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FEASIBILITY STUDY OF PV SYSTEM AND PVFC HYBRID SYSTEM TO MEET ENERGY DEMAND OF CUET

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Abstract— *Energy demand continues to grow, year after year. Traditional fossil energy sources such as oil and gas are ultimately limited and the gap between demand and supply is increasing. Energy crisis have to be met from alternative primary energy sources. 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 thesis 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. To meet energy demand of CUET, we considered its total electrical load in the process of simulation to get optimal cost of energy, cost effectiveness and efficient power of PV-Battery and PVFC-Battery systems.*

Index Terms— PV, PVFC, PEM, HOMER, CUET.

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, 48.5% of the total population of Bangladesh is enjoying the electric facilities. In Bangladesh per capita generation is 220 kWh (as June 2010) which is comparatively much lower than other developed countries in the world. At present installed capacity is 6,760 MW (March 2011), maximum generation is 4,699 MW (Feb 2011) and Peak demand is 5,800 MW (June 2010) [1]. Electricity generation is mostly dependent on natural gas, 77% of the total generation is dependent on it [2]. 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. 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, 4].

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 figure 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).

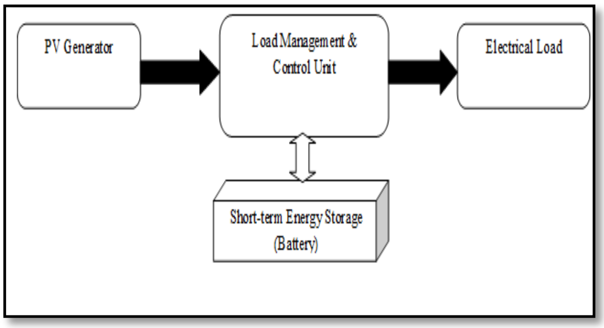

Figure 1: Block diagram of PV system

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 [5-7]. This hybrid system as shown in figure 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, i.e., hour to hour and season to season. Hydrogen is environmentally compatible and can be converted into electricity at a relatively high efficiency [8]. 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 reversely 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

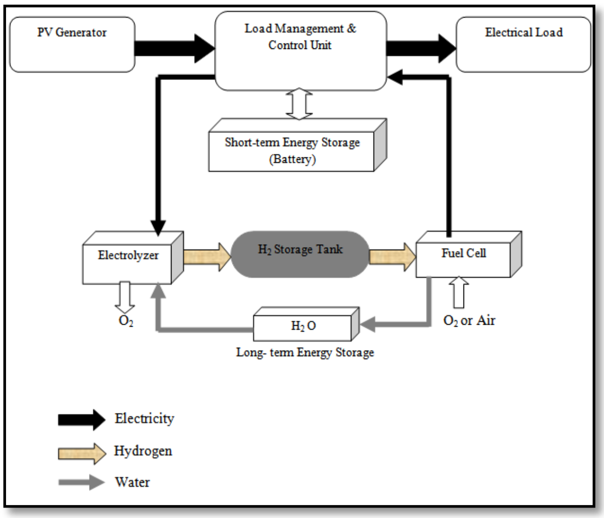

Figure 2: Block diagram of PVFC hybrid system

reacts with protons and electrons forming water and producing heat. Both the anode and the cathode contain a catalyst to speed up the electrochemical processes [9]. The theoretical cell voltage for a PEM fuel cell is about 1.23V at standard conditions [10]. 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

For observing the operating principle of fuel cell practically, we made a fuel cell kit in CUET electronics lab. We did the experiment and measured the parameters on 15th September, 2011 and depicted in figure 3, 4, 5 & 6. The practical fuel cell kit consists of some components such as: *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 was twisted to make electrodes. The electrodes were attached to the battery clip and voltmeter probes by wire. Then the electrodes were placed into a pot which was filled with water. Without any energy source voltmeter read 0.00 volt across fuel cell. After connecting a battery voltmeter read approximately 8.55 volt (figure 4). Touching the battery to the clip caused the water at the electrodes to split into hydrogen and oxygen. We saw the bubbles to form at the electrodes while the battery was connected. Platinum acted as a catalyst, something that made it easier for the hydrogen and oxygen to recombine. After removing battery we still measured voltage across fuel cell that was 1.55v (figure 5). At last, we got the stable output voltage of the fuel cell kit 1.03volt (figure 6) which is close to the typical fuel cell output voltage 1.23volt.

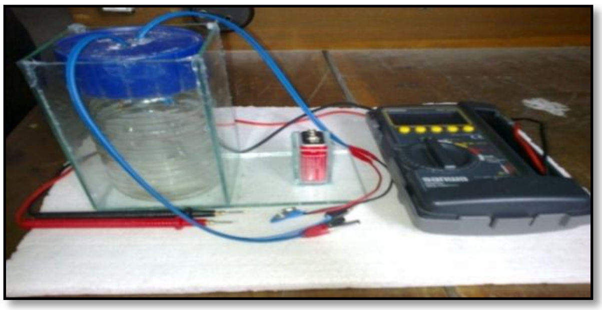

Figure 3: Components of fuel cell kit

Figure 4: Output voltage after connecting battery supply

Figure 5: Fuel cell output voltage just after disconnecting battery supply

Figure 6: Stable output voltage of fuel cell kit

4. LOAD ANALYSIS OF CUET

We divided the whole CUET campus in three zones.

Zone A: EME, CE+CSE building, 12 storied building, PEB, Academic section, Engineering section, Workshop, Library, Gallery, Medical centre, Post office, Bank, Auditorium, Transport section, Mosque, CUET school & college.

Zone B: Student halls & Extension.
Zone C: Residential area, Anser camp, guard shed, street light & water pump.

Total connected load in CUET region is 1786 kW. But the above mentioned zones never remain in peak at the same time interval. 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 we considered 424kw as maximum demand that is 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-5.00 PM	210kW (approximate)	5.00PM-8.00AM	40kW(approximate)
B	7.00PM -12.00 AM	140kW (approximate)	12.00AM-7.00PM	80kW(approximate)
C	7.00PM -12.00 AM	120KW (approximate)	12.00AM-7.00PM	70KW(approximate)

5. SIMULATION APPROACHES

HOMER is an abbreviation of Hybrid Optimization Model for Electrical Renewable [11]. 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 study is HOMER version 2.81. System models are at first drawn in HOMER. The schematic models that are created in HOMER are shown in figure 7 & 8.

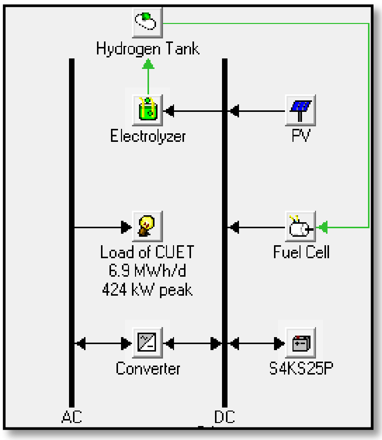

Figure7: Schematic model of PVFC-Battery hybrid system

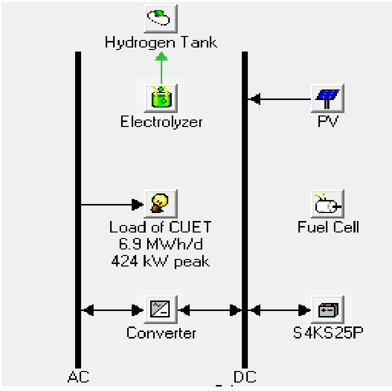

Figure 8: Schematic model of PV-Battery system

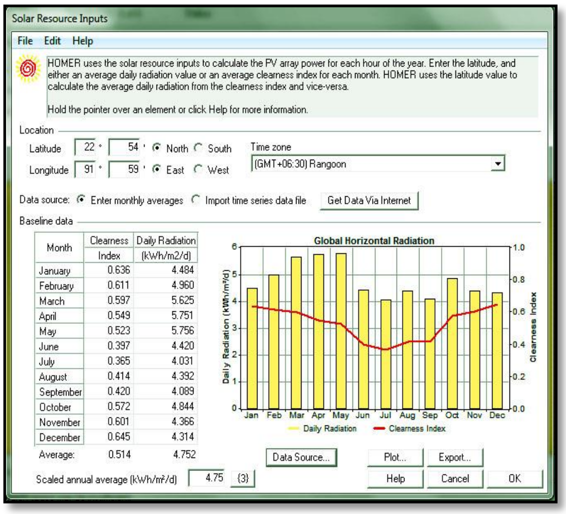

Figure 9: Solar resource inputs window of HOMER

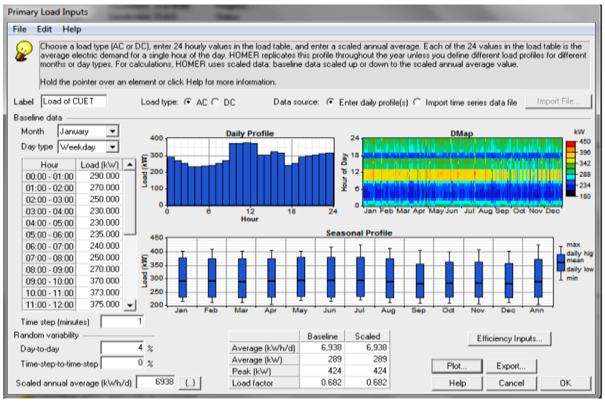

Figure 10: Primary load inputs window of HOMER

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 9 shows the monthly average daily solar radiation data and clearness index for CUET region. Load data of CUET is shown in figure 10.

6. SIMULATION RESULTS

Two configuration of system 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.

6.1 COST DETAILS OF SYSTEM COMPONENTS:

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

Table 2: Component cost details

Components	Capital cost	Replacement cost	O/M cost
PV	1340($/kw)	1200($/kw)	0
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:

The details of optimization result for PV system after simulation is shown in table 3, 4 & 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

So, cost of energy (COE) = $ 0.262/Kwh = 19.65 Taka. Optimization result of PVFC system is depicted in table 6, 7 & 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	$ 8,491,242
Levelized cost of energy	$ 0.278/kWh
Operating cost	$ 60,606/yr

So, cost of energy (COE) = $.278/Kwh= 20.85 Taka/Kwh. The analyzing tables show the less dependency on battery and low operating cost of PVFC system compared to PV system.

6.3 ANNUALIZED ENERGY CONSUMPTION:

Annualized energy consumption result is revealed in table 9.

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

Table 9 shows that the excess electricity is high for PV system and capacity shortage is almost similar for the both systems.

6.4 SENSITIVITY ANALYSIS:

The sensitivity of the effect of solar radiation on cost parameters (NPC, COE and operating) of complete system is shown in Tables 10 and 11.

Table 10: Sensitivity of solar radiation on NPC, COE and operating cost for PV system

Annual average radiation (kWh/m2/ day)	Total NPC ($)	COE ($/kW h).	Operatin g 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/m 2/day)	Total NPC ($)	COE ($/kW h).	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:

Figure 11 & 12 declare 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 figure 13 & 14 it can be observed that with production of PV power the capacity shortage is continuously decreasing for both of the system.

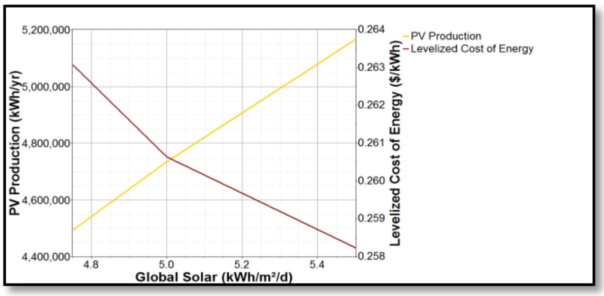

Figure 11: PV production vs. Cost of energy for PV system

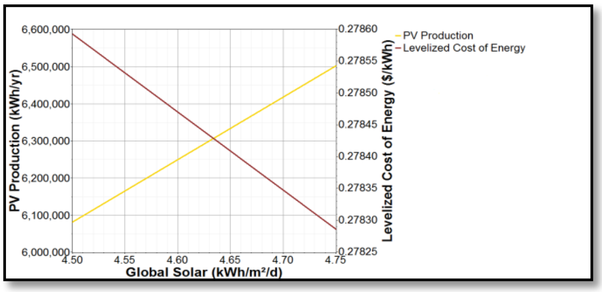

Figure12: PV production vs. cost of energy for PVFC system

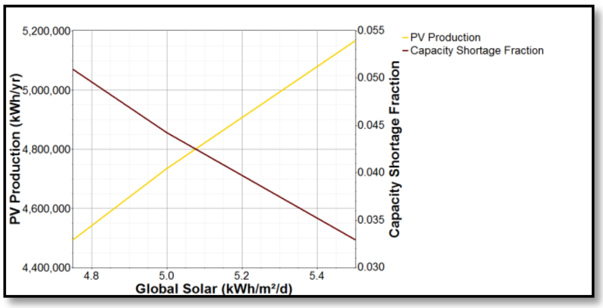

Figure 13: PV production vs. capacity shortage for PV system

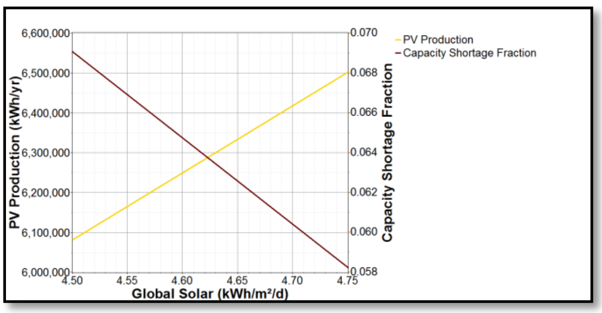

Figure 14: PV production vs. capacity shortage for PVFC system

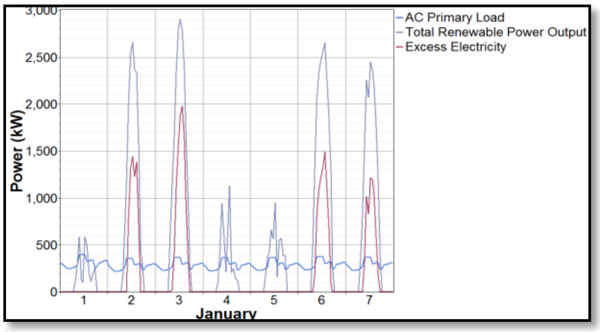

Figure 15: AC primary load, total renewable output and excess electricity for PV system

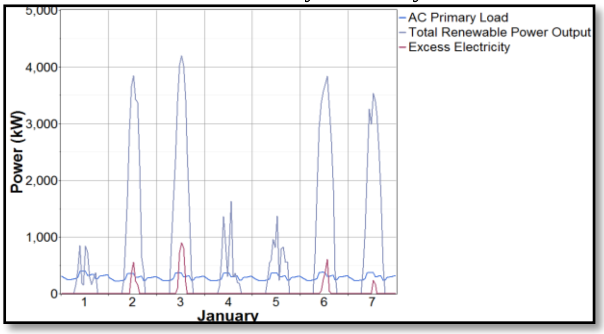

Figure 16: AC primary load, total renewable output and excess electricity for PVFC system

From the figure 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 battery *(ii)* it has low operating cost *(iii)* less dependence on PV and battery *(iv)* less wastage of electricity *(v)* fast cost reduction rate.

7. LIMITATIONS OF THE SYSTEMS

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 insolation. Its capacity is limited by geographical location.
4. 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, we estimated the load of CUET region and simulated it by HOMER to design the system architecture. We did not consider the design requirements for installing the plant in this region. 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 illustrated the potential of a hydrogen fuel cell storage system for producing electricity from photovoltaic energy in CUET region with a battery system. 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 [12]. 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 the most promising, cost effective and reliable energy source in the near future. 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 a revolution and its efficient stationary use is also proved today. Bangladesh government can adopt fuel cell technology to meet its energy demand in the near future.

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