American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Feasibility of Photovoltaic–Fuel Cell Hybrid System to Meet Present Energy Demand

Shah Mohazzem Hossain[a]*, Mohammad Naim Uddin[b], Khirul Alam Palash[c]

[a,b]*Department of EECE, Military Institute of Science & Technology (MIST), Dhaka, Bangladesh*
[c]*Department of EEE, Daffodil International University (DIU), Dhaka, Bangladesh*
[a]*Email: soneteee@gmail.com*
[b]*Email: naim_shekh@hotmail.com*
[c]*Email: khirul.eee@gmail.com*

Abstract

Energy demand continues to increase day by day. Energy crisis have to be met from alternative primary energy sources because traditional fossil energy sources such as oil, gas etc. are ultimately limited and the gap between demand and supply is increasing. Hydrogen, a clean energy carrier can be produced from any primary energy source. Fuel cells are very efficient energy conversion devices. The purpose of this research is to practically model a fuel cell kit and simulate a stand-alone renewable power system, referred to as “Photovoltaic–Fuel Cell (PVFC) hybrid system”, which maximizes the use of a renewable energy source. HOMER, the micro power optimization model, is employed to simulate the PV-Battery system and PVFC-Battery hybrid systems. In the process of simulation, the total electrical load of Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh is considered to meet its energy demand and to get optimal cost of energy, cost effectiveness and efficient power of PV-Battery and PVFC-Battery systems.

Keywords: PV; PVFC; Hydrogen; Electrolyzer; HOMER.

1. Introduction

Bangladesh is a small country with the total area of 144,000 square kilometers and a total population of more than 150 million. At present, 58.5% of the total population of Bangladesh is enjoying the electric facilities.

----

* Corresponding author.

In Bangladesh per capita generation is 221 kWh (as June 2014) which is comparatively much lower than other developed countries in the world [1]. At present installed capacity is 9,760 MW (March 2014), maximum generation is 6,699 MW (Feb 2014) and Peak demand is 7,800 MW (June 2014). Electricity generation is mostly dependent on natural gas, 79% of the total generation is dependent on it. It is considered as one of the driving forces of the economy of our country as three-fourths of the total commercial energy is provided by natural gas. Due to industrialization and an increasing standard of living, electricity demand has increased significantly during the last few decades, but the capacity for electricity generation has not kept pace with demand. The renewable energy sources (solar, wind, tidal, geothermal etc.) are attracting more attention as alternative energy. Among the renewable energy sources, the photovoltaic (PV) energy has been widely utilized in low power applications [2]. From an operational point of view, PV power generation may experience large variations in its output power due to intermittent weather conditions which may cause operational problems at the power station, such as excessive frequency deviations. The fuel cell back-up power supply is a very attractive option to be used with an intermittent power generation source like PV power because the fuel cell power has attractive features e.g. efficiency, fast load-response, modular production and fuel flexibility [3].

2. System Description

2.1 PV System

Photovoltaic cells convert solar radiation directly into DC electrical energy. Power conversion units are required to convert the power from direct current to alternating current (AC). PV System comprises of Photovoltaic cells (PV) with short-term energy storage e.g. battery. For load management and controlling, power conditioner circuit is also used in this system (Figure 1).

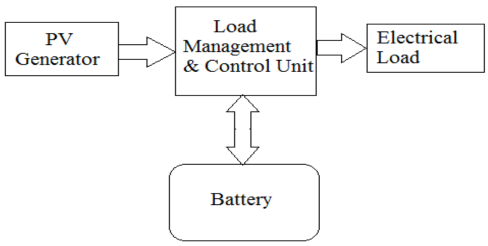

Figure 1: Block diagram of PV system

2.2 PVFC Hybrid System

A hybrid energy system based on new alternative technologies has been proved to be a feasible solution for stand-alone power generation at remote locations [4-6]. This hybrid system (Figure 2) is based on hydrogen technology which needs a hydrogen producing unit (Electrolyzer), a hydrogen storing unit (Tanks), and a hydrogen utilizing unit (Polymer Electrolyte Membrane Fuel Cell). Hydrogen is environmentally compatible and can be converted into electricity at a relatively high efficiency [7]. The excess electrical energy produced from solar cell is fed to the electrolyzer. Electrical current through the electrolyzer enables the decomposition of water into hydrogen and oxygen. Hydrogen is stored into hydrogen storage tank. Fuel cell is supplied by hydrogen from the storage tank. Hydrogen is oxidized on the anode and oxygen is reduced on the cathode. Protons are transported from the anode to the cathode through Polymer Electrolyte Membrane and electrons are carried to the cathode over an external circuit. On the cathode, oxygen reacts with protons and electrons forming

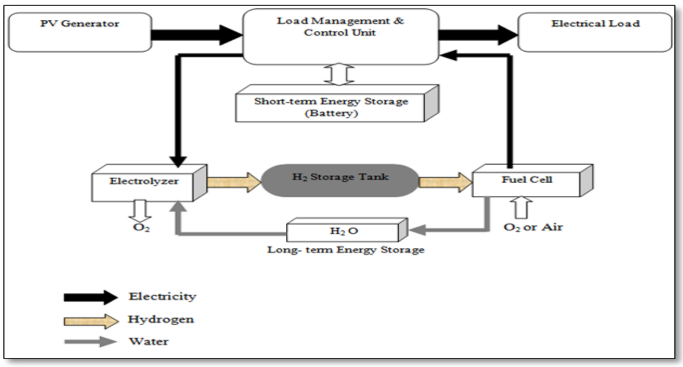

Figure 2: Block diagram of PVFC hybrid system

water and producing heat. Both anode and cathode contain a catalyst to speed up the electrochemical processes [8]. The theoretical cell voltage of a Polymer Electrolyte Membrane fuel cell is about 1.23V at standard conditions [9]. In order to produce a useful voltage for practical applications, several cells are connected in series to form a fuel cell stack. Thus conversion of solar and chemical energy into electricity is done in PVFC system.

3. Designed Fuel Cell Kit

The designed practical fuel cell kit consists of some components such as: *i)* Platinum coated nickel wire, or pure platinum wire, length 1 feet *ii)* 9 volt battery clip *iii)* 9 volt battery *iv)* covered glass pot with water *v)* volt meter. At first, Platinum coated wire is twisted to make electrodes. The electrodes are attached to the battery clip and voltmeter probes by wire. Then the electrodes are placed into a pot which is filled with water. Without any energy source voltmeter reads 0.00 volt across fuel cell. After connecting a battery voltmeter reads approximately 7.82 volt. Touching the battery to the clip caused the water at the electrodes to split into hydrogen and oxygen. The bubbles are seen to form at the electrodes while the battery is connected. Platinum acted as a catalyst, something that makes it easier for the hydrogen and oxygen to recombine. After removing the battery voltage across fuel cell is still measured that is 1.43V. At last, the stable output voltage of the fuel cell kit is got which is 1.05 volt and close to the typical fuel cell output voltage 1.26V.

4. Load Analysis

To facilitate the load analysis of the research, the whole Chittagong University of Engineering & Technology (CUET) campus is divided into three zones where total connected load in CUET region is 1842KW in Dec 2013. From the practical observation, it is obtained that the total peak load at any moment throughout the day never exceeds 400KW. So in the simulation approaches 424KW load is considered as maximum demand (Table 1).

Table 1: The peak load condition (approximate) of CUET

Zone	Peak Hour	Peak Load (KW)	Off Peak Hour	Off Peak Load(KW)
A	8.00AM-5.00PM	230	5.00PM-8.00AM	60
B	7.00PM-12.00AM	160	12.00AM-7.00PM	90
C	7.00PM-12.00AM	110	12.00AM-7.00PM	70

5. Simulation Process

HOMER is an abbreviation of Hybrid Optimization Model for Electrical Renewable [10]. This micro power optimization model simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. The software version that is used in this research is HOMER version 2.81. System models are at first drawn in HOMER. The designed schematic models (Figure 3 & Figure 4) are created in HOMER. Solar resource is most important parameter for calculating radiation data in a specified region. The annual average global solar radiation is about 4.75 Kwh/m^2/d.

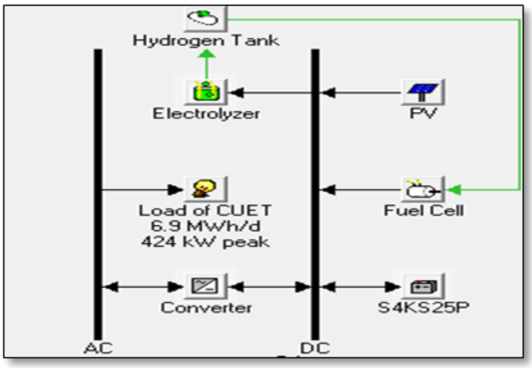

Figure 3: Schematic model of PVFC-Battery hybrid system

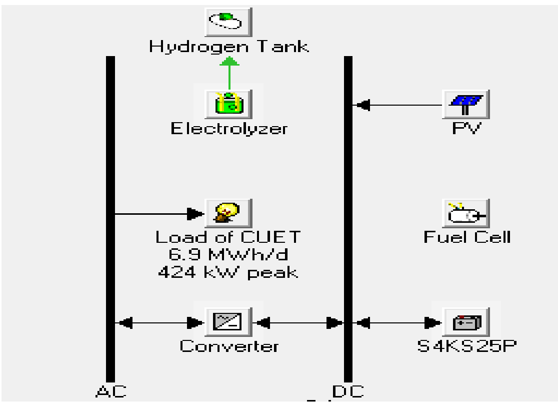

Figure 4: Schematic model of PV-Battery system

6. Simulation Results

In this paper PV system and PVFC hybrid system is discussed and overall simulation is performed in HOMER environment for sizing optimization which minimizes the system cost. Simulation results also provide comparison among these configurations.

6.1 Cost Details of System Components

Cost of each component used for two systems are given below in Table 2.

Table 2: Component cost details

Components	Capital cost	Replacement cost	Maintenance cost
PV	1440 $/kW	1260 $/kW	0 $/kW
Electrolyzer	12274 $	12100 $	32 $/hr
Fuel cell	64 $/kW	62 $/kW	0.04 $/hr
Hydrogen tank	625 $	570 $	0 $
Battery	980 $	870 $	6 $/hr
Converter	570 $	550 $	10 $/hr

6.2 Optimization Result of PV and PVFC System

The details of optimization result for PV system after simulation is shown in Table 3.

Table 3: System architecture for PV system

PV Array	3,190 kW
Battery	2,790 Surrette 4KS25P
Inverter	550 kW
Rectifier	550 kW

From the simulation result of PV system it is clear that,

Cost of energy (COE) = $ 0.272/kWh = 20.65 BDT

Optimization results of PVFC system are depicted in Table 4.

Table 4: System architecture for PVFC system

PV Array	4,585 kW
Fuel Cell	1,290 kW
Battery	1,790 Surrette 4KS25P
Inverter	440 kW
Rectifier	440 kW
Electrolyzer	2,478 kW
Hydrogen Tank	430 kg

Table 5: Cost summary for PVFC system

Total net present cost	$ 8,591,342
Levelized cost of energy	$ 0.288/kWh
Operating cost	$ 61,506/yr

So, for PVFC system, Cost of energy (COE) = $.288/kWh= 21.65 BDT/kWh (Table 5).

The above analyzing tables show the less dependency on battery and low operating cost of PVFC system compared to PV system.

6.3 Annualized Energy Consumption

The annualized energy consumption result is revealed in Table 6 which shows that the excess electricity is high for PV system and capacity shortage is almost similar for the both systems.

Table 6: Cost summary for PVFC system

Quantity (%)	PV system	PVFC system
Excess electricity	32.4	2.58
Unmet electric load	3.9	4.00
Capacity shortage	5.1	5.82

6.4 Sensitivity Analysis

The sensitivity of the effect of solar radiation on cost parameters (NPC, COE and operating) of complete system for both systems is shown in Table 7 and Table 8.

Table 7: Sensitivity of solar radiation on NPC, COE and operating cost for PV system

Annual average radiation (kWh/m2/day)	Total NPC ($)	COE ($/kWh).	Operating cost ($)	Capacity shortage (%)
4.75	8,033,115	0.263	99,062	5
4.75	8,004,610	0.262	98,672	10
5	8,004,610	0.261	98,672	5
5	8,004,610	0.261	98,672	10
5.5	8,004,610	0.258	98,672	5
5.5	8,004,610	0.258	98,672	10

Table 8: Sensitivity of solar radiation on NPC, COE and operating cost for PVFC hybrid system

Annual average radiation (kWh/m2/day)	Total NPC ($)	COE ($/ kWh)	Operating cost ($)	Capacity shortage (%)
4.5	8,425,044	0.279	60,051	10
4.75	8,495,892	0.278	61,106	5
4.75	8,491,242	0.261	60,606	10

The above tables clearly indicate that the cost of energy reduces significantly under higher availability of solar radiation for both systems.

6.5 Graphical Comparison of Systems

It can be noted that excess electricity is low for PVFC system and PVFC system is superior to PV system (Figure 5 & Figure 6).

Because, *(i)* it requires less number of battery *(ii)* it has low operating cost *(iii)* less dependence on PV and battery *(iv)*less wastage of electricity *(v)* fast cost reduction rate.

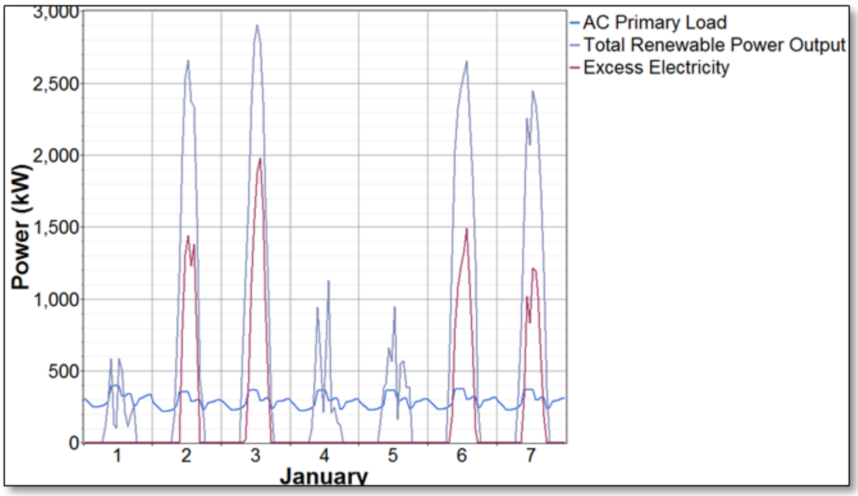

Figure 5: AC primary load, total renewable output and excess electricity for PV system

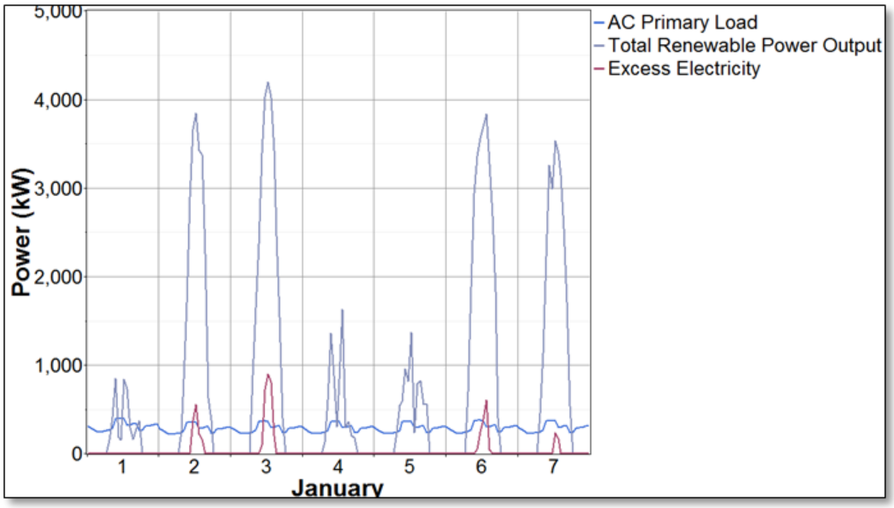

Figure 6: AC primary load, total renewable output and excess electricity for PVFC system

7. Limitations

This research has following limitations:

1. The simulation approaches concentrate only on the costs of two competitive systems and suggests the best architecture considering the cost only. It doesn't study the feasibility to install the systems.

2. The electrolyzer requires a huge amount of power to produce hydrogen. About 59% of the produced power was consumed by electrolyzer.

8. Future Scope

In this research, the total load of a region is estimated and simulated by HOMER software to design the system architecture. But this research doesn't consider the design requirements for installing the plant in this region or in any specific area. Further approaches demand some criteria such as: *i)* Detailed economic analysis of the required hardware based on availability of solar resource, *ii)* Simulation of controller and *iii)* System installation.

9. Conclusion

This paper shows a way to utilize excess solar energy by hydrogen fuel cell storage system for producing electricity from photovoltaic energy. The cost of a fuel cell prototype was high ~$3,170/KW in 2004, but the high volume production cost of today's technology has been reduced to $68/KW. Although this research shows that hydrogen energy storage system is economically slightly less competitive with battery storage systems but fast development of this technology clearly indicates that it will be the most promising, cost effective and reliable energy source in the near future than other alternative renewable energy sources. Among the different kinds of alternative energy sources, the fuel cell is becoming popular day by day because of it has less impact on environment compared to other fossil fuel power sources. So use of this system in transportation sector can compared to other fossil fuel power sources make today's world more sound and suitable for human being in the near future.

References

[1] Present energy situation of Bangladesh (2014, June 17) retrieved from website http://boi.gov.bd/key-sectors/power-industry.

[2] Pawlik J., Klaschinsky H., Dippel R., Mlynski M., Hlawenka A., Denneberg V(2007), Fuel Cells, 7(3), 190.

[3] Mierlo J. V., Maggetto G(2007), Fuel Cells, 7(2), 165.

[4] Thounthong P., Rael S., Davat B.(2006), Journal of Power Sources, 158(1), 806.

[5] Düsterwald H. G., Günnewig J., Radtke P.(2007), Fuel Cells, 7(3), 183.

[6] Wang Y., Choi S., Lee E.,(2009) Journal of Hydrogen Energy, 34(5), 2340.

[7] Agbossou K., Kolhe M., Hamelin J., and Bose T. K. (2004, September), "Performance of a Stand-Alone Renewable Energy System Based on Energy Storage as Hydrogen", IEEE Trans. On Energy Conversions, Vol. 19, Issue 3, pp.633-640.

[8] Fuel cell Technology (2004) retrieved from "Fuel cell handbook (seventh edition)" prepared by EG & G Technical services, Inc.; pp: 1-1 to 1-32, 3-1 to 3-22.

[9] El-Aal A. E. M. M. A., (2005, April 15) "Modelling and Simulation of a Photovoltaic Fuel Cell Hybrid System"; pp. 24.

[10] Information on Homer (2014, June 20) retrieved from website http://www.nrel.gov/homer.