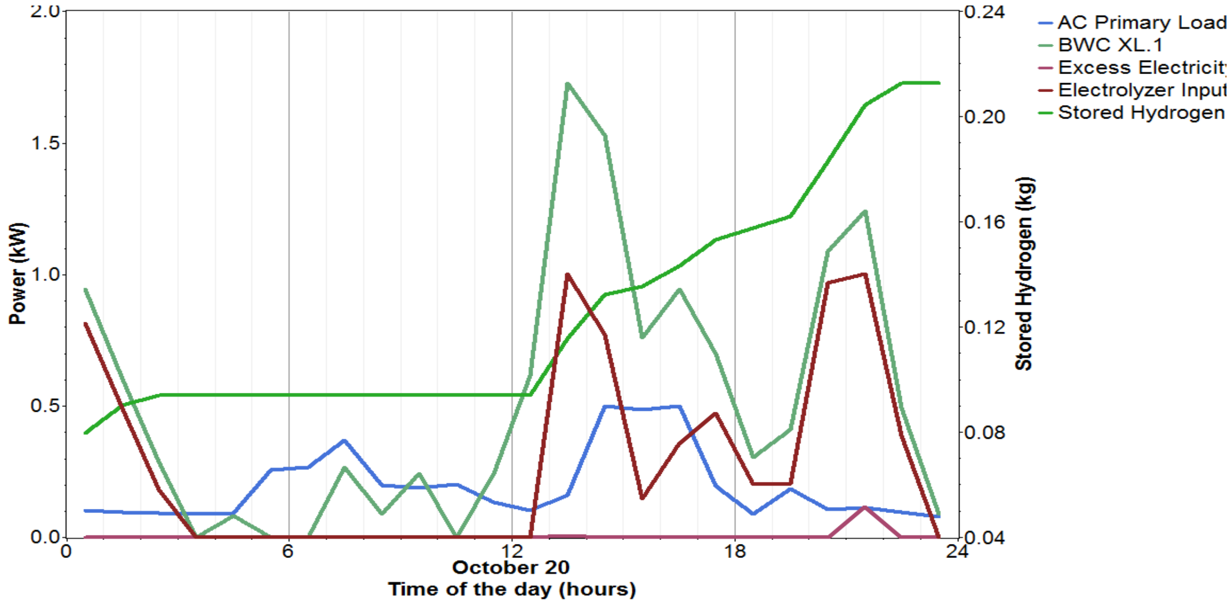

Figure 3.2: Control strategy of Power Outputs with Respect to Stored Hydrogen

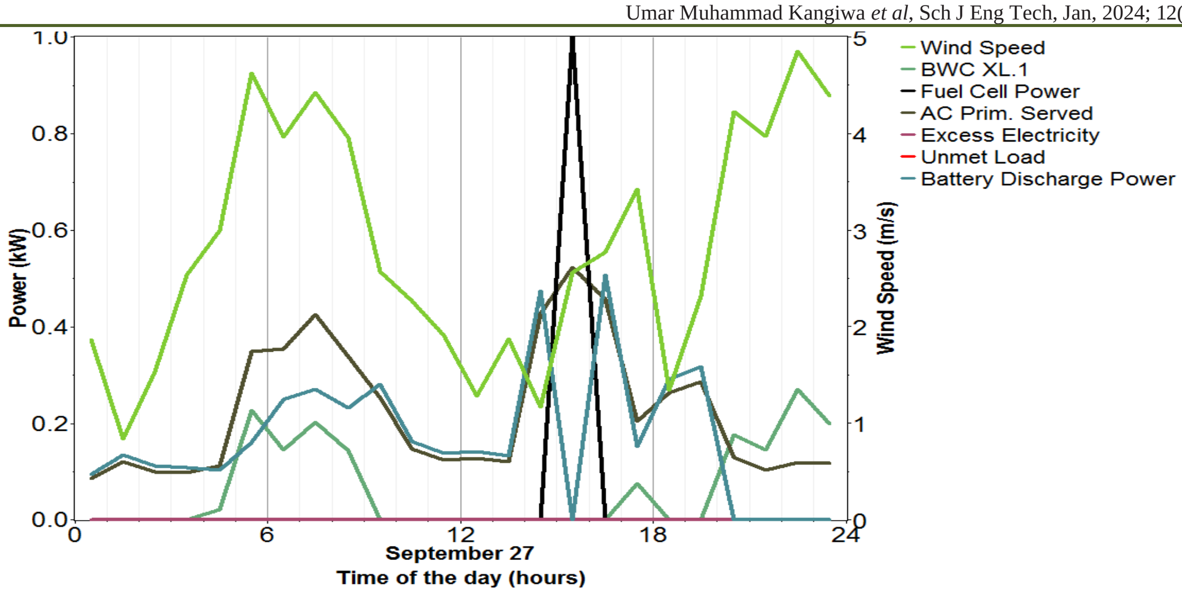

Figure 3.3: Control Strategy of Power Outputs with Respect to Wind speed

4. CONCLUSIONS

The performance of Wind-Battery-Fuel cell-Hybrid energy system has been investigated in comparison with Wind-PV-Battery-Fuel cell and PV-Battery-Fuel cell for stand-alone power supply. Wind-Battery-Fuel cell Hybrid system has been observed as optimal technically with lower excess electricity, unmet load and capacity shortage and higher system autonomy. While, economically the lower values of NPC, O&MC and COE were observed from this system. The sensitivity analysis of the optimal system caused declined of unmet load and capacity shortage to zero and enable decrease in NPC, O&MC and COE. It has also been revealed that wind speed has greater influence than the hub height on wind energy system optimization. The cycle charging controls strategy could be best for operating wind-battery-fuel cell-hybrid energy system and enabling enhancing stable, reliable and efficient stand-alone power supply. Based on this result, the optimal system should comprised; 2 kW BWC XL.1 wind turbine at 15m with 1 kW DC/AC Converter, 8 unit of 200Ah, 6FM200D Storage Batteries, 1 kW PEM Electrolyzer, 1 kg Hydrogen Storage Tank 1 kW PEM Fuel cell. This could be practicable to power residential load towards ensuring reduction of percentage lacking access to electricity in isolated areas. The remaining excess electricity could further be use for domestic water pumping and powering small scale business refrigerators. The excess stored hydrogen could be use for powering both stationary and automobiles, heating and welding, while, the stored oxygen could be use for hospitals.

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