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FEASIBILITY STUDY OF THE COST EFFECTIVE HYBRID POWER SYSTEM FOR CUET IN BANGLADESH

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Abstract- *Bangladesh is one of the developing countries. Every year the demand of electricity is increasing due to rapid urbanization and industrialization. But the whole demand of electricity cannot be met due to much dependence on fossil fuels for electricity generation. Hybrid power system technology may be used to reduce the great dependence on fossil fuels and to generate electricity at an affordable price. In this study, a methodology had been developed for getting the optimal planning of hybrid power system for rural areas where we selected our university named Chittagong university of Engineering and Technology (CUET) as suitable region. The study included the determination of optimal size of systems able to fulfill the primary load 1 (1212 kWh/d, 299 kW peak) and the primary load 2 (4.1 MWh/d, 368 kW peak) of CUET. It also showed the amount of reduction in emission of* CO_2 *when hybrid power system was involved.*

Keywords: Electricity generation, Feasible System, Hybrid Power, Optimization, Renewable Energy

1. INTRODUCTION

Bangladesh is an overpopulated country. Every year, the number of people is increasing. Most of the people of this country live in the rural areas and about 50% of total people living in the rural area are deprived of proper grid connected electricity [1]. In the electricity generation history of Bangladesh, the total installed capacity was 6639 MW and maximum peak generation was 4890 MW where the forecast maximum demand was 6765 MW in 2010-2011 and the per capita generation was 212 kWh [2]. The electricity generation of Bangladesh mostly depends on fossil fuels instead of renewable energy such as solar, wind, hydro, biomass etc. which are the cost effective sources of power generation. If the government of Bangladesh wants to ensure the proper electricity for all people, it is necessary to use the renewable energy sources along with the fossil fuels to generate electricity at affordable price. Moreover, hybrid power system may be the most suitable alternative option to provide the reliable electricity to the rural people of Bangladesh. Bangladesh is situated between 20.30 and 26.38° north latitude and 88.04 and 92.44° east longitude. Daily solar radiation of Bangladesh varies between 3.8 and 6.5 kWh/m2 [3]. The wind speed of Bangladesh remains 2 m/s to 5 m/s [4]. As the renewable energy sources such as solar, wind are intermittent, the fossil fuel generators have to be used to increase the reliability of the power system.

In this study, we had analyzed the feasibility of hybrid power system for our university named Chittagong University of Engineering and Technology (CUET). Then we had determined the unit price of the feasible electric power and the amount of the emission of CO_2.

The latitude and longitude of CUET are 22°27´ north and 91°58´ east respectfully. To bring out the feasible combination of hybrid power system such as PV- wind-diesel, PV– wind- battery, PV-diesel-battery-converter etc. we used the HOMER (Hybrid Optimization Model for Electric Renewables) software. It is a micropower optimization model software which is developed by National Renewable Energy Lab (NREL), a division of US department of energy. Different data including renewable resources, fuel price, component details such as generator, battery, converter, PV panel etc. have to be provided to HOMER. HOMER performs hundreds or thousands of hourly simulation to design an optimal power system for the desired load. The sensitivity analysis can be done by HOMER software to know the impact of variation of certain value (e.g. Hub height, diesel price, solar radiation etc.) on the cost of energy of the system. HOMER analyses each system configuration to decide whether it is feasible or not and estimates the cost of installing and operation of the system. Eventually HOMER provides a list of configurations to the designer sorted by the net present cost. The configuration which is at the top position of the list is known as the optimal configuration of the system.

2. DATA RELATED TO THE DIFFERENT RESOURCES

2.1 Solar Resources

In Bangladesh, there is no ground measurement data of solar radiation of CUET. So, we collected the solar radiation data from National Aeronautics and Space

Administration (NASA) (using latitude 22°27´ north and longitude 91°58´ east of CUET). HOMER synthesizes solar radiation values for each of the 8760 h of the year by using Graham algorithm. This algorithm produces realistic hourly data and it is easy to use because it requires only the latitude and the monthly average values [3]. The synthetic hourly solar radiation data created by the HOMER do not perfectly replicate the real data but it produce same simulation results as real solar radiation data. The monthly average solar radiation data is given in table 1.

Table 1: Average monthly solar radiation for CUET [8]

Month	Clearness index	Average radiation ($KWh/m^2/day$)
Jan	0.621	4.420
Feb	0.610	4.980
Mar	0.576	5.440
Apr	0.526	5.510
May	0.465	5.110
Jun	0.374	4.160
Jul	0.367	4.040
Aug	0.394	4.180
Sep	0.411	4.010
Oct	0.502	4.280
Nov	0.580	4.250
Dec	0.633	4.280
Average		4.552

2.2 Wind Resources

The highest wind speed of Bangladesh is found in coastal areas, which varies from 2.6 m/s to 12 m/s. [4]. Bangladesh has 580 km long coastal line [6]. We collected the wind speed data of CUET from Local Government and Engineering Department (LGED). Table 2 shows the monthly average wind speed of CUET. When the monthly average data of wind speed are provided to HOMER, it calculates the hourly data synthetically.

Table 2: Monthly average wind speed for CUET

Month	Wind speed (m/s)
Jan	0.76
Feb	1.34
Mar	1.29
Apr	2.22
May	2.38
Jun	3.07
Jul	2.39
Aug	2.11
Sep	1.43
Oct	0.92
Nov	0.64
Dec	0.58

2.3 Fossil Fuel

The renewable energy sources are intermittent in nature. So diesel generators and natural gas generators were added to the system for reliable power production. The diesel price was $0.85/litre and the natural gas price was $0.05/m3 in 2013.

3. LOAD PROFILE

The load profile of selected area had to be provided to HOMER where our selected area was CUET. The whole load of CUET had been divided into two categories. First one was primary load 1 which included all academic buildings such as EME building, Civil-CSE building, Administrative building, East-West gallery, Library etc. Second one was primary load 2 which included whole residential area of teachers and staffs of CUET, different Halls for students, bank, hospital and mosque. The average KWh/d of primary load 1 and 2 were 1212 and 4108 kWh/d respectively. Daily load curve of primary load 1 and 2 are shown in Fig. 1 and Fig. 2 respectfully.

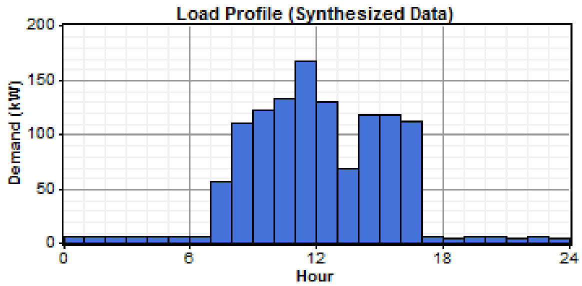


Fig.1: Daily load curve of primary load 1

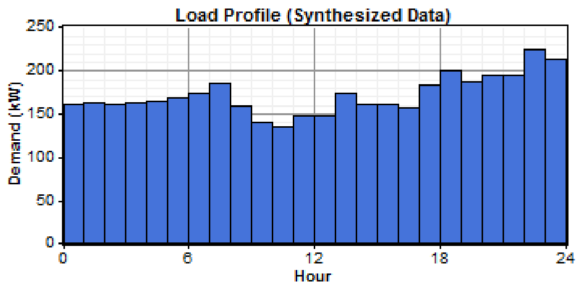


Fig.2: Daily load curve of primary load 2

4. SIMULATION DATA

In the hybrid power system, we need to know details of each component which have to be provided to HOMER. It includes the capital cost, replacement cost, operation and maintenance cost, diesel cost, natural gas cost etc. In this study, the available components we considered were PV, wind turbine, generator (diesel or natural gas operated), battery and converter. The details of these components are discussed in the following:

4.1 PV Array

The sunlight is directly converted into electricity by using solar cell. PV cell is actually a PN junction which is also known as Schotty barrier device. It is made from semiconductor material. PV cell converts the solar energy into DC current with an efficiency of 3 to 31% [5]. This converting efficiency depends on several factors such as temperature, wavelength, semiconductor material and design of solar cell etc. I-V characteristic equation of PV cell is given by [7]:

$$I = I_l - I_s\left(e^{\frac{qv}{kT}} - 1\right) \quad (1)$$

Where,

- k Boltzmann constant (1.38047 * 10^{-23} J/K)
- q electronic charge (1.60210 * 10^{-19} C)
- v voltage across the PV cell (V)
- T 273.2 + t_c is absolute temperature given as function of the temperature in °C (K)
- I_s reverse saturated current of the diode, typically 100 pA for silicon cell (A)
- I_l cell current due to photons (A)

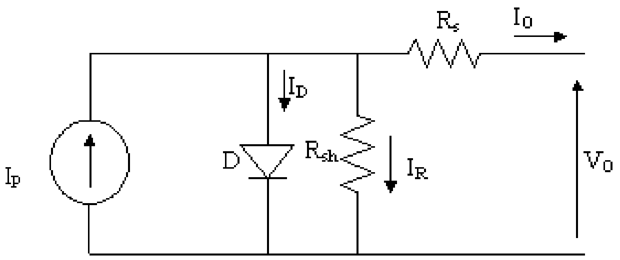


Fig.3: Equivalent ircuit of a PV cell

Fig. 3 shows the equivalent circuit of solar cell indicating cell photo current (Ip), shunt resistance (Rsh), series resistance (Rs).The cost of PV we considered was $825 per kW in 2013. We considered the installation cost too. So the cost of PV was increased to $900 per kW. The data related to this PV array had been found from the Greenfinity Energy Ltd, a renowned company which sells Solar panel in Bangladesh. Table 3 shows the specification of PV panel.

Table 3: PV array characteristics

Size (KW)	1
Capital ($)	900
Replacement($)	900
O & M ($ / year)	1
Derating factor	80%
Slope	22.5 deg
Azimuth	0 deg
Ground reflectance	20%
Tracking system	No tracking

4.2 Wind Turbine

The cost of wind turbine depends on the tower height and the technology used. The chosen wind turbine was 7.5 kW BWC Excel-R. The cost of turbine was about $26870 [9]. The cost of 100 ft standard guyed lattice tower and tower wiring kits were about $15000 [9]. Table 4 shows the total cost of wind turbine and other characteristics.

Table 4: Wind turbine characteristics [9]

Quantity	1
Capital ($)	41870
Replacement($)	26870
O & M ($ / year)	500
Quantities to consider (number)	0, 1
Life time (year)	25
Hub height (m)	30
Power rated (KW)	7.5

4.3 Generator's Rating and Cost

(1) Diesel Generator

There are five diesel generators in CUET. They are 125 KVA, 62.5 KVA, 75 KVA, 30 KVA and 19 KVA. But another one generator was needed to satisfy the whole load. Table 5 shows the rating and cost of generator which was found in the substation office of our university.

Table 5: Diesel generator rating and cost

KVA	Size (KW)	Capital ($)	O & M ($/hr)	Life time (hour)	Present Diesel Price ($/l)
125 (Chinese)	100	9838	.04	10000	0.85
62.5 (Chinese)	50	4750	.03	10000	
75 (Germany)	60	19375	.03	25000	
30 (Chinese)	24	2613	.03	10000	
19 (Germany)	15.2	6000	.03	20000	
75 (Germany)	60	19375	.03	25000	

(2) Natural Gas Generator

There are seven generators which had been used in our project. CUET had three gas generators but they had been damaged. So all gas generators used in our project have to be bought. Table 6 describes the rating and cost of gas generators provided by the CUET sub-station office.

Table 6: Natural gas generator rating and cost

Size (K)	Capital ($)	O & M ($/hr)	Life time (hour)	Natural gas price ($/m^3)
130	27,300	.04	20000	0.05
130	27,300	.04	20000	
60	17,000	.03	20000	
60	17,000	.03	20000	
60	17,000	.03	20000	
100	24,200	.03	20000	
25	8,800	0.03	20000	

4.4 Converter

The converter was used to maintain the power flow between AC and DC. Converter includes inverter and rectifier. The price of converter is given in table 7 which is provided by the Greenfinity Energy Ltd, a company which provides necessary equipments for solar panel establishment in Bangladesh.

Table 7: Converter characteristics

Size (KW)	Capital ($)	Replacement ($)	O & M ($/ yr)	Life time (year)
1	1000	1000	0	25

4.5 Battery Storage

When the load demand is less than available renewable energy, the excess energy can be stored in the battery storage. This stored energy can be used when load demand is increased. In this hybrid system, the battery Trojan L16P was used to store the excessive energy. The stored energy can be used at the time of shortage of renewable energy. Table 8 shows the cost and other characteristics of battery used.

Table 8: Battery cost and characteristics [10]

Quantity	1
Capital ($)	345
Replacement ($)	340
O & M ($/yr)	12
Nominal capacity (Ah)	360
Nominal voltage (V)	6
Round to trip efficiency (%)	85
Min. state of charge (%)	30
Life time throughput (kWh)	1075
Batteries per string	2

4.6 Economics and Constraints

In the economic section of HOMER software, the annual real interest rate and project life time were assumed 6% and 25 years respectively. Table 9 shows the constraints which had been assumed in the simulation.

Table 9: Constraints assumed in HOMER

Operating reserve	As percent of hourly load (%)	8
	As percent of annual peak load (%)	0
	As percent of solar power output (%)	0
	As percent of wind power output (%)	35
Maximum annual capacity shortage (%)		0,5

5. RESULT AND DISCUSSION

HOMER simulated provided data for various combinations to bring out the feasible hybrid system. The data related to the loads, renewable resources (solar and wind), different components (generator, battery, converter) had been given to the HOMER as mentioned in previous section. The system's simulations are performed by HOMER for each of 8760 hours in a year. The output showed different combinations of each energy source with net present cost, initial capital cost, operating cost, cost of energy etc. In this study, HOMER simulations had been divided into two scenarios. The first scenario included the HOMER simulation with diesel operated generators and renewable energy. The second scenario included the HOMER simulation with natural gas operated generators and renewable energy.

5.1 First Scenario

In this scenario the generators used in the system were run by diesel. After simulation, HOMER provided a list of different combinations of available sources. Simulation result of first scenario is shown in Fig. 4 where the diesel price is $0.85 per litre and maximum annual capacity shortage is 0%. The first and second columns in Fig. 4 show the presence of PV array and wind turbine. The columns third to eight show presence of generators (Gen1, Gen2, Gen3, Gen4, Gen5 and Gen6). The columns ninth to twelfth show the presence of battery, presence of converter in the system, size of PV array, number of wind turbine respectively. The sizes of generators (Gen1, Gen2, Gen3, Gen4, Gen5 and Gen6) are shown in thirteenth to eighteenth column respectively. The nineteenth to twenty-sixth columns show number of battery, size of converter, dispatch strategy, initial capital cost, operating cost ($/yr), total net present cost, cost of energy and renewable fraction respectively. The first optimal configuration of the hybrid system included PV, diesel generators, converters and battery storages as shown in the first row of Fig. 4. The second optimal configuration was the combination of PV, diesel generators, battery and converter. Here, the generator labeled Gen5 was not included. The third optimal configuration included PV, wind turbine, generators, battery storage and converter. The first configuration, the cheapest one, offered cost of energy $0.254/kWh when maximum annual capacity shortage 0%. Fig. 5 shows percentage of electricity production from PV array and different generators. It also shows the excess electricity, unmet electric load, capacity shortage, renewable fraction. The unmet load was 660 kWh/yr and nearly 0% of total produced electricity. Excess electricity was 11.5% of total production which can be supplied to the grid. The emission of CO_2 was reduced in hybrid power system due to use of renewable energy sources. The amount of CO_2 emission in this hybrid system was 1,065,810 kg/yr with 47% renewable fraction whereas it was increased to 1,729,480 kg/yr in the diesel only system. So the emission was reduced by 38% of CO_2. Table 10 shows the emission of different gases in this hybrid power system. Again if we considered maximum annual capacity shortage 5%, the cost of energy would become $0.255/kWh.

5.2 Second Scenario

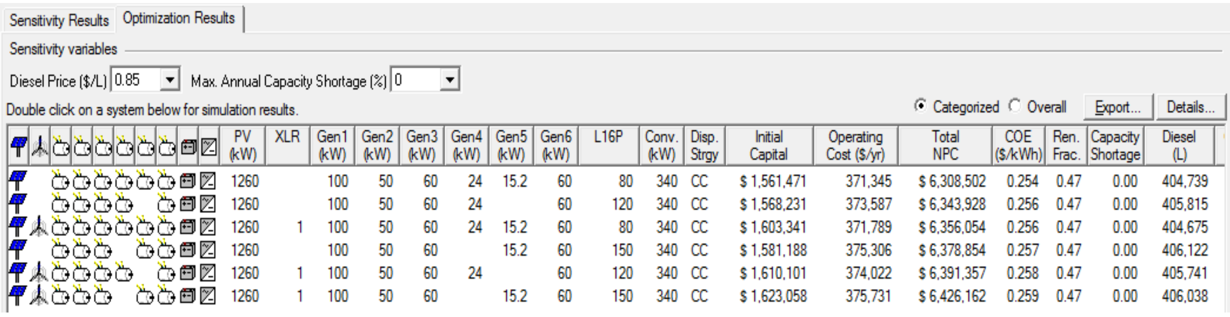
In this scenario, the generators used in the system were run by natural gas. Fig. 6 shows the simulation result for second scenario where the natural gas price is \$0.05/m3 and maximum annual capacity shortage is 0%. The first optimal configuration of the hybrid system included natural gas generators, converters and battery storages as shown in the first row of Fig. 6. It did not include PV array and wind turbine due to low price of natural gas (\$0.05/m3) in Bangladesh. The first configuration was the cheapest configuration which offered cost of energy \$0.035/kWh. Fig. 7 shows percentage of electricity production from different gas generators. The unmet load was 395kWh/yr and excess electricity was 0.0164 kWh/yr. Again if we considered maximum annual capacity shortage 5%, the cost of energy would become \$0.032/kWh.

Table 10: Emission of different gases

Pollutant	Emission (kg/yr)
Carbon dioxide	1,065,810
Carbon monoxide	2,631
Unburned hydrocarbons	291
Particulate matter	198
Sulfur dioxide	2,140
Nitrogen oxides	23,475

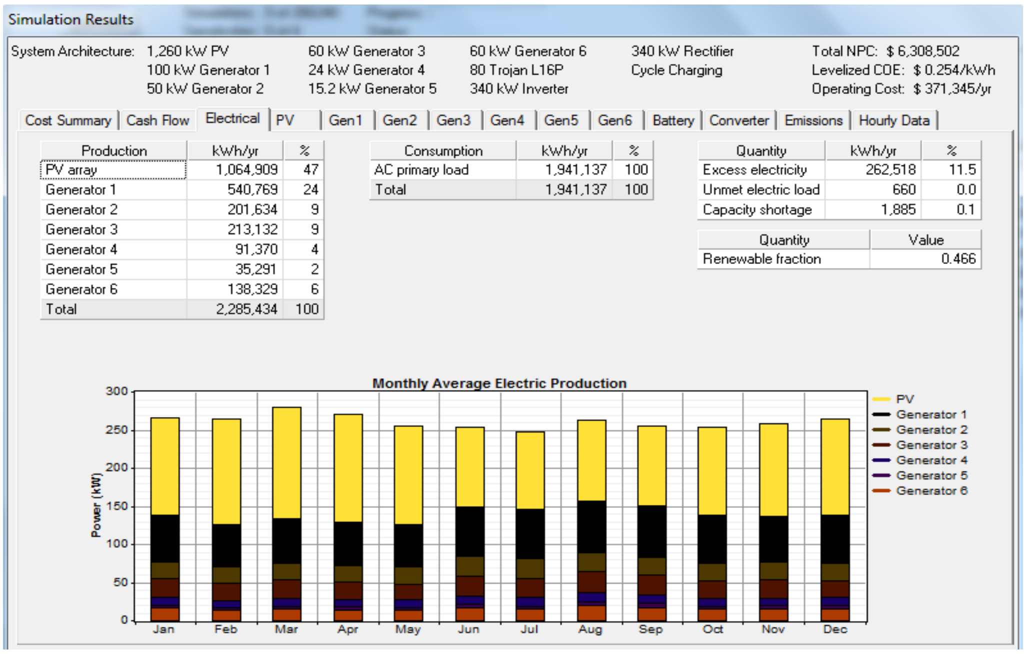
6. CONCLUSION

The demand of electricity in Bangladesh is increasing every year. But the govt. of Bangladesh cannot satisfy the whole people especially who live in rural areas. In this case, hybrid power system can be an acceptable solution because it utilizes renewable energy resources available in Bangladesh. As a result, the cost of energy is decreased, more people living in off-grid rural areas get electricity and the emission of Green House Gas (GHG) is also decreased. This study was about the design and cost analysis of hybrid power system in a rural area (CUET where the average solar radiation 4.552 kWh/m2/day). It indicated PV-diesel generator-battery-converter was the optimal hybrid combination which offered cost of energy \$0.254/kWh and about 38% reduction of CO2 emission every year. This study also indicated that natural gas generator-battery-converter would be the optimal combination if we used natural gas generator instead of diesel generator. It offered the cost of energy \$0.035/kWh but natural gas is not available in many areas especially rural areas of Bangladesh. So PV-diesel generator-battery-converter is the optimal combination of hybrid power system for the electrification of rural areas (off-grid or grid-tied) having considerable average solar radiation (about 4.552 kWh/m2/day or more).



PV (kW)	XLR	Gen1 (kW)	Gen2 (kW)	Gen3 (kW)	Gen4 (kW)	Gen5 (kW)	Gen6 (kW)	L16P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)
1260		100	50	60	24	15.2	60	80	340	CC	\$ 1,561,471	371,345	\$ 6,308,502	0.254	0.47	0.00	404,739
1260		100	50	60	24		60	120	340	CC	\$ 1,568,231	373,587	\$ 6,343,928	0.256	0.47	0.00	405,815
1260	1	100	50	60	24	15.2	60	80	340	CC	\$ 1,603,341	371,789	\$ 6,356,054	0.256	0.47	0.00	404,675
1260		100	50	60		15.2	60	150	340	CC	\$ 1,581,188	375,306	\$ 6,378,854	0.257	0.47	0.00	406,122
1260	1	100	50	60	24		60	120	340	CC	\$ 1,610,101	374,022	\$ 6,391,357	0.258	0.47	0.00	405,741
1260	1	100	50	60		15.2	60	150	340	CC	\$ 1,623,058	375,731	\$ 6,426,162	0.259	0.47	0.00	406,038

Fig.4: HOMER simulation result for first scenario with diesel price \$0.85/litre



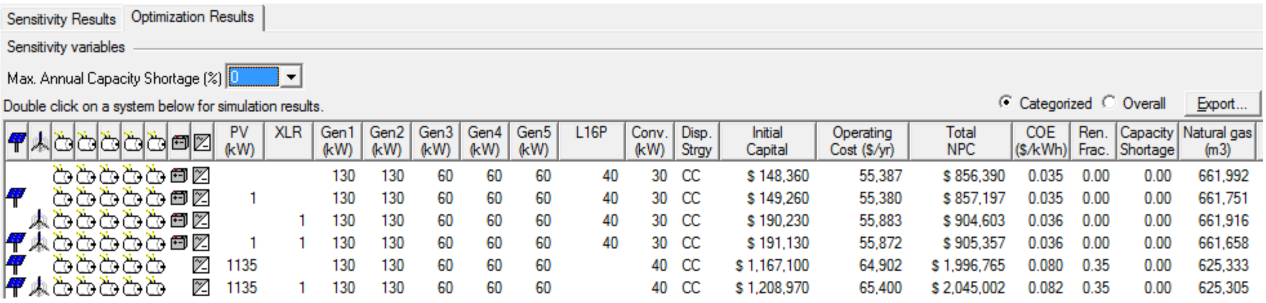
Production	kWh/yr	%
PV array	1,064,909	47
Generator 1	540,769	24
Generator 2	201,634	9
Generator 3	213,132	9
Generator 4	91,370	4
Generator 5	35,291	2
Generator 6	138,329	6
Total	2,285,434	100

Consumption	kWh/yr	%
AC primary load	1,941,137	100
Total	1,941,137	100

Quantity	kWh/yr	%
Excess electricity	262,518	11.5
Unmet electric load	660	0.0
Capacity shortage	1,885	0.1

Quantity	Value
Renewable fraction	0.466

Fig.5: Generation of electricity from different sources in hybrid system (for first scenario).



PV (kW)	XLR	Gen1 (kW)	Gen2 (kW)	Gen3 (kW)	Gen4 (kW)	Gen5 (kW)	L16P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Natural gas (m3)
		130	130	60	60	60	40	30	CC	$ 148,360	55,387	$ 856,390	0.035	0.00	0.00	661,992
1		130	130	60	60	60	40	30	CC	$ 149,260	55,380	$ 857,197	0.035	0.00	0.00	661,751
	1	130	130	60	60	60	40	30	CC	$ 190,230	55,883	$ 904,603	0.036	0.00	0.00	661,916
1	1	130	130	60	60	60	40	30	CC	$ 191,130	55,872	$ 905,357	0.036	0.00	0.00	661,658
1135		130	130	60	60	60		40	CC	$ 1,167,100	64,902	$ 1,996,765	0.080	0.35	0.00	625,333
1135	1	130	130	60	60	60		40	CC	$ 1,208,970	65,400	$ 2,045,002	0.082	0.35	0.00	625,305

Fig.6: HOMER simulation result for second scenario with natural gas price $\$0.05/m^3$

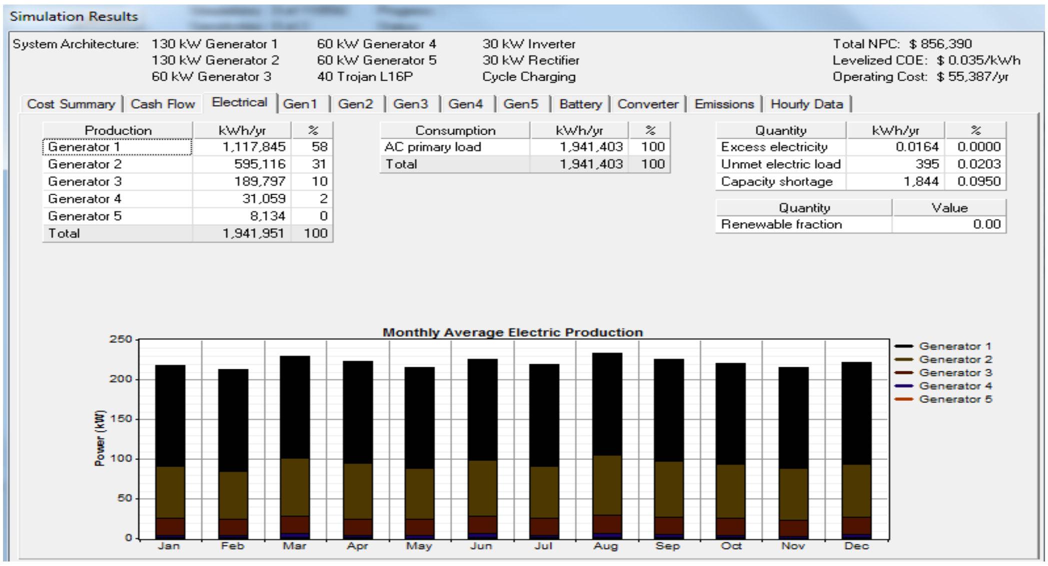


Fig. 7. Generation of electricity from different sources (for second scenario).

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8. NOMENCLATURE

Symbol	Meaning	Unit
k	Boltzmann constant	(J/K)
q	Electronic charge	(C)
v	Voltage across the PV cell	(V)
T	Absolute temperature	(K)
I_s	Reverse saturated current	(A)
I_l	Cell current due to photons	(A)
I_p	Photo current	(A)
I_d	Diode current	(A)
R_{sh}	Shunt resistance	(ohm)
R_s	Series resistance	(ohm)