CHAPTER 1
INTRODUCTION

1.1 Background

In Bangladesh electric power consumption per capita is increasing portentously as demand is projected to increase in line with Gross Domestic Product (GDP) growth. The government of Bangladesh (GoB) has the master plan to generate 24,000MW of electricity by 2021, 40,000 MW by 2030, and 60,000 MW by 2041[1]. The power generation plan and year-wise peak demand forecast in Bangladesh is shown in Figs. 1.1 and 1.2, respectively.

Fig.1.1 Power generation plan in Bangladesh (MW) [1]

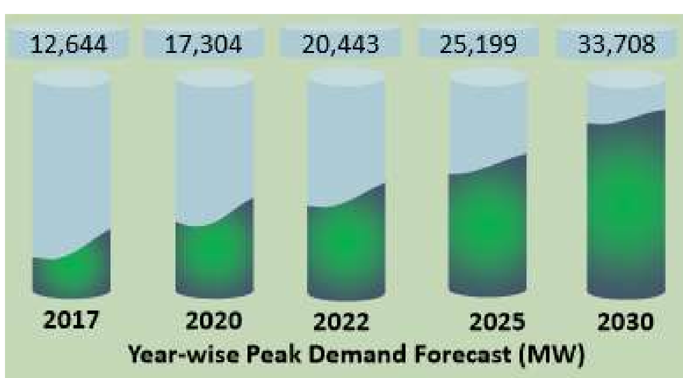


Fig. 1.2 Year-wise peak demand forecast in Bangladesh (MW) [1]

The generation of electricity is mostly dependent on non-renewable fuels. Approximately 91.54% of electricity is produced from fossil fuels whereas 5.56% from import and the rest 2.9% of power is generated from the sources of renewable energy. As there is a huge requirement of power to be a developed country, renewable energy can play a significant role not only to mitigate the future electricity demand but also for the electrification of remote areas in the country. For this, renewable energy policy is laid down to generate 10% of electricity from renewable sources by 2020in 2008 [2]. Solar energy has excellent potential with an average solar radiation varies between 4 to 6.5 $kWh/m^2/day$ [3]. Solar energy is comparatively expensive than conventional means of electricity generation. The rural areas of Bangladesh may be ideal for utilizing renewable energy which will progressively moving away from the traditional kerosene-based devices and turning to higher environment friendly solar panel use.

Bangladesh possesses a favorable atmosphere for the biogas production also. The perfect temperature is approximately 35^0 for biogas. The temperature ranges from 6^0 to 40^0 here. But the digester inside temperature is at 22^0-30^0, which is a prime requirement. Biogas is normally produced in anaerobic digestion from raw substances. Organic matters for biogas are cheaply available from farm animal waste. It does not only produce gas and electricity but also gives organic fertilizer for the farmers [4]. Although wind power technology is one of the cheapest clean power options, Bangladesh still far behind being utilizing this resource. Few places like Patenga, Feni, Kuakata, Kutubdia, and Munshiganj have huge possibility to generate electricity from wind power. Because the average wind speeds of these areas are more than 6.2 m/s which is viable for harnessing wind power [5]. Bangladesh has limited hydropower potentiality due to its unfavorable topography. At present, the Kaptai hydropower has installed capacity of 230 MW which is the principal share of electricity produced from renewable sources. However, the

Bangladesh Power Development Board (BPDB) identified Sangu (140 MW) and Matamuhuri (75 MW) potential sites for large hydropower plants. Expert has identified more locations which are suitable for hydropower around the country [5].

Renewable energy sources are plenty in nature, yet no one can depend only on one renewable source as solar, wind or biomass etc. are not 100% dependable due to their fluctuating continuity over the period of time. In other words, due to inconsistency and unstable condition of nature, hybrid generation of power is preferable than individual renewable energy resource such as solar, biogas, etc. due to maintenance and operational requirements. Therefore, in the recent past, due attention is given to integrating two or more renewable energy resources for the generation of electricity in remote areas which are considered as suitable solution. Hybrid energy sources will enhance the dependability of the system as if there is a lack of performance by any component. Therefore, from the combination of solar PV, biogas, biomass, wind, tidal power, geothermal power, hydroelectricity etc sources, hybrid electricity generation is preferable.

Though, most of the additional power generation today now a day comes from liquid fuel based power plants, the price of these liquid fuels is always on the rise. The government has to subsidize fuel price heavily which results in continuous losses for the power generation units of the government. Not only fuel price, the government has to subsidize generated electricity as well to make it affordable to the customers. Hence, finding out an alternative source of electricity to reduce the burden of energy subsidy on the government is necessary.

In Sunamganj, Habigonj, Netrokona, Kishoregonj, Sylhet, Maulvibazar and Brahmanbariadistricts, approximately 373 haors are avialble.These 373 haors cover an area of about 85,000 ha which is around 43% of the total area of the haor region [6]. Ballar Char, Sandwip, Urirchar, Swarna Dweep (JahajerChor/ Jahejjarchor), Hatiya, Manpura Island, Char Sakuchia, Char Nizam, Char Kukri Mukri, Char Lakshmi, Char Montaz, Nijhum Dwip, Dal Char, Char Gazi, Char Faizuddin, etc. are some remote island in Bangladesh [7]. According to Banglapedia sources, the braided Jamuna has 56 large chars and 226 small sandy and vegetated chars. The Padma has a total of 13 large and 18 small island chars. Of all the rivers, the Jamuna reportedly has the highest area i.e., 45 per cent under chars within-bank area, followed by the Padma (30 per cent) and the Lower Meghna (20 per cent) [8]. Those haors, islands and chars have very little access to energy compared to urban areas. Among the rural population, a large number of people live in remote areas like the coastal areas, chars and remote villages. These people still have a dream to have access to electricity because of grid connection to those remote areas is not economically feasible. One the other hand, the rural people who are connected with electricity, are yet to get the uninterrupted electricity supply and they are deprived of the benefit of electricity for load-shedding to perform their daily activities. Electrification is one of the important indicators for development. Considering this, GoB has recently has taken a decision to expand the grid connectivity to river island/chars. However, it is very difficult to get grid connection to the island located in Bay of Bengal like Saint Martin Swana Dweep, Nijum Dweep etc. due to its geographical location and surroundings water bodies. As there is a dearth of power availability in those areas, the economic growth is not remarkable. When power will be available in those areas, there will be economic emancipation. For that, advance planning and optimization is required to address that. In this respect, this paper will high light the design and optimization of hybrid energy system for a remote area of Bangladesh.

1.2 Motivation of the Study

The study area, Swarna Dweep does not have any access to grid electrification and the closest grid lines lie around 6 kilometers away. There is a approximately 4 kilometers wide Meghna channel separating Swrna Dweep from Noahkhali mainland. Because of its geographic position, providing grid electricity services in that area is quite challenging and expensive. Thus providing electricity services through alternative option i.e. solar PV, wind and biogas are viable option for the island. Moreover, this study could help by providing solutions to such problems as supplying electricity to other remote and urban areas which not only requires large investments but also incurs transmission and distribution power losses.

Due to increased population, escalation of GDP and to have universal access of electricity to all with the middle income country by 2021, more generation of electricity is required as per the target. For generation of electricity, Bangladesh greatly relays on domestic natural gas, coal and imported fuel. At present, gas production is 889.29 bcf which are expected to be reduced to 63.69 bcf in 2041-42. Again, the domestic coal is likely to finish by next decade [9].

Further, as per Power System Master Plan 2016, Bangladesh has planned to produce 50% electricity from domestic and imported coal by 2030 [10]. As fossil fuel is diminishing day by day, policymakers are questing for alternative fuel to produce electricity. As per the geographical location, Bangladesh has bestowed with enormous renewable energy sources which can be utilized to mitigate the increasing energy demand of the country. As per the target of Renewable Energy Policy, Bangladesh has aspired to achieve 10% (2000 MW) of total electricity generation will be from renewable energy by 2020 and more 10% (4000 MW) of total electricity generation by 2030 [11].

So utilization of renewable energy not only helps in curbing environmental degradation but also assist in achieving the energy security and saves from exhaustion of the fossil fuels.

Besides that, Bangladesh is a signatory of two development frameworks: one is the Paris Agreement on Climate Change, and the other is the 2030 Agenda for Sustainable Development Goals (SDGs) by the United Nations. As a signatory of the Paris Climate Agreement and a victim of climate change, Bangladesh is committed to contributing on its part by reducing the greenhouse gas emission by de-carbonization of energy plants and consumption of fossil fuels to keep the increase of temperature below 1.5°C and thus thwart the pace of global warming. Renewable energy sources are an effective tool for climate mitigation. Similarly, the UN Summit on Sustainable Development 2015 has a specific agenda for energy in SDG 7, which is to 'ensure access to affordable, reliable, sustainable and quality energy for all.' Sustainable and reliable energy is also crucial for the social, economic, environmental, educational, and cultural development of a country. The affordable, durable and reliable energy will ensure energy security which is vital to the national development of a nation. Bangladesh intends to achieve energy security for national development through fuel diversification with the increase generation from renewable energy sources. All these above reasons motivated the author to undergo research on hybrid power system.

1.3 Literature Review

Researchers around the world are relentlessly working for introducing hybrid systems since mid-eighties. Over the period of time, researchers have already proved that hybrid energy system is the most appropriate for the remote areas. By using optimization techniques, researchers have decreased the generation cost of electricity compared with traditional fossil fuels. Park investigated the generation of electricity by using photovoltaic energy where he proposes operation control of hybrid generating system or ship [12]. Nehrir highlighted a Matlab model to study the performance of a Wind/PV system and concluded that the use of an electric hot-water heater as a dump load made the renewable-only system more economically feasible [13].There has been substantial research done on different combination of hybrid system. Motin et al. have proposed hybrid solar-wind power system which is energy efficient [14]. By using Quasi-Newtonian method to provide the lowest cost electricity, Ashok develops a general model in India [15].Srinivasan not only examined the economic feasibility of using biogas for purpose of cooking but also indicated the benefits of using biogas [16]. Rahman et al. in their study highlighted on hybrid system comprising of biogas and PV resources to mitigate the domestic needs in rural areas of Bangladesh [17]. Rajbongshi, Borgohain, and Mahapatra suggested the Optimization of hybrid renewable energy consists of PV-biomass-diesel which is grid base for rural electrification by using HOMER in India [18]. Castellanos et al. focused on integrated renewable energy at rural area for generation of electricity by PV and biogas in West Bengal, India [19].

Mahalakshmi and Latha demonstrated a hybrid renewable energy consists of solar and biomass by using HOMER software to assess the economic feasibility for a textile factory in India which will help in environmental degradation [20]. Shahzad et al. proposed the techno-economic viability analysis of a hybrid renewable energy consists of solar-biomass off grid system for the rural electrification in Pakistan using HOMER software [21]. Gwavuya et al. evaluated the expenditure of energy generation from biogas in rural area in Ethiopia as well as highlighted the benefits of using biogas plants [22]. Bond and Templeton surveyed the biogas plants which are out of order and emphasis to undergo research on effective anaerobic process [23]. Schmid in his study showed that in Brazil Amazon the preference for local grids by PV systems is evaluated up to 100 KW but it is economically viable of converting diesel plants up to 50 KW peak power into renewable hybrid system [24].

Sarkar et al. made an endeavor to analyze the utilization possibility of solar energy in the telecommunication sector of Bangladesh [25]. Sowed et al. has used micro concentrated solar power which uses miniature solar collectors to focus sun light to convert into heat [26]. According to Monju and Ullah, examined the current power scenario and evaluated the potentiality of renewable energy in Bangladesh [27]. Ahmed et al. in their study has suggested few aspects which are significant to minimize the present power shortfall and narrated the ways to enhance the renewable energy in Bangladesh [28]. Ullah et al., suggested hybrid energy for grid connection which has positive impact on environment of Bangladesh [29]. Islam et al., highlighted the different aspects related to renewable energy like policy matters, research activities etc and finally ended with conclusion of lack of renewable experts [30]. Shakir, et al. suggested the potential locations for solar PV system for highest efficiency factors like hours of sunlight hours, monthly cloud coverage, amount of solar irradiation etc type of plane etc in Bangladesh [31]. Binayak B. et al. urged upon before switching to renewable energy for power production its potentiality to be measured with long term data in Nepal [32]. In Indonesia, Nazir et al. made a study of proposing micro hydro plant and Photo-Voltaic (PV) system which is analyzed by both MATLAB and HOMER and concluded that though initial cost is more, but it was better environmental impacts [33]. Luiz Carlos Guedes Valente et al. [17] illustrated the comparison between hybrid and traditional fossil fuel system where it is advocated that hybrid system is better than the other system in small villages of Brazil [34]. Pragya Nema et al in their review paper suggested the modeling of hybrid solar wind system and also cost effectiveness for that in remote areas [35].

Mondol et al have presented the hybrid renewable system of power production [36]. Nandi and Ghosh have articulated the preference of hybrid system which is combining solar-PV/wind though the cost of energy is a bit high in Bangladesh [37]. Mohibullah, Bhardwaj, and Garg used hybrid renewable energy solar, wind and biogas to generate electricity for a remote area in western Uttar Pradesh in northern of India by using HOMER software which is beneficial for environment [38]. Mishra, Panigrahi, and Kothari used the hybrid renewable source comprising of wind, solar and biomass in India by HOMER software where biomass is regarded as best source of energy [39]. Nfah investigated picohydro/biogas/PV systems for rural Cameroon where inclusion of biogas was to decrease the generation cost of hybrid systems and analysis is done by HOMER software [40]. Nguyen, Pham, Nguyen, Le, and Van suggested that the expenditure of generating the required electricity by using traditional diesel fuel was 1.6 times more than that of renewable biomass energy in Vietnam [41]. Soumya Mandal et al. in their study on prospect of solar-PV/biogas/diesel generator hybrid energy system of an off-grid area in Bangladesh has highlighted on the hybrid energy system configuration which is constituted of solar-PV, biogas generator, diesel generator and storage device [42].

In the above literature review, there is no study carried in Bangladesh combining Solar PV, wind, biogas for a remote island. This study made an endeavor to study combing Solar PV, wind, biogas as a hybrid energy source to mitigate the electricity demand in such an area.

1.4 **Objectives**

The objectives of the thesis are:

a. To carryout detail load study of Swarna Dweep.

b. To determine biogas and wind potential at Swarna Dweep.

c. To design and simulate the proposed hybrid solar PV, biogas and wind system by HOMER and optimizing the available potential.

d. To analyse the sensitivity to see the impact of those hybrid system investment cost and diesel fuel price on the optimum result.

e. To assess the economic feasibility on the design of the system.

1.5 Thesis Structure

The thesis is comprised of seven chapters. They are as follows:

The **chapter one** includes background, motivation of the study and objectives. In this chapter, literature review is consolidated biasing on the lecture of different researchers and scholars of the globe on renewable energy.

The **chapter two** gives a complete overview of the methodology of the thesis where flow chart of the methodology, site selection, data collection for load assessment, resources assessment and selection of parameters are discussed in brief.

The **chapter three** includes description of survey area and load assessment. This chapter also presents the renewable recourses available at survey area where solar, wind and biogas are the potential resources. Further, system components along with the cost and system modeling are discussed at a length. Besides that, it also projects an introduction for Fuzzy Expert System for validation of HOMER and functional test of the proposed system is performed by ETAP software.

The **chapter four** encompasses of the result received from HOMER and its analysis. HOMER has three simulation scenarios. All three scenarios of simulation, optimization are discussed elaborately. The best option is preferred considering cost of energy and net present value. Besides that, economic modeling and socio-economic benefits are highlighted.

The **chapter five** presents the analysis of sensitivity of HOMER.

The **chapter six** includes the validation by Fuzzy expert system and functional test by ETAP software. In this chapter, development and implementation of fuzzy expert system is described along with the comparison between HOMER and Fuzzy Expert System.

The **chapter seven** presents the conclusion of the thesis with a summary of the original contributions, significance and future work.

CHAPTER 2
DESIGN METHODOLOGY

2.1 Introduction

This chapter begins with the presentation of the proposed method for evaluating the optimum design of hybrid power system. A methodology has been developed for determining the optimum design of RE based hybrid power plant. Various necessary data have been collected from the meteorological department and other reliable sources. By collecting the various required data, the input parameters are fed to HOMER for optimization and to get the suitable configuration for the hybrid energy system.

2.2 Methodology

As the electricity generated from only the PV system or wind generator is not reliable to meet the load demand of an isolate area due to their intermittent nature, a hybrid energy system such as the incorporation of wind and biogasalong with the PV system will be beneficial as those are available at the survey site. It can be said that a hybrid PV-Wind-biogas-battery system is considered a reliable source of electricity. For this a remote area needs to be identified. The selected remote rural area for this study is Swarna Dweep. It is situated in the South-Eastern part of Bangladesh which lies about 4 km to the south of the Noakhali district mainland.The potentiality of renewable energy sources and load of the survey area will be assessed. Further, it is required to assess the market feasibility of solar PV, wind and biogas along with the cost of equipment needed to install the plant. For the data collected from the survey, data is fed and analyzed by Hybrid Optimization Model for Electric Renewable (HOMER) software tools developed by National Renewable Energy Laboratory (NREL), Colorado, USA for simulation, optimization and sensitization. HOMER uses a micro power optimization model that simplifies the design of any grid connected or off-grid hybrid power systems. HOMER software was used for the modeling, simulation, optimization and sensitivity analysis for off-grid energy systems for diverse applications. Besides, the simulation, optimization and sensitivity analysis, economic analysis will be conducted to see the economic viability. The hybrid energy system is designed after giving due attention to the objectives and scope of the study. Additionally, besides the attainment of the objectives, Fuzzy Expert system will be used to validate the result of HOMER software and Electrical Transient Analyzer Program (ETAP) will be used for functional test of the proposed design of the HOMER.

The study area, Swarna Dweep has enormous potential of renewable resources like solar, wind, biogas etc. To get the best output, optimization is done regarding design and planning. HOMER will identify which is the best option among the proposed architecture.

2.2.1 **Flow Chart of the Methodology**

Flow chart of methodology is shown in Fig. 2.1.

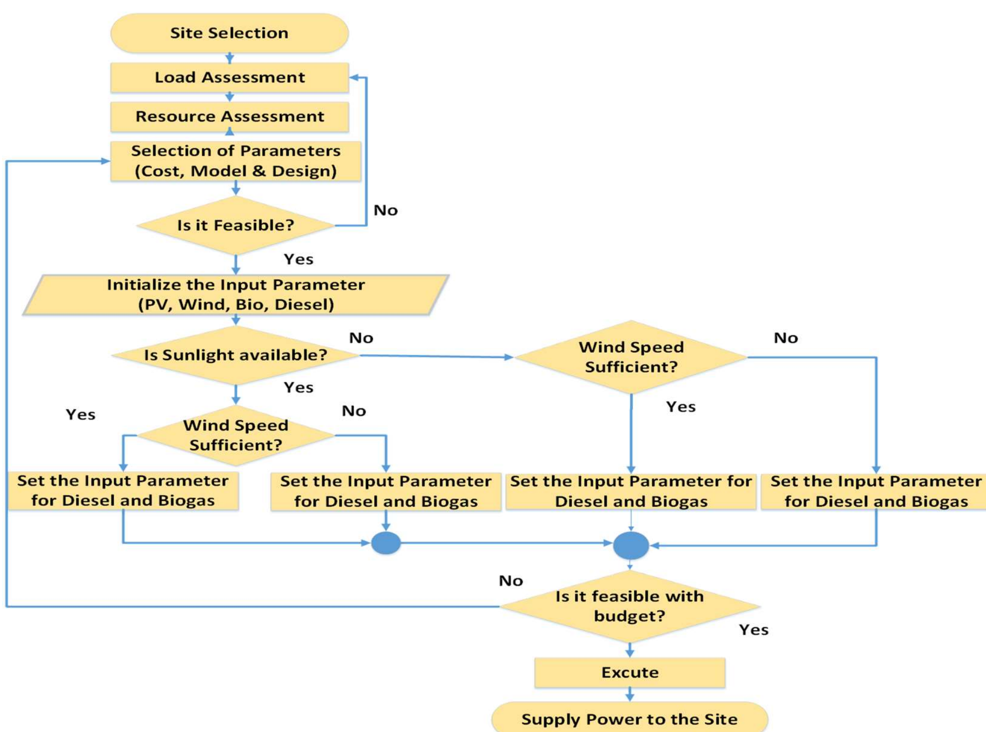


Fig. 2.1 Flow chart of methodology

However, the following action to be done in methodology stage:

2.2.2 **Site Selection**

The selected off-grid remote rural area for this study, named Swarna Dweep, is situated in the South-Eastern part of Bangladesh. It lies about 4 km to the south of the Noakhali district mainland and nearly 4.5 km west and about 13.5 km north-east of Hatiya. Swarna Dweep is located within the extent between 22°37ˈ35.5ˈˈNorth Latitude to 91°23ˈ3.6ˈˈEast Longitude and 22°25ˈ12.7ˈˈNorth Latitude to 91°11ˈ32.0ˈˈ East Longitude. This island is approximately 3 meter above sea level which is now 28 kilometer long and 14 kilometer wide in area (392 km^2). Hence, this area has been selected as an ideal place for installing the hybrid energy system.

2.2.3 **Data Collection for Load Assessment**

The remote area residential unit is simple and does not require large quantities of electrical energy used for lighting and electrical appliances. Generally the demand in Bangladesh is peak during the evening hours, mostly due to lighting load. In present days, as socio-economic condition of general mass has improved, the electricity demand also increased. As ceiling fan is not required, therefore the winter load has considered half of the summer load. There is a households load demand variation around 5 %. However, to assess the load, initially number of installation is taken in account and how more construction is likely to pop up. Then, the design requirement is considered. During load assessment, winter and summer load is taken in cognizance.

2.2.4 Resources Assessment

As Bangladesh has abundant of renewable resources due to it geographycal location, the survey area, Swarna Dweep is equally blessed with this renewable resouces too. Therefore, for this research, it is essential to collect some necessary data such as monthly average solar radiation and clearness index from NASA surface meteorology and solar energy database and average wind flow from the meteorological department of Bangladesh and SREDA. From primary sources, number of cattle avialble at survey area for biogasis taken into account along with grazing or no grazing calttle. Amont of renewable resoureces like solar, wind and biogas are avialble are dicussed in detailed later.

2.2.5 Selection of Parameters

The energy system components are diesel generator, solar PV modules, wind turbine, biogas generator, battery and power converter. The cost, models, number of units to be used, operating hours, etc. need to be specified in HOMER software for each of this equipment. Description of these components along with cost are given in the following sections. In the present simulation, the mainly component is three major renewable energy components which solar PV panel, wind turbine and biogas generator. Solar PV panel have the other component involved such as a battery, inverter and solar PV itself. The current produced from solar PV panel is in DC and current from biogas &diesel generator and wind turbine in AC. The inverter will change from DC to AC current and vice versa. The electricity produced from the renewable device will be feed into loads.Here, it is to mention that when sunlight is not available, power will be generated from other sources of energy. If sun and wind is not available or not sufficient, power will be produced from biogas or diesel.

2.2.6 **Implementation**

For implementation the study consists of 4 broad activities: planning, field work, data management and report writing. The planning stage includes the design of hybrid energy system and finalization of instrument. Field work includes physical data collection from survey area. Data management includes editing of filled in instruments, preparation of data entry format, data entry and its verification and data analysis.The hybrid energy system is designed after giving due attention to the objectives and scope of the study. Data collection was identified and then instruments was developed for the system. After identifying the objectives, the data collected from the surveyed area. Data collected from on ground questionnaire. Also, the key informants were interviewed based on availability.For the data collected from the survey, data is fed at first to HOMER software for simulation, optimization and sensitization. ETAP is used to design the system by using the best option for HOMER. ETAP and Fuzzy Expert system is used to validate the results of HOMER. Finally, the report is written based on the findings from collected data and the financial model developed from such analysis.

2.3 Conclusion

In methodoly, identification of site was the foremost work. Later, load and renewable resources assessment was done. For proposed hybrid system, different compoents alone with cost was assessed from the market. Due to intermittance of solar and wind, power will be alternatively generated from biogas or diesel. The produced power is expected to fulfill the demand of the study area.

CHAPTER 3

SYSTEM MODELLING

3.1 Introduction

This chapter encompasses the detail description of study area, Swarna Dweep. This remote area has its uniqueness as it is blessed with abundant of solar radiation, wind speed and biogas resources. For hybrid energy system, the availability of different hybrid components and their cost is assessed. Finally the system modeling is done with the available renewable resources.

3.2 Survey Area

The selected off-grid remote rural area for this study, named Swarna Dweep, is situated in the South-Eastern part of Bangladesh. It lies about 6 km to the south of the Noakhali district mainland and nearly 4.5 km west and about 13.5 km north-east of Hatiya. Swarna Dweep is located within the extent between 22°37'35.5''North Latitude to 91°23'3.6''East Longitude and 22°25'12.7''North Latitude to 91°11'32.0'' East Longitude. This island is approximately 3 meter above sea level that is now 28 kilometer long and 14 kilometer wide in area (392 km^2). Fig. 3.1 shows the map of Swarna Dweep.

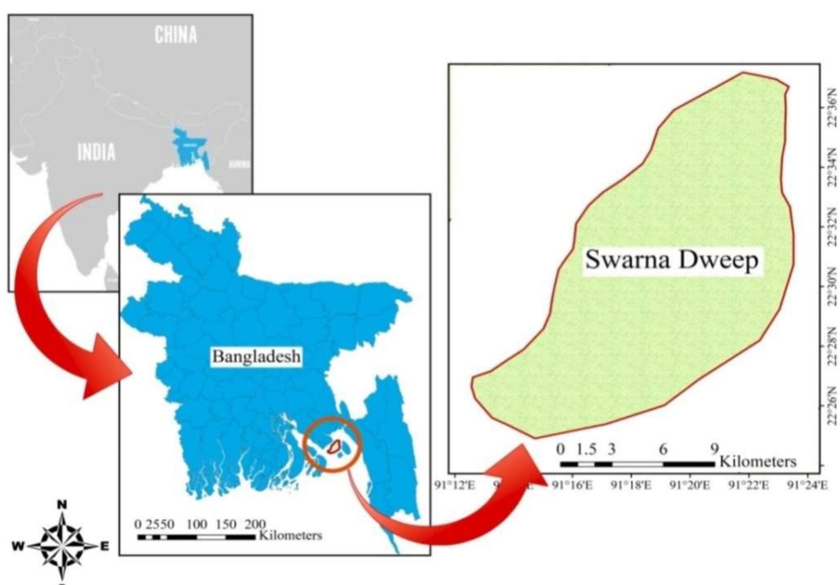


Fig. 3.1: Survey area map

Swarna Dweep is bounded by Sandweep in the East, by Urir Char in the north, by Bay of Bengal in the South, by Noakhali main land in the West. The average maximum temperature is 30^{o}C to 45^{o}C and the minimum is between 18^{o}C and 25^{o}C. However, the island has no access to grid electricity. Therefore it would be ideal for off-grid electrification of the island. Fig. 3.2 shows the survey area map along with the neighboring islands.

Fig. 3.2 Survey area map showing the neighboring islands

Swarna Dweep is surfaced in Bay of Bengal in 1978. Its original name was ‘Island Ruhulamin’, but later on it is renamed as Jahaijjar Island or the Jahaijjar Char under Noakhali district. It is later on renamed as Swarna Dweep (Golden Island). Total area of the island is almost half of Singapore (721.5 km²). Because of its geographical position, ensuring grid electricity services on the island in the near future seems to be challenging and expensive.

However, Bangladesh Army was given the responsibility of improving the improved law and security situation of this coastal area, afforestation and for habitation since 2013.

Before that, this island is allocated to the Bangladesh Army in 2012 for training purpose. From 2014, Bangladesh Army is exercising a large-scale troop exercise on the island. At present only one cyclone centre cum soldiers' accommodation is constructed. More 3 buildings of same design will be constructed. It is mention that the expansion of this area is largely hampered due to absence of required power. If there would be required power, the development would be accelerated.

3.2.1 **Load Assessment**

Survey area load can be determined by:

$$E_{demand} = \sum_{i=1}^{Load} P_{Load} \times m_{Load} \times n_{Load}$$

where P_{Load} is the power rating of a connected load, m_{Load} is the duration for operating a connected load and n_{Load} is the number of a particular connected load.

The study area is an isolated area where mainly members of Bangladesh Army are residing. There is at present one three storied building and more four similar pattern buildings are pipeline. The load demand is principally calculated based on the two season winter (November to February) and summer (March to October). Therefore, for the winter season, in fact, energy will consume by bulb, TV, mobile charger and fridge (Table 3.1) as ceiling fan will be used at limited scale. The total estimated energy demand of the study area for the winter season is 162.400 kWh/day whereas for the summer season, it increases to 498.400 kWh/day. Fan, light and TV will consume the maximum electric energy during the summer season. In all seasons, refrigerators, micro-oven, security lights, saver machine points, battery charger points are available to consume load. Therefore, the demand for electricity for this season is comparatively higher than other seasons.

TABLE 3.1 DAILY LOAD CONSUMPTION OF SELECTED AREA

Appliance	**Rated Capacity (W)**	**Quantity**	**Total Power (W)**	**Operation (h)**		**Total Energy (W)**		**Energy Consumption (W)**	
				Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Tube Light	20	60	1200	8	8	160	160	96,000	96,000
LED Bulb	9	65	585	8	8	72	72	4,680	4,680
Ceiling Fan	100	60	6000	16	0	1,600	0	96,000	0
LED TV	50	02	100	6	6	300	300	600	600
2 Pin socket (Auxiliary Load)	100	12	1200	6	6	600	600	7,200	7,200
Refrigerator	1500	4	6000	20	20	3,000	3,000	12,000	12,000
Security Light	9	40	360	12	12	108	108	4,320	4,320
2 Pin Socket for Micro oven	1500	4	6000	4	4	6,000	6,000	24,000	24,000
Shaver	200	15	3000	2	2	400	400	6,000	6,000
Air Condition	3000	10	30,000	8	-	24,000	0	2,40,000	0
Water Pump	1500	4	6000	6	4	9,000	6,000	3,600	1,600
Computer Point	50	10	500	8	8	400	400	4,000	4,000
Total Energy Consumption (KWh/Day)								498.400	162.400
Total Energy Consumption (KWh/Day)								660	

3.2.2 Estimation of Electrical Load of the Studied Area

Comparing the electricity demand of remote coastal area with urban area, it is generally low and does not require big amounts of electrical energy used for electrical appliances. In this island, mainly light, fan, mobile charger, television and fridge are considered as electrical load necessitated for domestic purposes. The seasonal profile of Swarna Dweep is shown in Fig. 3.3 where it is shown that load in November, December, January and February is relatively less.

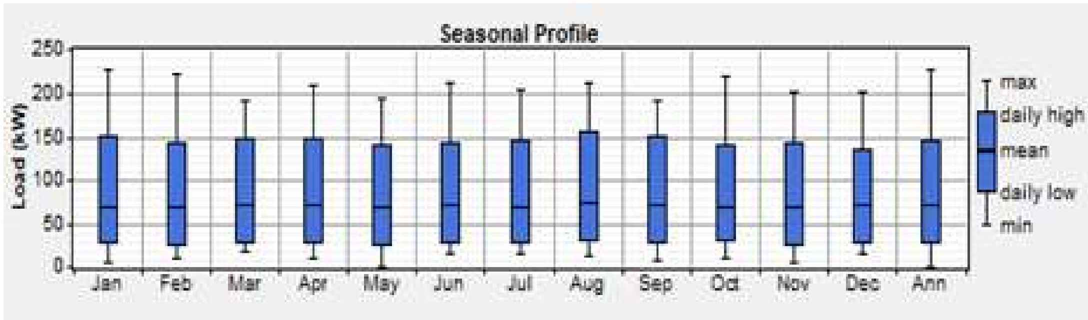


Fig. 3.3 Seasonal Profile of Swarna Dweep

At midnight hours, the power consumption of the survey area comes down to minimum where only the essential electrical appliances are used. The load demand rises up during morning hours when everybody gets ready for works. At the noon hours, the load demand raises little bit as people come for lunch and rest. Power consumption becomes the maximum during the evening hours as all members fall back to home and everyone switches on various entertainment appliances. Fig. 3.4 shows the primary load of Swarna Dweep.

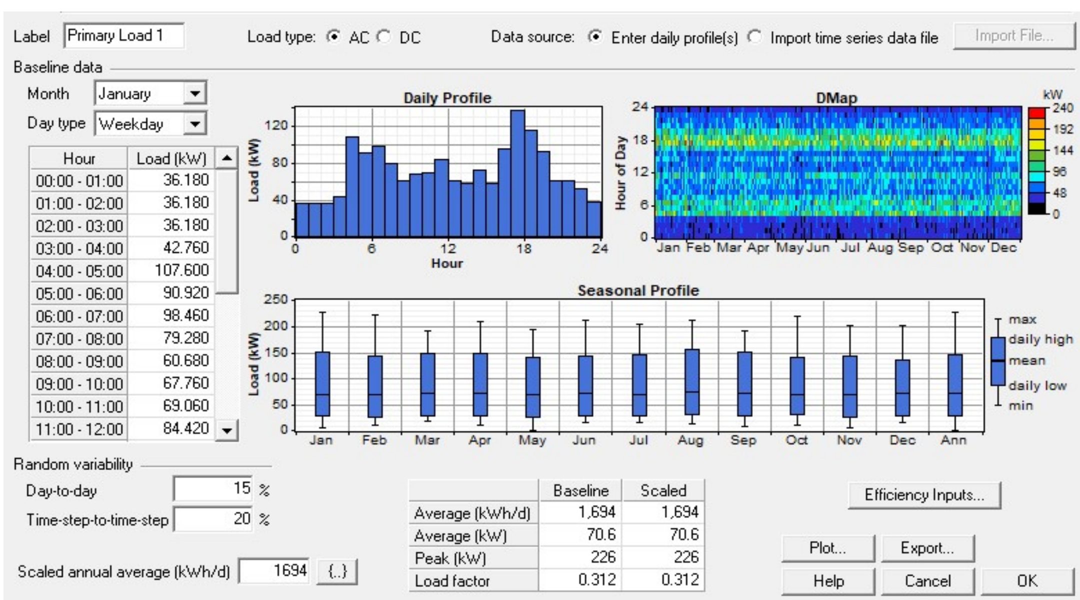


Fig. 3.4 Snapshot of Primary load

3.3 Renewable Resources at Swarna Dweep

3.3.1 Solar Resources

As used in HOMER software, the latitude and longitude of Swarna Dweep are 22°31ˈ35.5ˈˈ N, 91°17ˈ32.0ˈˈ E respectively. The data of solar radiation is obtained from NASA surface meteorology and solar energy database. HOMER calculates clearness index automatically from the daily radiation values that are shown in the Table 3.3.

TABLE 3.3 MONTHLY SOLAR RADIATION

Month	**Cleanness Index**	**Daily Radiation (KWh/m^2/d)**	
		RETScreen Expert	**HOMER**
January	0.613	4.35	4.348
February	0.590	4.95	4.809
March	0.575	5.57	5.422
April	0.520	5.65	5.450
May	0.498	5.25	5.475
June	0.366	4.05	4.072
July	0.342	3.89	3.771
August	0.379	3.91	4.020
September	0.394	3.83	3.848
October	0.530	4.29	4.506
November	0.572	4.23	4.182
December	0.624	4.24	4.206
Average	**0.486**	**4.51**	**4.508**

It is seen that the average solar radiation in both RETScreen and the HOMER is identical, that is 4.51kWh/m^2/day. The average annual clearness index is 0.486. The highest solar radiation was estimated at (5.475 kWh/m^2) in May while the lowest was

(3.771kWh/m^2) in July. It is obvious from the above table that the global solar radiations vary monthly, which ultimately varies PV system power output.

3.3.2 **Wind Resources**

Wind speed data obtained at 60 m above the surface of sea level for the different locations of Swarna Dweep, Bangladesh. Table 3.4 shows the wind speed of different locations of Swarna Dweep. The table demonstrated that wind speed of the survey area at 60 meter height is more than 6 meter/second. Latitude 22.3007 and longitude 91.2119 has the lowest wind speed and latitude 22.3343 and longitude 91.1931 has the highest wind speed.

TABLE 3.4 WIND SPEED OF DIFFERENT LOCATIONS OF SWANA DWEEP AT 60 METERS [43]

Latitude	Longitude	Wind Speed (m/s)
22.3007	91.2119	6.17680
22.3519	91.2031	6.32019
22.3431	91.1631	6.34225
22.3231	91.2242	6.30916
22.3131	91.1819	6.34225
22.3343	91.1931	6.36431
22.3643	91.1519	6.33122
22.2819	91.1342	6.25401
22.3007	91.1231	6.26504
22.2719	91.1619	6.35328

The Table 3.5 shows that the wind speed ranges from 6.232 to 6.360 m/s. The highest wind speed occurs in April. The annual average wind speed of Swarna Dweep is 6.31 m/sec at height 60 meters, which is measured by NREL, USA.

It can be also observed that from March to October the wind speed is higher than the annual average wind speed. Again, wind resources can be found for the same location from NASA by using RETScreen software at a height 10m for the terrain identical where it is observed that he wind speed from April to August is higher than the annual average wind speed (3.2 m/s). The variations in speed of wind fluctuate the system performance and configuration.

TABLE 3.5 MONTHLY WIND SPEED

Month	**NASA (10m) Wind speed (m/s) (From RETScreen Expert Software)**	**Measured by NREL (60 m) Wind speed (m/s)**
January	2.6	6.232
February	2.5	6.257
March	3	6.308
April	3.8	6.360
May	4.0	6.352
June	4.4	6.342
July	4.5	6.337
August	3.9	6.329
September	3.1	6.321
October	2.3	6.314
November	2.2	6.295
December	2.3	6.273
Average	**3.2**	**6.31**

Table 3.5 shows that at lower height wind speed are much lower to generate electricity. However, when the height is increased to 60 meters, the wind speed is more in same place that have a very high potential to generate electricity.

3.3.2.1 **Wind Resources Assessment by Windographer and WAsP Softwares**

The wind speed is simulated by Windographer and WAsPsoftwares. Fig. 3.5 presents the monthly temperature distribution over the year. The graph shows temperature distribution over a year in selected location. This temperature affects the availability of wind energy. This data is needed to complete the wind firm modeling.

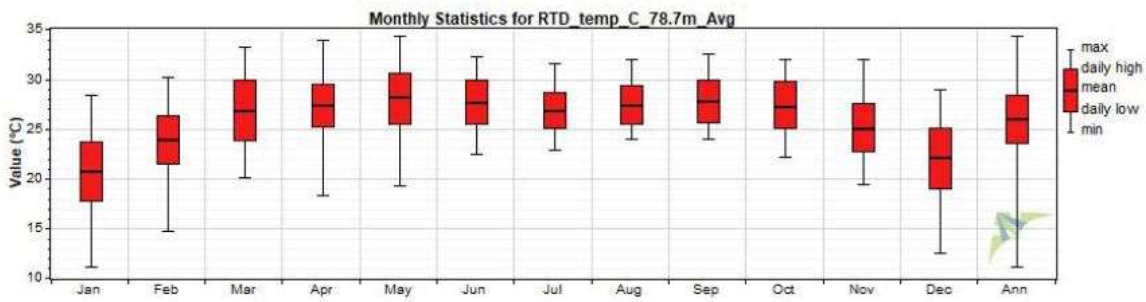


Fig. 3.5 Monthly temperature distribution over the year [43]

Fig. 3.6 shows the probability distribution function. Naturally, the wind's speed constantly varies. In order to predict a wind turbine's production it is required to know exactly how often the wind blows with what strength. Normally, the wind is measured with an anemometer and the mean wind speed is recorded after every 10 minutes. This data can be sorted into wind speed classes of 1 m/s each. The energy contained in the wind at a certain site may then be expressed by this frequency distribution.

C is the Weibull scale parameter in m/s; a measure for the characteristic wind speed of the distribution. C is proportional to the mean wind speed.k is the Weibull form parameter. It specifies the shape of a Weibull distribution and takes on a value of between 1 and 3. A small value for k signifies very variable winds, while constant winds are characterized by a larger k.

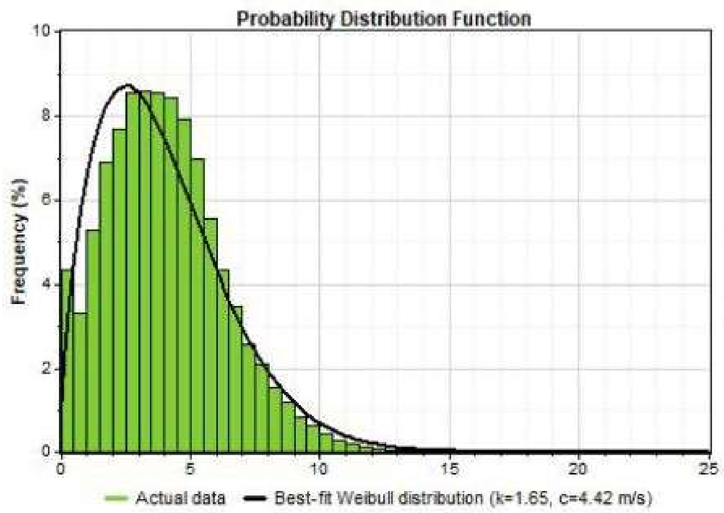


Fig. 3.6 Probability Distribution Function [43]

3.3.3 **Biomass Resources**

There are more than 200 buffaloes, 300 sheep and 1,200 hens, ducks and pigeons in the dairy farms. A large number of cattle (of which 2,538 are buffalo, 1,335 are cow and approximately 1,255 are sheep) are grazing in the island. Table 4.5 shows Livestock's Statistics at survey area. On average dung that can be obtained from a single healthy buffalo is 15 Kgs, a cow produces 10 kg of cow dung each day and 2 kgs by a sheep [44].

So, approximately 10.786 ton dung is available per day in the island considering the recovery rate of the dung cake 20%. There will be cost for collection and transportation of dung to gather in plant area of the Island. However, collection and transportation cost may be compensated by selling the slurry. Therefore, it can be said that in average 10.786 ton/day dung is available throughout the year. Table 3.6 shows the livestock's statistics at survey area and month wise cattle dung is shown in Table 3.7. Table 3.8 shows the calculation of electricity from Biogas at survey area.

TABLE 3.6 LIVESTOCK'S STATISTICS AT SURVEY AREA

Sl. No	Category	Bathan	Military Firm	Total
1.	Buffalo	2,331	207	2,538
2.	Cow	1,327	8	1,335
3.	Sheep	1065	190	1,255
				4,839

TABLE 3.7 MONTH WISE CATTLE DUNG RECOVERED FROM SURVEY AREA

Sl. No	Month	Tones/Day
1.	January	12.000
2.	February	11.000
3.	March	13.000
4.	April	12.000
5.	May	7.000
6.	June	8.000
7.	July	7.500
8.	August	8.500
9.	September	12.000
10.	October	11.500
11.	November	13.000
12.	December	14.000
Average		**10.785**

TABLE 3.8 CALCULATION OF AMOUNT OF DUNG TO BE RECEIVED FROM SURVEY AREA

Category	Total Cattle	Tentative Dung Cake (kg/Day)	Total Dung Cake (kg/Day)	Recovery Rate of Dung Cake 20% (kg/Day)
Cow	1335	10	13350	2,670
Buffalo	2538	15	38070	7,614
Goat	1255	2	2510	5,02
			50,095	10,786

Calculation of amount of electricity produced from dung

Total amount of cattle dung cake=10,786 kg

Total amount of biogas production = (10.786 ×0.034) m^3 = 366.72 m^3

Total production of electricity from Biogas= (366.72÷0.5) kW = 733.44 kW

I Kg of cattle dung cake produces = 0.034 m^3 of biogas [45]

From 0.5 m^3 of biogas can generate 1 kW of electricity [46].

3.4 Technical Specifications and Cost Assessment

3.4.1 System Components Assessment

The hybrid energy system of the study area is composed of PV modules, wind turbine, biogas, diesel generator and power converter. The different parameters like the cost, number of units to be used, operating hours, etc. need to be inserted in HOMER software for each of this equipment. The principal renewable hybrid energy source is solar PV, wind turbine and biogas to give input to HOMER. The current generated from Solar PV panel is in DC, which is converted to AC by using inverter and current from wind turbine, biogas and diesel generator in AC. The inverter also will change AC to DC current. According to AC and DC loads, electricity generated from the renewable device is given the input to loads. The schematic diagram of this system is shown in (Fig. 3.7). Description of these components is given in the following sections.

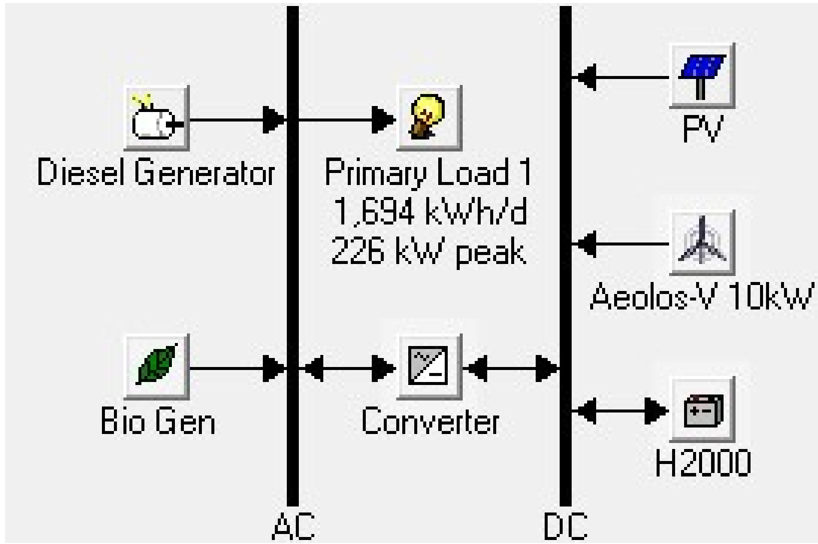


Fig. 3.7 Architecture of System Components

3.4.2 **Solar Photovoltaic**

370 watt JA Solar monocrystalline PV module is considered for this system. JA Solar is a renowned global manufacturer of solar technologies since May 2005. It has higher output power, excellent low-light performance, lower temperature coefficient. The installation cost of solar PV may vary from (100 Tk to 300 Tk/ W). Considering a more optimistic case, a 1W solar energy system's Operation & Maintenance (O&M) and replacement costs are taken as Tk 50 and Tk 50/W respectively. The lifetime of Solar PV arrays are taken as 12-year product warranty and 25-year linear power output warranty and no tracking system is included in the PV system. Table 3.9 presented the PV Module specification and Table 3.10 shows the parameters and costs considered for solar PV.

TABLE 3.9 SOLAR PV MODULE SPECIFICATION [47]

Item	Specification	Unit
Manufacturer	JA Solar	
PV Module Type	Mono-Si	
Module Model	JAM72S01-370/PR	
Module Efficiency	19	%
Power Capacity	370	Wp
Power Tolerance	0~+5	W
Rated Voltage (Vmpp)	39.45	V
Rated Current (Impp)	9.38	A
Open Circuit Voltage (Voc)	48.18	V
Short Circuit Current (Isc)	9.91	A

TABLE 3.10 PARAMETERS AND COSTS CONSIDERED FOR SOLAR PHOTOVOLTAIC [48]

Parameter	Unit	Value (BDT)
Capital Cost	BDT/W	100
Replacement Cost	BDT/W	50
Operation and Maintenance Cost	BDT/W/Yr	50
Lifetime	Years	25
Derating Factor	Percent	90

3.4.3 Wind Turbine

Availability of energy from the wind turbines depends greatly on wind variations. Therefore, wind turbine rating much lower compared to the average electrical load. In this analysis, Aeolos 10kW vertical axis wind turbine is preferred for wind energy. It is a low start wind speed with reliable vertical wind turbine. Outer rotor three-phase generator with a 1.5m/s start wind speed is used. It has both on grid and off grid applications where for off grid 300V and 380V for on grid is being used. For blades are made of aluminum alloy, Aeolos 10kW vertical axis wind turbines were preferred in commercial building, schools, supermarkets, etc. Even the wind speed is 30m/s or 40m/s, the design feature will limit maximum rotating speed to 260 rpm. It is not only safe but also reliable than others. Table 3.11 presented the Aeolos wind turbine 10 kW specifications and Table 3.12 shows the cost analysis for wind turbine.

TABLE 3.11 AEOLOS WIND TURBINE 10 KW SPECIFICATIONS [49]

Parameters	**Unit**	**Value**
Rated Power	kW	10 kW
Maximum Output Power	kW	12 kW
Output Voltage	V	300/380 V
Life time	Year	20
Rotor height	M(ft)	6(19.7)
Rotor Diameter	M(ft)	5.5(18)
Startup wind speed	m/s	2.5
Rated wind speed	m/s	11
Survival wind speed	m/s	52.5

TABLE 3.12 COST ANALYSIS FOR WIND TURBINE [48]

Parameter	**Unit**	**Value (BDT)**
Capital Cost	BDT/kW	2,50,000
Replacement Cost	BDT/kW	1,50,000
Operation and Maintenance Cost	BDT/Yr/ Turbine	5000
Lifetime	Years	20

3.4.4 **Biogas Generator**

Puxin Biogas Generator is considered for this setting. Its rated power is 3 KW and it is a single phase brush motor. Its output volt is 12 V and output current is 8.3 A. Table 3.13 shows the specifications of Puxin biogas generator. Capital cost includes cost of biogas plant and Table 3.14 shows the cost.

TABLE 3.13 SPECIFICATIONS FOR PUXIN BIOGAS GENERATOR [48]

Parameters	Unit	Value
Rated Power	kW	3
Maximum Output Power	kW	3.5
Frequency	Hz	50
DC Output	V , A	12V 8.3 A
Displacement	cc	389
Gas Consumption	m^3/h	3.5

TABLE 3.14 COSTS CONSIDERED FOR BIOMASS GENERATOR [50]

Parameters	Unit	Value
capital cost	Tk/kW	49.71
Replacement cost	Tk/kW	25
Operation and management cost	Tk/hr	7
Continue Working Time	Operating hour	Not more than 6 hours

3.4.5 **Diesel Generator**

Diesel generators are commonly used for remote electrification. This is because they are low cost, easy to install and easy to operate. In this analysis, generator cost is taken (7000 BDT/kW) and replacement cost is 5000 BDT/Kw. 750 kW single unit diesel generator from Generac Industrial Power Co. Ltd. is considered for the standby power system. The size of generator is taken 1.2 times larger than the peak load demand so that it can provide power in absence of the renewable power energy. Table 3.15 shows the parameters and cost which are considered for diesel generator.

TABLE 3.15 PARAMETERS AND COSTS CONSIDERED FOR DIESEL GENERATOR [51]

Parameters	**Unit**	**Value**
capital cost	Tk/kW	7000
Replacement cost	Tk/kW	5000
Operation and management cost	Tk/hr	5
Life time	Operating hour	45000
Minimum load ratio	%	15

3.4.6 **Battery Model**

Batteries are considered as a major cost factor in small-scale stand-alone power systems. The purpose of batteries is to store electrical energy. The stored energy is utilized during the time of when power is not available from the hybrid PV and wind generating units. The storage battery chosen is Hoppecke 16 OPzS from the manufacturer Hoppecke. The nominal capacity of the selected battery is 9,600 kWh with nominal voltage of 12V for single battery, lifetime throughput of 16322,400 kWh was considered. Replacement cost for battery is assumed about 95% of its capital cost. The specifications are shown in Table 3.16. It was assumed that the batteries will be charged by the PV arrays during day time and also by wind turbine when during its availability. Table 3.17 shows the cost analysis for battery.

TABLE 3.16 PARAMETERS AND COSTS CONSIDERED FOR HOPPECKE 16 OPZS STORAGE BATTERIES

Parameter	Unit	Value
Nominal voltage	Volt	2
Nominal capacity	Ah(kWh)	2000(4)
Lifetime throughput	KWh	6801
Round-trip efficiency	%	86
Minimum state of charge	%	30

TABLE 3.17 COST ANALYSIS FOR BATTERY [48]

Parameter	Unit	Value (BDT)
Capital Cost	BDT/kWh	7,000
Replacement Cost	BDT/kWh	6,000
Operation and Maintenance Cost	BDT/kWh/Year	500

3.4.7 **Power Converter**

The inverter converts the power from direct current (DC) to alternating current (AC) as the solar PV panels produce the power in DC. The hybrid system has both the AC and DC current systems. Therefore, it is necessary to convert the power from DC component to AC load for maintaining the flow of energy. The selected inverter details are given in Table 3.18. The installation and replacement cost are taken as 1000 BDT/Kw each. Again a converter needs to maintain flow of energy between AC and DC power system components. It is suggested that the rated power of the inverter should be equal to or larger than the peak load since the load will supply both from the renewable and non-renewable, even below the peak would be installed. Replacement cost is taken

100% of the capital cost, efficiency of converter is around 90% and the lifetime of the converter will end for 20 years. Table 3.19 shows the cost analysis for converter.

TABLE 3.18 PARAMETERS AND COSTS CONSIDERED FOR POWER CONVERTER [48]

Parameter	Unit	Value
Inverter lifetime	year	20
Efficiency	%	90
rectifier capacity relative to inverter	%	95
Rectifier efficiency	%	85

TABLE 3.19 COST ANALYSIS FOR CONVERTER [48]

Parameter	Unit	Value (BDT)
Capital Cost	BDT/ kW_{rated}	10,000
Replacement Cost	BDT/ kW_{rated}	10,000
Lifetime	Years	20

3.5 System Modeling

3.5.1 Introduction

In this paper, two types of system modeling are considered. They are (1) System Components Modeling and (2) Economical Parameters Modeling. The system components will help to project the generation of electricity, whereas the economic model will helps us in determining whether a proposed model is feasible or not.

3.5.2 System Components Modeling

3.5.2.1 Solar PV Modeling

Considering the monthly average solar radiation of Swarna Dweep, the power output (P_{pv}) of solar PV is obtained by HOMER software using equation (1) [52].

$$P_{pv} = Y_{PV}\, f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \left[1 + \alpha_p \left(T_c - T_{c,STC}\right)\right] \ldots. \quad (1)$$

where:

Y_{PV} = the rated capacity of the PV array, meaning its power output under standard test conditions [kW]

f_{PV} = the PV derating factor [%]

$\bar{G}_T$ = the solar radiation incident on the PV array in the current time step [kW/m^2]

$\bar{G}_{T,STC}$ = the incident radiation at standard test conditions [1 kW/m^2]

α_P = the temperature coefficient of power [%/°C]

T_c = the PV cell temperature in the current time step [°C]

$T_{c,STC}$ = the PV cell temperature under standard test conditions [25°C]

If the temperature coefficient is ignored, thenαp is assumed to be zero and Eq. (1) becomes [52]:

$$P_{pv} = Y_{PV}\, f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \ldots..(2)$$

3.5.2.2 **Wind Modeling**

The data source taken for the wind turbine is considered at height of 120 meters, using the power law as given in equation (3) [52].

$$\frac{U}{U_0} = \left(\frac{h}{h_0}\right)^{\alpha} \ldots.(3)$$

where

U is speed of wind at power height h,

U_o is the speed of wind at height of reference ho, and

α is the surface roughness (is mostly taken as 0.14).

Additionally, α is the surface roughness coefficient, usually assumed to be 1/7, but in this analysis it is determined as follows:

$$\alpha = [0.37 - 0.088\ln(V_0)] / \left[1 - 0.088\ln\left(\frac{h_0}{10}\right)\right] \ldots. \quad (4)$$

where $V_0$and $h_0$are the measured speed and height, respectively [53].

The HOMER calculates the power output of wind turbine as given in equation (5) [66].

$$\frac{\rho}{\rho_0} = \left(1 - \frac{\beta z}{T_0}\right)^{\frac{g}{R\beta}} \left(\frac{T_0}{T_0 - \beta z}\right) \ldots. (5)$$

where

ρ is the density of air at hub height,

ρ_o is the density of air at STP conditions (1.225 kg/m3),

T_o is temperature standard (288.16 K),

β is known as lapse rate (0.00650 K/m) and g is acceleration of gravity (9.81 m/s^2),

R is the gas constant (287 J/kg K) and z is the elevation (m)

The electrical energy produced by a rotor combining of two or more blades mechanically joined to an electrical generator is determined from Betz's expression for power based on kinetic energy where three key factors affect the amount of energy a turbine can harness from the wind: wind speed, air density, and swept area [53]

$$p_a = \frac{1}{2}\rho A v^3 C_P \ldots(6)$$

where C_P is the capacity factor of the wind turbine, A is the swept area of the blades, ρ is the air density and v is the wind speed at the hub height.

Air density can be calculated from the following equation [54]

$$\rho = \frac{P}{RT} \ldots (7)$$

Where *P* is air pressure (*Pa*), *R* is gas constant (*J=kg=k*) and *T* is the ambient temperature (*K*).

The amount of energy in the wind varies with the cube of the wind speed, in other words, if the wind speed doubles, there is eight times more energy in the wind (z3 =2x2x2=8). Small changes in wind speed have a large impact on the amount of power available in the wind.

3.5.2.3 **Generators**

To generate electricity, a generator consumes fuel. HOMER's generator module has the flexibility to model a wide variety of generators which encompasses internal combustion engine generators, micro-turbines, fuel cells, thermo-photovoltaic generators and thermoelectric generators. HOMER can model a power system comprising of three generators, each of which may be ac or dc and also each of which has the ability to consume different fuel.

The primary physical properties of the generator consists of its maximum and minimum electrical power output, its expected lifetime in operating hours, the type of fuel it consumes and its fuel curve. HOMER adopts the fuel curve, a straight line with a y-intercept and uses the following equation for the generator's fuel consumption [55]:

$$F = F_0 Y_{gen} + F_1 P_{gen} \ldots (8)$$

where F_o is the fuel curve intercept coefficient, F1 is the fuel curve slope, Ygen the rated capacity of the generator (kW), and Pgen the electrical output of the generator (kW). The units of F depend on the measurement units of the fuel. If the fuel is denominated in liters, the units of F are L/h. If the fuel is denominated in m3 or kg, the units of F are m3/h or kg/h, respectively. In the same way, the units of F_0 and F1 depend on the measurement units of the fuel. For fuels denominated in liters, the units of F_0 and F1 are L/h_kW.

HOMER uses the following equation to calculate the generator's fixed cost of energy [55]:

$$F_{gen,Fixed} = C_{om,gen} + \frac{C_{rep,gen}}{R_{gen}} + F_0 Y_{gen} C_{fuel,eff} \ldots (9)$$

where $C_{om,gen}$is the O&M cost in dollars per hour, $C_{rep,gen}$the replacement cost in dollars, R_{gen} the generator lifetime in hours, F0 the fuel curve intercept coefficient in quantity of fuel per hour per kilowatt, Ygen the capacity of the generator (kW), and $C_{fuel,eff}$the effective price of fuel in dollars per quantity of fuel. The effective price of fuel includes the cost penalties, if any, associated with the emissions of pollutants from the generator.

HOMER calculates the marginal cost of energy of the generator using the following equation [55]:

$$C_{gen,mar} = F_1 C_{fuel,eff} \ldots (10)$$

where F_1 is the fuel curve slope in quantity of fuel per hour per kilowatthour and $C_{fuel,eff}$is the effective price of fuel (including the cost of any penalties on emissions) in dollars per quantity of fuel.

3.5.2.4 **Battery Bank**

The battery bank is assembly of one or more individual batteries. HOMER models a single battery as a device capable of storing a certain amount of dc electricity at fixed round-trip energy efficiency, with limits as to how quickly it can be charged or discharged, how deeply it can be discharged without causing damage, and how much energy can cycle through it before it needs replacement. HOMER assumes that the properties of the batteries remain constant throughout its lifetime and are not affected by external factors such as temperature.

The assumption that lifetime throughput is independent of cycle depth means that HOMER can estimate the life of the battery bank simply by monitoring the amount of energy cycling through it, without having to consider the depth of the various charge–discharge cycles. HOMER calculates the life of the battery bank in years as [55]:

$$R_{batt} = min\left(\frac{N_{batt}Q_{lifetime}}{Q_{thrpt}}, R_{batt,f}\right) \ldots\ldots.(11)$$

where N_{batt} is the number of batteries in the battery bank, $Q_{lifetime}$ the lifetime throughput of a single battery, Q_{thrpt} the annual throughput (the total amount of energy that cycles through the battery bank in one year), and R_{batt}; f the float life of the battery (the maximum life regardless of throughput).

For its marginal cost of energy, HOMER uses the sum of the battery wear cost (the cost per kilowatthour of cycling energy through the battery bank) and the battery energy cost (the average cost of the energy stored in the battery bank). HOMER calculates the battery wear cost [55]:

$$C_{bw} = \left(\frac{C_{rep,batt}}{N_{batt}Q_{lifetime}\sqrt{\eta_{rt}}}\right) \ldots\ldots(12)$$

Where $C_{rep,batt}$ is the replacement cost of the battery bank (dollars), N_{batt} is the number of batteries in the battery bank, $Q_{lifetime}$ is the lifetime throughput of a single battery (kWh), and Z_{rt} is the round-trip efficiency.

3.5.3 **Economic Modelling**

3.5.3.1 **Total Net Present Cost**

HOMER uses the following equation to calculate the total net present cost [55]:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})}; \ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Where $C_{ann,tot}$ is the total annualized cost in USD, $'i'$ is the annual real interest rate in % (the discount rate), R_{proj} is the lifetime in year, and $CRF(i, N)$ is the capital recovery factor, given by the equation [55]:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1}; \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where 'i' is the annual real interest rate and $'N'$ is the number of years.

3.5.3.2 **Cost of Energy (COE)**

It is the average cost per KWh electricity production in a system. HOMER uses the following equation to calculate the levelized cost of energy [55]:

$$COE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}}; \ldots\ldots\ldots (15)$$

Where $C_{ann,tot}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year, and $E_{grid,sales}$ is the amount of energy sold to the grid per year (for this study $E_{grid,sales}$ value is zero as system is considered here are not grid connected or ready to grid connect).

So the cost of energy is therefore the average cost per KWh f useful electrical energy produced by the system but not the amount of energy utilized by the end users.

3.5.3.3 **Pay Back Period**

Payback period is essential for any kind of project selection. It is the time after the total project cost will be vanished by project cash inflows. It indicates that the project will be profitable after this period.

$$\text{PBP}=\frac{C_{Cap.}+C_{O\&M}+C_{Repl.}}{C_{Cashinflo}}\text{………………..... (16)}$$

Where C_{Cap} ,$C_{O\&M}$, C_{Repl} and $C_{Cashinflow}$ are the capital cost, operation & maintenance cost, replacement cost and annual cash inflows respectively. It should always less than the project lifetime, T for a feasible and profitable project.

3.5.4 Clearness Index

The clearness index is a dimensionless number between 0 and 1 indicating the fraction of solar radiation striking the top of the atmosphere that makes it through the atmosphere to strike the earth's surface. The following equation defines the monthly average clearness index [56,57]:

$$K_T = \frac{H_{ave}}{H_{0,ave}}\text{……(17)}$$

Where,

H_{ave} is the monthly average radiation on the horizontal surface of the earth (KWh/m^2/day)

$H_{o,ave}$is the extraterrestrial horizontal radiation, meaning the radiation on a horizontal surface at the top of the earth's atmosphere (kWh/m^2/day)

For a given latitude, we can calculate $H_{o,ave}$for any month of the year. So if we know either H $_{ave}$ or K_T, we can calculate the other using the above equation. Homer does exactly that every time we enter a value into monthly data on the solar resource inputs window.

3.5.5 **Renewable Fractions**

Renewable fractions are the fraction of the energy delivered to the load that originated from renewable power sources. Renewable fraction is calculated using following equation [58]:

$$f_{ren} = 1 - \frac{E_{nonren} - H_{nonren}}{E_{served} + H_{served}} \ldots\ldots(18)$$

Where, E_{nonren} is the non-renewable electrical production (kWh/yr)

$E_{grid,sales}$ is the energy sold to the grid (kWh/yr) (included in E_{served})

E_{nonren} is the non-renewable thermal production (kWh/yr)

E_{served} is the total electrical load served (kWh/yr)

H_{served} is the total thermal load served (kWh/yr)

3.5. 6 **Salvage value**

To calculate the salvage value of each component at the end of the project lifetime, HOMER uses the equation [55]:

$$S = Crep\,\frac{Rrem}{Rcomp} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

where S is the salvage value, Crep the replacement cost of the component, Rrem the remaining life of the component, and Rcomp the lifetime of the component. For example, if the project lifetime is 20 years and the PVarray lifetime is also 20 years, the salvage value of the PV array at the end of the project lifetime will be zero because it has no remaining life. On the other hand, if the PV array lifetime is 30 years, at the end of the 20-year project lifetime its salvage value will be one-third of its replacement cost.

3.6 Hybrid System Configurations

3.6.1 Different Scenarios of the Proposed of Hybrid System

In this study, the hybrid energy system may consists of Solar PV, wind turbine, biogas and diesel generator. In this hybrid system, there may be lot of combinations to generate power, which may not be financially viable. Therefore, three scenarios may be proposed which will be economically viable. The scenario A can be the configuration of Solar PV- wind turbine- biogas-diesel generator. Scenario B can be the configuration of Solar PV-wind turbine-biogas generator and scenario C can be the configuration of Solar PV- wind turbine-diesel generator.

3.6.2 Modeling of Renewable Hybrid Energy Systems Components

In the system, the different energy sources like diesel and biogas generator are integrated such that AC sources are connected to AC bus directly and DC sources are connected to the AC bus through converter. In this system, the DC sources are coupled to the DC bus and/or AC sources are connected to AC bus.

3.6.2.1 Scenario A -Solar PV-Wind-Diesel Generator

In scenario A, the proposed hybrid system consists of solar PV, wind, diesel generator, battery and convertor which is shown in Fig. 3.8.

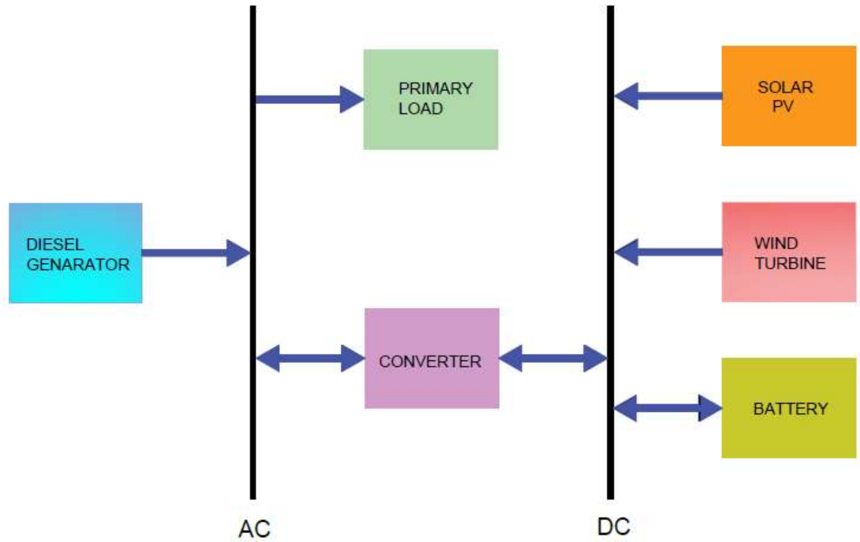


Fig.3.8 Hybrid system configuration of solar PV, wind, diesel generator

3.6.2.2 **Scenario B -Solar PV- Wind-Biogas Generator**

In scenario B, the proposed hybrid system consists of solar PV, wind, biogas generator, battery and convertor that are projected in Fig. 3.9.

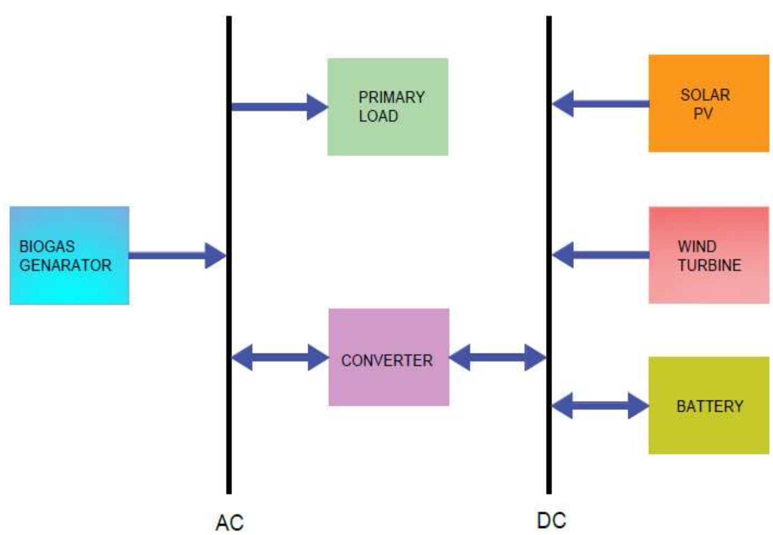


Fig. 3.9 Hybrid system configuration of solar PV, wind, biogas generator

3.6.2.3 **Scenario C -Solar PV-Wind-Biogas Generator-Diesel Generator**

In scenario C, the proposed hybrid system consists of solar PV, wind, biogas & diesel generator, battery and convertor which is projected in Fig. 3.10.

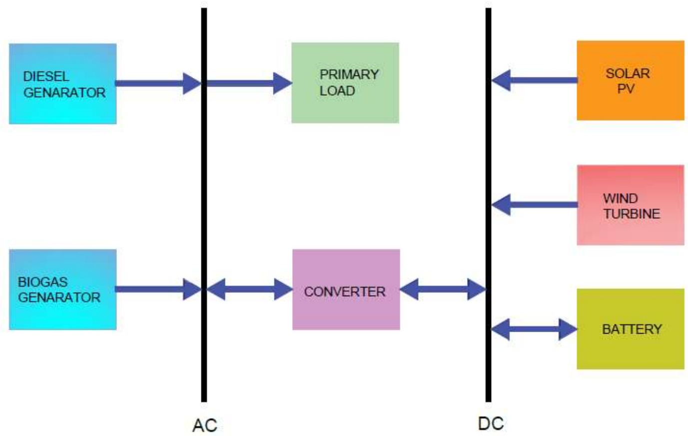


Fig. 3.10 Hybrid system configuration of solar PV, wind, Biogas and diesel generator

3.7 Modeling Validation by Fuzzy Expert System

3.7.1 Introduction

The developed PV-wind-diesel-biogas hybrid power plant is able to diversify the electricity generation leading energy security and continuous supply in case of irregularity. The proper evaluation of energy policy including PV-wind-diesel-biogas hybrid system in rural and remote areas of Bangladesh is important. Subsequently, energy forecasting is an important parameter for power management system in particular to its sustainability. However, precise energy forecasting can contribute in total power demand especially for the energy mix. Moreover, any experimental results or data recorded are required to be validated for its reliability as well as estimation of future active loads properly. Hence, several research works have been conducted for the precise forecasting with several methods such as linear regression, artificial neural network (ANN), fuzzy logic, response surface methodology, etc.

3.7.2 Block Diagram of Fuzzy Interface

The block diagram of fuzzy interface on hybrid energy system is shown in Fig. 3.11. The figure shows how to predict the total hybrid energy (TE) for a system. The energy parameters comprise PV, diesel generator (DG), biogas energy (BG) and wind power (WP) are fed in to the fuzzifier. The output obtained from fuzzifier is then transferred to the fuzzy inference system (FIS) known as heart of this intelligent approach using fuzzy rule base logic. The output obtained from this FIS is then finally converted into a crisp numeric value by defuzzification, which generates the predicted total hybrid energy (TE).

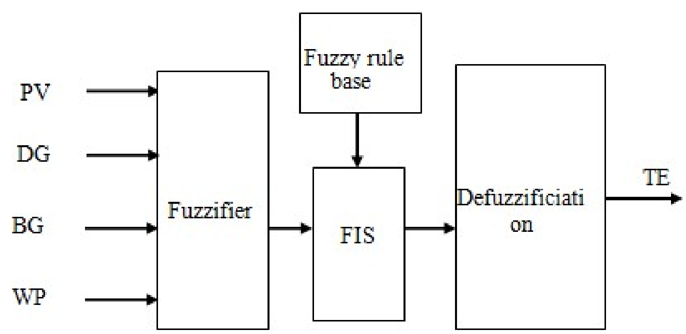


Fig. 3.11: Block diagram of fuzzy interface

3.8 Functional Test of the Proposed Configuration by ETAP Software

3.8.1 Introduction

ETAP is an electrical network modeling and simulation software tool used by power systems engineers to create an "electrical digital twin" and analyze electrical power system dynamics, transients and protection. ETAP is the inclusive analysis platform for the design, simulation, operation and automation of generation, distribution and industrial power systems. ETAP is used worldwide as high impact software. As a fully integrated enterprise solution, ETAP is a Real-Time Intelligent Power Management System not only to monitor, control, automate, simulate but also optimize the operation of power systems. ETAP has very vast capabilities such as Load flow analysis, Arc flash, Protection co-ordination studies, cable pulling, cable capacity study and much more. Because ETAP has integrated all the functionality required for Electrical studies, it is preferred over other software packages. This ETAP simulator is the excellent software to represent the real electrical power system and to study all the case studies of electrical power applications.

ETAP is a fully integrated AC and DC electrical power system analysis tool. Engineers use ETAP in thousands of worldwide companies and electric utilities in the design, analysis, maintenance and operation of electrical power systems.

3.9 Summary

In this chapter, the survey area is discussed at a length. The primary load is 1694 kWh and peak load is 226 kW. The site is blessed with considerable annual average global solar radiation of 4.51 kWh/m2 /day, average wind speed of 6.31 m/sec at 60 m height and average biogas is available 10.785 ton/day. The cost and parameter of hybrid energy system component are briefly highlighted here. System modeling as well as economic modeling is done. Finally proposed system configuration is also discussed.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

In this chapter, total results and analysis of HOMER is discussed. In simulation of HOMER, total three scenarios are obtained. They are Scenario A, Solar PV- wind-diesel generator -battery-converter, Scenario B, Solar PV- wind-biomass-battery-converter, Scenario C, Solar PV- wind-diesel generator-biomass-battery-converter. Obtained optimization results are analyzed in this chapter. Further, the financial, environmental and also social aspects have been compared with three scenarios. Finally, the best option is analyzed considering the power generation, cash flow, operation and maintenance cost etc.

4.2 HOMER

4.2.1 Introduction

The Hybrid Optimization Model for Electric Renewable energy (HOMER) is computer model software developed by National Renewable Energy Laboratory (NREL), USA. The objective of this software is to assist in the design of micro power systems with help of comparing various RE power generation technologies.

The HOMER software can display three main principles of simulation, optimization and sensitivity analysis. Hybrid system simulations display the system optimized for different system sensitivity variables. Based on technical and economic feasibility, this optimization model in the software allows the designers to evaluate offered designs of alternative system configurations. The variables that designers can evaluate on optimization and sensitivity analysis algorithms are in the economic and technical aspects of system configuration, uncertain cost calculations, the existence of sources and other variables. HOMER also shows the emissions, system control variables, economics and constraints during hybrid simulations. Fig. 4.1 illustrates the relationship between simulation, optimization and sensitivity analysis, which performs HOMER three primary tasks. The optimization oval encloses the simulation oval to represent the fact that a single optimization consists of multiple simulations. Similarly, the sensitivity analysis oval encompasses the optimization oval because a single sensitivity analysis consists of multiple optimizations.

Fig. 4.1 Conceptual relationship between simulation, optimization and sensitivity analysis [60]

4.2.2 **HOMER Modeling**

The simulation, optimization and sensitivity of the hybrid system are done by using HOMER. HOMER software was used for the modeling, simulation, optimization and sensitivity analysis for on and off-grid energy systems for diverse applications. In order to simulate an energy system, HOMER completes an annual energy balance calculation with a simulation time step of one hour (8760 h). On an hourly basis, it compares the energy demand to the hourly energy generated by the system. In order to obtain the energy balance, it performs calculations of energy exchange among the system components. This calculation is carried out for different energy system alternatives. Feasible systems that can meet the energy demand under the various constraints specified are identified and the system costs until the end of the project life are calculated. The components that make up the project costs include investment, operations and maintenance, fuel cost, replacements and interest. Penalties for capacity shortage and emissions can also be included in the evaluation process.

After the simulation process, all feasible system alternatives that gives the specified constraints are sorted, categorized and ranked based on the total net present cost (NPC). The energy system with the least total NPC is considered as the best. The techno-economic input to HOMER include daily energy demand, renewable energy resources, capital, replacement, operation and maintenance costs, technical details of components and operational constraints. Outputs from HOMER include component sizes, total NPC, levelised cost of energy (COE), unmet energy, capacity shortage, excess energy productions, renewable fraction (RF) and annual emissions among other.

4.3 Different Scenarios of Various Parameters of Hybrid Scenarios

The whole system has been designed as a stand-alone system. The system consists of Solar PV Panel, wind turbine, biogas generator, diesel generator, battery and converter. There are two buses in the system; AC and DC bus. The output energy of solar PV is stored in a battery, which is on the DC bus side. To convert AC from DC, a converter is used. The schematic diagram of this system is shown in chapter 3 (Fig. 3.7). Converter controls the system and decides the priority of solar, then wind, then biogas, then diesel and finally the storage battery. HOMER simulates different configurations of energy system components. The number of parameters affects the complexity and computation time and total number of potential values are involved in the design. The three different scenarios are proposed for further analysis:

a) Scenario A: Solar PV- wind-diesel generator -battery-converter
b) Scenario B: Solar PV- wind-biomass-battery-converter

c) Scenario C: Solar PV- wind-diesel generator-biomass-battery-converter

4.4 Scenario A-Solar PV-Wind-Diesel Generator

4.4.1 Introduction

This hybrid system consists of 150kW photovoltaic panel, the number of wind turbine in the selected scenario is 25, a 40kW diesel generator, 6000 unit batteries of total 24,000 kWh capacity and 650 kW converter. Solar irradiation during the month June, July and August are least so the percentage of electricity generated from PV is least. Less August and September, round the year, use of wind turbine is maximum. Diesel generator is used as an auxiliary power generation. Diesel generator has to serve only 872 hours in a year. Fig. 4.2 shows the block diagram of scenario A of the hybrid configuration system.

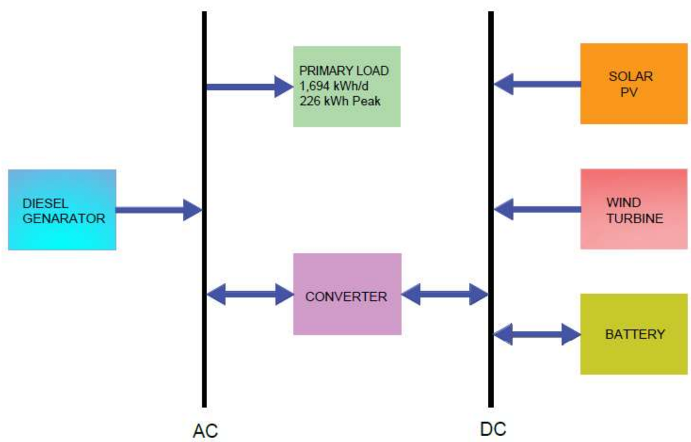
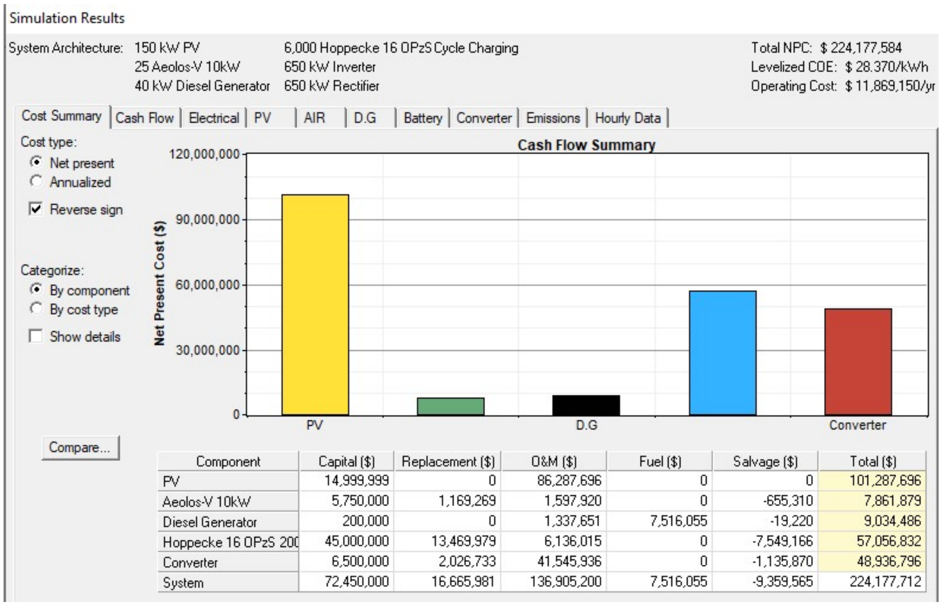


Fig. 4.2 Block diagram of Scenario A of the hybrid configuration system

4.4.2 Cash Flow Summary

Cash flow summary is presented in fig. 4.3 where capital cost is Tk 72,450,000, replacement cost is Tk 16,665,981, operation, maintenance (O&M) cost is Tk 136,905,200, and finally system cost is Tk 224,177,172. In this scenario, solar PV and diesel generator do not require any replacement. Total NPC is Tk 224,177,712, Levelized COE is Tk 28.370/kWh and operating cost is Tk 11,869,150 /year.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	14,999,999	0	86,287,696	0	0	101,287,696
Aeolos-V 10kW	5,750,000	1,169,269	1,597,920	0	-655,310	7,861,879
Diesel Generator	200,000	0	1,337,651	7,516,055	-19,220	9,034,486
Hoppecke 16 OPzS 200	45,000,000	13,469,979	6,136,015	0	-7,549,166	57,056,832
Converter	6,500,000	2,026,733	41,545,936	0	-1,135,870	48,936,796
System	72,450,000	16,665,981	136,905,200	7,516,055	-9,359,565	224,177,712

Fig. 4.3 Snapshot of Cash flow summary by components of scenario A

4.4.3 Generation of Electricity of the Scenario A

Generation of electricity is primarily done by PV array and wind. Diesel generator also produces a small percentage. In month of August and September, only diesel generator is being used due to bad weather condition in terms of sun shine and wind speed (Fig. 4.4).

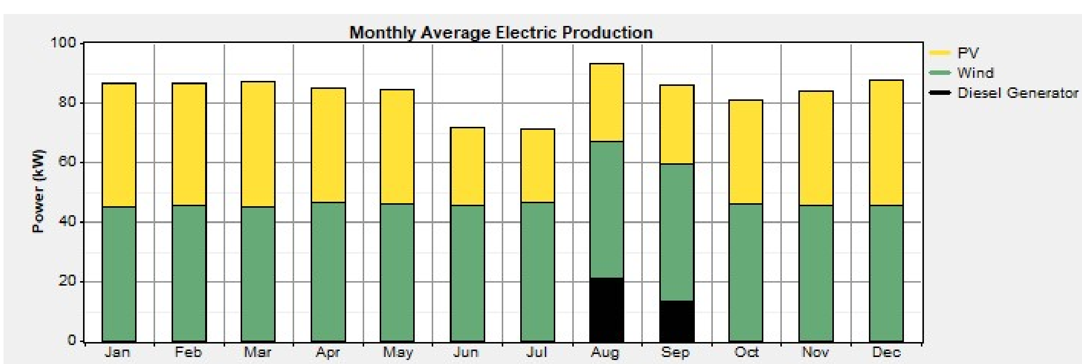


Fig. 4.4 Monthly average Electricity production of scenario A

The electricity generated by individual power units of the selected hybrid system is shown in Fig. 4.5. Power generation PV array accounts for 42% (307,162 kWh/year), wind is 55% (401,891 kWh/year) and diesel generator accounts for 3% (25,020 kWh/year) of total electricity produced by the hybrid system.

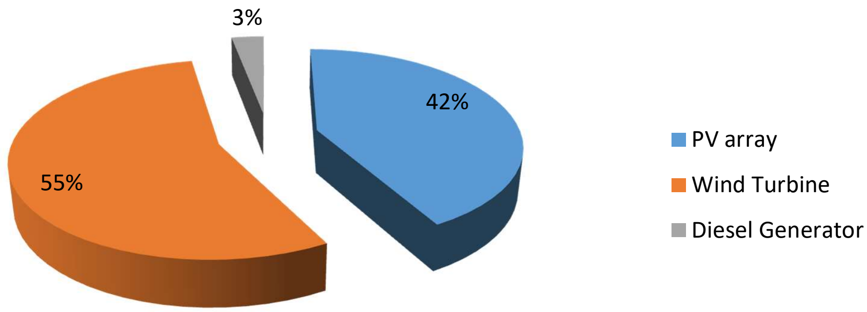
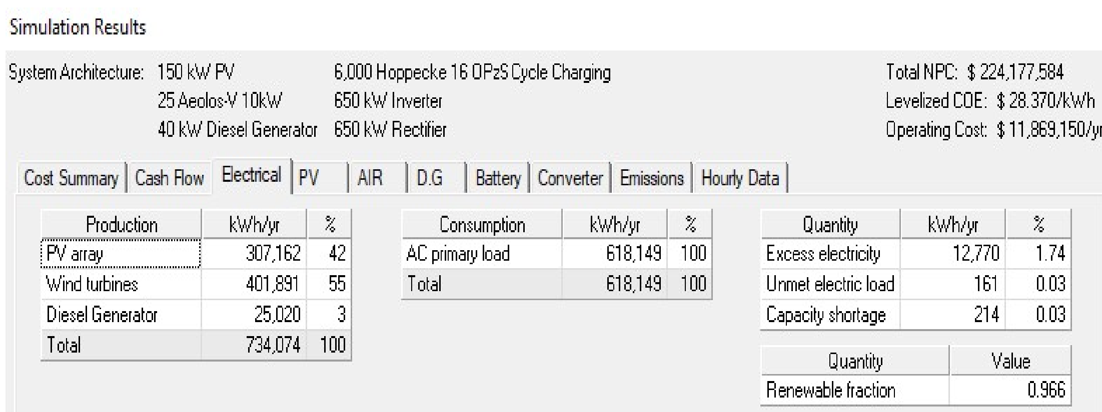


Fig. 4.5 Energy generation percentage share from each component of scenario A

From Fig. 4.6, it is seen that AC consumption load is 618,149 kWh/year which is 100%. Besides that, excess electricity produced 12,770 kWh per year, ummet electric load 161 kWh per year and capacity shortage 214 kWh per year.


Simulation Results

System Architecture: 150 kW PV; 25 Aeolos-V 10kW; 40 kW Diesel Generator; 6,000 Hoppecke 16 OPzS Cycle Charging; 650 kW Inverter; 650 kW Rectifier

Total NPC: $ 224,177,584
Levelized COE: $ 28.370/kWh
Operating Cost: $ 11,869,150/yr

Cost Summary | Cash Flow | Electrical | PV | AIR | D.G | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	307,162	42
Wind turbines	401,891	55
Diesel Generator	25,020	3
Total	734,074	100

Consumption	kWh/yr	%
AC primary load	618,149	100
Total	618,149	100

Quantity	kWh/yr	%
Excess electricity	12,770	1.74
Unmet electric load	161	0.03
Capacity shortage	214	0.03

Quantity	Value
Renewable fraction	0.966

Fig. 4.6 Snapshot of generation and consumption of electricity for Scenario A

4.4.4 **PV Array**

Fig. 4.5 shows the share of electricity generation via solar PV. As noticed from Fig. 4.7 generation is highest during the months March, April as the highest solar radiation striking the earth's surface in these months. Starting from June to September PV power generation is lower than the other months due to rain and cloud coverage of the sky. Table 4.1 shows the PV scheme simulation result.

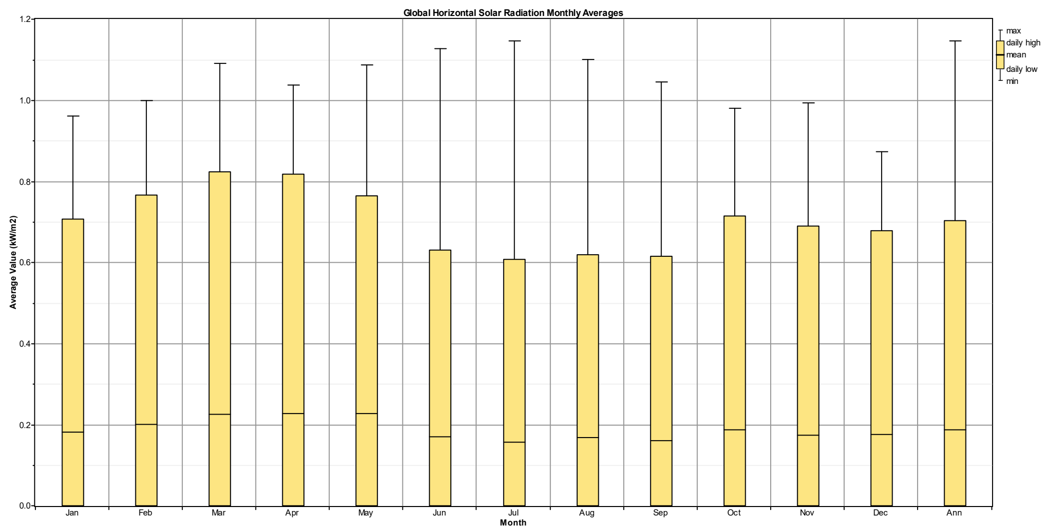


Fig. 4.7 PV array power output monthly averages of scenario A

TABLE 4.1 PV SCHEME SIMULATION RESULT

Quantity	**Unit**	**Value**
Rated capacity	kW	150
Mean output	kWh/d	842
Capacity factor	%	23.4
Total production	kWh/yr	307,162
Minimum output	kW	0
Maximum output	kW	181
PV penetration	%	49.7
Hours of operation	hr/yr	4,374
Levelized cost	Tk/kWh	25.8

The mean power output of PV is about 842 kWh/day. The rated power is 150 kW when sky is clear. Solar PV total hour of operation is 4,374 hour annually. Levelized COE for this system is BDT 25.8/kWh. Total electricity production is 307,162 kWh/year and hour of operation 4,374 hour/year.Fig. 4.8 shows the yearly PV output of scenario A.

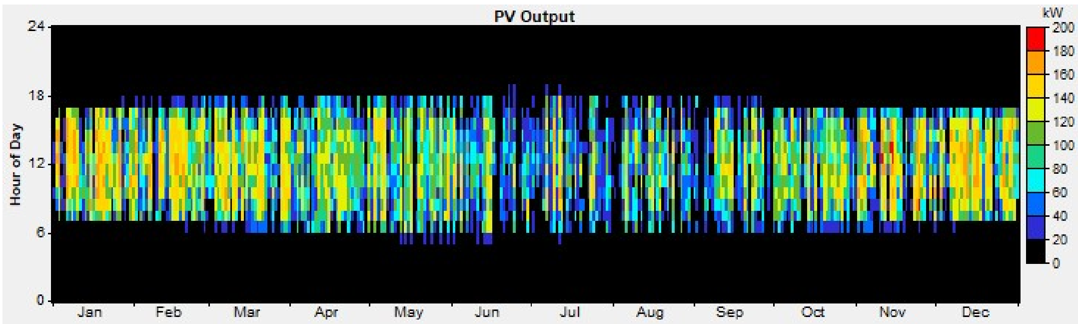


Fig. 4.8 Yearly PV output of scenario A

4.4.5 **Wind Turbine**

Fig. 4.9 shows the output of the wind turbine. We used 25 wind turbines. It fulfills the maximum demand. Almost round the year, wind is contributing to generate electricity.

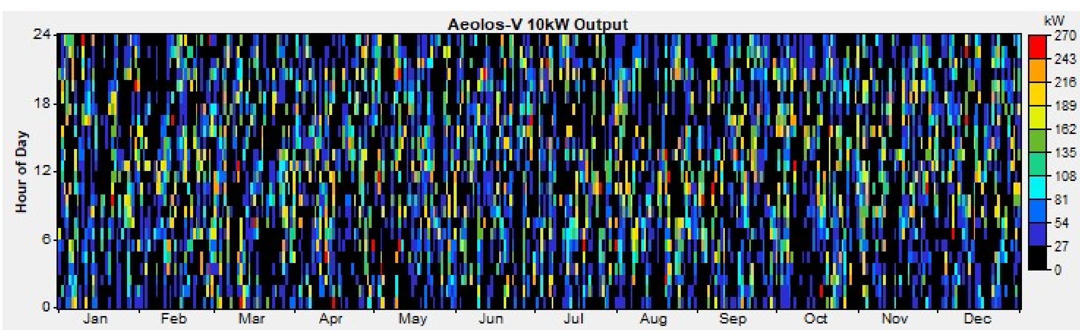


Fig. 4.9 Wind turbine output of scenario A

Table 4.2 shows the wind turbine simulation result. The rated capacity of wind turbine is 250 kW and the mean output is 46 kW. Maximum output is 250 kW.

TABLE 4.2 WIND TURBINE SIMULATION RESULT OF SCENARIO A

Quantity	Unit	Value
Total rated capacity	kW	250
Mean output	kW	46
Capacity factor	%	18.4
Total production	kWh/yr	401,891
Minimum output	kW	0
Maximum output	kW	250
Wind penetration	%	65.0
Hours of operation	hr/yr	6,497
Levelized cost	Tk/kWh	1.53

4.4.6 **Diesel Generator**

System load variation and continuous running of diesel generator at lower load depicts poor diesel engine performance (Fig. 4.10). Only in month of August and September diesel generator is operating. Diesel generator is used as backup power generation. The capacity of the diesel generator is 40 kW. When renewable sources are out of service the generator can fulfill the peak load.

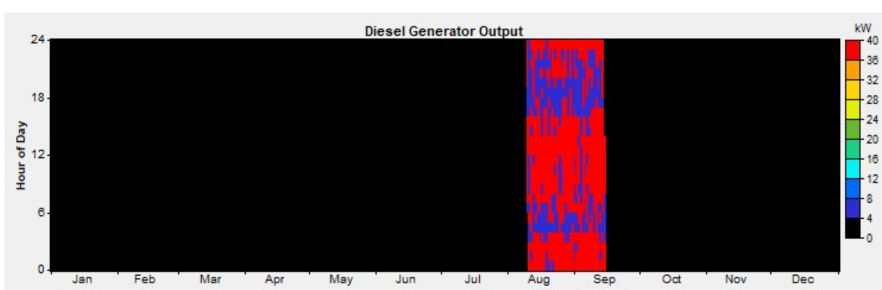


Fig. 4.10 Diesel Generator output of scenario A

Table 4.3 shows the diesel generator simulation result. Generator operates for 872 hours in the year. Electricity production is 25,020 kWh/year. The Fuel consumption is 9,045 L/year.

TABLE 4.3 DIESEL GENERATOR SIMULATION RESULT OF SCENARIO A

Quantity	Unit	Value
Hours of operation	hr/yr	872
Capacity factor	%	7.14
Fixed generation cost	TK/hr	332
Electrical production	kWh/yr	25,020
Min. electrical output	kW	6.00
Max. electrical output	kW	40.0
Fuel consumption	L/yr	9,045
Specific fuel consumption	L/kWh	0.362

4.4.7 **Battery**

Bus voltage is 12 volt. It will require 6,000 number battery of total 24,000 kWh capacity which will have 1000 strings in parallel, and string size is six. Table 4.4 is the battery simulation result and Fig. 4.11 snapshot of frequency histogram & monthly statistics of battery and state of charge of battery bank. Fig. 4.12 shows the battery bank state of charge of scenario A.

TABLE 4.4 BATTERY SIMULATION RESULT OF SCENARIO A

Quantity	Unit	Value
Nominal Capacity	kWh	24,000
Usable nominal capacity	kWh	16,800
Autonomy	Hr	238
Lifetime throughout	kWh	40,806,000
Average energy cost	TK/kWh	0.414
Energy in	kWh/yr	311,669
Energy out	kWh/yr	274,672
Losses	kWh/yr	30,983

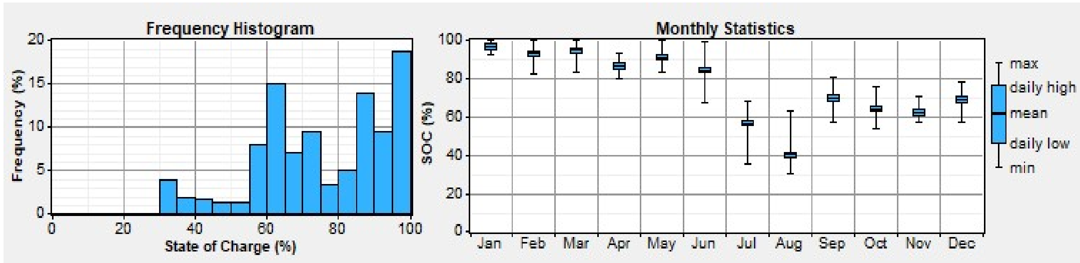


Fig. 4.11 Frequency histogram and monthly statistics of battery of scenario A

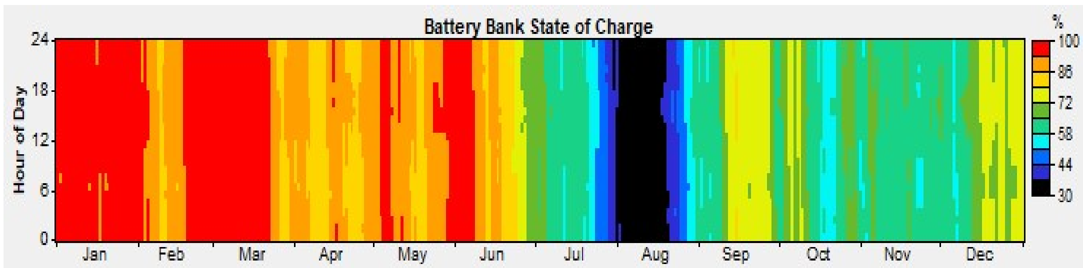


Fig. 4.13 Snapshot of battery bank state of charge of scenario A

4.4.8 Converter

Hours of operation is 8,631 hrs/yr for inverter and 128 hrs/yr for rectifier and amount of loss in inverter is 66,013 kWh/yr and rectifier is 145 kWh/yr. Table 4.5 shows converter simulation result and Figs. 4.13 and 4.14 snapshot of inverter output and rectifier output.

TABLE 4.5 CONVERTER SIMULATION RESULT OF SCENARIO A

Quantity	Unit	Inverter	Rectifier
Capacity	kW	650	650
Mean output	kW	68	1
Minimum output	kW	0	0
Maximum output	kW	226	27
Capacity factor	%	10.4	0.0
Hours of operation	Hrs/yr	8,631	128
Energy in	kWh/yr	660,110	968

Energy out	kWh/yr	594,097	823
Losses	kWh/yr	66,013	145

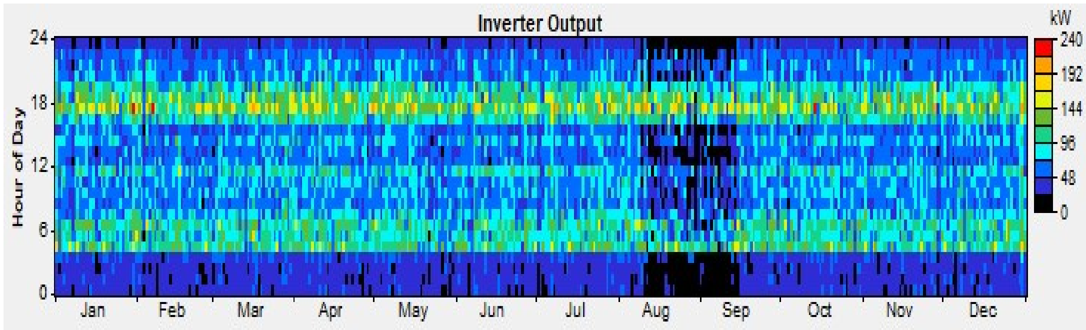


Fig. 4.13 Snapshot of inverter output of scenario A

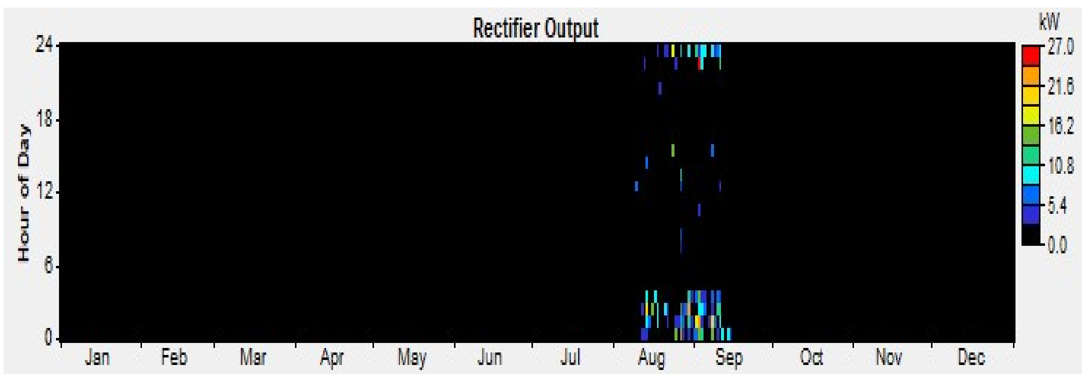


Fig. 4.14 Snapshot of rectifier output of scenario A

4.4.9 **Emissions**

Due to operation of the diesel generators, carbon dioxide and other gases are released. This emission of carbon dioxide gas is the main contributor of greenhouse effect. So the less the amount of this gas that can be released, the better it is for the environment. Table 4.6 shows the amount of carbon dioxide and other pollutant gas released per year.

TABLE 4.6 POLLUTANT RELEASED PER YEAR OF SCENARIO A

Pollutant	Emission (kg/yr)
Carbon dioxide	23,820
Carbon monoxide	58.8
Unburned hydrocarbons	6.51
Particulate matter	4.43
Sulfur dioxide	47.8
Nitrogen oxides	525

4.5 Scenario B-Solar PV- Wind-Biogas Generator

4.5.1 Introduction

This hybrid system consists of 100 kW photovoltaic panel, the number of wind turbine in the selected scenario is 25, 4800 unit attached batteries of total 19,200 kWh capacity and 650 kW converter. Solar irradiation during the month June, July and August is least so the percentage of electricity generated from PV is least. In month of August, the use of biogas is the maximum. Fig. 4.15 shows the block diagram of scenario B of the hybrid configuration system.

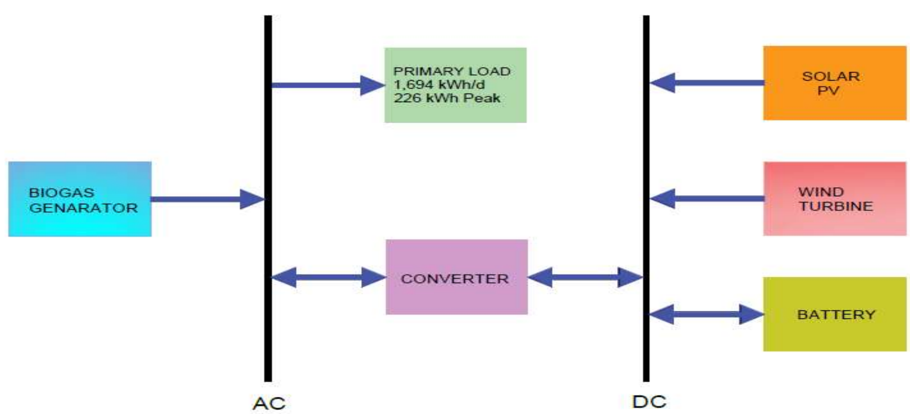
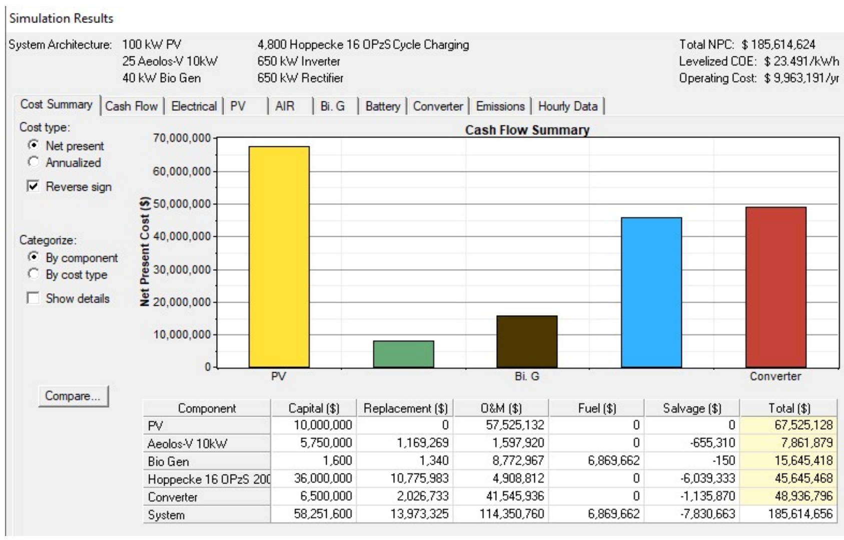


Fig. 4.15 Block diagram of scenario B of the hybrid configuration system

4.5.2 Cash Flow Summary

Cash flow summary is presented in Fig. 4.16 where capital cost is Tk 58,251,600, replacement cost is Tk 13,973,323, O&M cost is Tk 114,350,760 and finally system cost is Tk 185,614,656. . In this scenario, solar do not require any replacement. Total NPC is Tk 185,614,656, Levelized COE is Tk 23.491/kWh and operating cost is Tk 9,963,191 /year.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	10,000,000	0	57,525,132	0	0	67,525,128
Aeolos-V 10kW	5,750,000	1,169,269	1,597,920	0	-655,310	7,861,879
Bio Gen	1,600	1,340	8,772,967	6,869,662	-150	15,645,418
Hoppecke 16 OPzS 200	36,000,000	10,775,983	4,908,812	0	-6,039,333	45,645,468
Converter	6,500,000	2,026,733	41,545,936	0	-1,135,870	48,936,796
System	58,251,600	13,973,325	114,350,760	6,869,662	-7,830,663	185,614,656

Fig. 4.16 Snapshot of Cash flow summary of scenario B

4.5.3 Generation of Electricity

Monthly average Electricity production is given Fig. 4.17. Generation of electricity is primarily done by PV array and wind. Bio generator produces a small percentage. In month of August, bio-generator produces the maximum electricity. Except the month of January, February and December, biogas also produce electricity round the year.

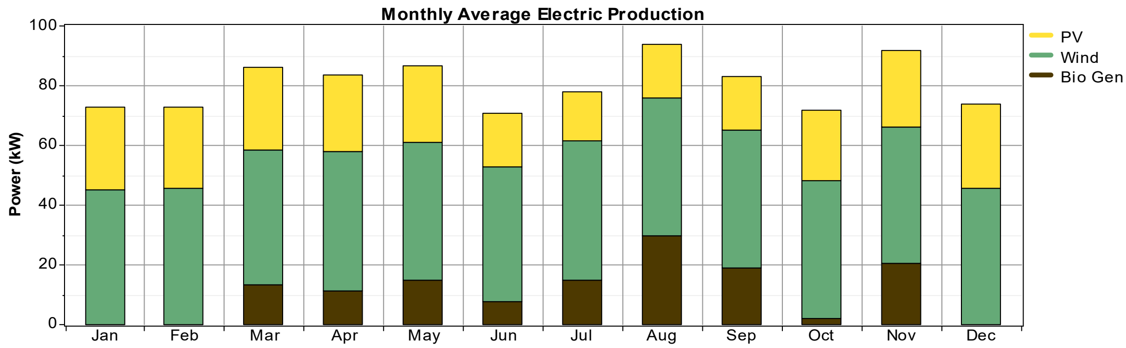


Fig. 4.17 Monthly average Electricity production

The electricity generated by individual power units of the selected hybrid system is shown in Fig. 4.18. PV array power production accounts for 29% (204,775 kWh/year), wind is 57% (401,891 kWh/year) and biogas generator accounts for 14% (98,040 kWh/year) of total electricity produced by the hybrid system.

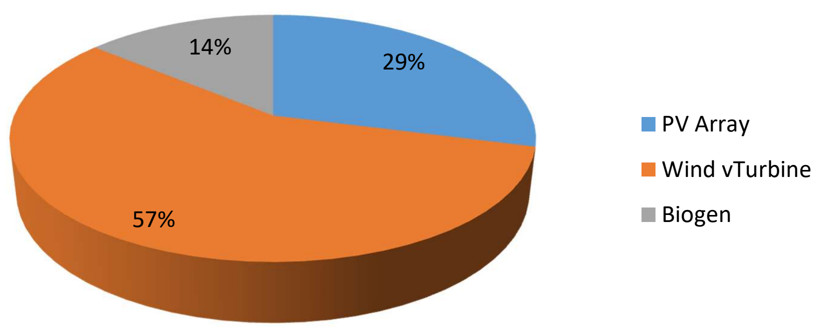
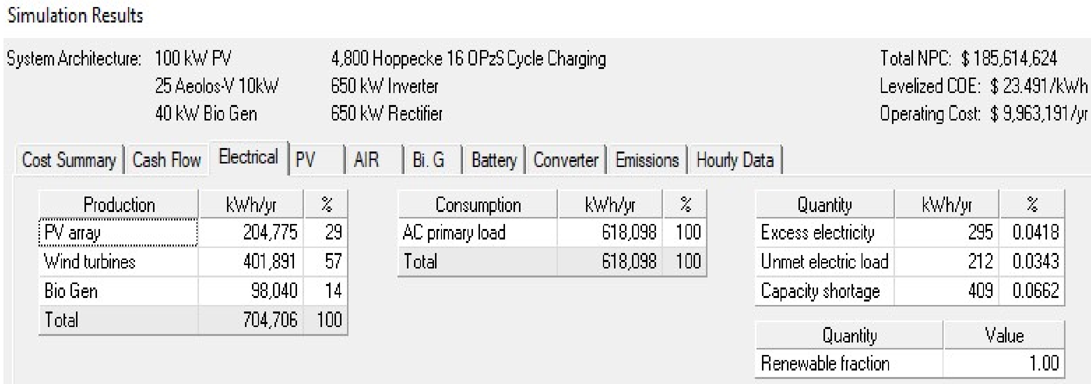


Fig. 4.18Energy generation percentage share from each component

From Fig. 4.19, it is seen that AC consumption load is 618,149 kWh/year that is 100%. Besides that, excess electricity produced 295 kWh per year, ummet electric load 212 kWh per year and capacity shortage 409 kWh per year.


Simulation Results

System Architecture: 100 kW PV | 25 Aeolos-V 10kW | 40 kW Bio Gen | 4,800 Hoppecke 16 OPzS Cycle Charging | 650 kW Inverter | 650 kW Rectifier

Total NPC: $ 185,614,624
Levelized COE: $ 23.491/kWh
Operating Cost: $ 9,963,191/yr

Cost Summary | Cash Flow | Electrical | PV | AIR | Bi. G | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	204,775	29
Wind turbines	401,891	57
Bio Gen	98,040	14
Total	704,706	100

Consumption	kWh/yr	%
AC primary load	618,098	100
Total	618,098	100

Quantity	kWh/yr	%
Excess electricity	295	0.0418
Unmet electric load	212	0.0343
Capacity shortage	409	0.0662

Quantity	Value
Renewable fraction	1.00

Fig. 4.19 Snapshot of generation and consumption of electricity for Scenario B

4.5.4 **PV Array**

Fig. 4.18 shows the share of electricity generation via solar PV. As noticed from Fig. 4.20 generation is highest during the months March, April due to the highest solar radiation striking the earth's surface in these months. Starting from June to September PV power generation is lower than the other months due to cloud coverage of the sky. Table 4.7 shows the PV scheme simulation result.

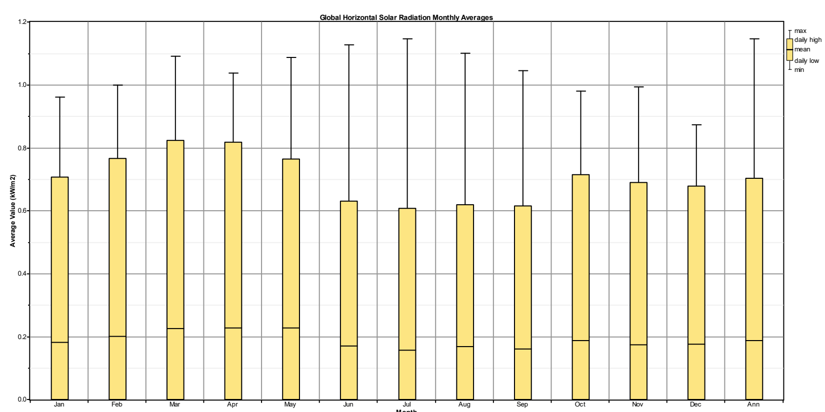


Fig. 4.20 PV array power output monthly averages

TABLE 4.7 PV SCHEME SIMULATION RESULT

Quantity	Unit	Value
Rated capacity	kW	100
Mean output	kWh/d	561
Capacity factor	%	23.4
Total production	kWh/yr	204,775
PV penetration	%	33.1
Hours of operation	hr/yr	4,374
Levelized cost	Tk/kWh	25.8

The mean power output of PV is about 561 kWh/day. The rated power is 100 kW when sky is clear. Solar PV total hour of operation is 4,374 hour annually. Levelized cost of electricity for this system is BDT 25.8/kWh. Fig. 4.21 shows the Daily map for Solar PV.

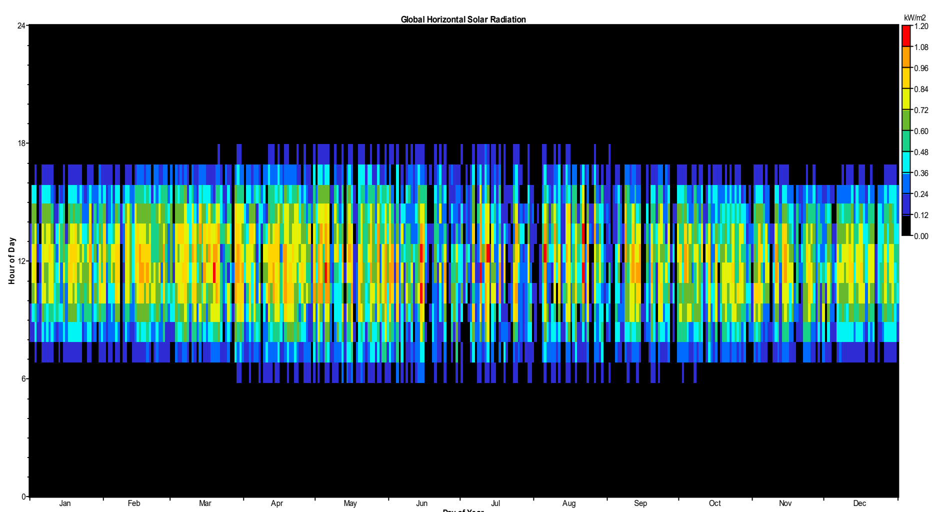


Fig. 4.21 Daily Map for Solar PV

4.5.5 **Wind Turbine**

Fig. 4.22 shows the output of the wind turbine. We used 25 wind turbines. It fulfills the maximum demand. Almost round the year, wind is contributing to generate electricity.

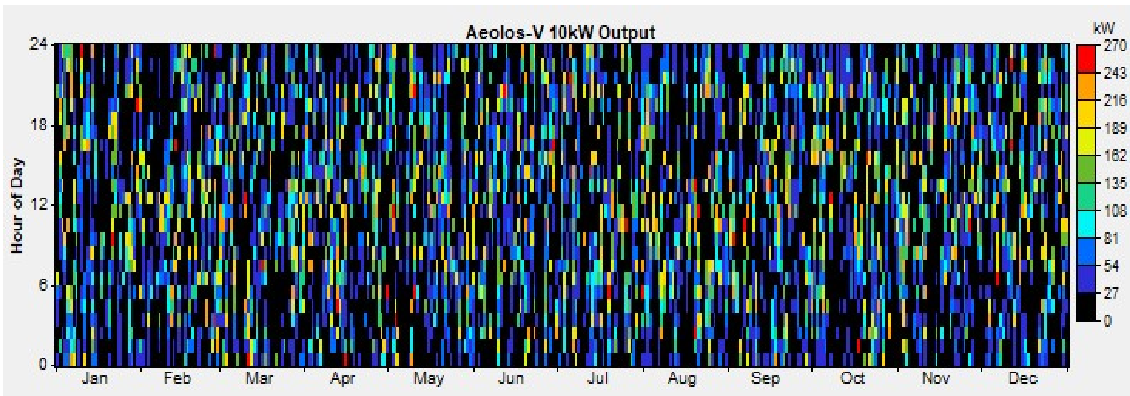


Fig. 4.22 Daily Map for Wind turbine

Table 4.8 shows the wind turbine simulation result. The rated capacity of wind turbine is 250 kW and the mean output is 46 kW. Maximum output is 250 kW.

TABLE 4.8 WIND TURBINE SIMULATION RESULT B

Quantity	Unit	Value
Total rated capacity	kW	250
Mean output	kW	46
Capacity factor	%	18.4
Total production	kWh/yr	401,891
Minimum output	kW	0
Maximum output	kW	250
Wind penetration	%	65.0
Hours of operation	hr/yr	6,497
Levelized cost	Tk/kWh	1.53

4.5.6 **Biogas Generator**

Fig. 4.23 shows the yearly biogas generator output and table 4.9 is the biogas generator simulation result.

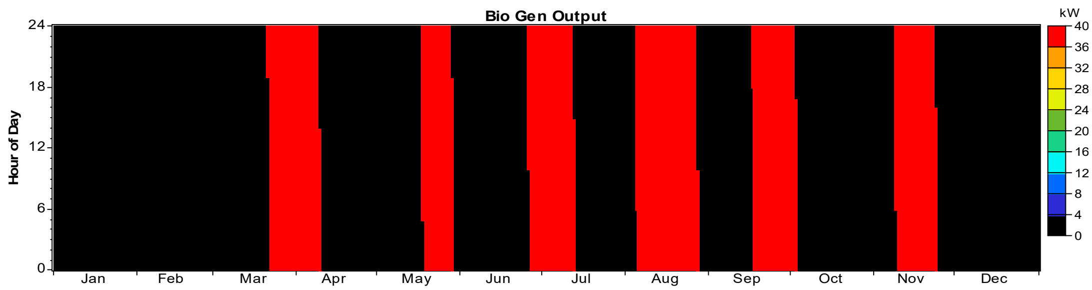


Fig. 4.23 Yearly biogas generator output

The rated capacity factor of the biogas generator is 28.0. Hours of operation of the biogas generator are 2,451 hours/year. Maximum electrical output is 40 kW.

TABLE 4.9 BIOGAS GENERATOR SIMULATION RESULT B

Quantity	**Unit**	**Value**
Hours of operation	hr/yr	2,451
Number of starts	starts/yr	6
Capacity factor	%	28.0
Fixed generation cost	Tk/hr	485
Electrical production	kWh/yr	98,040
Min. electrical output	kW	40.0
Max. electrical output	kW	40.0
Bio feedstock Consumption	t/yr	269
Specific fuel consumption	kg/kWh	1,918

4.5.7 **Battery**

Bus voltage is 12 volt. It will require 4,800 number battery of total 19,200 kWh capacity, which will have 800 strings in parallel, and string size is six. Table 4.10 is the battery simulation result and Fig. 4.24 shows snapshot of frequency histogram & monthly statistics of battery and Fig. 4.25 shows state of charge of battery bank.

TABLE 4.10 SHOWING THE SIMULATED RESULTS WITH RESPECT TO BATTERY

Quantity	Unit	Value
Nominal Capacity	kWh	19,200
Usable nominal capacity	kWh	13,440
Autonomy	Hr	190
Lifetime throughout	kWh	32,644,800
Average energy cost	Tk/kWh	0.044
Energy in	kWh/yr	278,576
Energy out	kWh/yr	250,942
Storage depletion	kWh/yr	10,300
Losses	kWh/yr	17,334
Annual throughout	kWh/yr	270,598

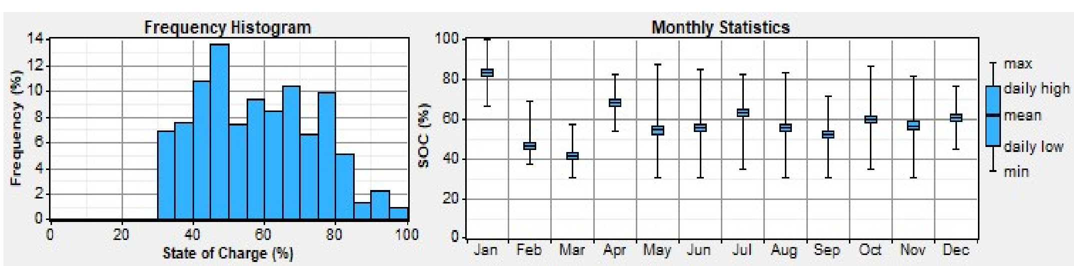


Fig. 4.24 Snapshot of frequency histogram and state of charge

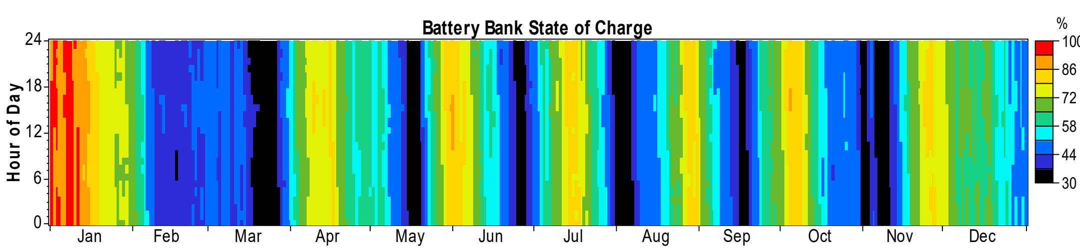


Fig. 4.25Snapshot of battery bank state of charge

4.5.8 Converter

Hours of operation is 8,352 hrs/yr for inverter and 408 hrs/yr for rectifier and amount of loss in inverter is 58,167 kWh/yr and rectifier is 514 kWh/yr. Table 4.11 shows converter simulation result and Figs. 4.26 and 4.27 shows snapshot of inverter output and rectifier output respectively.

TABLE 4.11 CONVERTER SIMULATION RESULT

Quantity	Unit	Inverter	Rectifier
Capacity	kW	650	650
Mean output	kW	60	1
Maximum output	kW	226	34
Capacity factor	%	9.2	0.1
Hours of operation	Hrs/yr	8,352	408
Energy in	kWh/yr	581,652	3,427
Energy out	kWh/yr	523,484	2,913
Losses	kWh/yr	58,167	514

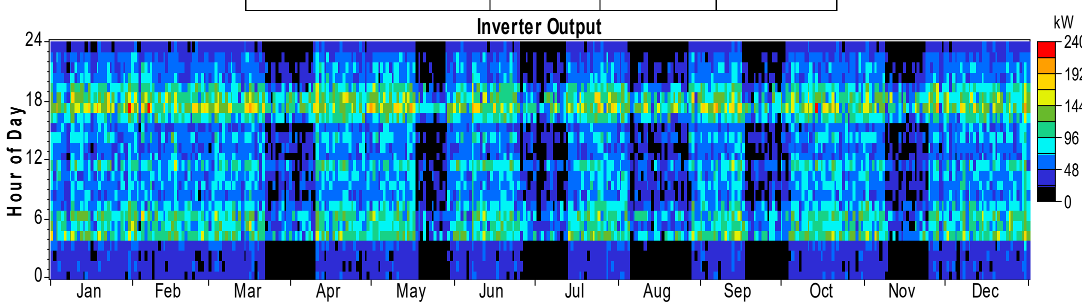


Fig. 4.26 Snapshot of inverter output

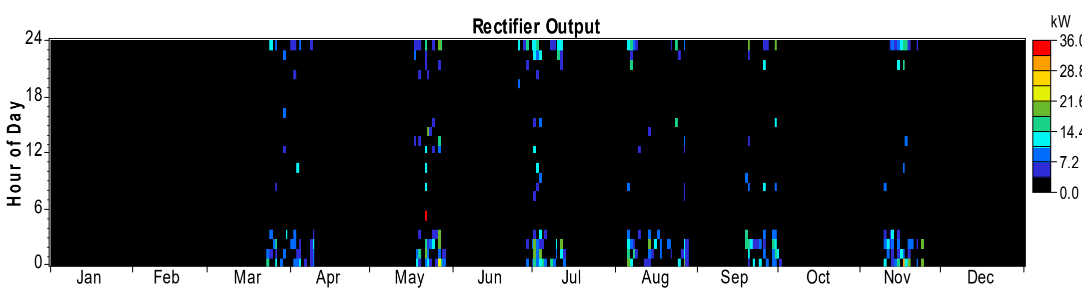


Fig. 4.27 Snapshot of rectifier output

4.5.9 Emissions

Due to operation of the biogas generators, carbon dioxide and other gases are released. This emission of carbon dioxide gas is the main contributor of greenhouse effect. So the less the amount of this gas that can be released, the better it is for the environment. Table 4.12 shows the amount of carbon dioxide and other pollutant gas released per year.

TABLE 4.12 POLLUTANTS RELEASED PER YEAR

Pollutant	Emission (kg/yr)
Carbon dioxide	46.5
Carbon monoxide	1.75
Unburned hydrocarbons	0.193
Particulate matter	0.132
Sulfur dioxide	0
Nitrogen oxides	15.6

According to all the previous mention benchmarks, scenario C is found to be the best option. It has minimum NPC and COE though renewable fraction of operation is a bit low than other two options. Scenario C is the best hybrid configuration among all the possible combination. The selected scenario, which includes Solar PV-wind-diesel generator-biomass-Battery-converter, is discussed below.

4.6 Scenario C-Solar PV-Wind-Biogas Generator-Diesel Generator

4.6.1 Introduction

The selected hybrid system consists of 100 kW photovoltaic panel, the number of wind turbine in the selected scenario is 25, a 30 kW biogas generator, a 40 kW diesel generator, 2400 unit batteries of total 9,600 kWh capacity, and 65 kW converter. Solar irradiation during the month June, July and August is least so the percentage of electricity generated in these years from PV is least. Round the year, wind turbine provides the maximum output. Less the month of January, biogas generator used round the year where from July to August uses the maximum. The total operation of biogas generator is 2,467 hour in a year. Diesel generator is used as an auxiliary power generation. Diesel generator has to serve only 1,203 hours in a year that is used also round the year when solar, wind and biogas resource are meager. Fig. 4.28 shows the block diagram of scenario C of the hybrid configuration system.

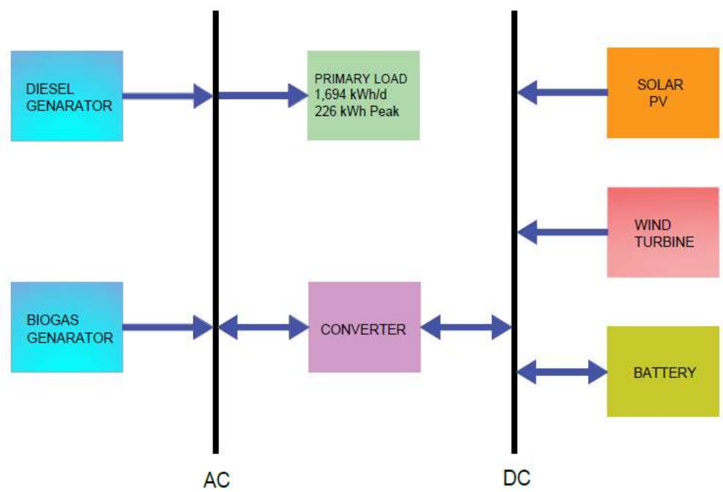
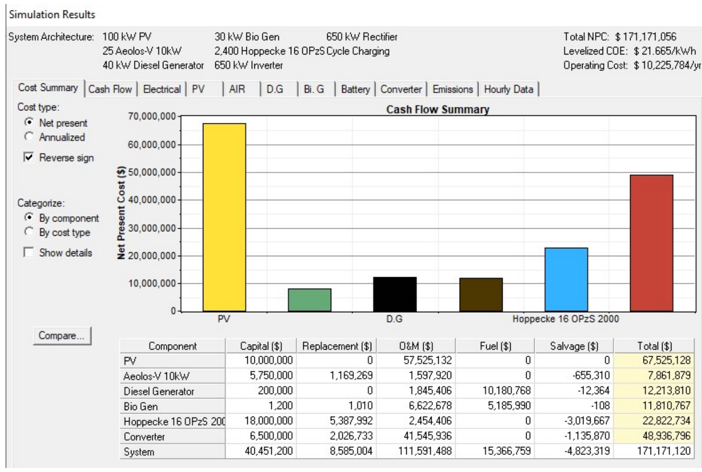


Fig. 4.28 Block diagram of scenario C of the hybrid configuration system

4.6.2 **Cash Flow Summary**

Cash flow summary is presented in Fig. 4.29 where capital cost is Tk 40,451,200, replacement cost is Tk 8,585.004, O&M cost is Tk 111,591,488 and finally system cost is Tk 171,171,120. In this scenario, solar PV and diesel generator do not require any replacement. Total NPC is tk 171,171,120, Levelized COE is Tk 21.665/kWh and operating cost is Tk 10,225,784 /year.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	10,000,000	0	57,525,132	0	0	67,525,128
Aeolos-V 10kW	5,750,000	1,169,269	1,597,920	0	-655,310	7,861,879
Diesel Generator	200,000	0	1,845,406	10,180,768	-12,364	12,213,810
Bio Gen	1,200	1,010	6,622,678	5,185,990	-108	11,810,767
Hoppecke 16 OPzS 200	18,000,000	5,387,992	2,454,406	0	-3,019,667	22,822,734
Converter	6,500,000	2,026,733	41,545,936	0	-1,135,870	48,936,796
System	40,451,200	8,585,004	111,591,488	15,366,759	-4,823,319	171,171,120

Fig. 4.29 Snapshot of Cash flow summary of scenario C

4.6.3 Generation of Electricity

Generation of electricity is primarily done by PV array and wind (Fig. 4.30). Bio generator and diesel generator generate a small percentage of electricity. In month of Jul and August, bio-generator and diesel generator produce the maximum electricity.

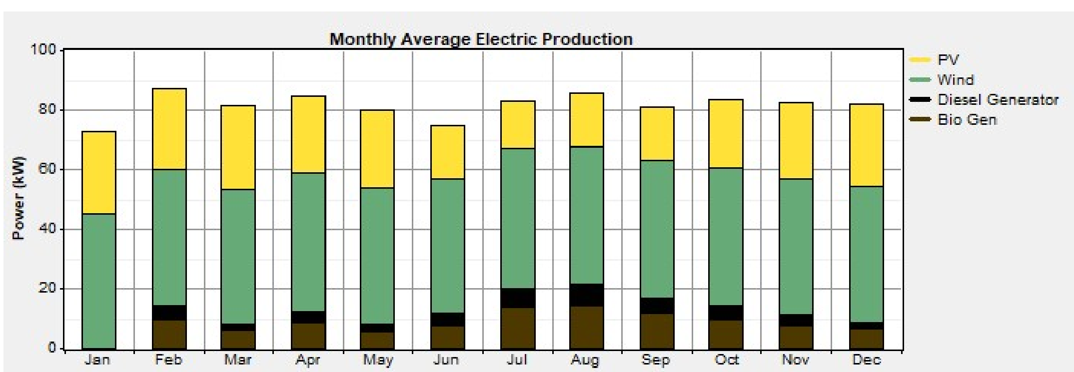


Fig. 4.30 Monthly average Electricity production

The electricity generated by individual power units of the selected hybrid system is shown in Fig. 4.31. PV array power production accounts for 29% (204,775 kWh/year), wind is 56% (401,891 kWh/year), biogas generator accounts for 10% (74,010 kWh/year) and diesel generator accounts for 5% (33,611 kWh/year) of total electricity produced by the hybrid system.

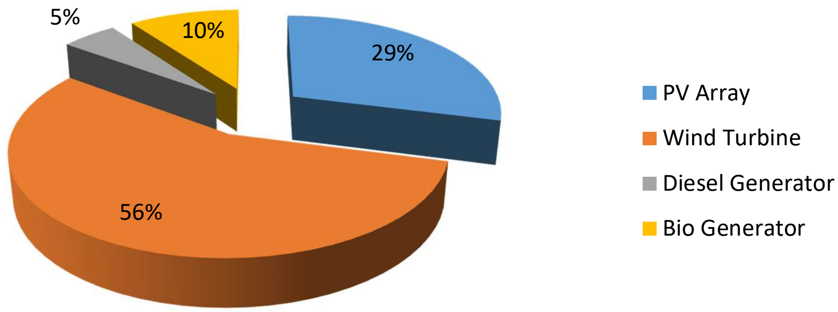
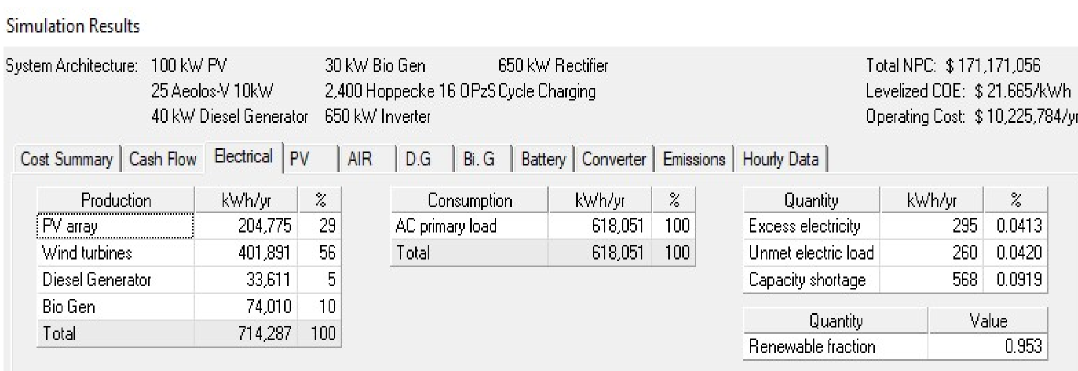


Fig. 4.31 Energy generation percentage share from each component

From Fig. 4.32, it is seen that AC consumption load is 618,051 kWh/year which is 100%. Besides that, excess electricity produced 295 kWh per year, ummet electric load 260 kWh per year and capacity shortage 568 kWh per year.



Simulation Results

System Architecture: 100 kW PV, 25 Aeolos-V 10kW, 40 kW Diesel Generator, 30 kW Bio Gen, 2,400 Hoppecke 16 OPzS Cycle Charging, 650 kW Inverter, 650 kW Rectifier

Total NPC: $ 171,171,056
Levelized COE: $ 21.665/kWh
Operating Cost: $ 10,225,784/yr

Cost Summary | Cash Flow | Electrical | PV | AIR | D.G | Bi. G | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	204,775	29
Wind turbines	401,891	56
Diesel Generator	33,611	5
Bio Gen	74,010	10
Total	714,287	100

Consumption	kWh/yr	%
AC primary load	618,051	100
Total	618,051	100

Quantity	kWh/yr	%
Excess electricity	295	0.0413
Unmet electric load	260	0.0420
Capacity shortage	568	0.0919

Quantity	Value
Renewable fraction	0.953

Fig. 4.32 Snapshot of generation and consumption of electricity for Scenario

4.6.4 **PV Array**

Fig. 4.31 shows the share of electricity generation via solar PV. As noticed from Fig. 4.33 generation is highest during the months March, April as the highest solar radiation striking the earth's surface in these months. Starting from June till September

PV power generation is lower than the other months due to rain and cloud coverage of the sky. Table 4.13 shows the PV scheme simulation result.

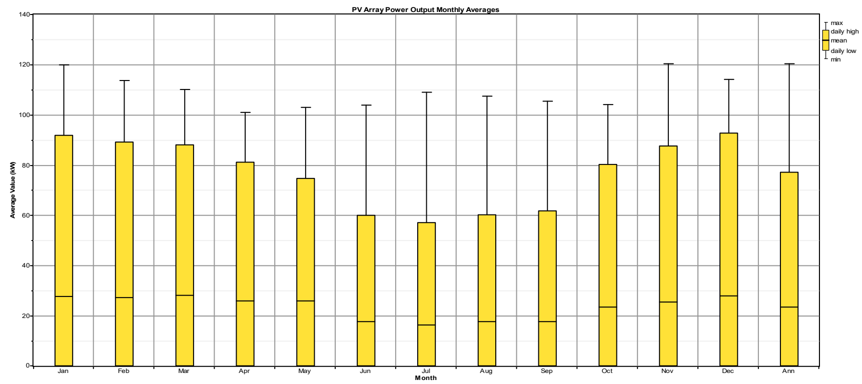


Fig. 4.33 PV array power output monthly averages

TABLE 4.13 PV SCHEME SIMULATION RESULT

Quantity	**Unit**	**Value**
Rated capacity	kW	100
Mean output	kWh/d	561
Capacity factor	%	23.4
Total production	kWh/yr	204,775
Minimum output	kW	0
Maximum output	kW	120
PV penetration	%	33.1
Hours of operation	hr/yr	4,374
Levelized cost	Tk/kWh	25.8

The mean power output of PV is about 561 kWh/day. The rated power is 100 kW when sky is clear. Solar PV total hour of operation is 4,374 hour annually. Levelized cost of electricity for this system is BDT 25.8/kWh. Fig. 4.34 shows the yearly PV output.

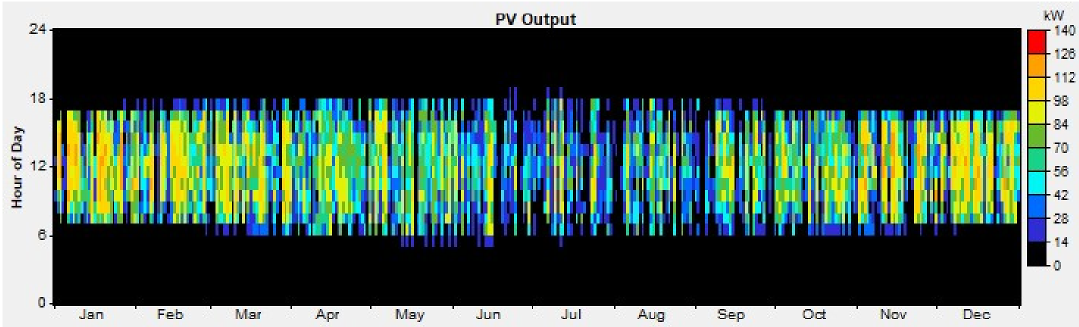


Fig. 4.34 Yearly PV output

4.6.5 **Biogas Generator**

Fig. 4.35 shows the yearly biogas generator output and Table 4.14 is the biogas generator simulation result.

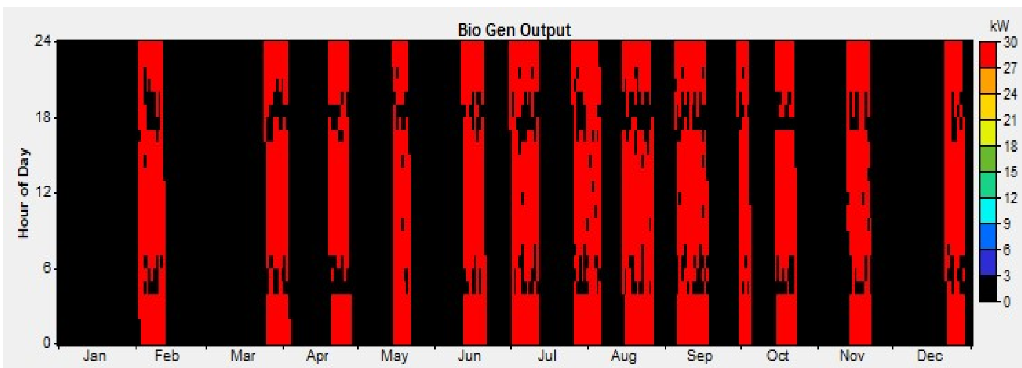


Fig. 4.35 Yearly biogas generator output

The rated capacity factor of the biogas generator is 28.2. Hours of operation of the biogas generator is 2,467 hours/year. Maximum electrical output is 30 kW.

TABLE 4.14 BIOGAS GENERATOR SIMULATION RESULT

Quantity	**Unit**	**Value**
Hours of operation	hr/yr	2,467
Number of starts	starts/yr	241
Capacity factor	%	28.2
Fixed generation cost	Tk/hr	363
Marginal generation cost	Tk/kWh	0.367

Electrical production	kWh/yr	74,010
Min. electrical output	kW	30.0
Max. electrical output	kW	30.0
Bio feedstock Consumption	t/yr	203
Specific fuel consumption	kg/kWh	1,919

4.6.6 **Wind Turbine**

Fig. 4.36 shows the output of the wind turbine. We used 25 wind turbines. It fulfills the maximum demand. Round the year, wind turbine contributes the production of electricity.

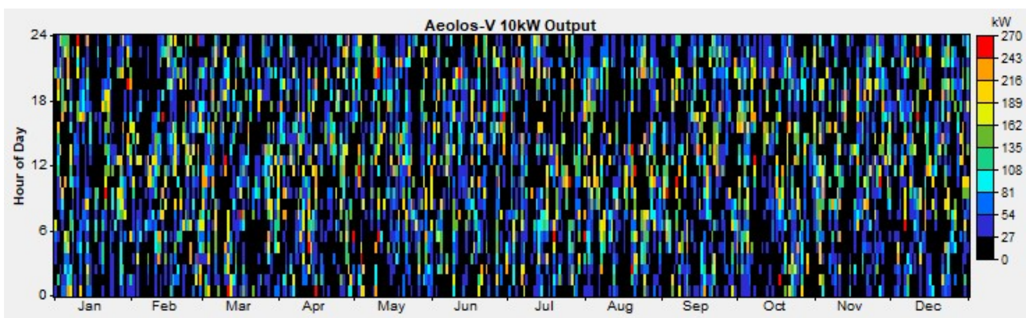


Fig. 4.36 Wind turbine output

Table 4.15 shows the wind turbine simulation result. The rated capacity of wind turbine is 250 kW and the mean output is 46 kW. Maximum output is 250 kW.

TABLE 4.15 WIND TURBINE SIMULATION RESULT

Quantity	**Unit**	**Value**
Total rated capacity	kW	250
Mean output	kW	46
Capacity factor	%	18.4
Total production	kWh/yr	401,891
Minimum output	kW	0
Maximum output	kW	250

Wind penetration	%	65.0
Hours of operation	hr/yr	6,497
Levelized cost	Tk/kWh	1.53

4.6.7 **Diesel Generator**

System load variation and continuous running of diesel generator at lower load depicts poor diesel engine performance. We used diesel generator as backup power generation. The capacity of the diesel generator is 40 kW (Fig. 4.37). When renewable sources are out of service the generator can fulfill the peak load.

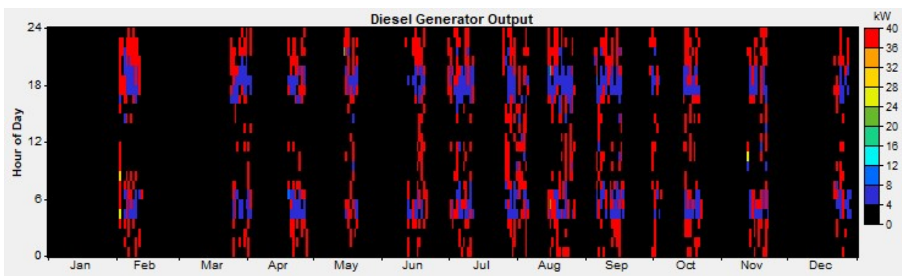


Fig. 4.37 Diesel Generator output

Table 4.16 shows the diesel generator simulation result. Generator operates for 1,203 hours in the year. The efficiency of the generator is 27.9%.

TABLE 4.16 DIESEL GENERATOR SIMULATION RESULT

Quantity	**Unit**	**Value**
Hours of operation	hr/yr	1,203
Number of starts	starts/yr	425
Capacity factor	%	9.59
Fixed generation cost	Tk/hr	322
Electrical production	kWh/yr	33,611
Min. electrical output	kW	6.00
Max. electrical output	kW	40.0
Fuel consumption	L/yr	12,252

Specific fuel consumption	L/kWh	0.365
Fuel energy input	kWh/yr	120,564

4.6.8 **Battery**

Bus voltage is 12 volt. It will require 2400 number battery of total 9,600 kWh capacity, which will have 400 strings in parallel, and string size is six. Table 4.17 is the battery simulation result and fig. 4.38 shows snapshot of frequency histogram & Fig. 4.39 shows monthly statistics of battery and state of charge of battery bank.

TABLE 4.17 BATTERY SIMULATION RESULT

Quantity	**Unit**	**Value**
Nominal Capacity	kWh	9,600
Usable nominal capacity	kWh	6,720
Autonomy	Hr	95.2
Lifetime throughout	kWh	16,322,400
Average energy cost	Tk/kWh	0.878
Energy in	kWh/yr	286,313
Energy out	kWh/yr	249,258
Storage depletion	kWh/yr	2,744
Losses	kWh/yr	34,311
Annual throughout	kWh/yr	268,782

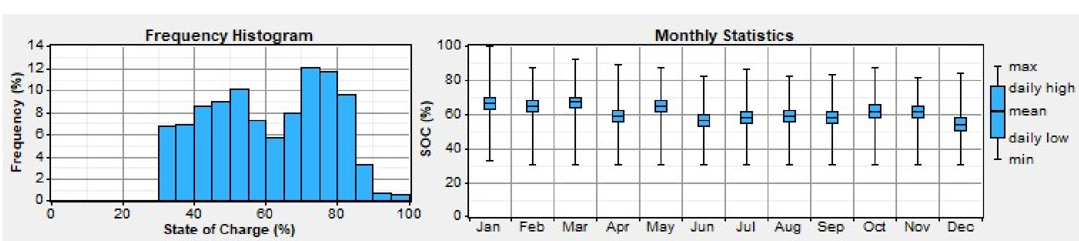


Fig. 4.38 Snapshot of frequency histogram and monthly statistics of battery

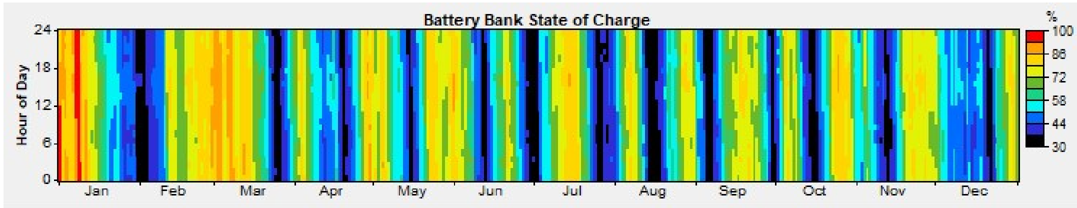


Fig. 4.39 Snapshot of battery bank state of charge

4.6.9 **Converter**

Hours of operation is 8,163 hrs/yr for inverter and 593 hrs/yr for rectifier and amount of loss in inverter is 57,560 kWh/yr and rectifier is 1,247 kWh/yr. Table 4.18 shows converter simulation result and Figs. 4.40 and 4.41 shows snapshot of inverter output and rectifier output respectively.

TABLE 4.18 CONVERTER SIMULATION RESULT

Quantity	**Unit**	**Inverter**	**Rectifier**
Capacity	kW	650	650
Mean output	kW	59	1
Maximum output	kW	226	34
Capacity factor	%	9.1	0.1
Hours of operation	Hrs/yr	8,163	593
Energy in	kWh/yr	576,384	8,314
Energy out	kWh/yr	518,744	7,067
Losses	kWh/yr	57,640	1,247

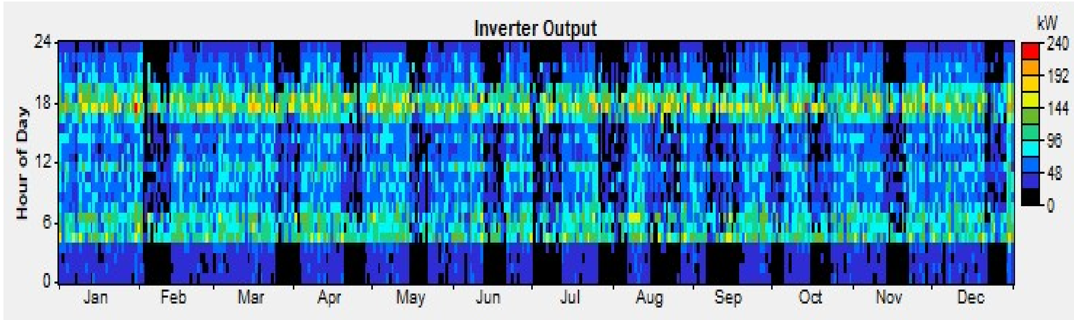


Fig. 4.40 Snapshot of inverter output

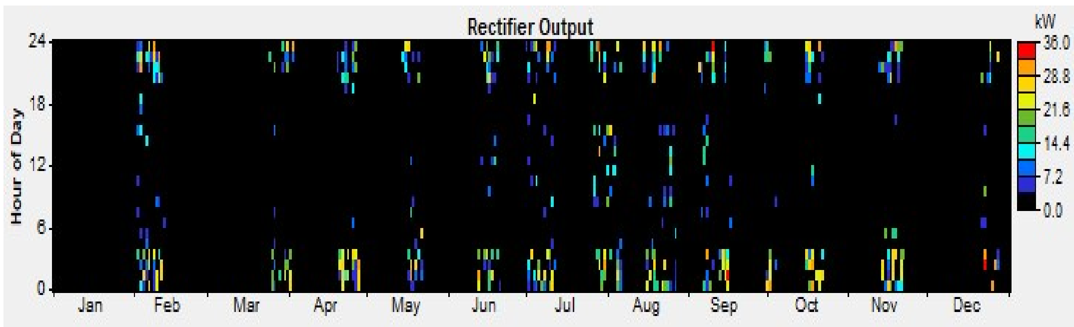


Fig. 4.41 Snapshot of rectifier output

4.6.10 **Emissions**

Due to operation of the diesel and biogas generators, carbon dioxide and other gases are released. This emission of carbon dioxide gas is the main contributor of greenhouse effect. So the less the amount of this gas that can be released, the better it is for the environment. Table 4.19 shows the amount of carbon dioxide and other pollutant gas released per year.

TABLE 4.19 POLLUTANTS RELEASED PER YEAR

Pollutant	**Emission (kg/yr)**
Carbon dioxide	32,300
Carbon monoxide	81
Unburned hydrocarbons	8.97

Particulate matter	6.1
Sulfur dioxide	64.8
Nitrogen oxides	722

4.7 Analysis of Results

Analysis of HOMER result for the combination of selected hybrid power system for Swarna Dweep Island is illustrated in this section. After introducing all the input variables into the modeling tool, the software is run repeatedly to get the results. The simulation results are presented in an increasing order of NPC from top to bottom. So a renewable based hybrid power system is selected, based primarily on minimum NPC. Moreover, COE and renewable fraction could be used for ranking of power generating schemes in order to get the best renewable based hybrid combination. COE is measured in Bangladeshi Taka (Bangladeshi currency).

4.8 Simulation Model

Fig. 4.42 shows the architecture of the hybrid power system design using HOMER that consists of PV array, wind turbine, bio-generator, converter, load, battery for an off grid area. To estimate the system performance under different situations, HOMER simulates this arrangement on different costs such as the estimated initial capital cost, operation and maintenance cost, replacement cost, COE, etc. The main components of the grid connected hybrid system are wind turbine, PV array, bio-generator, battery bank and a power converter.

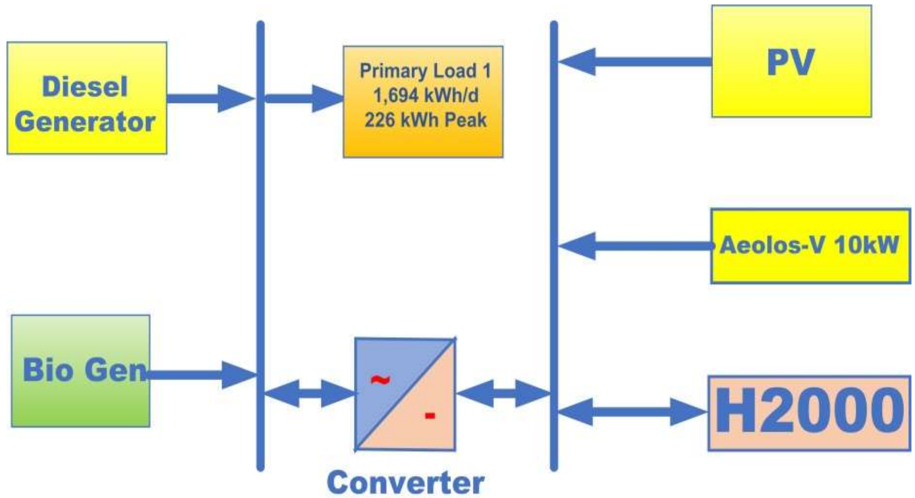
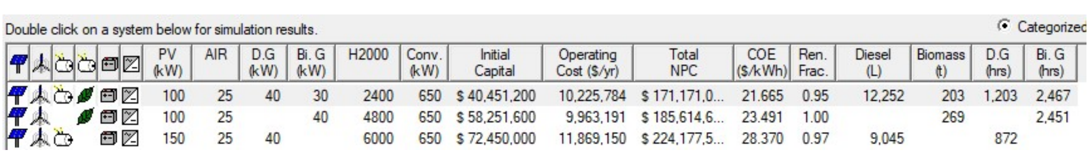


Fig. 4.42Architecture of the hybrid power system design using HOMER

4.9 Analysis of Different Scenarios of the Hybrid Configurations

4.9.1 Simulation Analysis

It is the key target to obtain the hybrid energy production model which costs the least per kWh or least NPC. After several of simulations, HOMER displays the hybrid configurations with respect to NPC and cost/kWh. The output simulation is a list of feasible combinations of PV, wind, biogas, diesel generator, converter and battery for hybrid system set-up. The best energy system were selected with less NPC, less COE, high renewable fraction, less excess electricity and less fuel consumption. Fig. 4.43 shows the screenshot of simulation results of the hybrid configuration system from HOMER.


Double click on a system below for simulation results. Categorized

PV (kW)	AIR	D.G (kW)	Bi. G (kW)	H2000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Biomass (t)	D.G (hrs)	Bi. G (hrs)
100	25	40	30	2400	650	$ 40,451,200	10,225,784	$ 171,171,0...	21.665	0.95	12,252	203	1,203	2,467
100	25		40	4800	650	$ 58,251,600	9,963,191	$ 185,614,6...	23.491	1.00		269		2,451
150	25	40		6000	650	$ 72,450,000	11,869,150	$ 224,177,5...	28.370	0.97	9,045		872	

Fig. 4.43 Screenshot of Simulation results of the hybrid configuration system from HOMER

4.9.2 **Optimization Analysis of the Different Scenario**

In Fig. 4.43, a list has been presented of different configurations with respect to the ascending order of respective COE and NPC. Primary load of Swarna Dweep is 1694 kWh/d and peak load is 226 kW. Scenario A consists of PV array (100 kW), a wind turbine (250 kW), a diesel generator (40 kW), biogas generator (30 kW), converter (650 kW) and 2400 batteries which is economically the most feasible with COE 21.655 Tk /kWh and a minimum NPC of Tk 171,171,120 without any annual energy shortage.

The second optimum system configuration (scenario B) is the combination of solar arrays (100kW), a wind turbine (250 kW), biogas generator (40 kW), converter (650 kW) and 2000 batteries. In this configuration, diesel generator has been eliminated and the number of battery has been more doubled (4800). In this combination, Total NPC is increased slightly to Tk 185,614,656 and COE has increased slightly to Tk 23.491 Tk/kWh.

The third optimum system configuration (scenario C) is the combination of Solar PV, wind turbine, diesel Generators, battery storage, and inverter, In this scenario, the number of diesel generators are equal to the first configuration, but the solar arrays is increased to 150 kW from 100 kW and biogas generator has been removed. In this condition, the Total NPC grows significantly.

TABLE 4.20 OPTIMIZED SYSTEM ARCHITECTURES FOR THE HYBRID SYSTEM

Scen ario	System Configurations	Size of PV (kW)	Number of wind Turbine	Size of Diesel Generato r (DG)(kW)	Size of Biogas Generator (BG) (kW)	Number of Battery (2000Ah /12 V)	Size of Inverter (kW)
A	PV-Wind-DG	150	25	40	-	6000	650
B	PV-Wind-BG	100	25	-	40	4800	650
C	PV-Wind-BG-DG	100	25	40	30	2400	650

In summary of the optimized systems in table 4.20, three hybrid energy systems are presented. Out of three, in scenario B, BG and scenario A, DG is considered as a part of hybrid system. The scenario A and B requires more storage capacity 6000 and 4800 (2000 Ah/12 V) respectively.

4.9.3 **Comparison based on replacement cost and O&M cost**

The comparison between replacement cost and operation &maintenance cost of different scenarios are exhibited in the Fig. 4.44. In all the cases, scenarios A is the best option comparing with replacement cost and operation &maintenance cost.

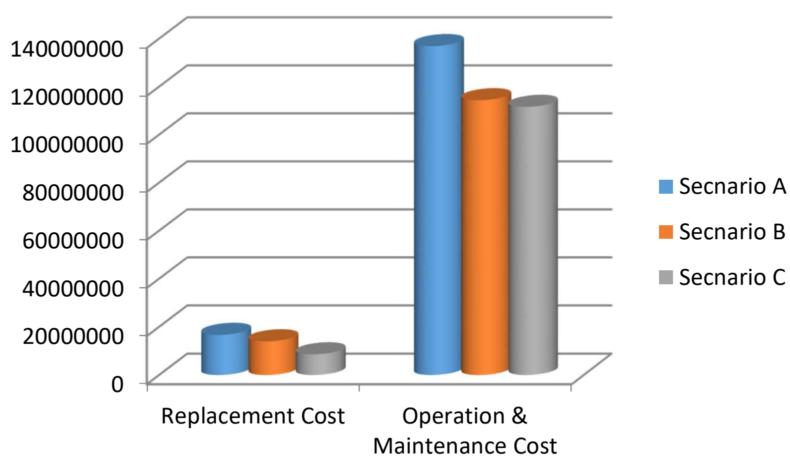


Fig. 4.44 Comparison of scenarios based on replacement cost and operation and maintenance cost

4.9.4 **Comparing of Electricity Production by Three System Configurations**

The total electricity generation (kWh/year) and the excess electricity (%) generation for the three scenarios are shown in Table 4.21. Among the three scenarios, scenario B generates the excess electricity while the scenario C generates the highest excess electricity. The main reason for producing excess electricity is due to the greater solar radiation and wind speed. In scenario B, a very small amount of electricity is produced by bio generator and by diesel generator while the maximum electricity is being generated by PV and wind turbine. For the three scenarios, all components do not share the production electricity less scenario C where all components equally share the generation of electricity. We know, renewable energy depends on weather condition. As the hybrid system produces excess electricity, this electricity can be either stored into the battery or can be used during bad weather condition. As a result, uninterrupted supply of electricity can be possible throughout a year without causing any trouble. Table 4.22 shows electrical consumption for proposed three scenarios of hybrid energy system and Table 4.23 shows electrical quantity for proposed three scenarios of hybrid energy system

TABLE 4.21 ELECTRICAL PRODUCTIONS FOR PROPOSED THREE SCENARIOS OF HYBRID ENERGY SYSTEM

Production	**Scenario A**		**Scenario B**		**Scenario C**	
	kWh/Yr	**%**	**kWh/Yr**	**%**	**kWh/Yr**	**%**
PV Array	307,162	42	204,775	29	204,775	29
Wind Turbines	401,891	55	401,891	57	401,891	56
Diesel Generator	25,020	3	-	-	33,611	5
Biogas Generator	-	-	98,040	14	74,010	10
Total	734,074	100	704,706	100	714,287	100

TABLE 4.22 ELECTRICAL CONSUMPTION FOR PROPOSED THREE SCENARIOS OF HYBRID ENERGY SYSTEM

	Scenario A		Scenario B		Scenario C	
Consumption	kWh/Yr	%	kWh/Yr	%	kWh/Yr	%
AC Primary Load	618,149	100	618,098	100	618,051	100
Total	618,149	100	618,098	100	618,051	100

TABLE 4.23 ELECTRICAL QUANTITIES FOR PROPOSED THREE SCENARIOS OF HYBRID ENERGY SYSTEM

	Scenario A		Scenario B		Scenario C	
Quantity	**kWh/Yr**	**%**	**kWh/Yr**	**%**	kWh/Yr	%
Excess Electricity	12,770	1.74	295	0.0418	295	0.0413
Unmet Electric Load	161	00.3	212	0.0343	260	0.0420
Capacity Shortage	214	0.03	409	0.0662	568	0.0919
Renewable Fraction	-	0.966	-	1.00	-	0.953

From the electrical analysis Table 4.21, it can be seen that for scenario C configuration, the generation of electricity is 714,287 kWh/Yr whereas for scenario A has the generation of electricity 734,074 kWh/Yr. This is also indicated for 100 kW solar PV generation of electricity is 204,775 kWh/Yr and for 150 kW, it is 307,162 kWh/Yr. Again, for 250 kW wind, the production of electricity is 401,891 kWh/Yr for all scenarios. For scenario C has a higher amount of capacity shortage and unmet load than the other systems with 295 kWh/Yr of excess electricity. The scenario A has the highest amount of excess amount of electricity.

4.9.5 Economic Analysis

As HOMER aims to minimize the total NPC both in finding the optimal system configuration and in operating the system, economics play a crucial role in the simulation. The indicator chosen to compare the different configurations' economics is the levelized COE and the total NPC are taken as the economic figure of merit.

4.9.5.1 **Economic Inputs of the Three System Configurations of Hybrid System**

The project's lifetime is considered to be 25 years with an annual discount rate of 6%.The cash flow summary generated by HOMER illustrates the cost involved in the energy system, as well as the COE and NPC for all scenarios. The system fixed capital costs include various civil constructions, logistics, labour wages, required licenses, administration and government approvals and other miscellaneous costs. In Table 4.24, the cost analysis is presented.

TABLE 4.24 COST ANALYSIS OF THREE-HYBRID RENEWABLE ENERGY SYSTEM

Scenario	**System**	**Initial Capital (Tk)**	**Operating Cost (Tk)**	**Total NPC (Tk)**	**COE (Tk/kWh)**	**Renewable Fraction**
A	PV-Wind-DG	72,450.000	11,869.150	224,177.5	28.370	0.97
B	PV-Wind-BG	58,251.600	9,963.191	185,614.6	23.491	1
C	PV-Wind-BG-DG	40,451.200	10,225.784	171,171120	21.665	0.95

From the cost analysis, it can be seen that the PV-Wind-BG-DG system with battery storage has the lowest initial capital and lowest NPC. Further, this configuration has lowest COE and lowest renewable fraction. Other two configurations have more initial capital, NPC, COE and renewable fraction.

4.9.5.2 **Summary of performance parameters of three different system configurations**

Table 4.25 shows the summary of performance parameters of three different system configurations. The important parameters of the three different configurations are stated here. Comparing the configurations, capital cost, replacement cost, O & M cost, NPC, COE and finally the production of electricity, the best option can be chosen. Therefore, the best option is solar PV-wind-biogas, diesel generator configuration.

TABLE 4.25 SUMMARY OF PERFORMANCE PARAMETERS OF THREE DIFFERENT SYSTEM CONFIGURATIONS

Parameters	**Scenario A (Solar PV-Wind-DG)**	**Scenario B (Solar PV-Wind-BG)**	**Scenario C (Solar PV-Wind-BG-DG)**
PV (kW)	150	100	100
Aeolos-V 10kW (No)	25	25	25
Diesel Generator (kW)	40	-	40
Bio Generator (kW)	-	40	30
Battery (No)	6,000	4,800	2,000
Converter (kW)	650	650	650
Capital Cost (Tk)	72,450,000	58,251,600	40,451,200
Replacement Cost (Tk)	16,665.981	13,973.325	8,585,004
O&M Cost (Tk)	136,905,200	114,350,760	111,591,488
Fuel Cost (Tk)	7,516,055	-	15,366,759
Total Electricity Production (kWh/yr)	734,074	704,706	714,287
Excess Electricity (kWh/yr)	12,770	295	295
Unmet Electric Load(kWh/yr)	161	212	260
Capacity Shortage(kWh/yr)	214	409	568
Renewable Fraction (%)	0.966	1.00	0.953

NPC (Tk)	224,177,712	185,614,656	171,171,120
COE (Tk/kWh)	28.370	23.491	21.655
Carbon Emission (Kg/yr)	23,820	46.5	32,300

4.9.6 **Environmental Analysis**

Hybrid system is very popular due to its reliability and extra benefits which enhance social, economic and environmental status of proposed regions and peoples. This system offers low Carbon di oxide (CO_2) emission, continuous power supply, reduction the COE, additional income from biomass fertilizer. As a result peoples of projected area becomes educationally development by increasing the rate of literacy, economically benefitted for minimum COE, development in agriculture and environment keeps healthy, sound and green. Accordingly, the results from the emission analysis performed by HOMER are presented in Table 4.26.

TABLE 4.26 CO_2 EMISSIONS RELATED TO EACH SYSTEM CONFIGURATION

Scenario	System Configurations	Carbon Di Oxide (kg/Yr)	Carbon Mono oxide (kg/Yr)	Unburned Hydro Carbons (kg/Yr)	Particulate Matters (kg/Yr)	Sulfur Dioxide (kg/Yr)	Nitrogen Oxides (kg/Yr)
A	PV-Wind-DG	23,820	58.8	6.51	4.43	47.8	525
B	PV-Wind-BG	46.5	1.75	0.193	0.132	0	15.6
C	PV-Wind-BG-DG	32,300	81	8.97	6.1	64.8	722

All the system configurations generate negative CO_2 emissions, meaning operating the system prevents emissions that would otherwise be caused. The negative CO_2 emissions are related to the amount of electricity the systems sell to the customers. Since the Bangladesh electricity is manly produced from fossil fuels, replacing it with electricity produced from clean energy sources like solar and wind reduces the CO_2 emissions.

From the perspective of emissions, all system configurations cause the same negative environmental impact but the scenario A prevents more CO_2 emissions than the other systems.

4.10 **Analysis of the Best System Configurations of Hybrid System**

4.10.1 **Cash flow summary**

Fig. 4.49 shows the cash flow summary for the optimal system. The capital cost of the wind makes up only 14.21 percentage of the system's total capital cost, whereas almost 24.72 percentages of the initial investments go to the PV arrays. Once installed, there is no replacement cost of solar and diesel generator whereas wind and biogas contributes 13.62 percentage and less than 1 percentage respectively. However, in O&M, solar, wind, biogas requires 55.56 percentage, 1.43 percentage and 5.93 percentages respectively of O&M cost. In total system cost, solar bears 39.45 percentage, wind 4.59 percentage, Diesel generator 7.14 percentages and biogas generator 6.9 percentages which is given in Fig.4.45.

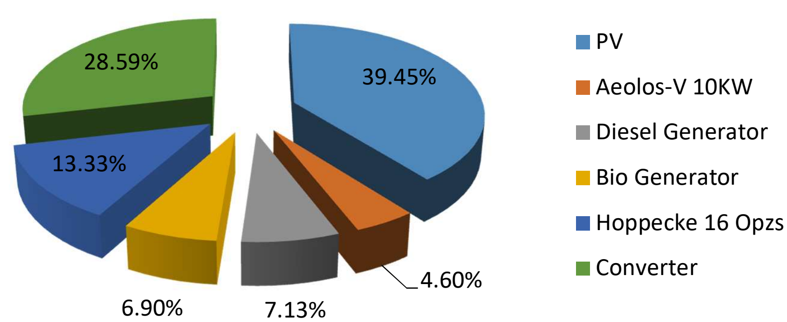


Fig. 4.45 Capital cost percentage by components for Scenario C

4.10.2 **Cost Summary**

Out of all the components, PV draws the most expense in the whole project lifetime. The total NPC of the PV is BDT 67,525,128. Converter comes second, total cost of wind turbine is BDT 48,936,796. Battery comes third in terms of NPC of Tk 22,822,734. The expense for the diesel generator is BDT 12,213,810. The NPC of bio-generator and wind turbine and is Tk 11,810,767 and Tk 7,861,879. Fig. 4.46 shows the cash flow summary in terms of NPC by component type for the best scenario. Table 4.27 shows the summary of cost of the components of the best option.

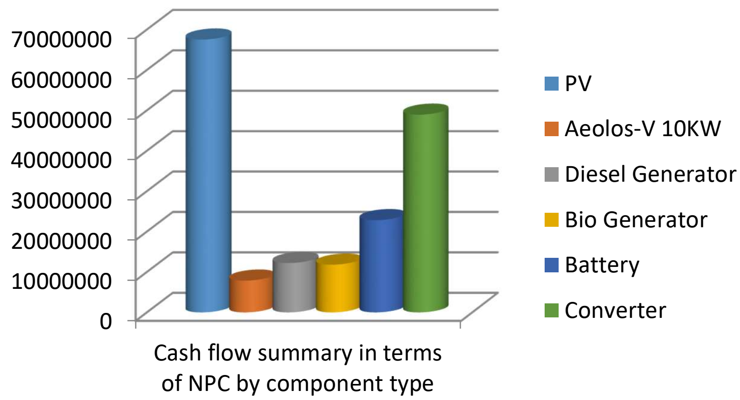


Fig. 4.46 Cash flow summary in terms of NPC by component type

TABLE 4.27: SUMMARY OF COST OF THE COMPONENTS FOR THE SCENARIO C

Component	Capital (Tk)	Replacement (Tk)	O&M (Tk)	Fuel (Tk)	Salvage (Tk)	Total (Tk)
PV	10,000,000	0	57,535,132	0	0	67,525,128
Aeolos-V 10KW	5,750,000	1,169,269	1,597,920	0	-655,310	7,861,879
Diesel Generator	200,000	0	1,845,406	10,180,768	-12,364	12,213,810
Bio	1,200	1,1010	6,622,678	5,185,990	-108	11,810,767

Generator						
Battery	18,000,000	5,387,992	2,454,406	0	-3,019,667	22,822,734
Converter	6,500,000	2,026,733	41,545,936	0	-1,135,870	48,936,796
System	40,451,200	8,585,004	111,591,488	15,366,759	-4,823,319	171,171,120

The best optimized configuration is scenario C. 100 kW PV array, 25 Wind turbine (10 kW each), a diesel generator with a rated power of 40 kW, 30 kW biomass generator, 2000 piece of storage battery and 650 kW converter is the most commercially reliable in terms of COE (21.655 Tk/kWh), NPC (171,171,120 Tk) and initial capital is 40,451.200. This system is considered at (6.629 m/s) of wind speed and (Tk 65/l) of diesel cost. The Hybrid energy system has the electricity generation mix of 29 % from PV, 56% from the wind turbine, 5% from diesel generator and 10% from biogas resources.

4.11 Electrical Demand and Supply

The total electricity generated by solar and wind is 714,287 kWh/yr with solar PV 29%, wind 56%, diesel 5% and biogas 10%.

Electricity generated per month $= \frac{Total\ Electricity\ Generated\ per\ Year}{Number\ of\ month\ per\ Year} = \frac{714287}{12} = 59{,}523.92$ kWh/Month.

Electricity generated per day $= \frac{714287}{Number\ of\ Days\ per\ year} = \frac{714287}{365} = 1956.95 = 1957$ kWh/day

The daily demand is 1694 kWh/day, therefore the hybrid system can sustain the demand of the building. The excess electricity generated with the hybrid system was 295 kWh/yr that is 0.0413% of the total energy produced.

4.12 Overall Energy Performance

The Hybrid energy system is estimated to produce 714,287 kWh per year having an electrical energy mix of 29 % from PV, 56% from the wind turbine, 5% from diesel generator and 10% from biogas resources. Over the year 714,287 kWh is generated per year by the island and 295 kWh per is excess electricity which is reliable. The system produces more electrical energy per annum than the yearly electrical energy requirements of the island, indicating that the system on average achieves a positive energy balance every year. Despite a positive electricity balance, electricity is still required from the grid (260 kWh/year) throughout the year, primarily due to periods when the system does not produce enough electricity. Energy storage (568 Kwh/year) may mitigate the use of electricity from the grid since the system does have a positive net energy balance for the year.

4.13 **Pay Back Period**

The payback period means that the number of years required recovering the cost of the investment and for cost benefit analysis of our system it is needed.

$$PBP=\frac{C_{Cap.}+C_{O\&M}+C_{Repl.}}{C_{Cashinflow}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

$C_{Cap.} + C_{O\&M} + C_{Repl.}$=40,451,200+8,585,004+111,591,488=160,627,692 Taka

1. **Case 1**

Considering twenty taka per kilowatt hour and total capital cost of Hybrid system is 160,627,692 TK, it is estimated that the payback time in year around nine.

Again, Considering 1 kWh = 20 Tk

Total capital cost of Hybrid system = 160,627,692Tk

Annual income = 14,279,840 TK (as annual consumption = 714287-295=713,992 kWh)

So, Payback Period in year = 160,627,692/14,279,840=11.24 ≈12 years

2. Case 2

Considering 1 kWh= 25 Tk

Total capital cost of Hybrid system = 160,627,692Tk

Annual income = 17,849,800TK (as annual consumption = 714287-295=713,992 kWh)

So, Payback Period in year = 160,627,692/17,849,800 =8.99 ≈9 years

3. Case 3

Considering 1 kWh= 30 Tk

Total capital cost of Hybrid system = 160,627,692 Tk

Annual income = 10,709,880 TK (as annual consumption = 714287-295=713,992 kWh)

So, Payback Period in year = 160,627,692/10,709,880 =7.49 ≈8 years

4.14 **Internal Rate of Return (IRR)**

The total system initial cost is 171,171,120 Tk and for annual income total generation of electricity is considered 714,287 kWh/yr and excess is electricity is 295 kWh/yr. So 714287-295=713,992 kWh/yr electricity is consumed. Considering price of 1 KWh of electricity is 25 Tk. Therefore annual income stands =713,992x 25= 17,849,800 Tk. On the termination year, the annual income will increase due to the salvage value amounting 4,823,319 Tk. So total annual income on 25th year will be 17,849,800+4,823,319=22,673,119 Tk. After calculating, the IRR comes 9.33% will portrays the beneficial for the project which is projected in Fig. 4.47.

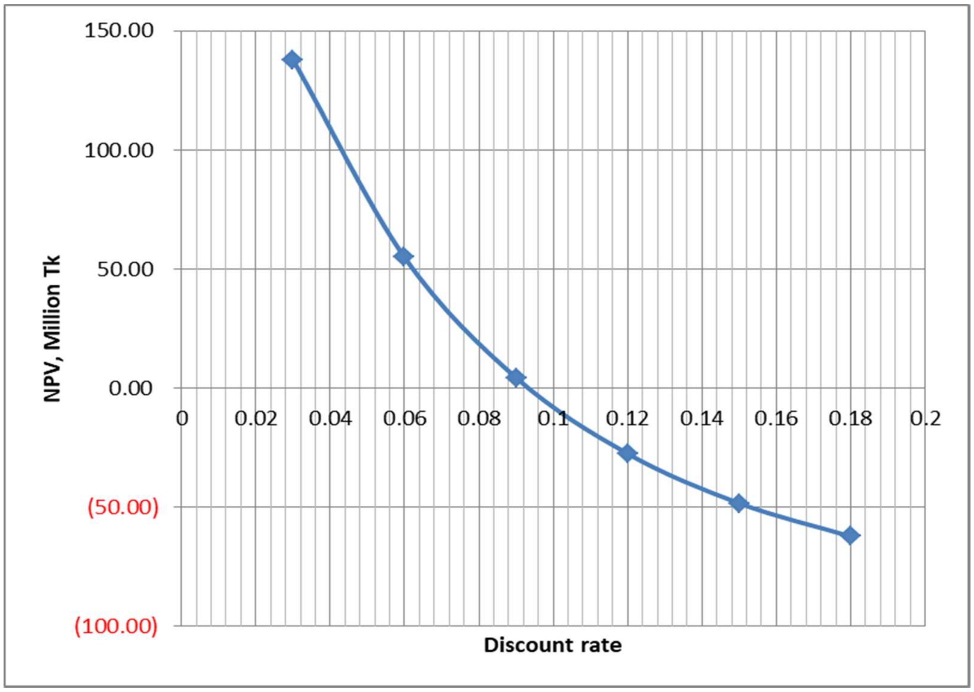


Fig. 4.47: IRR of the Project

4.15 Comparing COE and NPC of Hybrid System with Previous Literature of other Countries

In the different scenarios in different regions of Bangladesh load varies from 35 - 850 kWh/day with different system configurations. Among the demonstrated example, COE ranges from $ 0.27/kWh to $ 0.454/kWh. Comparing with other countries, among the list, Turkey has the highest COE: $ 0.82/kWh, Nigeria is the lowest COE $ 0.396 and Thailand has COE $ 0.59/kWh of hybrid energy. NPC also varies from regions to regions and country to country. The comparative study demonstrates that the results obtained from this research comparing with other research given Table 4.28, the COE is lowest amongst all amounting COE $ 0.254. However, NPC is little more as system configuration is larger than other.

TABLE 4.28 COMPARING THE COE AND NPC OF HYBRID SYSTEM WITH PREVIOUS LITERATURE OF OTHER COUNTRIES

Location	Software Used	Load and System Configuration	COE and NPC	Comparing COE & NPC of study area with other study areas
The Study Area, SwarnaDweep, Bangladesh	HOMER	Load: 1694 KWh/day Solar PV :100 kW Wind Turbine: 250kW Diesel generator: 40 kW Biogas Generator:30 kW	COE: $ 0.254/kWh NPC: $ 2013,777	
Bandarban, a hilly area in Bangladesh[59]	HOMER	Load: 35 KWh/day Solar PV :4 kW Wind Turbine: 1 kW Diesel generator: 4 kW	COE: $ 0.454/kWh NPC: $ 52542	COE is 178.74 % higher, NPC is 2.7% lower
Saint Martin Island, Bangladesh [60]	HOMER	Load:78 kWh/day Solar PV: 8 kW Wind turbine: 3 kW No. of Battery: 25 (12 V, 200 A h)	COE: $ 0.34/kWh NPC: $ 136,158	COE is 133.85 % higher NPC is 6.76% lower
East Southern part of Bangladesh [61]	HOMER	Load: 146 kWh/Day Solar PV:25 kW Wind Turbine:14 Kw No of Battery: 285	COE: $ 0.47/kWh NPC: $ 391,492	COE is 185% higher, NPC is 19.44% lower
Sitakunda, Bangladesh [62]	HOMER	Load:169 kWh/day Solar PV: 27 kW Wind turbine: 39 kW No. of Battery: 370	COE: $ 0.363/kWh NPC: $ 319,132	COE is 142.91 % higher, NPC is 15.84% lower
Rural & off grid areas, Bangladesh [63]	HOMER	Load: 850 kWh/day Solar PV:50 kW Wind turbine: 40 kW No. of battery:135	COE: $ 0.27/kWh NPC: $ 1,285,761	COE is 106.29 % higher, NPC is 63.84% lower
Palari Village, Chhattisgarh, India [64]	HOMER	Load: 492.6 kWh/ day Solar PV: 20 kW Hydro: 30 kW Biodiesel: 10 kW	COE: $ 0.420/kWh NPC: $ 673,147	COE is 165.35 % higher, NPC is 33.42% lower
Remote areas, Malaysia [65]	HOMER	Load: 1156 kWh/day Solar PV: 20 kW Generator 1 size: 50 kW Generator 2 size: 50 kW	COE: $ 0.28/kWh NPC: $ 152,909	COE is 110.23 % higher NPC is 7.59% lower
Remote island, Thailand [66]	HOMER	Load: 306 kWh/day Solar PV: 15 kW	COE: $ 0.59/kWh NPC: $ 542,027	COE is 232.28 % higher, NPC is 26.92%lo

		Wind turbine : 10 kW Diesel generator: 25 kW Battery capacity: 140 kWh		lower
Kavakli campus of Kirklareli University, Turkey [67]	HOMER	Load: 36 kWh/day Solar PV: 120 kW Diesel Generator : 50 No. of battery: 120	COE: $ 0.82/kWh NPC: $ 1,849,654	COE is 322.83 % higher NPC is 91.85% lower
Lade II in Kwara State, Nigeria [68]	Homer	Load: 2.5MWh/day Solar PV: 1.5 MW Diesel Generator: 350 kW No of Battery: 1200	COE: $ 0.396 /kWh NPC: $ 4,909,206	COE is 175.68 % higher NPC is 243.78% higher

4.16 Socio-economic Benefits

The study has already evaluated its reliability, electricity generation, economic cost, etc. It can be said that the study has not only environmental benefits but also it has socio-economic benefits. The generation of this hybrid system not only supplies reliable electricity supply to the off grid areas of Bangladesh but also makes effective contribution in the social life. The best system configuration (solar PV-wind-diesel-biogas) Hybrid renewable energy system would enhance the alternative sources of electricity generation. It is likely to provide sustainable and uninterrupted energy supply in the rural and remote areas and lead to energy security. This will minimize the GHG Emission, resulting in a net reduction of the GHGs which is beneficial for both domestic and global. It will encourage to capacity building and also contribute to the technology transfer in installation and operational of Renewable Energy -Fossil Hybrid Power Plants which have low emission and cost effective than 100% fossil fuel based plants. Further, a number of households currently mitigating their lighting needs with traditional kerosene will shift over the electricity, which will also contribute to reduce fire-hazards. This will improve the overall quality of life of people living in the survey area that will enjoy reliable electricity supply and related other socio-economic benefits, like longer study hours, getting connected to TV and other media/communications with the outside areas, including global exposures.

4.17 Conclusion

The project's lifetime is considered to be (25 years) with an annual discount rate of 6%. The best optimized configuration is scenario C. 100 kW PV array, 25 Wind turbine (10 kW each), a diesel generator with a rated power of 40 kW, 30 kW biomass generator, 2000 piece of storage battery and 650 kW converter is the most commercially reliable in terms of COE (21.655 Tk/kWh), NPC (171,171,120 Tk) and initial capital is 40,451.200. This system is considered at (6.629 m/s) of wind speed and (Tk 65/l) of diesel cost. The Hybrid energy system has the electricity generation mix of 29 % from PV, 56% from the wind turbine, 5% from diesel generator and 10% from biogas resources. As the system produces more than the demand, the system on average achieves a positive energy balance every year. From the cash flow, it can be seen that the PV-wind-BG-DG system with battery storage has the lowest initial capital and lowest NPC. Further, this configuration has lowest COE and lowest renewable fraction. The site is blessed with considerable annual average global solar radiation of 4.51 kWh/m^2 /day and average wind speed of 6.63 m/sec at 120 m height which is ideal for hybrid sources.

CHAPTER 5

SENSITIVITY ANALYSIS

5.1 Introduction

In sensitivity analysis, system's control parameters can be varied to examine the effect of control parameters on system's performance. It helps the system designer to choose most economical system configuration for a given range of control parameters. In this study, two types of sensitivity variables are chosen to conduct sensitivity analysis.

A sensitivity analysis exposes how sensitive the outputs are to changes in the inputs. In a sensitivity analysis, the HOMER user enters a range of values for a single input variable. A variable for which the user has entered multiple values is called a sensitivity variable. Magnitude of an hourly data set, such as load and renewable resource data, can be a sensitivity variable. Each combination of sensitivity variable values defines a distinct sensitivity case. HOMER performs a separate optimization process for each sensitivity case and presents the results in various tabular and graphic formats. One of the primary uses of sensitivity analysis is in dealing with uncertainty. Sensitivity analysis is used to evaluate trade-offs and how much additional capital investment is required to achieve required renewable energy production. Sensitivity analysis can determine which technologies or combinations of technologies, are optimal under different conditions. It can be determined at what price, or under what conditions, a product competes with the alternatives.

In this study sensitivity, analysis has been undertaken to study the effects of variation in solar radiation, wind speed, diesel price and availability of biomass to make appropriate recommendations in developing a hybrid renewable energy system. The selected scenario (Solar PV, wind, biogas and diesel configuration) was chosen for sensitivity analysis where the system was very much cost effective in terms of COE, NPC and initial cost. There are six different sensitivity results scenarios. They are: variation in wind speed and solar radiation, variation in wind speed and diesel price, variation in solar radiation and diesel price, variation in solar radiation and biomass resource, variation in diesel price and biomass resource, and variation in biomass resource and wind speed. Fig. 5.1 to 5.6 shows sensitivity results in terms of different variables.

Keeping biogas and diesel price fixed, Fig. 5.1 shows the sensitivity analysis between wind speed and solar radiation showing the COE

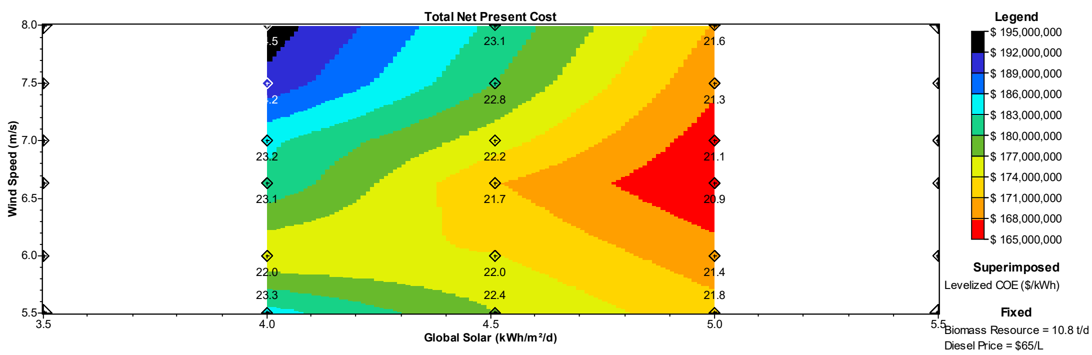


Fig. 5.1 Sensitivity analysis (variation of wind speed with respect to solar radiation)

Keeping wind and diesel price fixed, Fig. 5.2 shows the sensitivity analysis between biogas resource and solar radiation showing the COE.

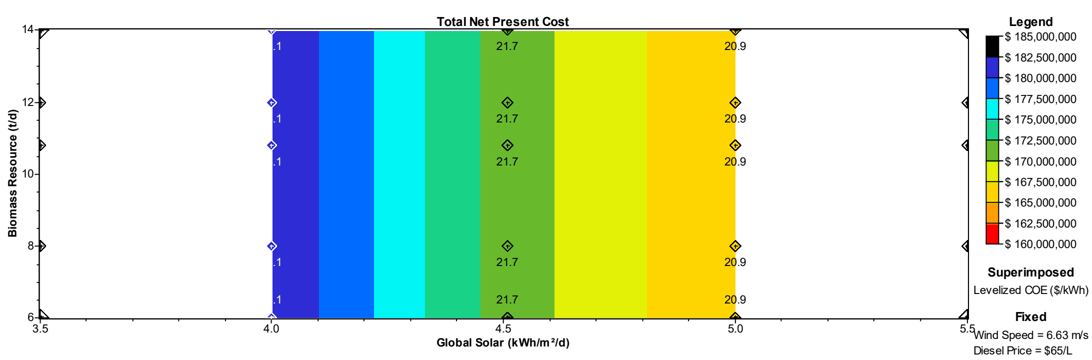


Fig. 5.2 Sensitivity analysis (variation of biomass resource with respect to solar radiation)

Keeping wind and biogas resource fixed, Fig. 5.3 shows the sensitivity analysis between diesel price and solar radiation showing the COE.

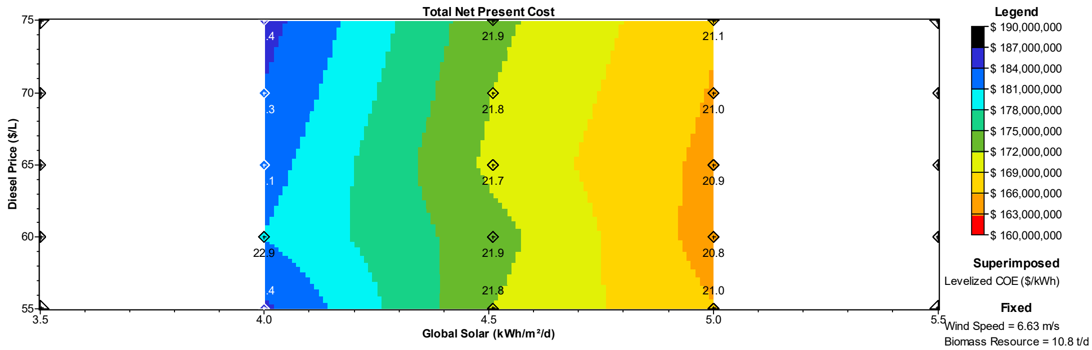


Fig. 5.3 Sensitivity analysis (variation of diesel price with respect to solar radiation)

Keeping solar radiation and diesel price fixed, Fig. 5.4 shows the sensitivity analysis between biogas resource and wind speed showing the COE.

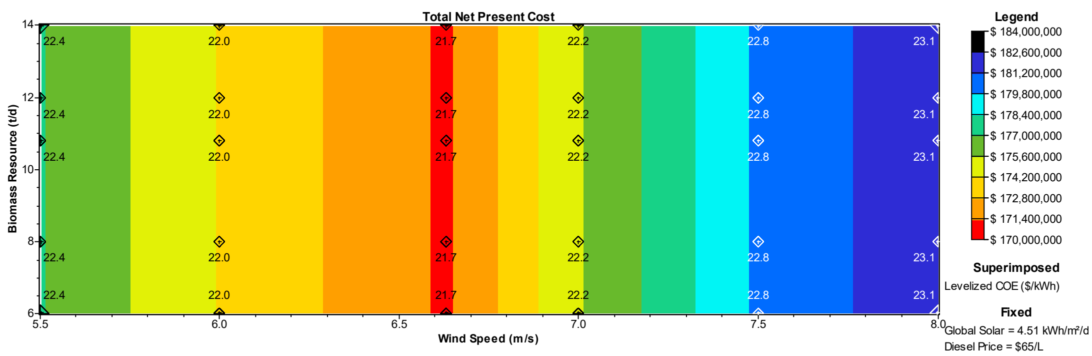


Fig. 5.4 Sensitivity analysis (variation of biomass resource with respect to wind speed)

Keeping solar radiation and biogas resource fixed, Fig. 5.5 shows the sensitivity analysis between diesel price and wind speed showing the COE.

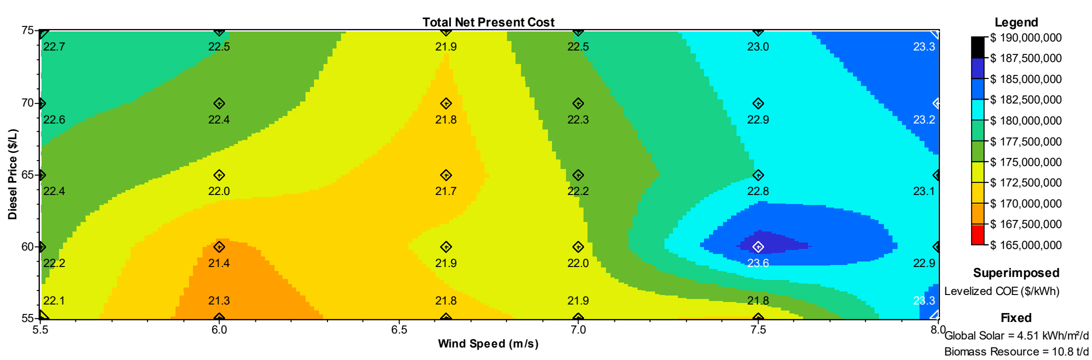


Fig. 5.5 Sensitivity analysis (variation of diesel price with respect to wind speed)

Keeping solar radiation and wind speed fixed, Fig. 5.6 shows the sensitivity analysis between diesel price and biogas resource showing the COE.

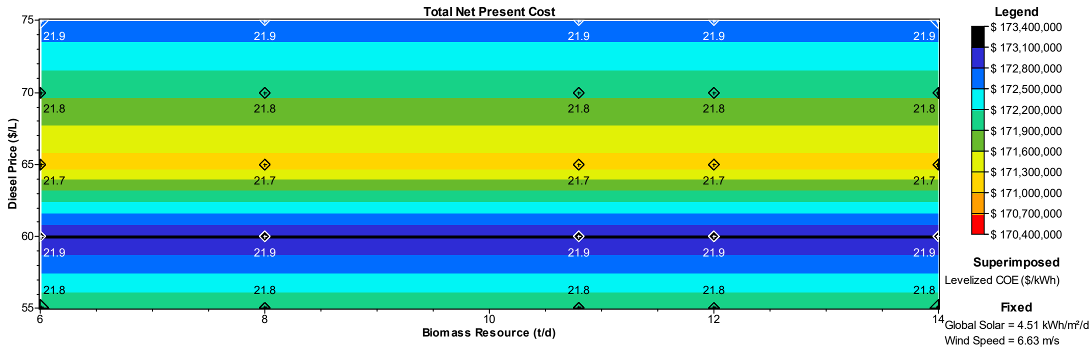


Fig. 5.6 Sensitivity analysis (variation of diesel price with respect to biomass resource)

5.2 Sensitivity Analysis Results

5.2.1 Introduction

For sensitivity analysis, wind speeds were varied from 6 to 8 m/s, solar irradiance from 3.5 to 5 kWh/m2/day, biomass resource from 8 to 14 ton/day for each location and diesel price varied from 55 to 75 tk/l. The parameters (solar radiation, wind speed, biogas and diesel price) have huge impact on the cost analysis of the system as the efficiency of the renewable components of the hybrid system hugely depends upon these parameters.

In HOMER, four types are graph are represented to analyze the sensitivity. They are:

a. Optimal system type graph
b. Surface plot graph
c. Line graph
d. Spider graph

5.2.2 Optimal system type graph

The graphical (Fig 5.7 to Fig 5.12) sensitivity results show solar radiation, wind speed and biogas varies from minimum to maximum with the different values of diesel prices. The fuel price is fixed at Tk 65/L, 70/L and 75/L, the solar radiation is depicted on the x-axis and wind speed on the y-axis.

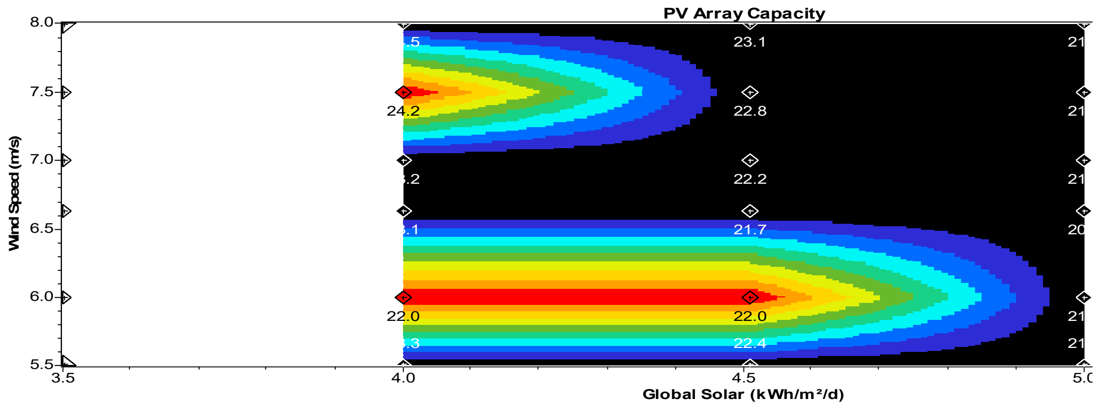


Fig 5.7 COE-When Diesel Price is 65Tk/Litre

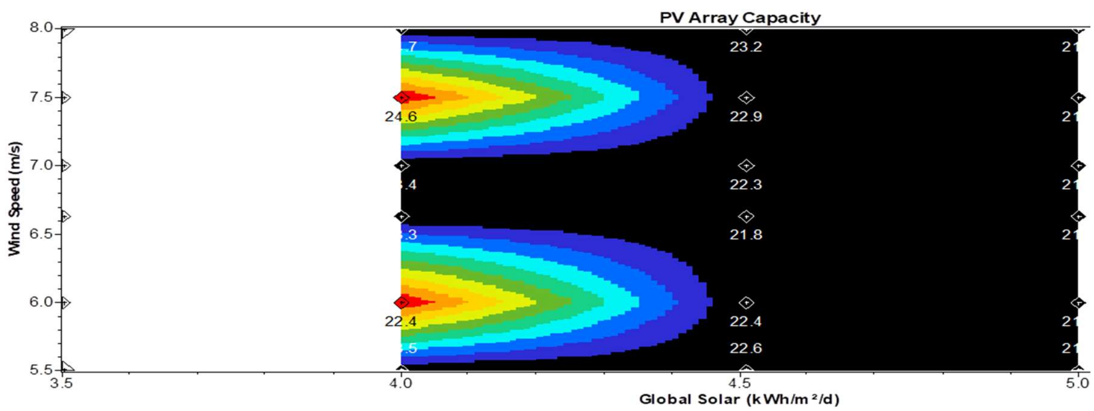


Fig 5.8 COE-When Diesel Price is 70 Tk/Litre

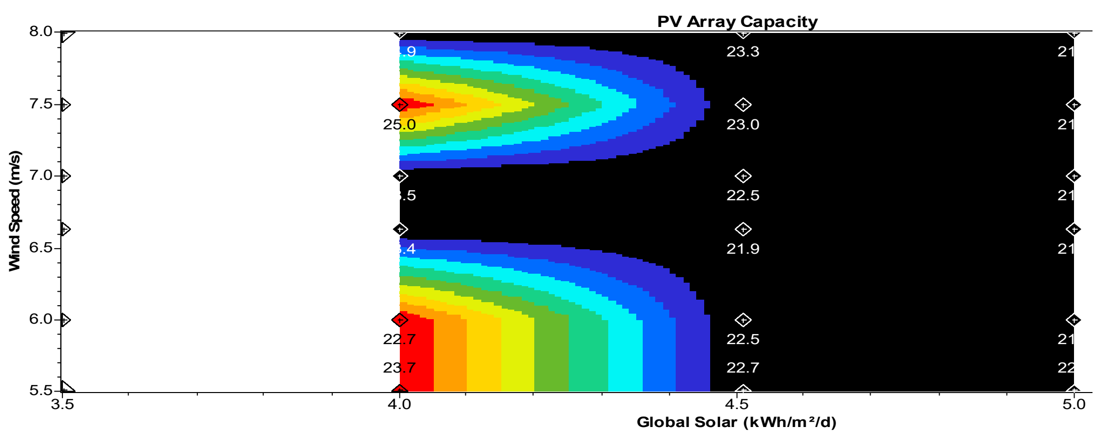


Fig 5.9 COE-When Diesel Price is 75Tk/Litre

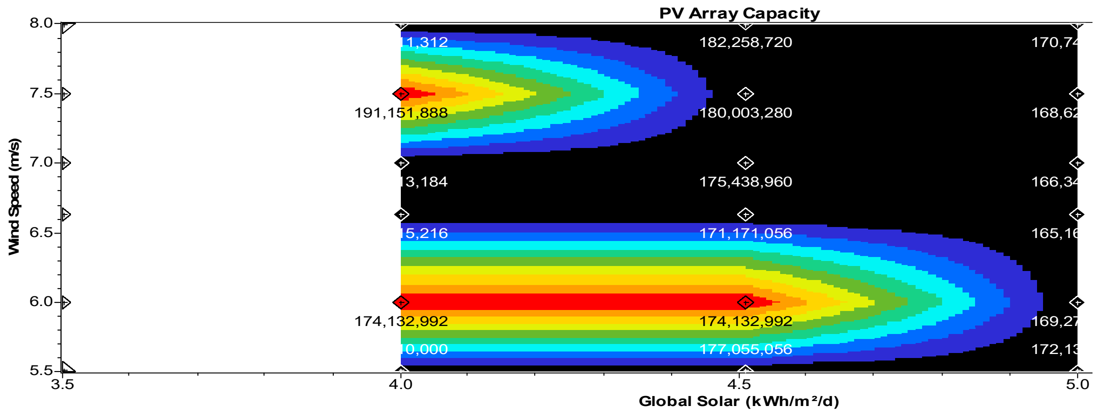


Fig 5.10: NPC-When Diesel Price is 65Tk/Litre

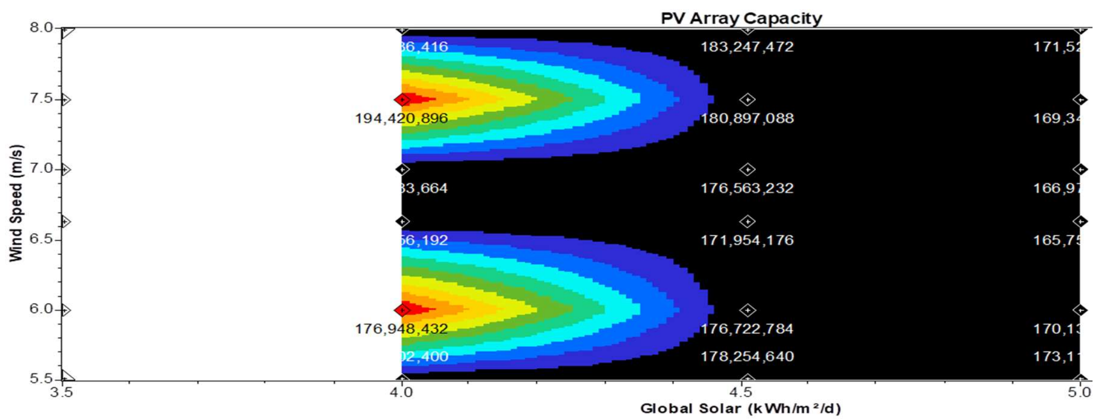


Fig 5.11 NPC-When Diesel Price is 70 Tk/Litre

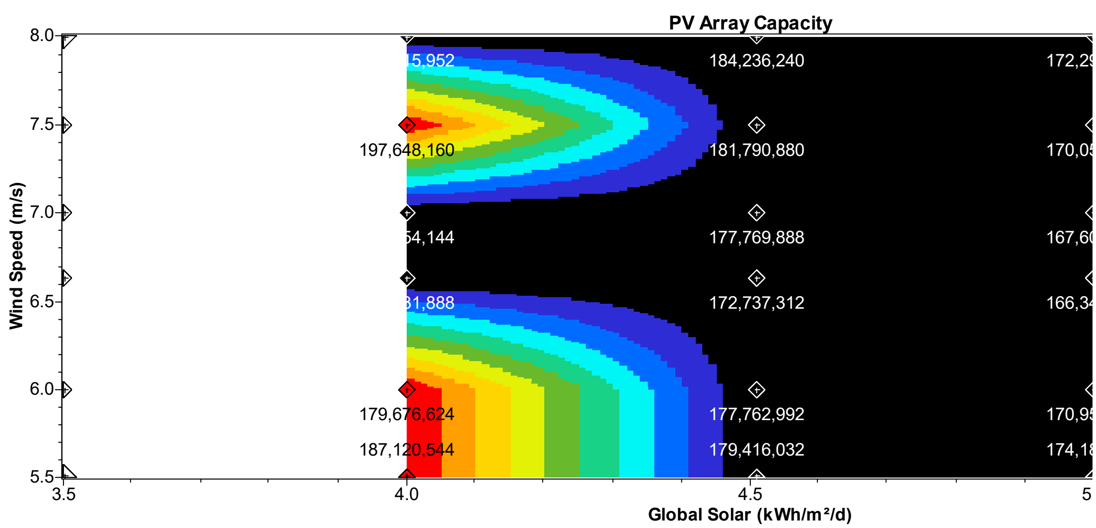


Fig 5.12 NPC-When Diesel Price is 75Tk/Litre

This shows that cost of energy or net present cost is lower when the solar radiation is higher. Again, higher value of fuel cost, the cost of energy or net present cost is higher and with the lower value of fuel cost, the cost of energy or net present cost is lower.

5.2.3 **Surface plot type graph**

In Fig. 5.13, it can be seen that with the variation of renewable energy resource, different types of optimum system configurations are found for Swarna Dweep. The surface plot type graph in fig. 5.13 illustrates total NPC was the primary value and COE was the superimposed value where the solar irradiance (lies between 4 to 5 kWh/m^2/day) and the wind speed (is found from 5.5 to 7.5 m/s) are taken consideration. The chosen variables are amount of solar radiation of the site and the price of diesel fuel. It is seen that less than 60 Tk/l and from 4.5 to 5 KWh/m^2/d, the system is more economical.

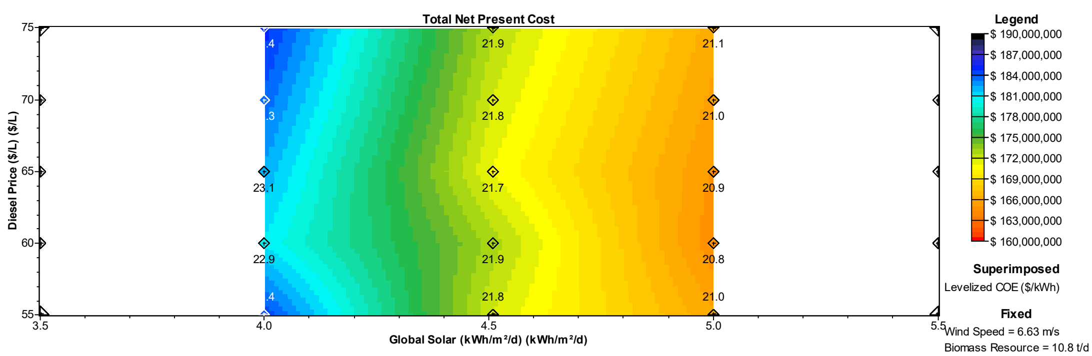


Fig. 5.13 Diesel price and global solar radiation variations on NPC and COE

Fig. 5.14 demonstrates that the levelized COE is increasing with increasing wind speed and decreasing irradiance. Fig. 5.15 with increasing diesel price and increase amount of biomass resources, COE also increases, while it decreases with decreasing wind speed and increasing irradiance.

If solar irradiance increases from 4 to 5 kWh/m^2/day keeping the wind speed at 5.5 m/s, the levelized COE decreases from 23.3 to 21. 8 Tk/ kWh. Similarly, keeping the solar irradiance at 5 kWh/m^2/day, if the wind speed increases from 5.5 to 7.5 m/s, the levelized COE decreases from 24.5 to 21.6 Tk/ kWh.

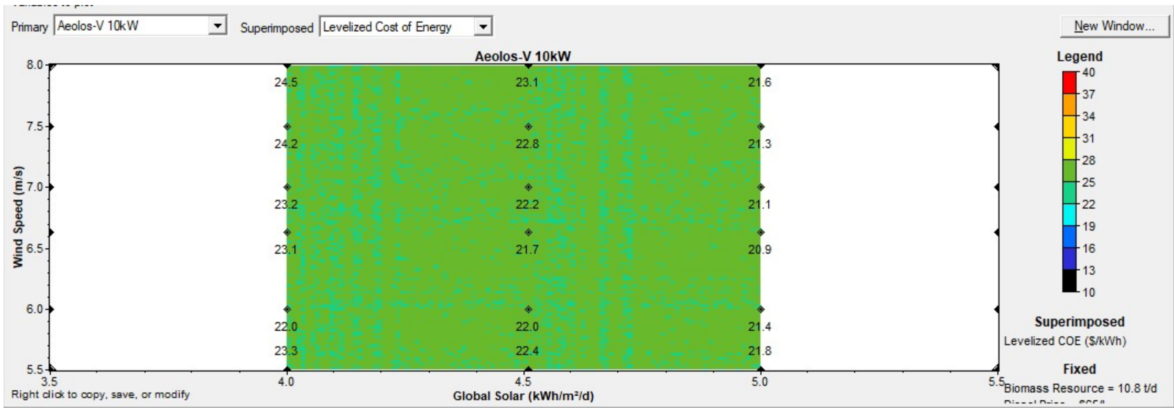


Fig. 5.14 Effect of Wind Speed and global solar radiation keeping biomass resources and diesel price fixed.

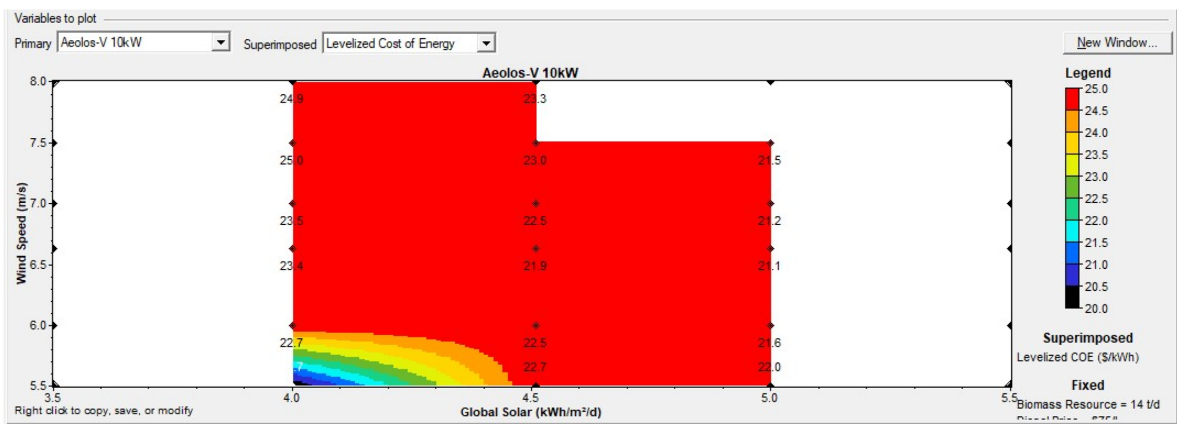


Fig. 5.15 Wind Speed and global solar radiation by varying the biomass resources and diesel price

5.2.4 **Line graph**

The Line graph shown in Fig. 5.16 demonstrated the results of a sensitivity analysis where in x-axis solar radiation is taken and rest three variables like wind speed (6.63 m/s), biogas resources (10.8 ton/day) and diesel price (65 TK/L) are fixed. Fig. 5.17 shows the sensitive analysis between levelized COE and total NPC basing upon three fixed variables. Now if any one parameter is increased or decreased, the sensitivity graphs changes where the levelized COE and NPC vary. If the fig. 5.16 and 5.17 are compared, then it is found that due to change of three variables like wind speed (6.63 m/s to 8 m/s), biogas resources (10.8 ton/day to 14 ton /day) and diesel price (65 TK/L to 7o Tk/L) the levelized COE and NPC have also been changed.

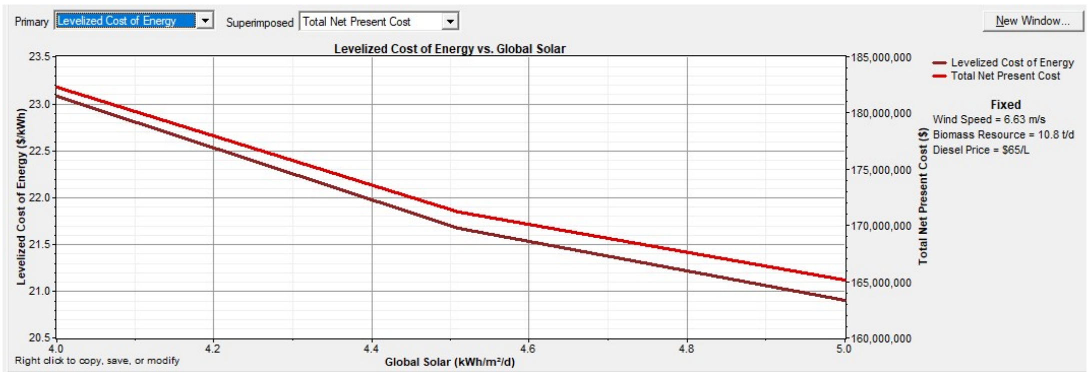


Fig. 5.16 Effect of total COE and NPC by varying few key parameters

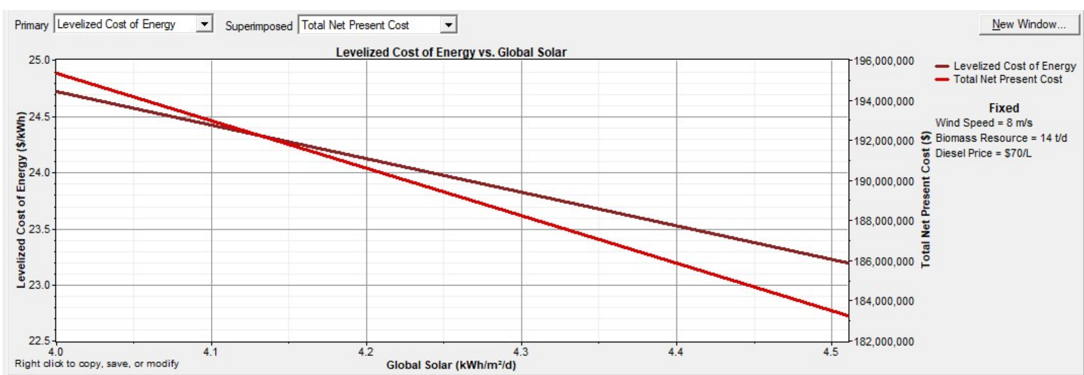


Fig. 5.17 Effect of total COE and NPC by varying few key parameters

5.2.5 **Spider graph**

The spider graph in Fig. 5.18 illustrates the outcomes of a sensitivity analysis on four variables. For fixed system configuration i.e. W-PV-DG-BG system, four uncertain input variables such as average wind speed, solar irradiance, biogas resources and the diesel price are given the input. Fig. 5.18 demonstrated the sensitive of the total NPC related to each type of the uncertain variable and the relative steepness of the four curves delineates that the total NPC is more sensitive to average wind speed, solar irradiance and the diesel price than to the biogas resource variable. Certainly, such information can help a system designer to form the restrictions of a confidence interval or to prioritize efforts to reduce uncertainty.

Fig. 5.18 The graph illustrates the effect of variations in four key sensitivity variables.

In Fig. 5.19, keeping four parameters value such as solar radiation 4.51 KWh/m^2/day, wind speed 6.63 m/s, biomass resources 10.8 ton/day and diesel price 65 tk/l, best estimation is found in Fig. 5.19, But when only wind speed is changed out of four parameters, total graph has represented different which is shown in Fig 5.20.

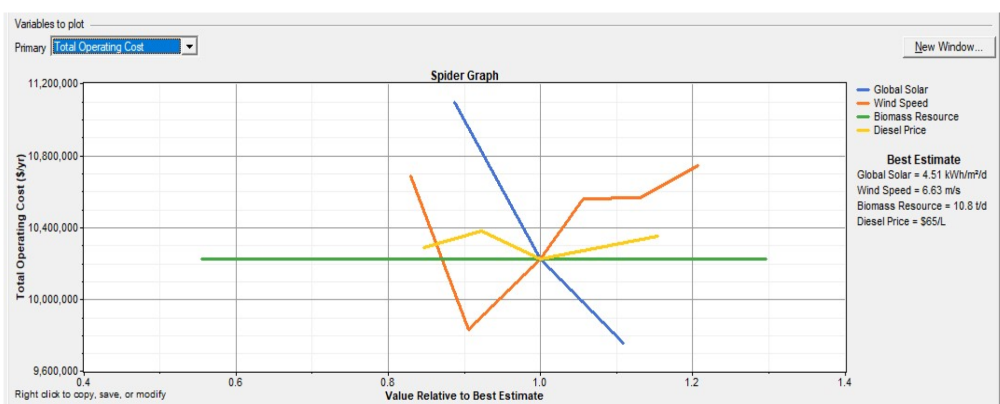


Fig. 5.19 The graph illustrates the best estimate considering key variables.

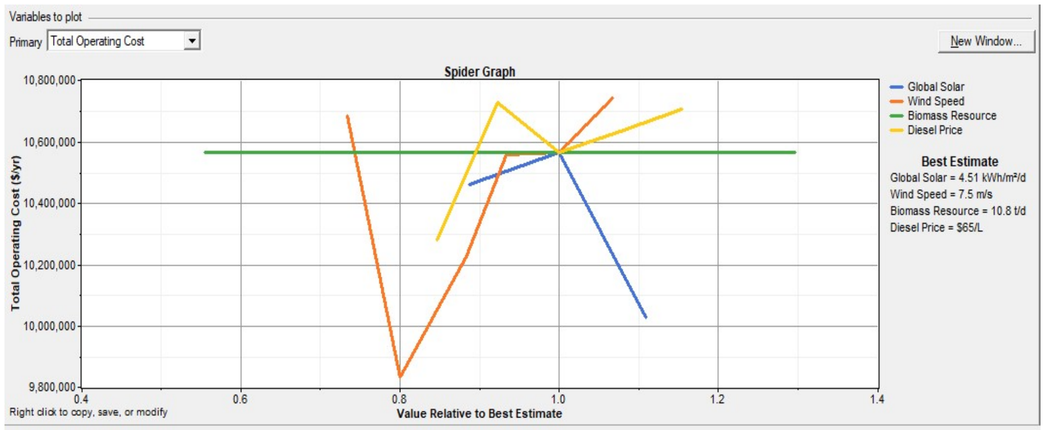


Fig. 5.20 The graph illustrates best estimate varying key variables.

5.3 Conclusion

Sensitivity analysis is performed based on considering the uncertain parameters and removing the unrealistic combinations of optimum energy model. Here the selected model (Solar PV, wind, biogas and diesel configuration) was chosen where the system was very much cost effective in terms of COE, NPC and initial cost. HOMER shows how the cost of the system fluctuations with a fluctuation in wind energy, solar radiation or prices of the diesel. The renewable energy sources, such as solar and wind, are intermittent in nature. Therefore, different values of solar irradiance and wind speed are considered as the sensitivity variables which definitely help to select the optimum system configuration.

CHAPTER 6

Validation by Intelligent System and Functional Test

6.1 Development of Fuzzy Expert System

6.1.1 Structure of Fuzzy Expert System

The fuzzy logic in terms of fuzzy set theory is basically a branch of mathematics developed by Zadeh at the University of California in 1965 [69]. Fig. 6.1 shows the fundamental composition of the fuzzy Expert system (FES) for predicting total hybrid energy (TE) as output considering four energy parameters namely photovoltaic (PV), diesel generator (DG), biogas energy (BG) and wind power (WP) as input parameters. It is noted that the FES gives a functional relationship between output parameter with the input parameters with mathematical modeling based on fuzzy set theory as shown in Equation (21):

$$TE = f\left(PV, DG, BG, WP\right) \quad (21)$$

Generally, FES has four parts: (1) fuzzification- that takes the numerical value as inputs and transfers into fuzzy structure, (2) knowledge base- that grips a set of linguistic term, IF - THEN rules, (3) decision making logic- which constructs the control actions based on the information from fuzzification module, and (4) defuzzification-which generates the final output[70]. However, each rule set on point 2 can be distributed into Mamdani and Sugeno modules. In case of Mamdani module, the predecessor and consequence portions are in fuzzy set form, whereas, in case of Sugeno module, the predecessor portion is in the form of a fuzzy set and the later part is direct equation or constant. In this study the rule set has been assessed using Mamdani type fuzzy expert system (FES) model because of its simplicity and wider application of equation (21). Moreover, the

Mamdani model works well with the specific rule grounded inference structure, creates linear interpolation between the rules and output, and finally it develops the expected output parameter.

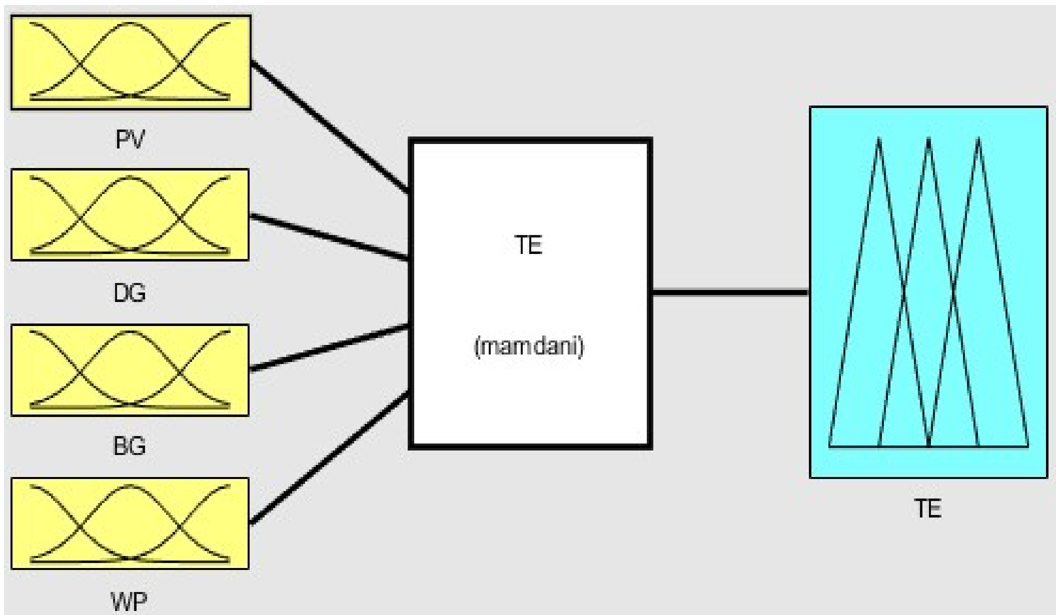


Fig. 6.1: General structure of Fuzzy expert system

6.2 Implementation of Fuzzy Expert System

In this work, four energy parameters such as photovoltaic (PV), diesel generator (DG), biogas energy (BG) and wind power (WP) have been used as input parameters and total hybrid energy (TE) is the output parameter. For fuzzification of these factors the linguistic variables low (L), medium (M), and high (H) are used for the inputs and output, respectively. In this study, a Mamdani max-min inference system has been used [70-71]. The units of the input and output variables are kW. In this work, prototype triangular fuzzy sets for the fuzzy variables, namely, photovoltaic (PV), diesel generator (DG), biogas energy (BG), wind power (WP) and hybrid energy (TE) are set up using MATLAB Toolbox. The membership values for photovoltaic is shown in the Fig. 6.2. The development of membership functions considered in this study is mainly from the statistical data and human expertness [71]. For the input and output parameter, a fuzzy associated memory is created by using If-Then rules. Total of 48 rules have been formed and few of them are shown in Fig. 6.3.

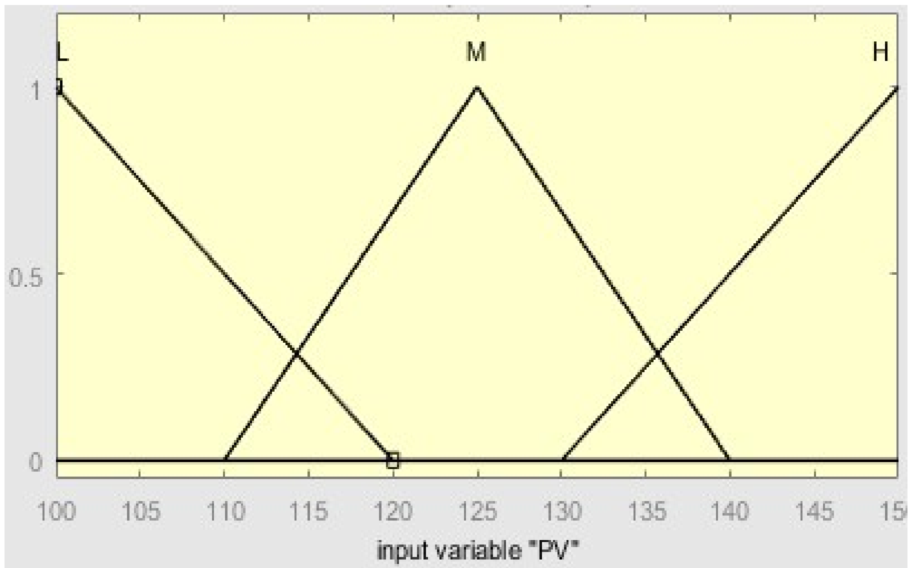


Fig. 6.2 Membership function plot for photovoltaic (PV)

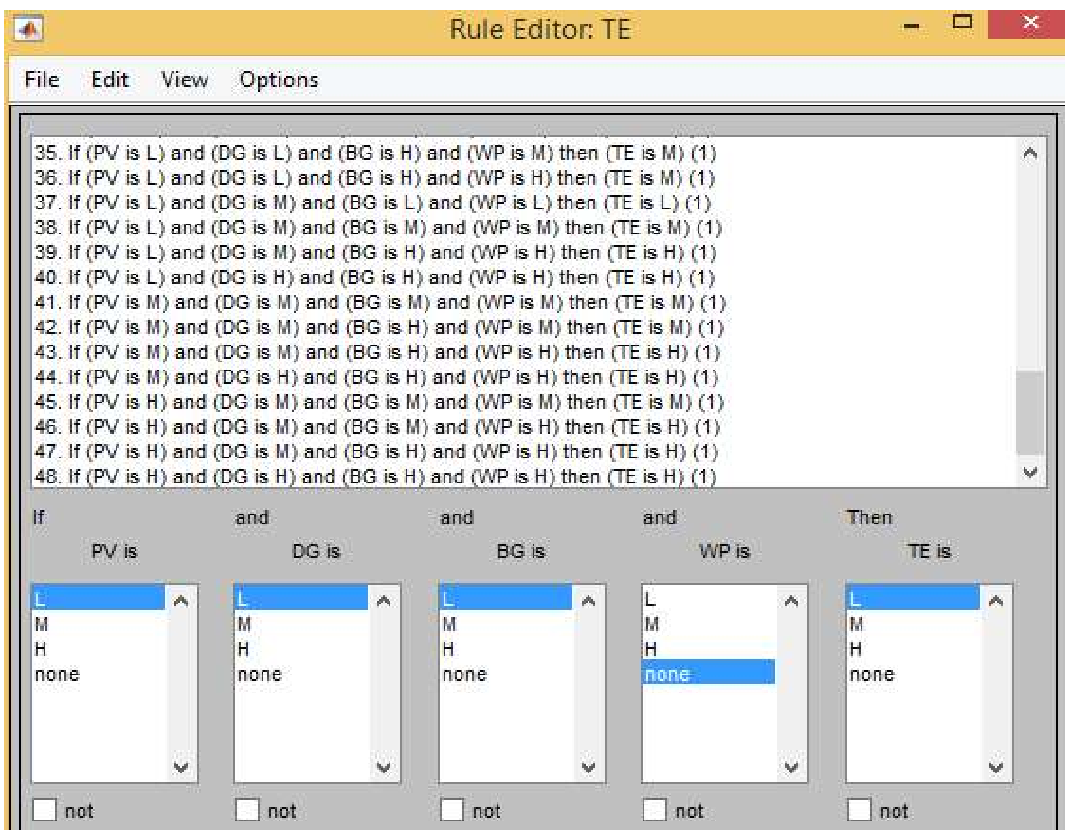


Fig. 6.3 FES rule editor

6.3 Operation of the Fuzzy Expert System Model

Fuzzy expert model has been developed based on input variables of photovoltaic (PV), diesel generator, biogas energy, and wind power and hybrid energy as the output parameter. The final output hybrid energy of the fuzzy expert system is verified by using MATLAB Fuzzy Toolbox as shown in Fig. 6.3. The output result can be verified by changing values of the input variables in the MATLAB® rule viewer as shown in Fig. 6.4. For example, if PV is 100 kW, DG is 40 kW, BG is 30 and Wind is 250 kW, then all forty eight fuzzy rules are assessed concurrently to find out fuzzy output energy (TE) as 730 MW which is very close to the result obtained from Homer. Usually, outputs of active fuzzy rules are aggregated in order to achieve the final output [72].

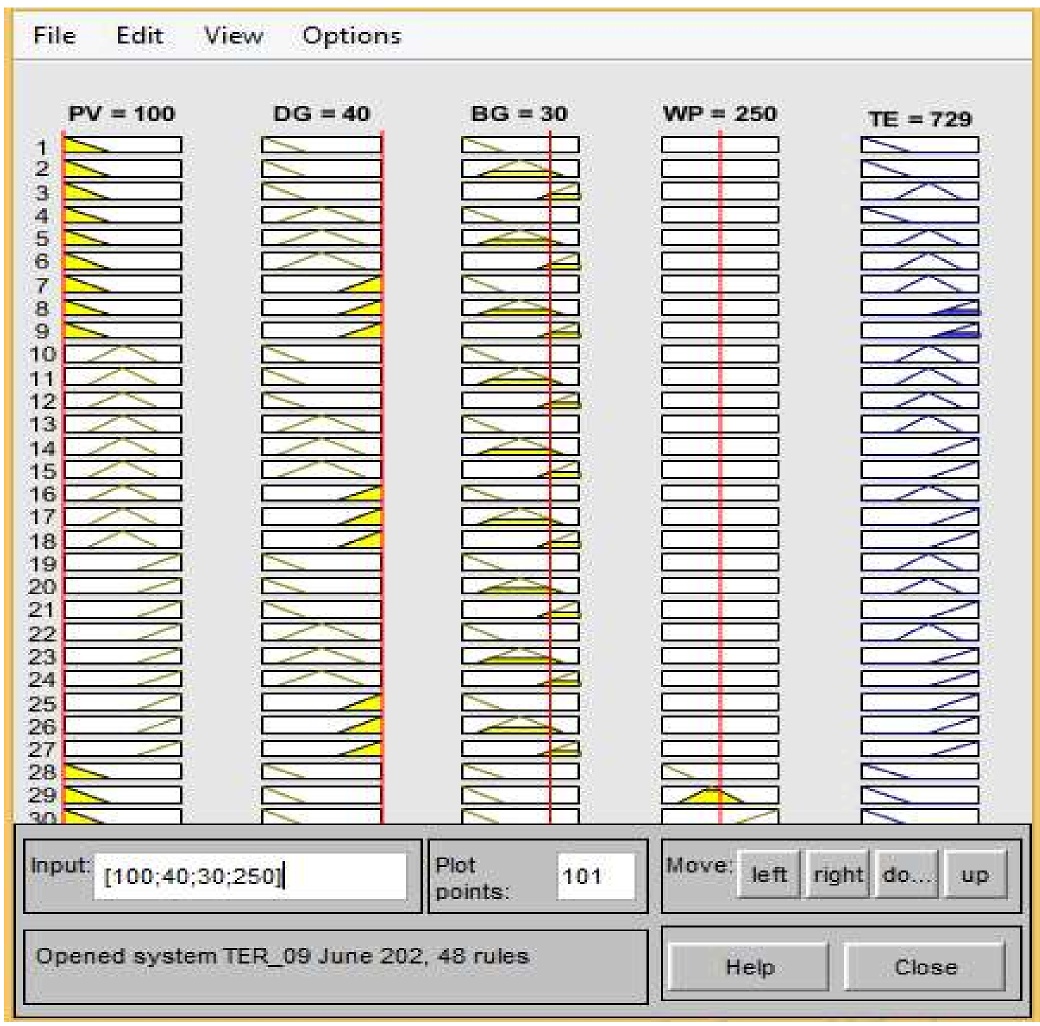
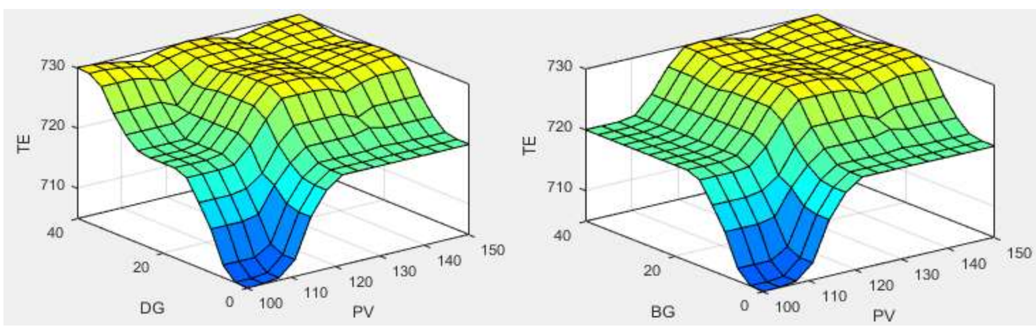


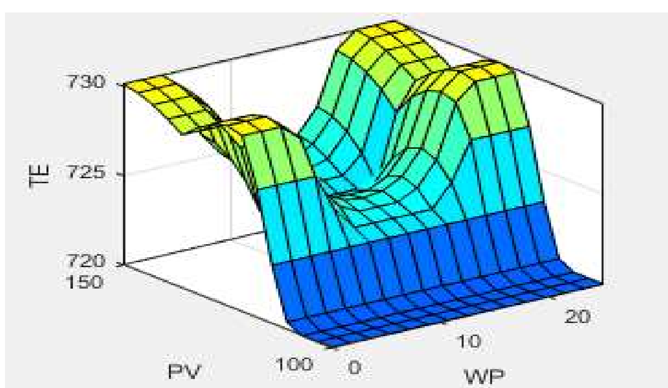
Fig. 6.4 Rule viewer of the fuzzy inferring system

6.4 Fuzzy Control Surfaces

Using MATLAB the fuzzy control surfaces are developed as shown in Fig. 6.5, (a), (b) and (c). It may serve as visual depiction of how fuzzy expert system operates dynamically over time. These are the mesh plot of the example relationship between input variables photovoltaic, diesel generator, biogas energy, and wind power and hybrid energy as the output variable. The design generally verifies the rules and the membership functions and observes if they are correct or not and whether revisions are important to develop the output [73].As per the requirement of the expected output curve, the rule base for the fuzzy sets can be adjusted. Fig. 6.5 (a) shows that hybrid energy (TE) raises slowly with small increase of PV and diesel generator, but it increases extremely at higher value PV and diesel generator. A similar pattern is observed in other control surfaces as shown in Figs. 6.5 (b) and 6.5 (c).



(a) (b)



(c)

Fig. 6.5 Control surfaces of the fuzzy inferring system

The overall system can be visualized from above Fig. 6.5. However, the accuracy of the rules and membership functions can be verified from these control surfaces. The plot shows that if there is a deviation from input variables; the amount of total hybrid energy will be changed accordingly.

6.5 Comparison between HOMER and Fuzzy Expert System

The results of the developed FES have been compared with another software results by using Homer. Sample data is shown in Table 6.1. The mean relative error between Homer and FES is found as 1.6 % which is within the acceptable limit. Hnece, the result shows the good perfromance of the developed expert model.

TABLE 6.1 COMPARISONS OF RESULTS

Observation No	Input Variables				Output - Homer	Output - FES	Relative Error (%)
	PV (kW)	DG (kW)	BG (kW)	WP (kW)	TE (MW)	TE (MW)	
1	100	40	30	249	715	729	1.96
2	100	0	40	250	704	720	2.27
3	150	40	0	251	734	730	0.56
Mean Relative Error							**1.60**

6.6 ETAP Functional Test Analysis

6.6.1 Construction of Hybrid Model for ETAP Analysis

The configuration of renewable hybrid energy sources are solar PV, wind, biogas and diesel generator. The solar power system can be defined as the system that uses solar energy for power generation with solar panels. In solar PV system, there is solar generator. In solar generator, each panel has 110 Watt and total no of panel is 112. All these panels are connected in series and parallel. Other parameters are attached as annexes.

The panels are connected in series. There is DC to AC inverter having the capacity 50 kW, 125 V/0.22 kV. Inverter is connected to a common bus (0.22 kV) which is connected with a 150 kVA transformer (0.22/0.4 kV). Transformer (T-2) is connected with a common bus (0.4 kV). A 2500 AH Battery (125V) Bank is also connected with an Inverter (150 kW, 125V/0.22 kV) which is connected with 50 kVA (T-4) Transformer (0.22/0.4 kV). GC- M battery is used with a capacity 2515 AH and 31 plate. Total 70 batteries are required. Transformer secondary is connected with a common bus (0.4 kV). A 30 kW biogas generator is used in this system which is connected with 50 kVA (T-12) Transformer (0.22/0.4 kV). Biogas generator has prime mover rating 40 kW and RPM is 1500. Its efficiency is 95%. Transformer secondary is connected with a common bus (0.4 kV). A 40 kW Diesel Generator is used in this system which is connected with 50 kVA (T-14) Transformer (0.22/0.4 kV). Diesel generator has prime mover rating 40 kW and RPM is 1500. Transformer secondary is connected with a common bus (0.4 kV). A 250 kW Wind Turbine Generator is used in this system which is connected with 200 kVA (T-16) Transformer (0.22/0.4 kV). Generic is considered for wind turbine and wind speed is 6 m/s. Its efficiency is 95%. Turbine swept area is 2828 m^2 and air density is 1.225. Diameter is 60 m and RPM is 15. Transformer secondary is connected with a common bus (0.4 kV). There are four lumped Load each having the load 50 kVA amounting total 200 kVA load. A 200 automatic Capacitor Bank is used in this system for Power Factor Improvement which is connected with common 0.4 kV bus and parallel with load. Wind generators, Solar panels, Bio & Diesel Generator hooked up together through the same wiring system. The setup is straightforward and will vary slightly based on the individual energy systems that we are using.

6.6.2 **Operation of the System Configuration by ETAP**

There are 112 solar panels connected in series and parallel, which is connected by cable to inverters. The inverter has the rating of 50 kW. Each combination is generating 5.7 A electricity making total 5.7x10=57 A which is flowing through bus 4 via transformer T-2. Storage device battery is also connected to main bus via transformer T-4 flowing 19.4 A to main bus. 30 kW biogas generator is connected to main bus via transformer T-12 flowing 10.7 A to main bus. 40 kW diesel generator is connected to main bus via transformer T-14 flowing 10.7 A to main bus. 250 kW wind turbine is also connected to main bus via transformer T-16 flowing 455.6 A to main bus. From common main bus, the load is consuming the power. Out of four loads, 50 kVA load is carrying 72.4 A and 100 kVA load is carrying 144.8 A. 200 KVAR PFI is connected for power factor improvement. From the figure it is found that the current is flowing in normal direction. When wind, biogas and diesel generator is kept open, the transformer T2 and T4 are found overloaded. When only wind is kept open, biogas and diesel generator are overloaded. When wind and diesel generator is kept open, the transformer T2, T4 and T12 are found overloaded. Again, when wind capacity is increased to 300 kW, the current is flowing in reserve direction. Therefore, it proves that the hybrid system configuration is functionally all right. Fig. 6.6 shows single line diagram of proposed hybrid system, Fig. 6.7 shows single line diagram of hybrid system – when solar PV and battery is open, Fig. 6.8 shows single line diagram of hybrid system - when biogas generator is open, Fig. 6.9 shows single line diagram of hybrid system - when diesel generator is open and Fig 6.10 shows single line diagram of hybrid system - when wind turbine is open.

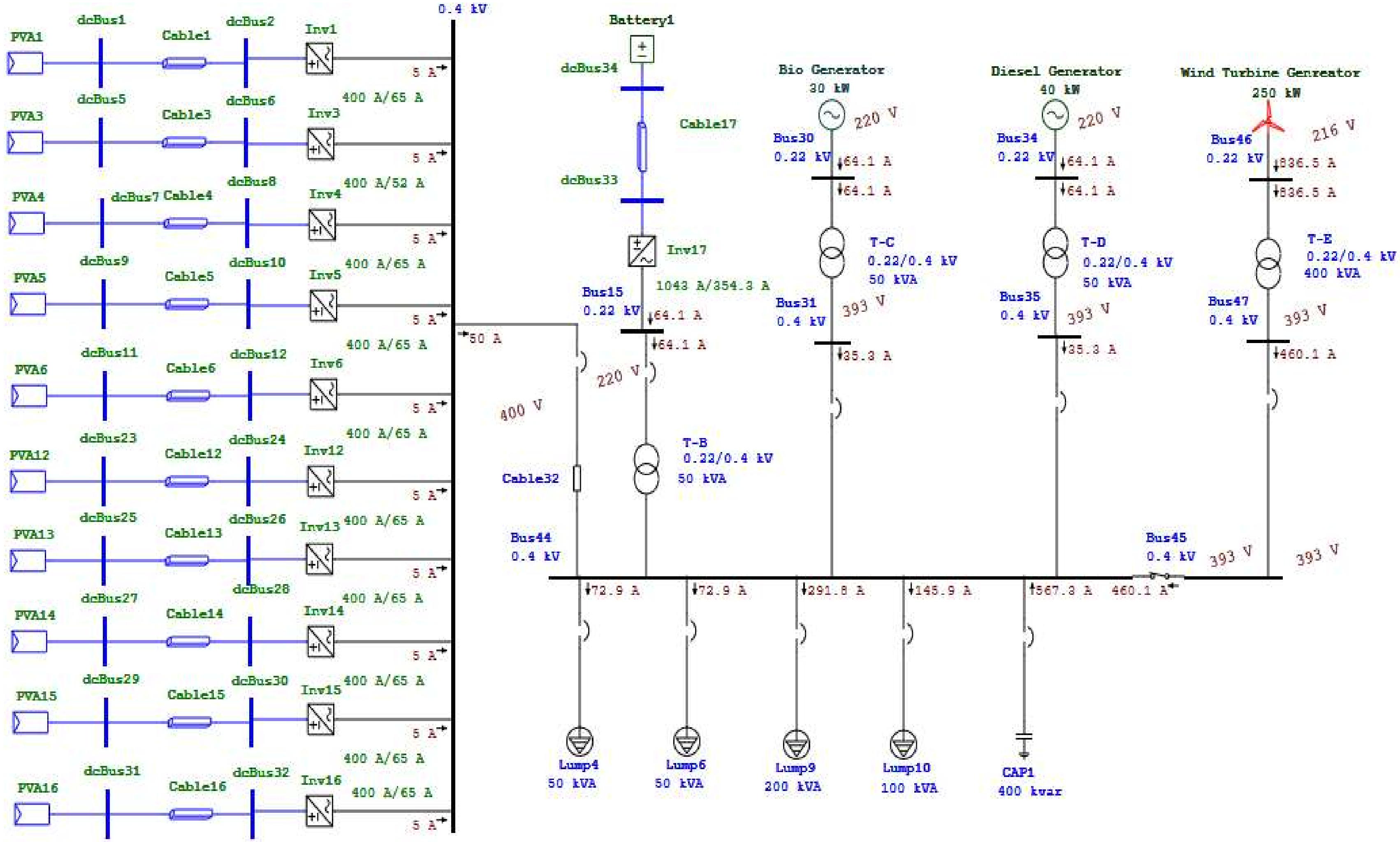


Fig 6.6 Single Line Diagram of Proposed Hybrid System

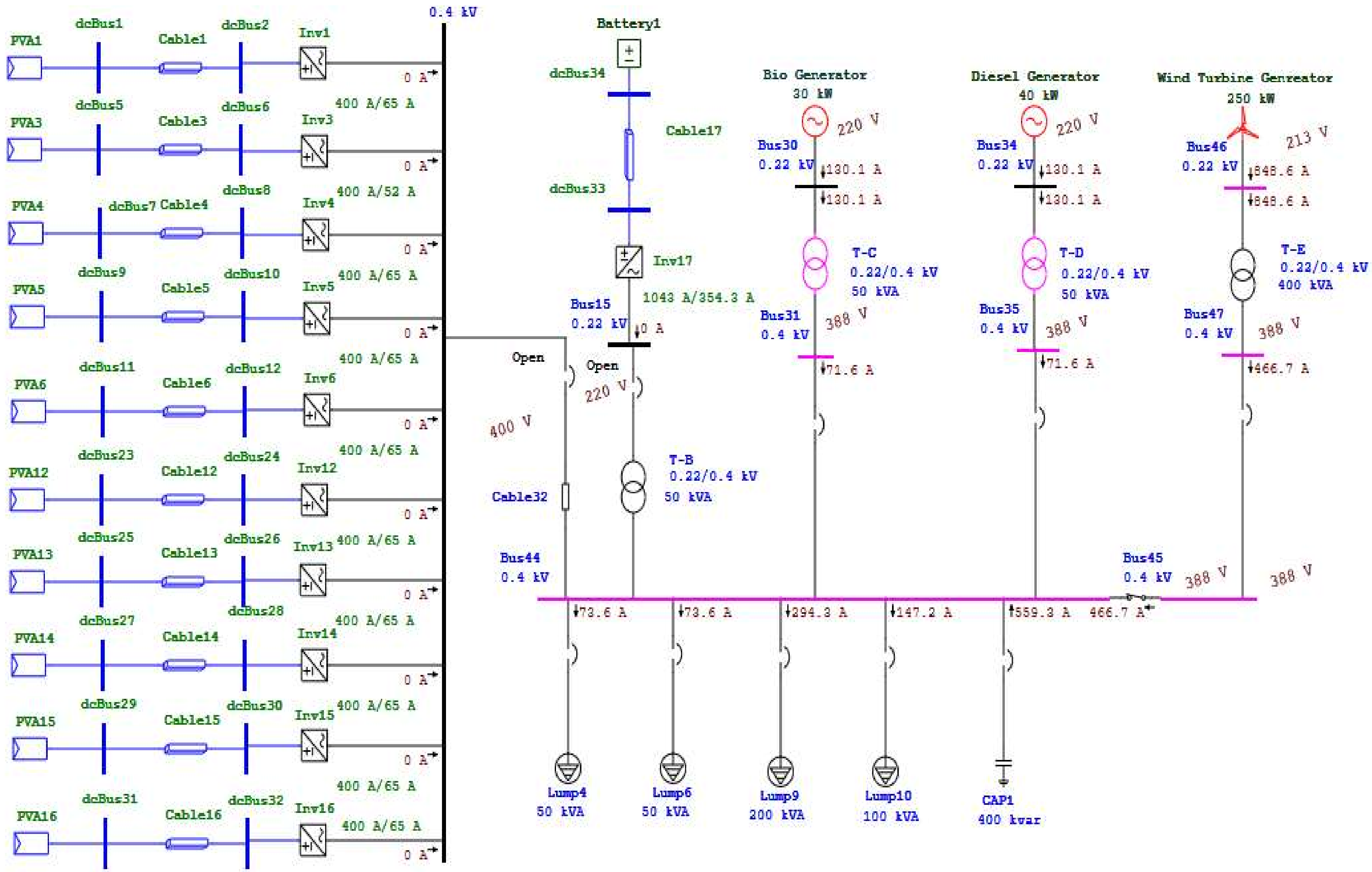


Fig 6.7 Single Line Diagram of Proposed Hybrid System-when Solar PV and Battery is Open

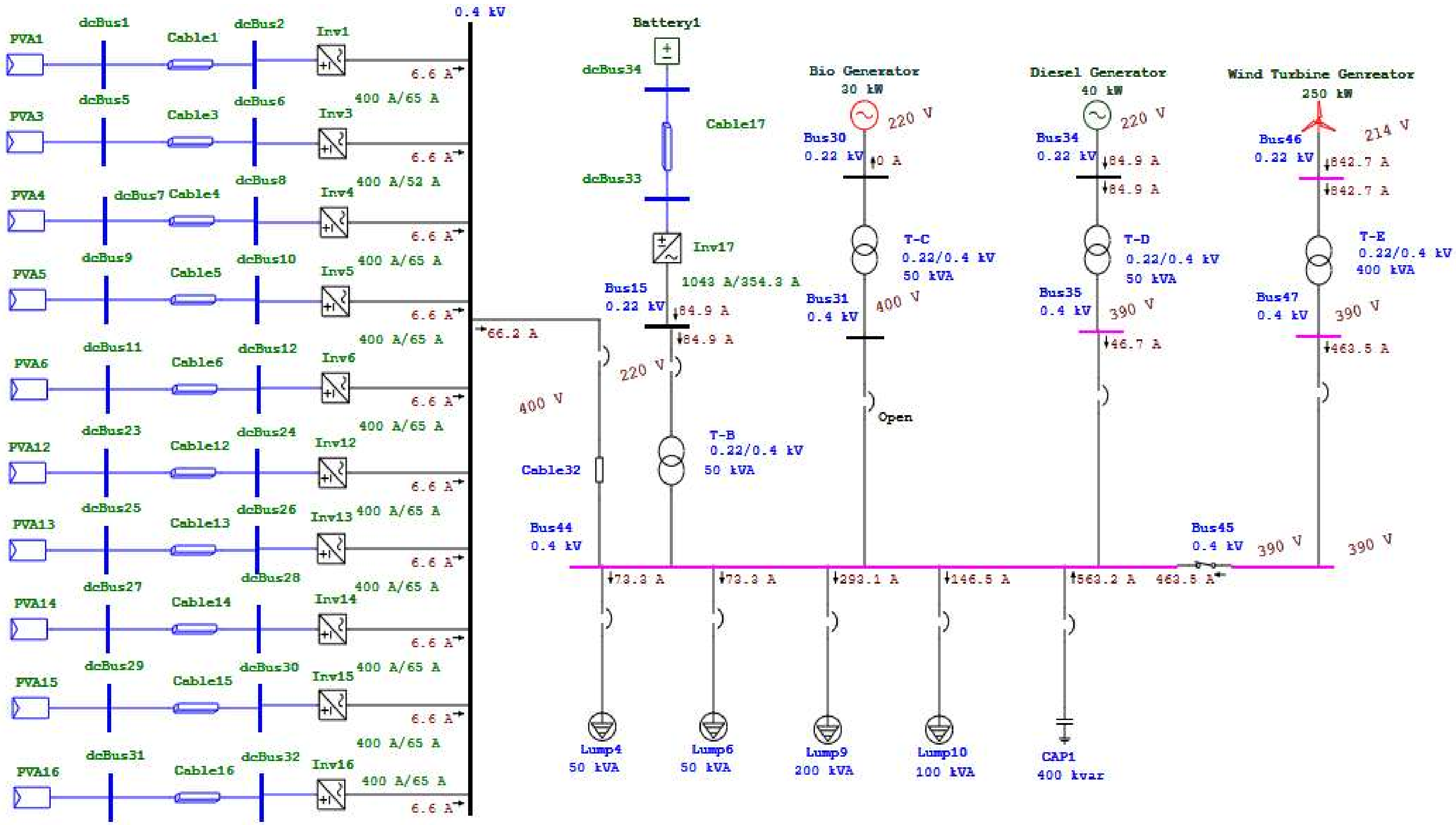


Fig 6.8 Single Line Diagram of Proposed Hybrid System-when Biogas Generator is Open

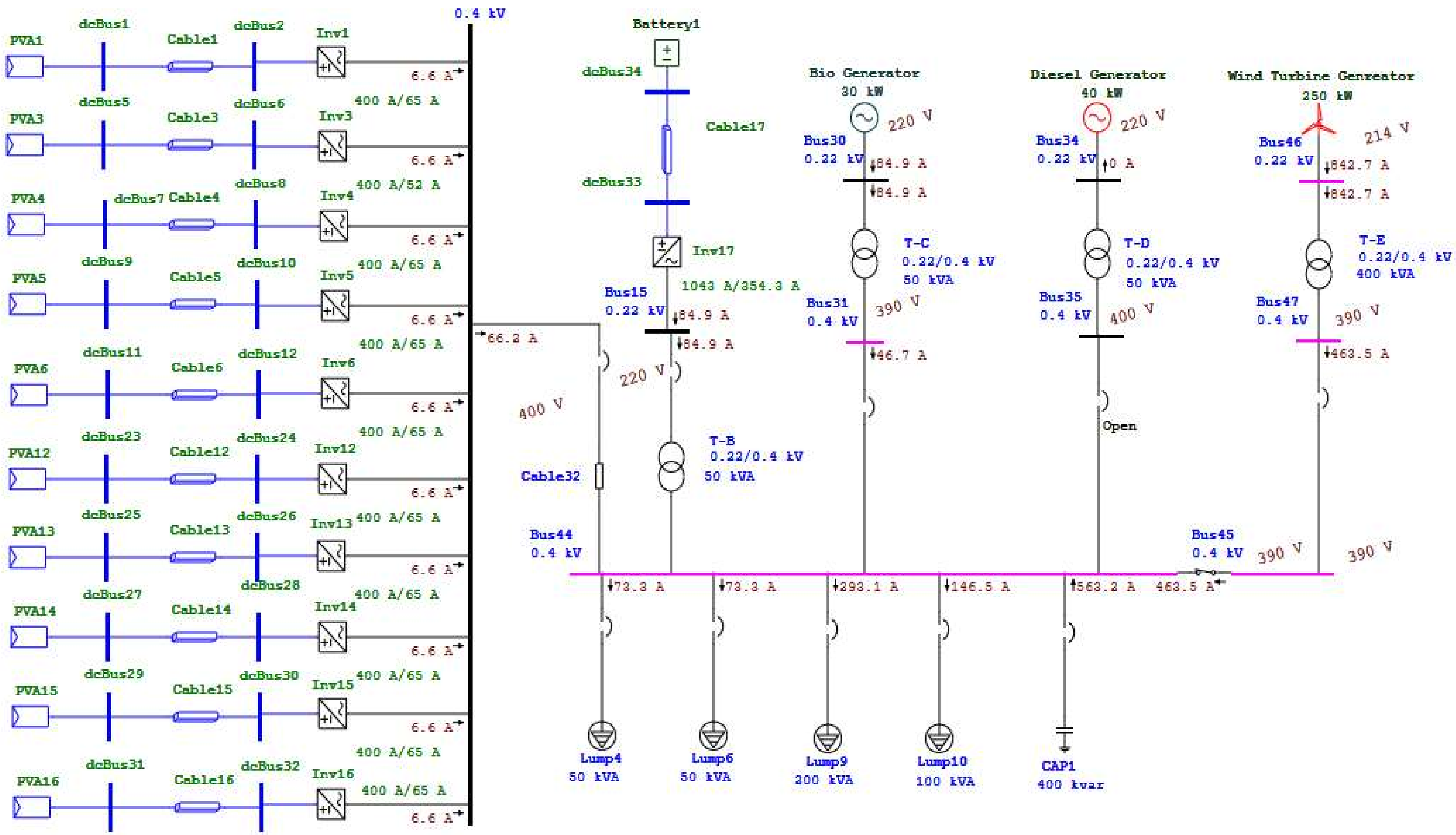


Fig 6.9 Single Line Diagram of Proposed Hybrid System-when Diesel Generator is Open

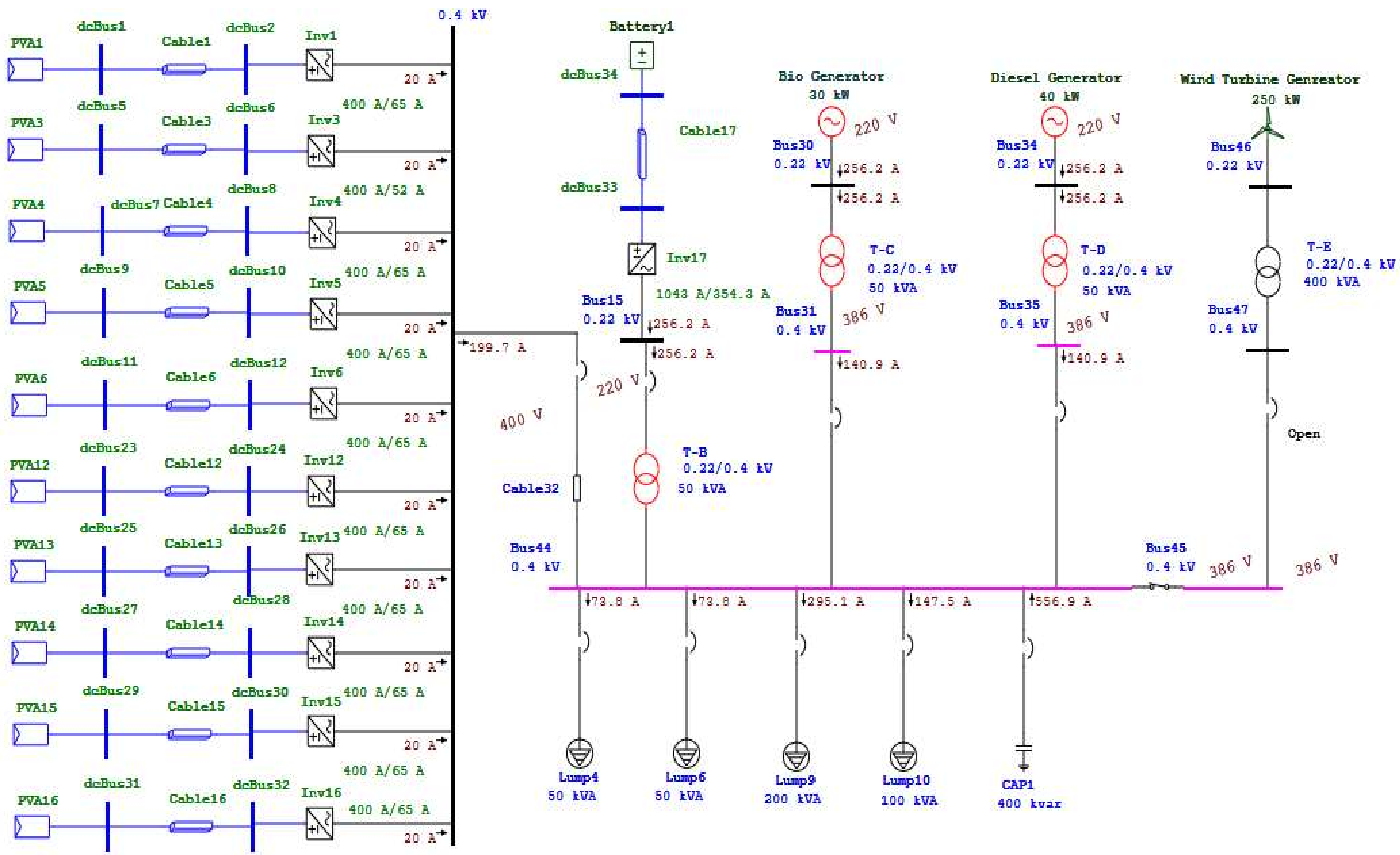


Fig 6.10 Single Line Diagram of Proposed Hybrid System-when Wind Turbine is Open

6.7 Summary

The fuzzy expert system is a computer program that helps in solving problems demanding substantial human expertness by using explicitly exhibited domain knowledge and computational decision procedures. Fuzzy inference is the process of developing the mapping from a given input to an output using fuzzy logic which then offers a base from which decisions can be made or patterns perceived. In this relationship input variables are photovoltaic (PV), diesel generator (DG), biogas energy (BG), and wind power (WP) and Total Energy is the output variable. The design generally verifies the rules and the membership functions and observes if they are correct or not and whether revisions are important to develop the output. Here the input data is taken from HOMER. After analysis by using MATLAB, the fuzzy control system was develop to validate the HOMER result. It is found the HOMER results have only 1.6% relative errors from the Fuzzy expert system. Therefore, HOMER results are validated. Further, the proposed design is run by ETAP software to judge the functional test whether the design is ok or not. The design is simulated with number of options and finally the proposed design is perfectly all right.

CHAPTER 7
CONCLUSION

7.1 Conclusion

In this work, design and optimization of hybrid energy system for an off grid area of Bangladesh has been done where Swarna Dweep is considered for the study area. In this study area, a detail survey is conducted for assessing the renewable energy resources and the required components of the proposed hybrid components cost also assessed from the local markets. The site is blessed with considerable annual average global solar radiation of 4.51 kWh/m^2 /day, average wind speed of 6.31 m/sec at 60 m height and average biogas is available 10.785 ton/day. The renewable energy resources and components cost is the parameters for input of HOMER. HOMER is used for simulation, optimization and sensitivity analysis of the proposed hybrid model in Swarna Dweep. Payback period and internal rate of return are calculated and compared with the hybrid energy systems reported in the literature. There are three combinations of the hybrid energy system. Out of three, the best combination composed of 100 kW PV array, 25 Wind turbine (10 kW each), a diesel generator with a rated power of 40 kW, 30 kW biomass generator, 2000 piece of storage battery and 650 kW converter is the most commercially reliable in terms of COE (21.655 TK/kWh), NPC (171,171,120 Tk) and initial capital is 40,451.200. The Hybrid energy system has the electricity generation mix of 29 % from PV, 56% from the wind turbine, 5% from diesel generator and 10% from biogas resources. Due to availability of plenty of renewable resources like solar, wind, biogas etc. available in the study area, Swarna Dweep, the best optimization is ascertained in proposed configuration C. HOMER augmented to identify the best option.

As the system produces more than the demand, the system on average achieves a positive energy balance every year because the proposed hybrid system was able to produce 1957 kWh/day against the 1694 kWh/day required for lighting and power loads. Besides that by economic modeling, the economic viability is tested. Considering 25 taka per kilowatt hour, the payback period is only 9 years and considering 30 taka, the payback period is 8 years. After calculating, the IRR becomes 9.33% which is beneficial as the interest rate is considered 8% for the project. Besides that, this result is compared with the results of different countries of the world. It was evident that the COE is the lowest but NPC is little more as the system configuration is larger than the compared one. However, if no solar resources are available or there is very low wind speed, the electricity demand can be met with a hybrid system comprising of biogas and diesel generators. In this scenario, the cost of electricity supply will increase, thereby making the system less attractive to users. The island is also located far from the national electrical grid. Therefore, solar PV-wind-diesel-biogas-Battery hybrid system proposed here can be used as energy sources in Swarna Dweep.

Moreover, Fuzzy expert system is also used to validate the HOMER software. The results of the developed FES have been compared with another software results by using Homer. The mean relative error between Homer and FES is found as 1.6 % which is within the acceptable limit. Henece, the result shows the good perfromance of the developed expert model. Again, the proposed hybrid sytem is tested by ETAP software where is seen that the functional test of the designed proposed hybrid system is performed satisfactorily. But if more loads is applied or for any reason any of the three sources is open, then system will be unstable.

This study was done for Swarna Dweep Island. Similar study to implement renewable hybrid power system for other off grid areas of the country can be done as well. Producing electricity from biomass and wind is still a relatively new concept in our country. Government should make people aware of its potential, so that larger number of people can utilize it in the future. Government can provide soft loans with lower interest rate to the consumers who want to implement renewable based hybrid system for themselves. Much of the country experiences severe load shedding throughout the year. The proposed method of producing electricity from renewable energy sources can be utilized in areas of the country with heavy load shedding. This would reduce the load pressure on the grid. Government of Bangladesh should further expand the scope of research on different renewable energy sources. There should be an extended legislative support for investors. The GoB should ensuring proper use the knowledge, skills, expertise and facilities are available in the country and also encourage local manufacturing and assembling of Renewable Energy Technology (RET) components.

7.2 **Future Work**

Any engineering research can't cover all aspects and investigates all important points at once. Some points need to be reinvestigated and studied in future works. Separately from the studies applied in the course of this thesis work; that seems to be of the highest importance.

The research works creates the scopes for work in many other related areas. The following hybrid energy options are identified for further work:

a. Considering new construction plan, similar analysis can be performed at Swarna Dweep.

b. Similar work by using more improved or latest version of other algorithm for better results.

c. Hybrid energy system may have more renewable sources of energy such as solar, wind, biogas and tidal instead of solar, wind and biogas.

d. For standalone mode instead of solar, wind and biogas, only solar or combination of solar-biogas or combination of wind-biogas or combination of solar wind may be designed off grid area.

e. Similar analysis, only biogas can be taken into consideration due to huge amount of cattle are normally grazing in remote village or island.

Future research efforts in hybrid energy for electricity production will result in reduced production cost and increasing acceptability by wider sector of society. The future proposed Hybrid Renewable Energy System will assist generation of economical and environmentally safe energy that is universal. In addition, energy management and optimization system of the renewable energy system can be further improved by adding the artificial intelligence.

LIST OF PUBLICATIONS

International Journal

1. **Md Rosaidul Mawla** and Md. Ziaur Rahman Khan, Design and Optimization of Hybrid Energy System for a Remote Area of Bangladesh, International Journal of Advance Research and Innovative Ideas in Education, Volume 6 Issue 3 2020, pp 985-986,DUI: 16.0415/IJARIIE-11195.

2. **Md Rosaidul Mawla**, Nasrin Sultana, MSAAF Shiblee, **Myths, Safety and Awareness of Lightning Protection in Bangladesh**, American Journal of Electrical and Computer Engineering, International Journal of Electrical Components and Energy Conversion. Vol. 6, No. 2, 2020, pp. 7-13. doi: 10.11648/j.ijecec.20200602.112.

3.Sagor Biswas, MSAAF Shiblee, Shah Mohazzem Hossain**, Md Rosaidul Mawla,** Electricity generation through Bio-waste and Solar: An Alternate Way to Mitigate the Electricity Demand for Individual Owner House in Remote Areas of Bangladesh, International Journal of Scientific & Engineering Research Volume 9, Issue 9, September-2018, pp 5-9.

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1. **Md Rosaidul Mawla** and Md. Ziaur Rahman Khan, A Study on Sustainable Development Goal 7: Future Plan to Achieve the Affordable and Clean Energy-Bangladesh Perspective, 2020 IEEE Region 10 Symposium (TENSYMP), 5-7 June 2020, Dhaka, Bangladesh, pp 421-426.

2. **Md Rosaidul Mawla,** MSAAF Shiblee, Md. Ziaur Rahman Khan, Mohd Muinul Haq Mamun, Md. Mahadi Hasan and Nasrin Sultana, Statistical Analysis of Lightning Myths and Suggestive Measures in Context of Bangladesh, 4^{th} International Conference on Electrical

Engineering and Information & Communication Technology, 22-24 September, 2018, pp 666-671.

3. **Md Rosaidul Mawla,** Md. Ziaur Rahman Khan, Design and Optimization of Hybrid Energy System for an Off Grid Area of Bangladesh by using HOMER and Validation by RETScreen, International Conference on Mechanical, Industrial and Energy Engineering 2020, 19-21 December, 2020, Khulna, Bangladesh.

4.**Md Rosaidul Mawla,** Md. Ziaur Rahman Khan, Generation of Electricity from Biogas Source- An Alternative Way to fulfill the Electricity Demand in Remote Area of Bangladesh, International Conference on Mechanical, Industrial and Energy Engineering 2020, 19-21 December, 2020, Khulna, Bangladesh.

5. **Md Rosaidul Mawla**, Md. Ziaur Rahman Khan, A Study on Generation of Electricity Plan by 2041 for Sustainable Development in Bangladesh, International Conference on Mechanical, Industrial and Energy Engineering 2020, 19-21 December, 2020, Khulna, Bangladesh.

6. **Md Rosaidul Mawla**, Md. Ziaur Rahman Khan, Net Energy Metering-An Optimistic Endeavour for Augmenting Renewable Power Generation in Bangladesh, International Conference on Mechanical, Industrial and Energy Engineering 2020, 19-21 December, 2020, Khulna, Bangladesh.

7. Salim Reza, M S A A F Shiblee, **Md Rosaidul Mawla**, Jannatul Nime Jein and Md Mahmudur Rahman, Design and Analysis of Solar PV System for Marine Fishing Trawlers in Bangladesh, 4th International Conference on Electrical Engineering and Information & Communication Technology, 22-24 September, 2018, pp 677-680.

8. Md. Mahadi Hasan, Abdul Hasib Chowdhury, Md. Ali Azam Khan and **Md Rosaidul Mawla**, Comparative Study and Analysis of Switching Transient Behaviour of Overhead

Transmission Lines and Underground Cables, 4th International Conference on Electrical Engineering and Information & Communication Technology, 22-24 September, 2018, pp 21-26.

9. M.G Zakir, A S M Nasim, A Islam, M A Hossain, **Md Rosaidul Mawla** & M A R Sarkar, Transient Analysis of VVER–1200 Nuclear Power Reactor in the Event of AC Power Failure, International Conference on Mechanical Engineering and Renewable Energy 2019 (ICMERE2019) 11 – 13 December, 2019, Chittagong, Bangladesh.

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