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A HYBRID SYSTEM TO MEET ENERGY DEMAND OF BANGLADESH: A FEASIBILITY STUDY BY SOFTWARE SIMULATION

C. K. Das[1,*], A. A. A. Rashid[1], M. Rahman[1] and M. A. Kader[2,‡]
[1]Department of Electrical & Electronic Engineering
Chittagong University of Engineering & Technology, Chittagong-4349, Bangladesh
[2] Department of Electrical & Electronic Engineering
International Islamic University Chittagong, Bangladesh
E-mail: *choton46@yahoo.com,‡rubel05cuet@yahoo.com

Abstract: Energy demand continues to increase day by day. Energy crisis has 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 ever increasing. Hydrogen, a clean energy carrier can be produced from any primary energy source. Fuel cells are very efficient energy conversion devices. The purposes of this work are to model a fuel cell kit and simulate a stand-alone renewable hybrid system which maximizes the use of a renewable energy source. HOMER, the micro power optimization model, is employed to simulate the systems. In the process of simulation, the total electrical load of Chittagong University of Engineering and Technology is considered as a test area of Bangladesh 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: Photovoltaic, Fuel Cell, Hybrid System PEM, Homer.

1. INTRODUCTION

Bangladesh is a small country with total area of 144,000 square kilometers and a total population of more than 160 million. At present, 48.5% of the total population of Bangladesh is enjoying the electric facilities. In Bangladesh per capita generation is 220 kWh which is comparatively much lower than other developed countries in the world. The total power generation in Bangladesh is around 6,170 MW, whereas the peak demand is 10, 283 MW which is much higher than the supply [1]. Electricity generation is mostly dependent on natural gas, 77% of the total generation is dependent on it [1, 2]. This is considered as one of the driving forces of the economy of Bangladesh 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, biomass, 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. 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. 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, 4]. The cost of a fuel cell prototype was high (~$3,000/kW) in 1990, but the high volume production cost of today's technology has been reduced to $61/kW [5]. The world is rapidly running towards alternative renewable energy sources. Among the different kinds of alternative energy sources, the fuel cell is becoming popular day by day. Environmental impacts of the fuel cell are relatively small compared to other fossil fuel power sources. Its use in transportation sector is going to make revolution and its efficient stationary use is also proved today. So, Bangladesh government can adopt fuel cell technology to meet its energy demand in the near future.

2. CONCEPT OF PV SYSTEM AND PVFC HYBRID SYSTEM

2.1 PV System

It 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 as shown in Fig. 1. 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).

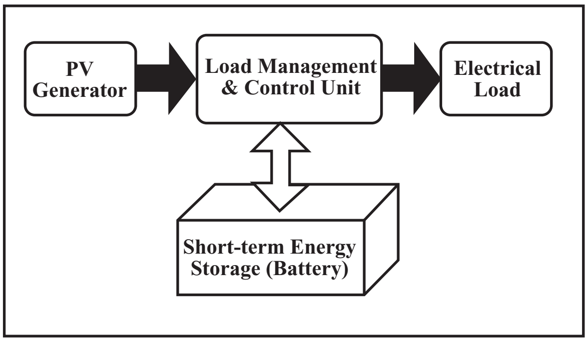


Fig. 1 Block diagram of PV system.

2.2 PVFC Hybrid System

Photovoltaic system combined with fuel cell is the basic architecture of PVFC system. A hybrid energy system based on such alternative technologies has been proved to be a feasible solution for stand-alone power generation at remote locations [6-8]. This hybrid system as shown in Fig. 2, is based on hydrogen technology which needs a hydrogen producing unit (Electrolyzer), a hydrogen storing unit (Tanks), and a hydrogen utilizing unit (PEM Fuel Cell). The main purpose of the hydrogen storage system is to store energy over short and long periods of time. Hydrogen is environmentally compatible and can be converted into electricity at a relatively high efficiency [9]. A solar cell module which is the basic element of each PV system, converts the sun's rays or photons directly into electrical energy. The output power varies proportionally with solar radiation and inversely with temperature. 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 PEM and electrons are carried to the cathode over an external circuit. On the cathode, oxygen reacts with protons and electrons forming water and producing heat.

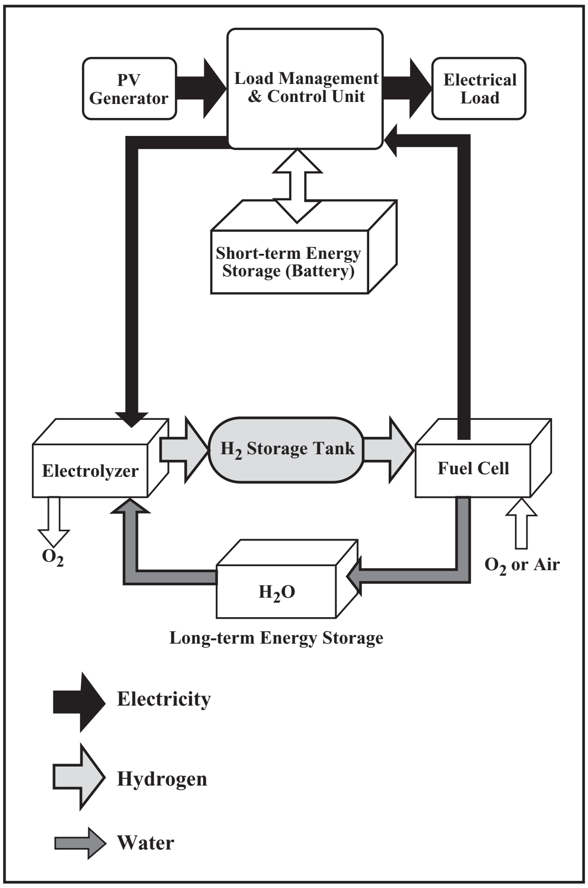


Fig. 2 Block diagram of PVFC hybrid system.

Both the anode and the cathode contain a catalyst to speed up the electrochemical processes [10]. The theoretical cell voltage for a PEM fuel cell is about 1.23V at standard conditions [11]. 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. THE DESIGNED FUEL CELL KIT

In this work, a fuel cell kit has been made and the functioning of the fuel cell has been observed practically. The experimental setup and measurements are depicted in Fig. 3–Fig. 6. The practical fuel cell kit consists of - i*)* One foot of platinum coated nickel wire, or pure platinum wire , ii) a 9 volt battery, iii) a 9 volt battery clip, iv) a covered glass pot with water, v) a 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 8.55 volt (as depicted in Fig. 4). 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 the fuel cell is still measured 1.55 volt (as shown in Fig. 5). At last, the stable output voltage of the fuel cell kit is got which is 1.03 volt (as represented in Fig. 6) and close to the typical fuel cell output voltage 1.23volt.

Fig. 3 Components of fuel cell kit.

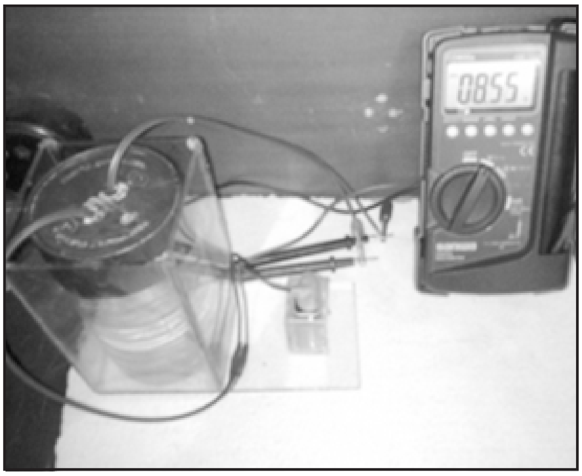


Fig. 4 Output voltage after connecting battery supply.

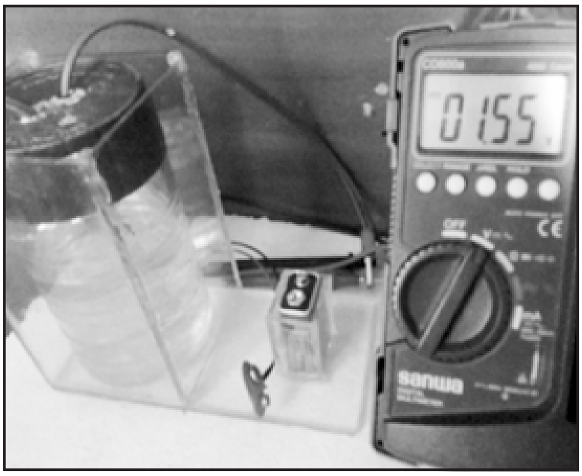


Fig. 5 Fuel cell output voltage just after disconnecting the battery supply.

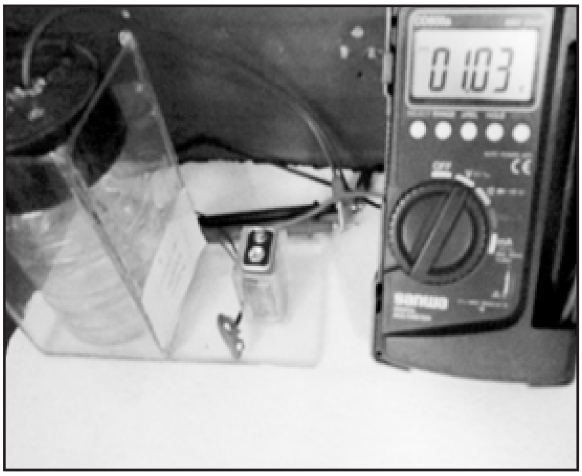


Fig. 6 Stable output voltage of fuel cell kit.

4. LOAD ANALYSIS OF CUET

To facilitate the analysis of the research, the whole Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh campus is divided into three zones like as: (i) Zone A: EME, CE and CSE building, 12 storied new academic building, PEB, Academic section, Engineering section, Workshop, Library, Gallery, Medical centre, Post office, Bank, Auditorium, Transport section, Mosque, CUET school & college. (ii) Zone B: Students' halls and Extension. (iii) Zone C: Residential area, Anser camp, guard shed, street light & water pump. Total connected load in CUET region was 1786 kW on January 2012. But the above mentioned zones never remain in peak at the same time interval. During the mentioned period it was observed that the total peak load at any moment throughout the day never exceeds 400 kW. So, in simulation 424 kW load is considered as maximum demand as shown in Table 1.

Table 1 The peak load condition of CUET.

Zone	Peak Hour	Peak Load	Off Peak Hour	Off Peak Load
A	8.00AM-5.00PM	210 kW (approx.)	5.00PM-8.00AM	40kW (approx.)
B	7.00PM-12.00AM	140 kW (approx.)	12.00AM-7.00PM	80kW (approx.)
C	7.00PM-12.00AM	120 kW (approx.)	12.00AM-7.00PM	70 kW (approx.)

5. SIMULATION APPROACHES

HOMER is an abbreviation of Hybrid Optimization Model for Electrical Renewable [12]. 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 2.81. The schematic models that are created in HOMER are shown in Fig. 7 and Fig. 8. Solar resource is the most important parameter for calculating radiation data in a specified region. In this simulation approach, the calculated annual average global solar radiation by HOMER is about 4.75 Kwh/m^2/d for CUET region. This value of solar radiation is got in the software by:

- Placing the latitude and longitude of CUET (Raozan, Chittagong).
- Selecting the time zone (Rangoon (GMT+6.30) is the closest approximation).
- And getting the solar radiation data via internet.

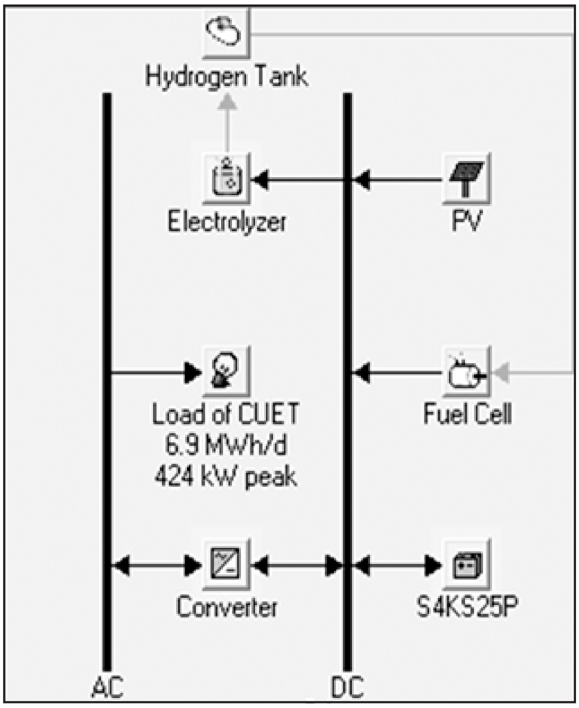


Fig. 7 Schematic model of PVFC-Battery hybrid system.

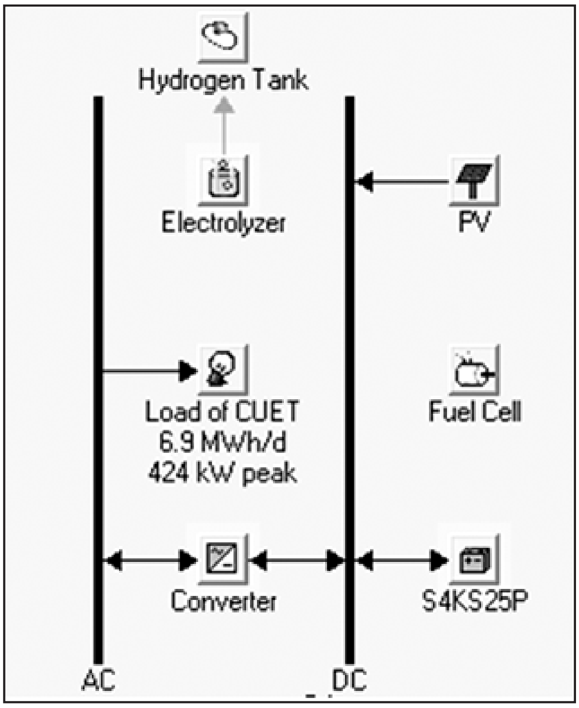
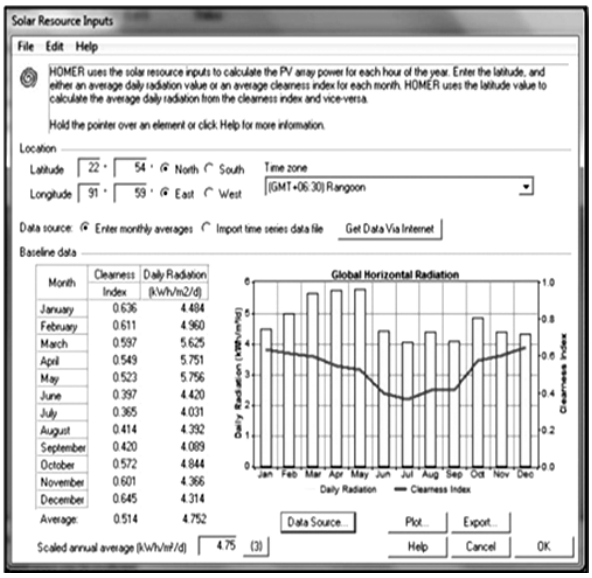


Fig. 8 Schematic model of PV-Battery system.

Fig. 9 shows the monthly average daily solar radiation data and clearness index for CUET region. The load data of CUET used in the simulation is shown in Fig. 10.



HOMER uses the solar resource inputs to calculate the PV array power for each hour of the year. Enter the latitude, and either an average daily radiation value or an average clearness index for each month. HOMER uses the latitude value to calculate the average daily radiation from the clearness index and vice-versa.

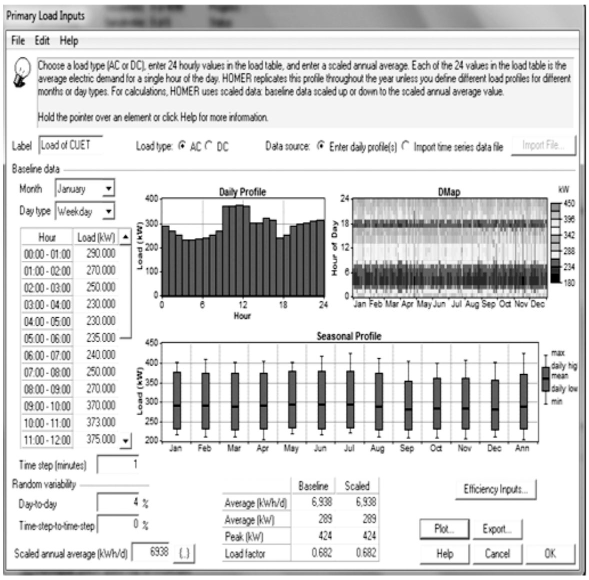
Hold the pointer over an element or click Help for more information.

Latitude 22 ° 54 ' ● North ○ South
Longitude 91 ° 59 ' ● East ○ West
Time zone (GMT+06:30) Rangoon
Data source: ● Enter monthly averages ○ Import time series data file

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.636	4.484
February	0.611	4.960
March	0.597	5.625
April	0.549	5.751
May	0.523	5.756
June	0.397	4.420
July	0.365	4.031
August	0.414	4.392
September	0.420	4.089
October	0.572	4.844
November	0.601	4.366
December	0.645	4.314
Average:	0.514	4.752

Scaled annual average (kWh/m²/d) 4.75 (3)

Fig. 9 Solar resource inputs window of HOMER.



Choose a load type (AC or DC), enter 24 hourly values in the load table, and enter a scaled annual average. Each of the 24 values in the load table is the average electric demand for a single hour of the day. HOMER replicates this profile throughout the year unless you define different load profiles for different months or day types. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value.

Hold the pointer over an element or click Help for more information.

Label Load of CUET
Load type: ● AC ○ DC
Data source: ● Enter daily profile(s) ○ Import time series data file
Month January
Day type Weekday

Hour	Load (kW)
00:00 - 01:00	290.000
01:00 - 02:00	270.000
02:00 - 03:00	250.000
03:00 - 04:00	230.000
04:00 - 05:00	230.000
05:00 - 06:00	235.000
06:00 - 07:00	240.000
07:00 - 08:00	250.000
08:00 - 09:00	270.000
09:00 - 10:00	370.000
10:00 - 11:00	373.000
11:00 - 12:00	375.000

Time step (minutes) 1
Random variability
Day-to-day 4 %
Time-step-to-time-step 0 %
Scaled annual average (kWh/d) 6938 (.)

	Baseline	Scaled
Average (kWh/d)	6,938	6,938
Average (kW)	289	289
Peak (kW)	424	424
Load factor	0.682	0.682

Fig. 10 Primary load inputs window of HOMER.

6. SIMULATION RESULTS

Two configurations of system are studied in this research. One is PV system and another one is PVFC hybrid system. Simulation is performed in HOMER environment for sizing optimization which minimizes the system cost. Simulation results also provide comparison among these configurations [12].

6.1 Cost Details of System Components [12]

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

Table 2 Component cost details.

Components	Capital cost	Replacement cost	Operational and maintenance (O/M) cost
PV	1340 $/kW	1200 $/kW	0 $/kW
Electrolyzer	12074 $	12000 $	30 $/hr
Fuel cell	61 $/kW	60 $/kW	0.05 $/hr
Hydrogen tank	525 $	500 $	0 $
Battery	950 $	800 $	5 $/hr
Converter	500 $	500 $	10 $/hr

6.2 Optimization Result of PV and PVFC System [12]

The details of optimization result for PV system after simulation is shown in Table 3, Table 4 and Table 5.

Table 3 System architecture for PV system.

PV Array	3,090 kW
Battery	2,730 Surrette 4KS25P
Inverter	450 kW
Rectifier	450 kW

Table 4 Net Present Costs (NPC) for PV system

Costs	PV	Surrette 4KS25P	Converter	System
Capital ($)	4,140,600	2,593,500	32,143	6,766,243
Replacement ($)	0	1,085,382	13,412	1,098,794
O&M ($)	0	171,312	8,068	179,381
Salvage ($)	-36,632	0	-3,175	-39,807
Total ($)	4,103,968	3,850,195	50,448	8,004,611

Table 5 Cost summary for PV system

Total net present cost	$ 8,004,610
Levelized cost of energy	$ 0.262/kWh
Operating cost	$ 98,672/yr

From the simulation result of PV system it is clear that, the cost of energy (COE) = \$0.262/kWh = 19.65 BDT (as shown in Table 5). Optimization results of PVFC system are depicted in Table 6, Table 7 and Table 8.

Table 6 System architecture for PVFC system.

PV Array	4,485 kW
Fuel Cell	1,190 kW
Battery	1,690 Surrette 4KS25P
Inverter	420 kW
Rectifier	420 kW
Electrolyzer	2,378 kW
Hydrogen Tank	400 kg

Table 7 Net Present Costs (NPC) for PVFC system.

PV components			
Costs	PV	Surrette 4KS25P	Converter
Capital ($)	6,009,900	1,605,500	30,000
Replacement ($)	0	671,903	12,518
O&M ($)	0	106,051	7,530
Salvage ($)	-53,170	0	-2,964
Total ($)	5,956,731	2,383,454	47,084
FC components			
Costs	Fuel cell	Electrolyzer	Hydrogen tank
Capital ($)	72,590	12,064	568
Replacement ($)	0	5,003	1,100
O&M ($)	21,432	376	0
Salvage ($)	-7,947	-1,185	-27
Total ($)	86,074	16,259	1,641
System cost			
Capital ($)	7,730,622		
Replacement ($)	690,524		
O&M ($)	135,389		
Salvage ($)	-65,292		
Total ($)	8,491,243		

Table 8 Cost summary for PVFC system

Total net present cost	$ 8,491,243
Levelized cost of energy	$ 0.278/kWh
Operating cost	$ 60,606/yr

So, for PVFC system the cost of energy (COE) = $.278/kWh= 20.85 BDT/kWh (as shown in Table 8).

The above analyzing tables show the less dependency on battery and low operating cost of PVFC system compared to PV system. The following points can be noted from the above tables:

- PV panels of large rating are required for PVFC-Battery system than in PV-Battery system.
- The necessity of converter for PVFC-Battery system is lower than that for PV-Battery system.
- Battery requirement for PV-Battery system is much higher than that for PVFC-Battery system.
- Total net present cost is higher for PVFC-battery system than that for PV-battery system.
- The levelized costs of energy for both systems are almost equal.
- The operating cost for PV-battery system is much higher than that for PVFC-system.

6.3 Annual Energy Consumption [12]

The annual energy consumption result is revealed in Table 9 which shows that the excess electricity is high for PV system and capacity shortage is almost similar for the both systems.

Table 9 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 [12]

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 10 and Table 11.

Table 10 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 11 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 [12]

Fig. 11 and Fig.12 state that, with the increase of global solar radiation, cost of energy for both systems is decreasing. Capacity shortage is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide. HOMER keeps track of such shortages and calculates the total amount that occurs over the year. From Fig. 13 and Fig. 14, it is clear that with production of PV power the capacity shortage is continuously decreasing for both systems.

From Fig. 15 and Fig. 16, it can be noted that excess electricity is low for PVFC system and PVFC system is superior to PV system. Because, (i) it requires less number of batteries, (ii) it has low operating cost, (iii) less dependence on PV and battery, (iv) less wastage of electricity, and (v) fast cost reduction rate.

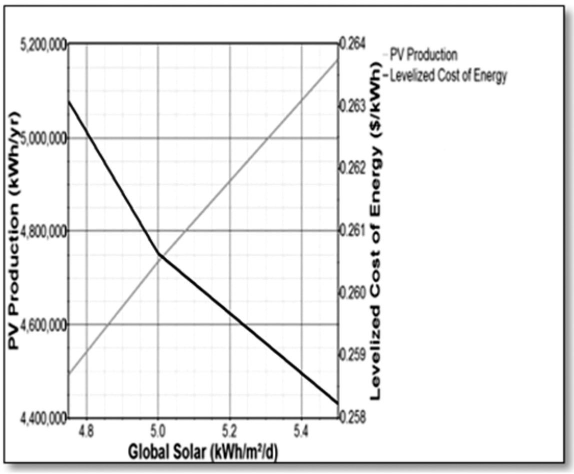


Fig. 11 PV production vs. Cost of energy for PV system.

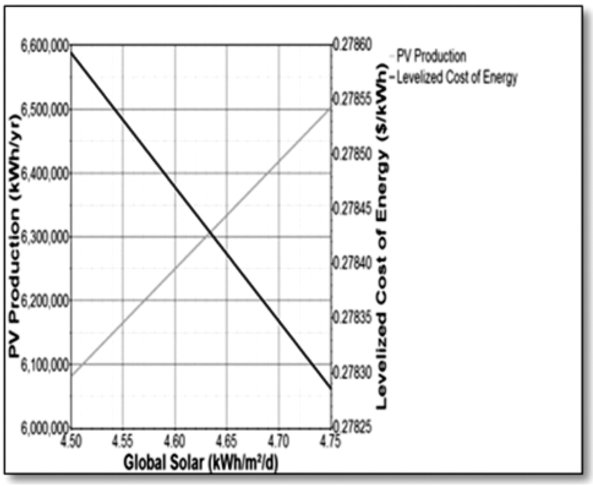


Fig. 12 PV production vs. cost of energy for PVFC system

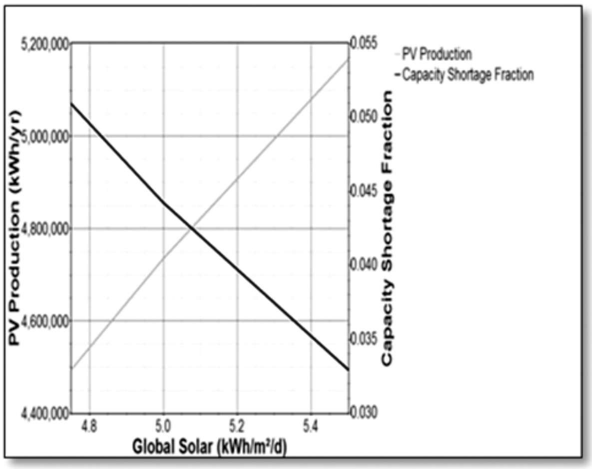


Fig. 13 PV Production vs. capacity shortage for PV system

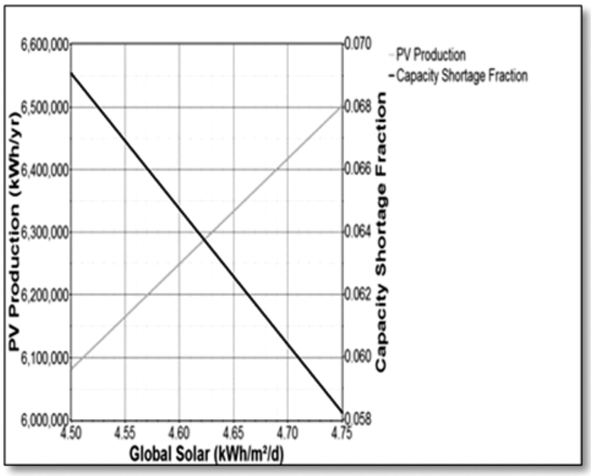


Fig. 14 Production vs. capacity shortage for PVFC system.

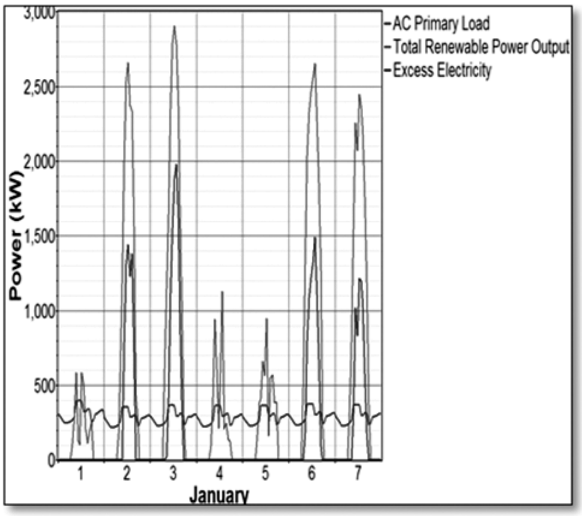


Fig. 15 AC primary load, total renewable output and excess electricity for PV system.

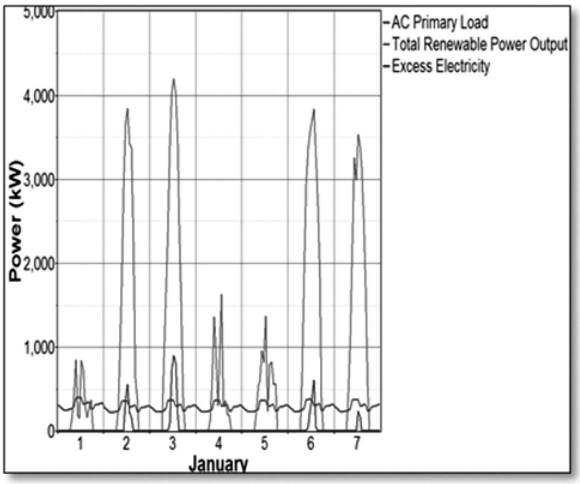


Fig. 16 AC primary load, total renewable output and excess electricity for PVFC system.

7. LIMITATIONS OF THE SYSTEMS

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. In PVFC system the fuel cell power generation is significantly lower than that by PV cell. It was only 2% in the simulation result.

3. Fuel cell doesn't work under high insulation. Its capacity is limited by geographical location.

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

5. Though the cost of solar cell is decreasing day by day, its cost is quite high still now. As the solar cell cost comprises the large portion of cost table, it increases the expense of the PV and PVFC hybrid system significantly.

8. FUTURE RESEARCH

In this research, the load status of CUET region as an area of Bangladesh is taken as standard and simulated it by HOMER 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 presents the potential of a hydrogen fuel cell storage system for producing electricity from photovoltaic energy in CUET region with a battery system. In this work, the practical fuel cell kit has been made to observe the operating principle of a fuel cell. The result obtained from the simulation employed on PV and PVFC model system indicates that the PVFC system is superior to PV system in many aspects. The resultant cost of energy obtained from the simulation output that should be closely equal to the real as the capital, replacement and other costs of the components have been assumed so precisely according to their price in international market. Although this study 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 a promising, cost effective and reliable energy source in the near future.

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