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Optimum Design of a Grid Connected PV/Battery Hybrid System for Commercial Load in Bangladesh: Effects of PV, Battery, and Dispatch Strategies

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ABSTRACT

This study investigates the potentiality of a grid connected PV/Battery system for a daily 900 kWh commercial load in northern region of Bangladesh. The effects of two PV modules (monocrystalline and polycrystalline) by considering cost of energy (COE) and net present cost (NPC) by means of two dispatch strategies is investigated in the study. Five battery types namely (lead acid (LA), Li-ion, zinc flow, vanadium flow, and nickel-iron) are selected to determine the cost effective hybrid system using HOMER software. The outcomes indicate that grid connected polycrystalline/LA system in Load following (LF) strategy has the optimized COE ($0.05/kWh) and NPC ($307,657). The study also shows the effects of sell-back price on the COE. Moreover, the article focuses the social, economic and environmental benefits of executing the hybrid system.

Keywords: renewable energy, battery, HOMER, COE, grid

1. INTRODUCTION

Bangladesh is considered one of the fastest rising economies in the Southern-Asia, and till now, Bangladesh ranked as 8th in the world's largest populated country [1]. The country has a very limited energy reserve whereas the traditional energies such as oil, natural gas etc. are mostly used for power generation and gradually diminishes the sources. Fig. 1 shows the electricity generation scenario from different sources in Bangladesh [2] and it is cleared that large part of the energy comes from gas. According to the Sustainable & Renewable Energy Development Agency of Bangladesh (SREDA), renewable energy donates around 3% of the country's total power mix which is a matter of concern for an under developing country like Bangladesh [2].

For last couple of years, renewable energy is becoming popular because of its benefits of simple accessibility, non-exhaustible and easy generation system. From Fig. 2 it is seen that large portion of generated electricity comes from solar energy.

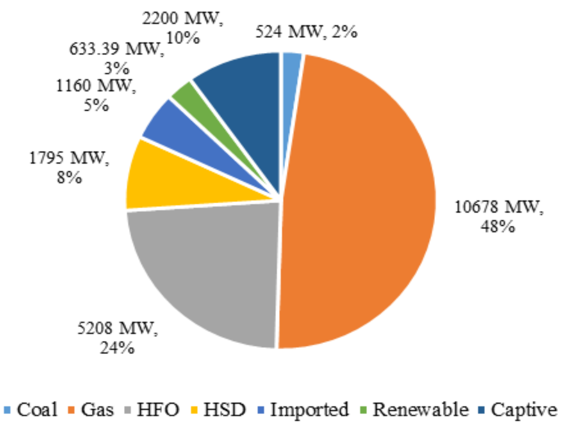
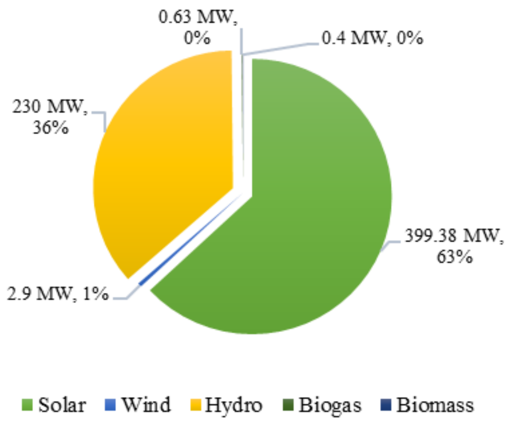


Fig.1 Electricity Generation Scenario in Bangladesh

Fig.2 Renewable Energy Generation Summary



Because of geometrical location, renewable energy has enormous prosperity in Bangladesh particularly in case of solar energy. The average length of daylight hours in coastal regions of Bangladesh is 6.5 hours [3, 4], which is ideal for the utilization of solar energy. Battery allows us to store the surplus energy from photovoltaic cell. Common types of batteries are lithium-ion, lead acid, zinc flow, vanadium flow, nickel-iron etc. Lithium-ion batteries are very popular in domestic grid connected solar PV storage system [5, 6]. On the other hand, LA batteries are used for off grid systems where additional storage is required [4]. At the moment of power shortage from RE sources, the grid electricity can be used to meet the demand. When power production by solar is larger than the demand, then the extra electricity can be supplied to the grid therefore making profit [7].

In this study, a PV/Battery power configuration is considered for finding a cost-effective hybrid system. For this regard, two PV module (monocrystalline and polycrystalline) and five different batteries (lead acid (LA), Li-ion, zinc flow, vanadium flow, and nickel-iron) are used with the load following (LF) and Cyclic charging (CC) strategies.

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The aim of this work is to specify a cost-effective PV-Battery energy system for commercial used in the Northern region of Bangladesh.

2. METHODOLOGY

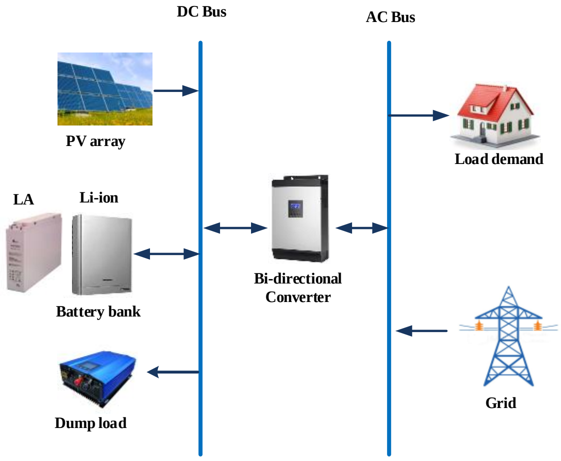

Fig.3 Schematic Diagram of PV/Battery/Grid system

The system is consisted of PV array, batteries and a bi-directional converter which deals with AC and DC interface as shown in Fig. 3. When electricity is generated at PV module, surplus energy is stored in suitable battery. Bi-directional converter is adopted to transfer DC current to AC current or vice versa. The system is also integrated into grid connection mode. If the load demand is not fulfilled with the electricity produced, then unmet load is fulfilled from the national grid. On the other hand, if the electricity produced by PV panel is greater than the energy demand, the excess electricity can be diverted using dump loads for various others uses. HOMER (Hybrid Optimization Model for Electrical Renewable) is utilized to examine the viability of the arrangement. HOMER takes meteorological resource data, hourly load data, hardware technical and economic details etc. as input and provides optimum sizing of the components and economic details as output. The operating procedure of the HOMER is presented graphically in Fig. 4 [3].

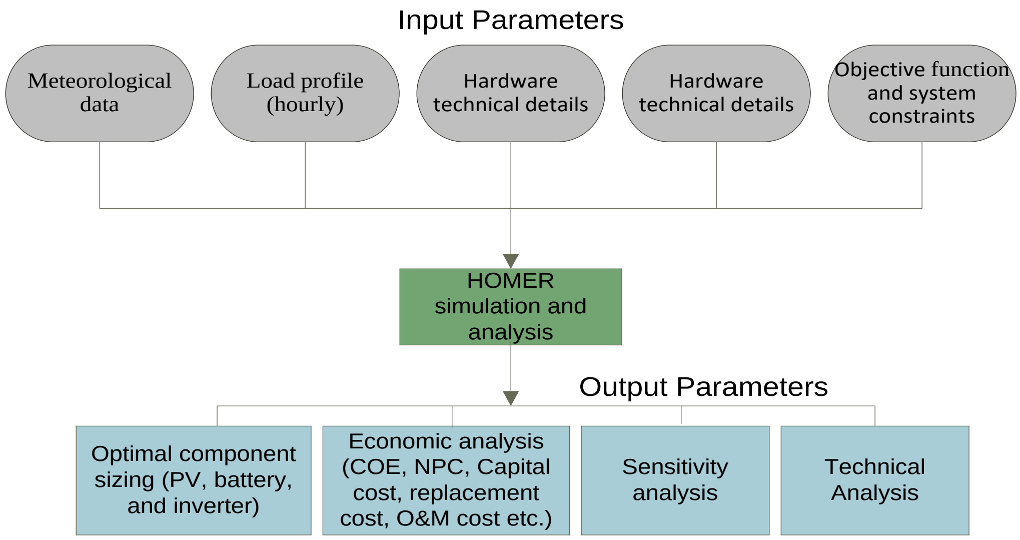

Fig.4 Operating principle of HOMER approach

3. METROLOGICAL DATA AND ESTIMATED LOAD OF THE STUDY AREA

The study considers a commercial area near Rajshahi railway station, Rajshahi, Bangladesh (24°22.5'N, 88°36.2'E). The proposed study area is national grid-connected but the electricity supplied by the grid is not enough to fulfill the demand due to frequent load-shedding. The proposed system will compensate the problem. All the relevant meteorological solar irradiation and temperature data are obtained from the HOMER. Fig. 5 shows the yearly solar radiation and ambient temperature of the nominated region.

Table 1 shows the individual load demand for small business center, shop, bank, office, small hotel etc. The entire maximum load demand of the area is 900 KWh/day.

Fig.5 Hourly average annual solar irradiation data for the particular area.

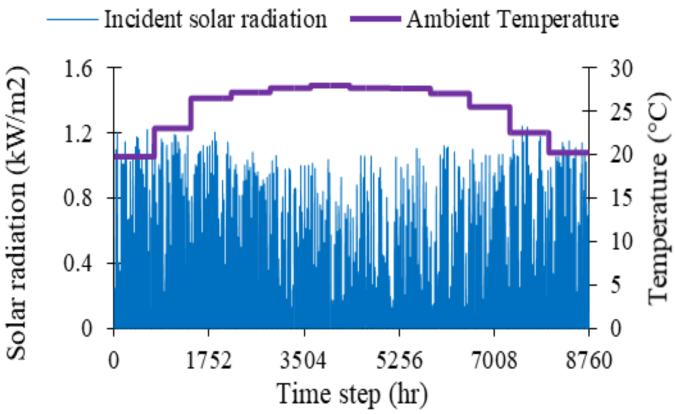

Fig. 6 shows the average load demand for the selected area which is composed of various stores, mills and offices.

Table 1 Estimation of Load Demand

Appliances	No. of Appliances	Total demand (kWh/day)
Small Business Center	4	100
Village Store	15	30
Small Market	10	60
Rice & Flour Mills	2	500
Small Hotel	3	150
Auditorium	1	10
Bank, Office, Pharmacy	10	30
Miscellaneous	-	20
Total		900 kWh/day

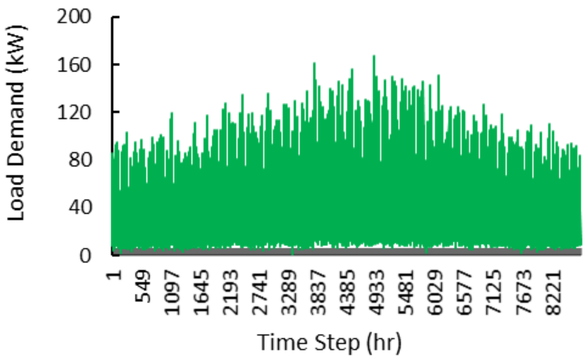

Fig.6 Hourly average annual load demand data for the particular area**.**

4. System Components

The system compounds of PV module, batteries and inverter. The technical descriptions, costs and lifetime of the hardware constituents is presented in Table 2.

4.1 PV Module

In the study, two types of PV modules are considered. E20-327 model is used as monocrystalline solar panel which is a residential panel. The PV module has 327W nominal power, approximately 20.5% average efficiency, 54.8V rated voltage, and 6A rated current and life time of 25 years. The other solar panel is polycrystalline (model: Peimer SG325P). The module needs $550/kWh capital cost, $550 replacement cost, $10/kWh O $ M cost, and 25 years duration [8].

4.2 Battery Storage

The energy generated in the system is stored in battery until it is fully charged (100%) and additional energy is dumped. Five several types of batteries are considered for the analysis. Surrette 6CS25P is considered as LA battery. LA battery has a round trip efficiency of 80%, battery efficiency ratio of 0.237 and maximal charge and discharge current of 279 A each [9].

Li-ion (model: Tesla Power wall 2.0) has characteristics of 13.2 kWh nominal capability, theoretical voltage 220V, maximum charge 31.8 A, and maximum discharge current of 31.8A. Li-ion battery has a round trip efficiency of 89%, a maximum depth of discharge of 100%, and a lifespan of 10 years. The capital cost of each one unit is $6,500 where the replacement cost is $6,000 [10].

The vanadium flow battery can deliver limitless energy ability simply by utilizing higher electrolyte storage tanks. The capital and replacement cost of VFB is $200 each [11].

The zinc flow battery (model: ZBM2) has specifications of operating range of 40-60V, maximum capacity of 10kWh/day, energy efficiency (80%) and internal operating temperature of 15^0C to 50^0C. The capital and replacement cost is $8000 each [11].

Iron Edison nickel iron 1000Ah has specifications of nominal voltage of 1.2V (per cell), charging voltage 1.65 V (per cell) and efficiency approximately 80%. The capital cost of Ni-Fe type battery is $970 [11].

4.3 Inverter

To covert AC current to DC or vice-versa a bi-directional inverter is linked connecting two buses. The efficiency of conversion and the lifespan of the inverter is 95% and 10 years, correspondingly. The capital charge is $300/kW, replacement cost is $300/kW, and O&M cost is $10/kW/yr. [8].

Table 2 Technical and economic data of hardware components used for the simulation [8-10]

Components	Technical Description	Capital Cost ($/kW)	Replacement Cost ($)	O&M Cost ($/yr)	Lifetime (yr)
Monocrystalline PV	327W	1300	-	10	25
Polycrystalline PV	325W	550	550	10	30
LA	4.92 kWh	1100	1000	10	15
Li-ion	13.2kWh	6,500	6,000	0	10
Zinc Flow		8,000	8,000	0	
VFB		200	200	0	15
Ni-Fe		970	970	2.5	-
Inverter	1kW	300	300	10	10
Discount Rate (%)	10				
Grid purchase ($/kWh)	0.097				
Grid sales ($/kWh)	0.12				

5. ECONOMIC ASSESSMENT

Economic hybrid energy system is decided based on minimum COE ($/kWh) and NPC ($) [12].

5.1. Cost of Energy (COE)

COE is the ratio of overall annualized cost to the full electrical energy served in a year (excluding excess heat) and is deduced by equation (1).

$$COE = \frac{C_A}{E_S} \quad (1)$$

Where C_A ($/year) is the overall annualized cost and E_S (kWh/yr) is the total electrical load delivered in a year.

5.2. Net Present Cost (NPC)

NPC indicates the total initial cost, maintenance cost, operating cost, replacement cost, and fuel minus the salvage values of all the components during its project lifetime. It is determined by equation (2), wherever CRF (i,n) refers capital recovery factor and calculated by equation (3).

$$NPC = \frac{C_A}{CRF\ (i,n)} \quad (2)$$

$$CRF\ (i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (3)$$

Here, i indicates real interest rate and calculated by equation (4), where i´ is the nominal interest rate, and f indicates yearly inflation rate.

$$i = \frac{i' - f}{1 + f} \quad (4)$$

6. RESULTS AND DISCUSSION

The obtained outcomes are analyzed depending on the economical, technical, and eco-friendly indicators to justify a cost-economic commercial hybrid energy system. System sizing is decided following on the COE and NPC considering some important performance parameters such as excess energy (EE, kWh/yr.), battery performance, unmet load, capacity shortage etc.

6.1 Effects of Dispatch Strategies

In the circumstances, the optimized outcomes of PV/battery systems are discussed in two different strategies. From Table 3 it is realized that PV/battery with polycrystalline solar panel gives lower COE ($0.05/kWh) with LF strategy compared to the CF (0.052 $/kWh) strategy. In the case of monocrystalline solar panel, both COE and NPC exhibits high value compared to polycrystalline panel. In case of stand-alone system, CC strategy gives slightly better result ($0.31/kWh) than LF. Furthermore, grid-connected hybrid system gives better economic model compared to all stand-alone hybrid energy systems.

Table 3 Optimization summary of PV/battery system using different strategies.

Parameters	Grid Connected				Stand-alone			
	Monocrystalline		Polycrystalline		Monocrystalline		Polycrystalline	
	LF	CC	LF	CC	LF	CC	LF	CC
COE ($/kWh)	0.089	0.091	0.050	0.052	0.44	0.50	0.32	0.31
NPC ($)	573,400	645,466	307,657	342,784	2,009,53	2,108,57	1,656,230	1,556,230
PV module (kW)	268	324	478	505	583	558	946	932
Battery (strings)	29	62	23	32	762	765	486	492
Inverter (kW)	152	172	180	178	167	169	158	159
Excess Energy (kWh/yr)	32,047	49,592	196,977	247,097	492,496	492,496	1,051,621	1,051,621
Unmet load (kWh/yr)	0	18	160	3	262	263	248	250
Capacity Shortage (kWh/yr)	328	348	360	320	336	337	360	360
PV energy (kWh/yr)	424,102	498,575	716,645	800,824	914,002	916,003	1,422,132	1,432,100
Grid Purchases (kWh/yr)	133,343	122,624	110,762	104,364	-	-	-	-
Grid Sales (kWh/yr)	139,745	176,334	234,425	256,367	-	-	-	-
Storage Depletion (kWh/yr)	388	324	0	162	342	342	332	332

Table 4 Battery effects on the Polycrystalline PV/Battery/Grid connected system (For LF Strategy)

Parameters	LA	Li-ion	Zinc Flow	VFB	Ni-Fe
COE ($/kWh)	0.050	0.052	0.053	0.091	0.14
NPC ($)	307,657	319,765	324,278	756,878	1,112,235
PV module (kW)	478	497	460	1,012	2,208
Battery (strings)	23	48	7	-	9
Inverter (kW)	180	182	176	184	190
Excess Energy (kWh/yr)	196,977	212,245	178,537	925,424	2,437,543
Unmet load (kWh/yr)	160	0	0	0	12
Capacity Shortage (kWh/yr)	360	350	356	360	358
PV energy (kWh/yr)	716,645	770,678	708,067	1,585,423	3,281,126
Grid Purchases (kWh/yr)	110,762	110,145	112,248	19,388	75,748
Grid Sales (kWh/yr)	234,425	239,564	223,736	310,634	379,456

6.2 Effects of Battery Technology

Since polycrystalline panel gives better result than monocrystalline in grid-connected mode at LF strategy in Table 3**,** consequently, polycrystalline panel based PV/Battery energy system is justified for different types of battery in grid-connected mode in Table 4. From the table, it is obtained that LA battery at LF strategy has the lowermost COE ($0.050/kWh) and NPC ($307,657) compared to other types of battery storage. On the other hand, Li-ion is the second economic storage system for PV/Battery energy system integrated with grid connection followed by zinc flow, VFB, and Ni-Fe batteries. From the overall study it is cleared that battery storage has great impact for selecting a cost-effective PV/battery hybrid energy system.

7. Competitive Analysis of Different Arrangements

The optimized outcomes are analyzed depending on the monocrystalline and polycrystalline solar panel using five types of batteries for meeting a commercial load demand. From Table 3, it is seen that, with polycrystalline solar panel, a Load Following (LF) strategy has the least COE (0.050$/kWh) and NPC ($307,657). Various performance parameters are presented in Table 4 for different types of batteries in which LA battery gives the optimum result.

From the study, it can be said that optimum configuration for the grid-connected system is polycrystalline panel combined with LA battery using LF strategy. The cost summary for this arrangement is exposed in Fig. 7. The total capital cost for the system is 391,612$. Among all the capital costs, 50% of the initial cost is needed for grid-connected issue. In operating cost, battery requires maximum O & M cost. All the other expenses such as replacement cost and salvage values for the solar panel and batteries has minor impact on the total system.

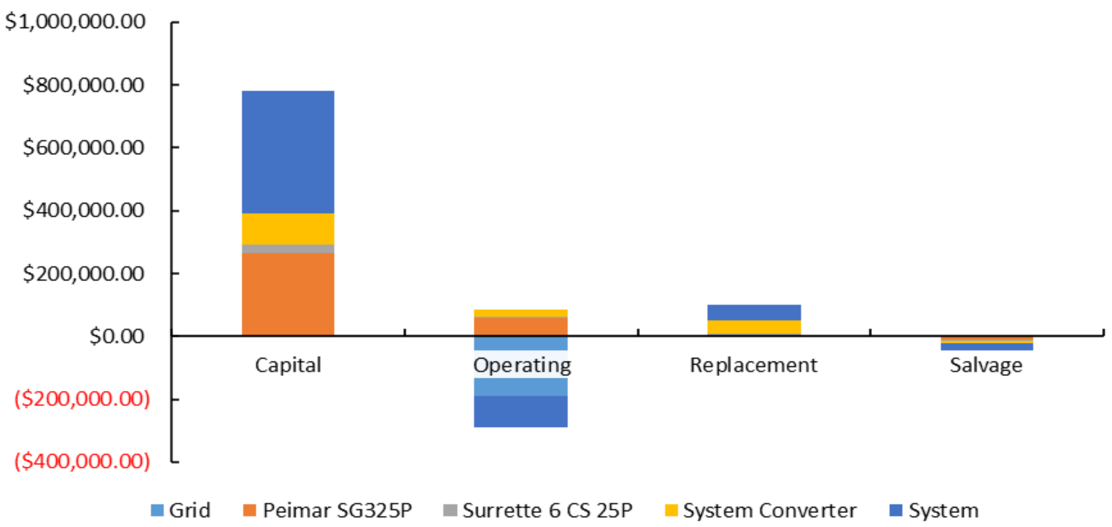

Fig.7 Cost summary for Polycrystalline PV/ LA Battery/Grid based LF hybrid configurations

8. Sensitivity Analysis

In this analysis, the study investigated the variation of COE against the sell back price of energy that will be sent to the national grid. In Fig. 8, it can be seen that, COE decreases as the sell back price of energy increase. In this study, optimum COE is 0.05 $/kWh against sell-back price of 0.12$/kWh. On the other hand, as the proposed system is grid connected, there will be no environmental pollution which makes the system eco-friendly.

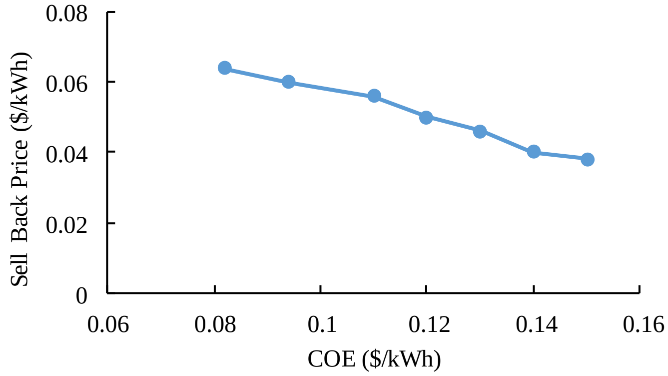

Fig.8 Effects of sell-back price on the COE

9. Conclusion

A commercial area along with load demand of 900 kWh/day was selected for the study. The study investigated various cost parameters and performance indicators using different types of battery with two different strategies. The contribution of the paper is that it undoubtedly justify the proper dispatch strategy to optimum hybridized scheme depending on techno-economic and ecological factors. For the polycrystalline solar panel, LF strategy has the least COE of $0.050/kWh and NPC of $307,657 using LA battery with grid connected mode. This combination gives the best optimal result. The consequence of the work could be influential to implement such arrangements for better energy supply in the region where grid connection is available.

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