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# Feasibility Study of Renewable Energy Resources and Optimization of Hybrid Energy System of Some Rural Area in Bangladesh

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**Abstract** Currently some rural areas of Bangladesh are powered by diesel generators with fuel. To reduce dependence on fossil fuel and improve power system, the government is planning to enhance locally available renewable energy for power generation. Optimization of renewable hybrid energy system looks into the process of selecting and combining the best types of components and their sizing with appropriate operation strategy. This work is designed to presents an optimized technique of a multi-source hybrid energy system which includes renewable energy resources such as biomass, solar radiation as a primary resources and a battery tank which has been used to cover the emergency load demand and a diesel generator for backup. The HOMER software was employed to do the simulations for optimization of hybrid energy system to find out the finest, cost effective and environmentally viable energy system. A detailed feasibility study and techno-economic evaluation of a renewable solar–biomass hybrid system analysis, description and expected performance of the proposed system were presented. The developed biomass / solar / diesel hybrid energy system can supply electricity to the region under consideration at hourly average of a typical day of approximately 11KW. The optimal operation shows that the Cost of Energy (COE) of the system is $ 0.077/KWh where the quick rental power plant in Bangladesh can provide electric power at a rate of $ 0.097/KWh. Finally, a performance analysis on its load consumption and renewable energy resource was performed to evaluate the economic analysis and identify which variable has the greatest impact on the PV system.

***Keywords:*** *biomass, cost of energy, hybrid energy system, homer, optimization*

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## 1. Introduction

Electricity is one of the most important ingredients required to alleviate poverty and it is one of the driving forces of the economic development of societies. Currently 1.3 billion [1] people of the whole world do not have access to electricity. With an estimated world average growth rate of 2.8%, the electricity demand is expected to be double in 2020 [2]. With the absence of new technique The International Energy Agency declared a projection result that in 2030 one billion people lacking access to electricity [3]. Most of those people live in remote villages, far away from utility grid.

The electricity supply for the remote area and village is commonly powered by diesel generators. [4] However, they felt more and more stressed since they often face exaggerated fuel costs due to significant rise in diesel price and extra costs of transport. [5] Fortunately remote areas have much locally available renewable energy resources. [6] Power generation in the country is almost entirely dependent on fossil fuels mainly natural gas that accounted for 62.31 % of the total installed electricity generation capacity was 8075 MW in 2015. Coal is expected to be the main fuel for electricity generation. [7] In Bangladesh about 96% of grid electricity generated from fossil fuel which is emitting abundant $CO_2$ in the atmosphere and the power sector alone contribute 40% to the total $CO_2$ emission [8]. Whereas in most cases it is not possible to eliminate all fossil fuel energy production systems but, it is possible to combine traditional technology with renewable energy technologies in order to minimize fossil fuel energy production cost by effective utilization of renewable energy resources for energy production.

To conduct the research, the simulation models and computer tools are generally required. A review of research process of optimizing the hybrid RES was carried out in [9]. Among the simulation tools, HOMER (Hybrid Optimization Model for Electric Renewable) software is one of the most widely used. It helps us to draw the design of micro power systems and to establish the comparison of power generation technologies across a wide range of applications [10]. The pre-feasibility study of power generation using hybrid renewable energy with hydrogen energy storage was conducted in [11], a small Hydro/PV/Wind hybrid system in Ethiopia was examined in [12], and the economic performance of hybrid photovoltaic–diesel–battery power systems for residential loads in hot regions was analyzed in [13].

In order to obtain electricity from a hybrid energy system reliably and at an economical price, its design must be optimal in terms of operation and component selection. The optimization of hybrid energy systems in the context of minimizing excess energy and cost of energy is addressed by Razak, Sopian and Ali [14]. An algorithm based on energy concept to optimally size solar photovoltaic (PV) array in a PV/wind hybrid system was reported [15]. Different system developments in hybrid energy system for Thailand were published [16]. Different aspects of PV, wind, diesel and battery-based hybrid system including optimal sizing and operation have been detailed [17]. Kamel and Dahl [18] and Khan and Iqbal [11] used the Hybrid optimization model for electric renewable (HOMER) software [19] to find optimum sizing and minimizing cost for hybrid power system with specific load demand in standalone applications. Genetic algorithm has been used to find the optimum sizing along with the suitable operation strategies to meet different load demand by Ashok [20].

Solar radiation is the radioactive energy output from the sun derives from a nuclear fusion reaction. In every second about $6*10^{11}$ kg of $H_2$ is converted to He with a net mass loss of about $4*10^{3}$ kg which is converted through Einstein relation to $4*10^{20}$ J [21]. The intensity of solar radiation reaching earth's surface is around 1369 watts per square meter [22]. Several term such as latitude, longitude, hour angle, solar azimuth angle etc which are closely related to solar geometry are calculated in order to find solar radiation. Solar photovoltaic effect has been employed to convert solar radiation into energy.

To calculate biomass resources a survey has been taken to know rice husk production rate at different rice mills in a certain area. A variety of conversion techniques are used for manufacturing Bio fuel from biomass. Biomass conversion can be of any of following form [23] such as Thermo-Chemical conversion, Biochemical conversion, Pyrolysis etc. This work attempts to develop a general model using simulation software HOMER (Hybrid Optimization Model for Electric Renewable) in order to find an optimal hybrid energy among different renewable energy combinations. Renewable energy resources Solar PV, Biomass with battery tank and diesel generator for backup are considered in this model and environmental constraints are considered.

The research is basically on a project on power supply system for a small remote area in Bangladesh. The report is based on investigating the feasibility of utilizing solar and biomass to meet the power requirements of this remote area in conjunction with the battery storage. Specially, some fundamental research works in this study are reported, including system design, feasibility study, and techno-economic evaluation. We have a look on analyzing the expected performance of the planned system in detail. Moreover, it has been examined the effects of the PV, Generator, battery bank capacity on the system's reliability and economic performance. Finally, sensitivity analysis on load and all renewable energy resource is considered to find out the maximum economic analysis and to select which variable has the greatest impact on the results.

## 2. Materials and Methods

### 2.1. Renewable Energy Resources

As pointed out earlier, Bangladesh is one of the most densely populated countries with 79% of the population living in rural area and only 30% of its total population has access to the electricity [24]. Taking an average solar radiation of 1900 KWh per square meter total annual solar radiation in Bangladesh is equivalent to 1010 X 1018 J. At present total yearly consumption of energy is about 700 X 1018 J. This show even if 0.07% of the incident radiation can be utilized total requirement of energy in the country can be met. At present energy utilization in Bangladesh is about 0.15 watt/sq. meter land area where as the availability is above east longitude. Annual amount of radiation varies from 1840 to 1575 KWh /m$^2$ which is 50-100%208 watt/sq. meter [25].There are about 500 auto rice mills in Bangladesh that produce 8–9 million metric tons of rice husk annually [26]. The potential of energy from biomass and small hydro power plants is estimated at 566 MW and 125 MW respectively. In case of biogas there is potential about 800 MW with 3 million potential households with adequate cattle/poultry [27].

### 2.2. Solar Radiation

For Latitude 24°38´N (Mymensingh, Bangladesh) and for the value of solar constant according to NASA/ASTM is 1353 watts per square meter (W/m$^2$) (Mary Bellis). The monthly average of daily global radiation is calculated as given in following Table 1.

**Table 1. The monthly average of daily global radiation form sun**

| Month | a (constant) | b (constant) | Clearness index | Radiation in a clear day (Ho) In Kw/m$^2$-day | Average radiation(H) In Kw/m$^2$-day |
|---|---|---|---|---|---|
| Jan. | 0.38 | 0.35 | 0.586 | 8.84 | 5.90 |
| Feb. | 0.34 | 0.40 | 0.573 | 9.26 | 5.95 |
| Mar. | 0.31 | 0.47 | 0.564 | 9.45 | 5.93 |
| April. | 0.28 | 0.53 | 0.529 | 9.12 | 5.40 |
| May. | 0.23 | 0.64 | 0.544 | 8.56 | 4.25 |
| June. | 0.20 | 0.70 | 0.419 | 8.90 | 3.9 |
| July. | 0.19 | 0.71 | 0.382 | 8.50 | 3.60 |
| Aug. | 0.19 | 0.74 | 0.350 | 8.85 | 3.47 |
| Sep. | 0.28 | 0.45 | 0.399 | 8.65 | 4.12 |
| Oct. | 0.31 | .49 | 0.555 | 9.2 | 5.75 |
| Nov. | 0.35 | 0.38 | 0.575 | 8.86 | 5.8 |
| Dec. | 0.36 | 0.37 | 0.575 | 8.6 | 5.70 |

## 2.3. Biomass

A survey has been taken to know rice husk production rate at different rice mills in a certain local area [28].The result of that survey is shown in Table 2, Where, 1 sack= 15 kg. There are lots of Auto rice mills in the area under consideration. The production rate of rice husk of those mills remains almost same through the year except rainy season. In rainy season, their production rate reduces to half to their original production rate. The monthly average of daily production of rice husk is shown graphically in Figure 1.

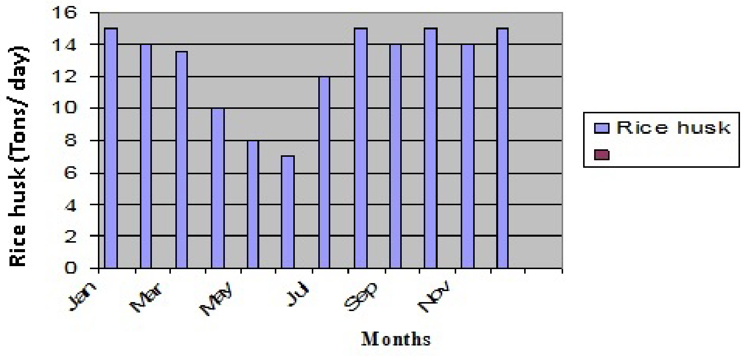



**Figure 1.** Monthly average of daily production of rice husk

**Table 2. Survey result of rice husk production rate at different rice mills in a certain local area**

| No. | Name of the Rice mills | Monthly production |
|---|---|---|
| 1. | Akber Auto rice mills | 150 sacks/day=150 *30 sacks per month =67.5 tons/month |
| 2. | Romzan Auto rice mills | 60 sacks/day=60*30 sacks /month=27 tons/month |
| 3. | Hazy Auto rice mills | 100 sacks/day=100*30 sacks/month= 45 tons/month |
| 4. | Zoynal Auto rice mills | 60 sacks /day =60*30 sacks /month =27 tons/month |
| 5. | Umar Bepary Auto rice mills | 100 sacks/day=100*30 sacs/month =45 tons/month |
| 6. | Bisu Auto rice mills | 60 sacks/day=60*30 sacks /month=27 tons/month |
| 7. | Maa Auto rice mills | 100 sacks/day=100*30 sacks/month = 45 tons/month |
| 8. | Sejuti Auto rice mills | 150 sacks/day=150 *30 sacks/month =67.5 tons/month |
| 9. | . Master Auto rice mills | 150 sacks /day=150 *30 sacks/ month =67.5 tons/month |
| 10. | . Vai Bon Auto rice mills | 100 sacks/day=100*30 sacks/month = 45 tons/month |

## 2.4. Optimization

The optimization process utilizes genetic algorithms to change the variables of the hybrid system model, in terms of sizing and operation, in such a way as to minimize the life cycle costs or net present value costs of the designed hybrid system while meeting demand requirements. Minimizing net present value costs and unsatisfied demand are achieved by selecting both an appropriate system configuration and optimizing system controller settings, i.e. the values for the operation decision variables, as part of a system operation strategy. The genetic algorithm, which used to optimize the hybrid energy system were divided into many section such as creation of initial population of object section, database & parameter section, power flow section, main algorithm and sub algorithm section as shown in Figure 1 [29]. The genetic optimization operations are performed through the processes of follows:

1. Selection (selecting the best objects and a few other objects randomly for creating new objects).
2. Recombination (mixing values between 2 selected objects).
3. Mutation (changing values in one object) and
4. Reinsertion (reinserting the newly formed objects into the 'old' population to form the new population).

Overview of the developed algorithm is shown in the following Figure 2.

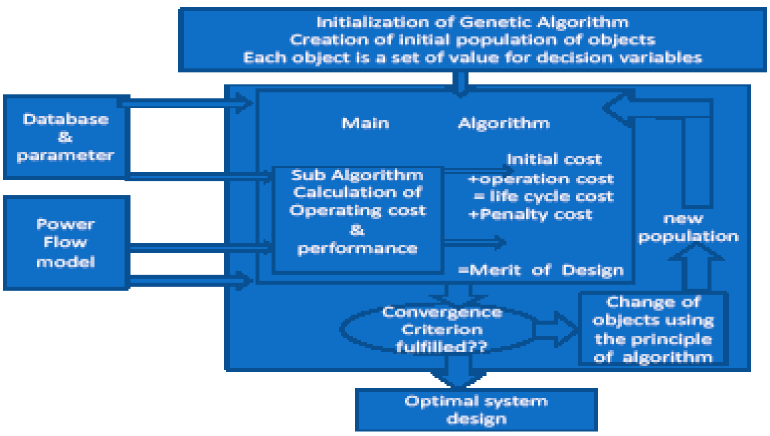



**Figure 2.** Flowchart of the developed algorithm

## 2.5. Power Flow System

This system is based on a description of current flows through the system which depend on the optimized design decision variables, included efficiency losses and other descriptive design parameter. At time't' the power flow system is checked, whether the renewable energy can provide the desired load demand, or not. After got it, the battery and diesel generator are kept idle, only considered renewable energy supply power to the region. When we didn't got energy, we checked the power flow model, with the renewable energy + battery tank for providing the desired load demand, or not. If yes, then the diesel generator remains idle, renewable energy + battery supply power to the region under consideration. If no, the power flow system supplies the power to region with help of the renewable energy+ battery tank +diesel generator.

## 2.6. Load Profile

The hybrid energy system is proposed for the area under consideration which has a load profile of hourly average of almost 11KWh. The graphical representation of that load profile for a typical day in January is shown in Figure 3.

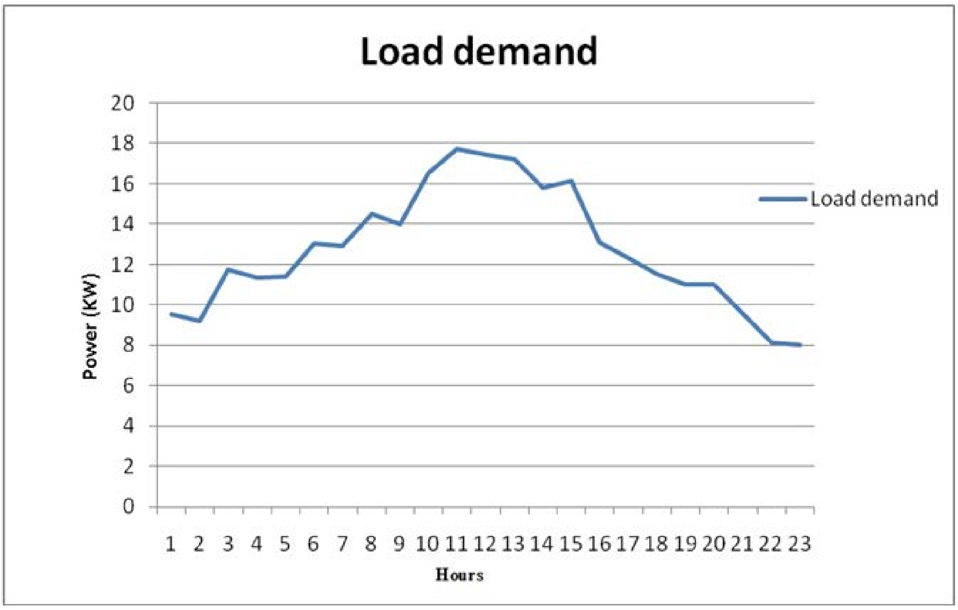



**Figure 3.** Hourly load demand of a typical day in January

The energy system consists of a gas generator, diesel generator, solar PV array, battery bank, and an AC/DC converter. The lifetime of the project is estimated at 20 years with a fixed annual interest rate of 5%.

## 2.7. Proposed Hybrid System Components and Cost are given in Table 3

**Table 3. Technical parameters and cost assumptions of Photovoltaic (PV) array, of Gas Generator, Diesel Generator and converter**

| Item | Photovoltaic (PV) array | Gas Generator | Diesel Generator | Converter |
|---|---|---|---|---|
| Capital cost | $ 2.54 /W | $ 180 /KW | $ 160 /KW | $ 180 /KW |
| Operation & Maintenance cost | $ 0.0007/KW | $ 0.002/KW | $ 0.002/KW | $ 0.002/KW |
| Replacement costs | $ 2.54 /KW | $ 180 /KW | $140 /KW | $125 /KW |
| Lifetime | 25 years | 3500 Hours | 10,000 Hours | 80,000 Hours |

## 2.8. Hybrid System Control Parameters and Constraints

HOMER assumed all prices escalate at the same rate over the project lifetime. With this assumption, inflation can be factored out of the analysis simply by using the real interest rate (inflation-adjusted) rather than the nominal interest rate (the rate at which one could get a loan) when discounting future cash flows to the present. We used the real interest rate, which is roughly equal to the nominal interest rate minus the inflation rate. The real interest rate is considered as 5% and the project lifetime is taken on 25 years. The capacity shortage penalty is not considered. The system control parameters used in the simulation run are summarized in following Table 4.

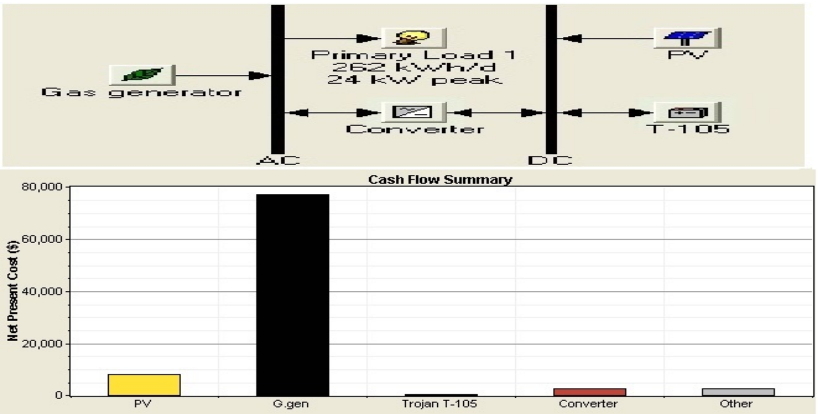
**Table 4. hybrid system control parameters and constraints**

| Parameter | Value |
|---|---|
| Maximum unserved energy | 0% |
| Maximum renewable fraction | 0 to 100% |
| Minimum battery life | N/A |
| Maximum annual capacity shortage | 0, 4, 6 and 10% |

# 3. Result and Discussion

## 3.1. Model-1 (Gas Generator and Photovoltaic Array)

The hybrid energy system consists of gas generator, solar PV, battery and converter is shown with its cost flow summary is shown in Figure 4.




| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| PV | 7,500 | 0 | 374 | 0 | 0 | 7,874 |
| Gas generator | 2,340 | 74,021 | 1,419 | 0 | -832 | 76,948 |
| Trojan T-105 | 120 | 349 | 0 | 0 | -42 | 427 |
| Converter | 400 | 0 | 1,994 | 0 | 0 | 2,394 |
| Other | 2,000 | 0 | 653 | 0 | 0 | 2,653 |
| System | 12,360 | 74,370 | 4,440 | 0 | -874 | 90,297 |

**Figure 4.** Hybrid energy system with gas generator and photovoltaic array and it's cost flow summery

As shown from the cash flow summary of model -1, the total cost of the system is $90,297 where cost of the gas generator, solar PV, battery, converter and others are $ 76948, $ 7874, $ 427, $ 2394 and $ 2653 respectively. The gas generator cost is 85.2% of the total cost. So we can say that the gas generator determine the merit of the hybrid energy system. The monthly electricity production rate of model- 1 is shown in Figure 5

| Production | kWh/yr | % |
|---|---|---|
| PV array | 4,187 | 4 |
| Gas generator | 91,322 | 96 |
| Total | 95,510 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC primary load | 94,171 | 100 |
| Total | 94,171 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess electricity | 54.9 | 0.06 |
| Unmet electric load | 1,460 | 1.53 |
| Capacity shortage | 3,038 | 3.18 |

| Quantity | Value |
|---|---|
| Renewable fraction | 1.00 |

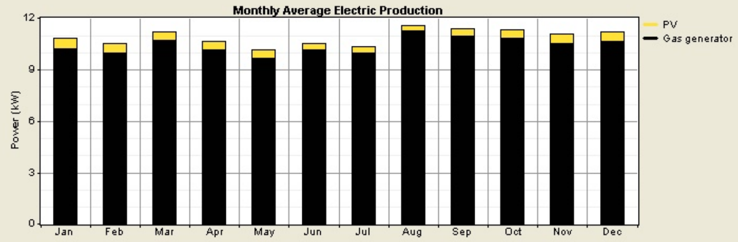


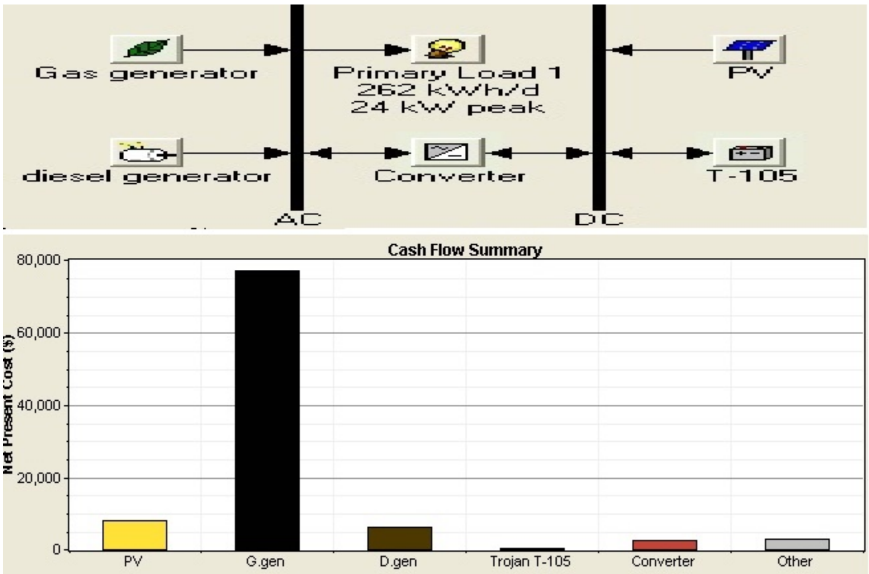

**Figure 5.** The monthly electricity production rate of model -1 in a year

For hybrid energy system model-1 the total amount of electricity produced by the system is about 95.510 MW where gas generator contributed 91.322 MW and solar PV 4.187 MW. This amount of power can serve 98.47% of annual load demand with renewable fraction 1.00. It can be observed that the annual unmet load reduced from 4.91% to 1.53% in hybrid energy system in model- 1. The Cost of Energy (COE) for model-1 is $ 0.077 /kWh. The hourly power supply to the area under consideration is illustrated in Figure 6.


**Figure 6.** Hourly power supply to the region under consideration from model-1

## 3.2. Model-2 (Gas Generator, Photovoltaic Array and Diesel Generator):

This optimal design solution assumed that the biomass resources are reliable and would be consistently available to be used for power generation. But in practice the location under consideration is vulnerable to the natural calamity. Usually there is also an extended period when there is less biomass production due to unusual weather during rainy season. There is a possibility for sudden increase of load demand during summer due to warm weather. When these external factors (weather and load demand) are taken into consideration it is necessary to add a diesel generator to the hybrid energy system model- 1. By utilizing the diesel fuel properly we try to minimize the annual unmet load as lowest as possible. The optimal biomass/ solar/ diesel hybrid energy system which include battery tank for emergency power supply and diesel generator for backup is shown in Figure 7.




| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| PV | 7,500 | 0 | 374 | 0 | 0 | 7,874 |
| Gas generator | 2,340 | 74,021 | 1,419 | 0 | -832 | 76,948 |
| diesel generator | 640 | 659 | 53 | 5,063 | -212 | 6,203 |
| Trojan T-105 | 120 | 301 | 0 | 0 | -1 | 420 |
| Converter | 400 | 0 | 1,994 | 0 | 0 | 2,394 |
| Other | 2,000 | 0 | 762 | 0 | 0 | 2,762 |
| System | 13,000 | 74,980 | 4,602 | 5,063 | -1,045 | 96,601 |

**Figure 7.** The hybrid energy system with gas generator, PV array and diesel generator and it's cost flow summery

As shown from the cash flow summary of the hybrid energy system model- 2 the total cost of the system is $ 90601 where cost of the gas generator, solar PV, battery, converter, diesel generator and others are $ 76948, $ 7874, $ 427, $ 2394, $ 6203 and $ 2762 respectively. The gas generator cost is 79.6% of the total cost which mostly responsible for higher the cost of energy of the system.

The monthly electricity production rate for the hybrid energy system model- 2 is shown in Figure 8. For hybrid energy system configuration-2 the total amount of electricity produced by the system is about 95.690 MW where gas generator contributed 90.150 MW, solar PV 4.187 MW and diesel generator 1.352 MW

| Production | kWh/yr | % |
|---|---|---|
| PV array | 4,187 | 4 |
| Gas generator | 90,150 | 94 |
| diesel generator | 1,352 | 1 |
| Total | 95,690 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC primary load | 94,323 | 100 |
| Total | 94,323 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess electricity | 104 | 0.11 |
| Unmet electric load | 1,307 | 1.37 |
| Capacity shortage | 2,736 | 2.86 |

| Quantity | Value |
|---|---|
| Renewable fraction | 0.986 |

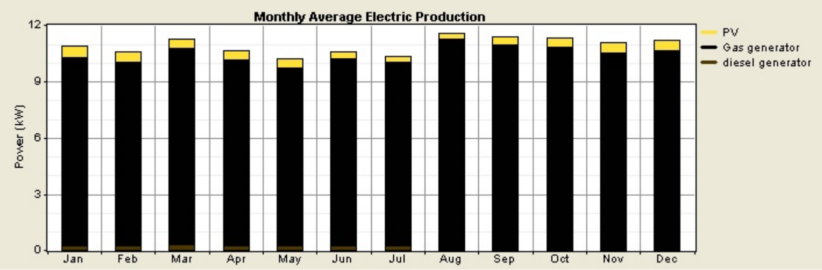



**Figure 8.** The monthly electricity production rate of the hybrid energy System model -2

This amount of power can serve 98.63% of annual load demand with renewable fraction 0.986. It can be observed that the annual unmet load reduced from 1.53% to 1.37% in the hybrid energy system in model- 2. The Cost of Energy (COE) for model- 2 is $ 0.082 /KWh which is increased by $ 0.005 with respect to hybrid energy system model- 1. The hourly power supply to the area under consideration from the hybrid energy system model- 2 is illustrated in Figure 9.


**Figure 9.** Power supply from optimal energy system vs time in hour

## 3.3. Comparative Result of Different Simulated Systems

With the two renewable resources and diesel fuel for backup considered the analysis will be to determine the optimal one out of eight combinations for the area under consideration. Iterative results of certain components are shown in Table 5.

**Table 5. Iteration results (partial) of hybrid energy system component sizes and cost**

| No. | PV (KW) | Gas Generator (KW) | Diesel Generator (KW) | T.105 | Conv. (KW) | Initial Cost ($) | Operating Cost ($/yr) | Net Present Cost ($) | COE ( $ /KWh) | Ren. Frac. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | _ | 13 | _ | _ | _ | 4,340 | 6,043 | 79,651 | 0.070 | 1.00 |
| 2. | _ | 13 | _ | 12 | 4 | 4,860 | 6,228 | 82,749 | 0.071 | 1.00 |
| 3. | _ | 13 | 4 | _ | _ | 4,980 | 6,520 | 86,235 | 0.076 | 0.98 |
| 4. | _ | 13 | 4 | 12 | 4 | 5,500 | 6,696 | 88,946 | 0.076 | 0.98 |
| 5. | 3 | 13 | _ | _ | 4 | 12,240 | 6,232 | 89,907 | 0.078 | 1.00 |
| 6. | 3 | 13 | _ | 12 | 4 | 12,360 | 6,254 | 90,297 | 0.077 | 1.00 |
| 7. | 3 | 13 | 4 | _ | 4 | 12,880 | 6,689 | 96,234 | 0.084 | 0.99 |
| 8. | 3 | 13 | 4 | 12 | 4 | 13,000 | 6,708 | 96,601 | 0.082 | 0.99 |

It can be observed from the Table 2 that optimized model-1 optimized with only biomass resource without any battery storage and diesel generator backup. The initial cost, operating cost and net present cost are $ 4340, $ 6043 and $ 79651 respectively. Its resultant cost of energy is $ 0.070 /KWh. When the battery storage and diesel generator backup added to it, the cost of energy is become $ 0.076 /KWh. In this case, the initial cost, operating cost and net present cost are $ 5500, & 6696 and $ 88946 respectively. Now we try to utilize another renewable energy resource solar radiation which has done by adding solar PV array to optimized model-3 as shown in Table 2. In this case battery tank and diesel generator are not considered but a converter has been employed for conversion purpose. For this optimized model-3, the initial cost, operating cost and net present cost are $ 12240, $ 6232 and $ 89907 respectively. The cost of energy of this model is $ 0.078/KWh. Now we add a battery tank to the previous model for storage purpose which has been done. This model can supply electricity to the region under consideration with renewable fraction 1 and its cost of energy is $0.077/KWh, where the initial cost, operating cost and net present cost are $ 12360, $ 6254 and $ 90297 respectively. When the weather condition, natural disaster, emergency load demand etc. are taken into the consideration, we need to add a diesel generator to hybrid energy system for backup which has been performed as shown in Table 2. The initial cost, operating cost and net present cost of optimized model-6 are $ 13000, $ 6708 and $ 96601 respectively. The cost of energy in this case is $ 0.082 /KWh. The quick rental power plant in Bangladesh can provide electric power at a rate of 0.099$ /KWh (Bulk power tariff planned, Bangladesh, bdnews24.com) where this optimal model can provide power at a rate of 0.079$ /KWh which is about 20% less than that of the quick rental power plant in Bangladesh.

# 4. Conclusion

This research has done for the up-to-date progress of this technology, which includes the feasibility study, component simulations, system optimization and control technologies of the hybrid system. The feasibility study of renewable energy resources indicates that the selected location blessed with considerable global solar radiation and biomass generations which are prospective candidates for the deployment of the hybrid energy system

The study shows that the local area existing diesel generator could be replaced by a hybrid renewable energy power generation system. The combination of diesel generator, solar energy, and biomass and battery storage can supply continuous power to this locality. The optimal hybrid system produced 95.690 MW of power where gas generator contributed 90.150 MW, solar PV 4.187 MW and diesel generator 1.352 MW. This power can serve 98.3% of annual load demand with renewable fraction 0.99. However, there are some dumped energy of the total production, due to timing mismatch between power demand and generation. If we consider a small percentage capacity shortage or some degreed of unmet peak load, the sizes of the system components could be reduced and the system's performance could be enhanced economically.

From the case study a solar PV / biomass hybrid energy system with battery for emergency power supply and diesel generator for backup will provide 24-hour electric supply to every household in the village at the unit cost of 0.079$ /kWh. The result also showed that the proposed hybrid solar and bio mass power system with battery storage is practical and cost effective solution for this remote area.

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