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Optimization and Life Cycle Cost Analysis of Renewable Energy Supply Options for Academic Buildings - A Case Study

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ABSTRACT

In this paper focuses on realizing alternate power supply sources to the academic buildings located at Manipal, Karnataka, India, and analyzing the possible combination of the hybrid energy sources. The main emphasis is on steering the optimization and life cycle cost analysis of the hybrid energy sources. The hybrid energy system optimization and feasibility study are carried out using HOMER Software and the results are verified with Linear Programming. The case study is conducted with the involvement of photovoltaic, Wind turbine and diesel generator (DG) along with the battery bank. Further, the DG was integrated with the renewable energy sources to smoothen the power circulation and enhance the reliability issues. The realistic climate data obtained from the NASA website for the location Manipal (13.347° N, 74.75° E) and estimates the solar and wind power using the models developed.

Keywords: Photovoltaic, Wind, Life Cycle Cost, Optimization, HOMER
JEL Classifications: Q21, Q40, Q41

1. INTRODUCTION

In India, most of the rural areas are still undeveloped which are to be provided with electricity. For the development of these areas, standalone wind and solar energy systems can play a vital role. The abundant availability of solar energy for the entire year makes solar energy systems more attractive. Electricity needs of schools, hospitals and other social places can be met by wind, diesel generator (DG) and solar energy systems, which may positively improve education healthcare and various services for the population.

This paper presents the optimization and costs analysis of hybrid energy system by using HOMER software Al-Karaghouli and Kazmerski (2010), http://homerenergy.com. These include the mathematical model. The details of all the system components (photovoltaic [PV], Wind, and DG), the power converters, the energy storage (battery) and their sizing are also sketched. From the account of the system components, a mathematical model was formulated. Mathematical modeling of energy systems involves representing the arrangement of energy options (either single or hybrid) computationally and simulating its operation over time or under varying conditions or scenarios. The cost model is the annualized cost of a component which includes annualized capital cost, annualized replacement cost, annual operation and maintenance (O and M) cost, and annual fuel cost (generator). This model (economic and environmental cost model) was derived through the annualized total cost of different configurations of the power system. An algorithm was formulated to be used to solve the optimization problem which links the power generation model and the cost model together. This software performs a simulation and optimization process to determine how a particular system configuration would behave in a given setting over a long period of time.

The process of optimization and analysis of sensitivity in HOMER software is quite practical since its simulation logic is less specific compared to other time series simulation models for micro-power systems (e.g., Hybrid2, PV-Design Pro, and PV*SOL) and its input complexity is minimized so that the computation is faster than other models Lambert et al. (2005),Kumaravel and Ashok (2015).

2. SYSTEM DESCRIPTION

Solar and wind energy being intermittent in nature, needs a storage device or alternate energy source for backup. In the particular case in addition to Wind turbine, DG is involved to provide a continuous supply to the load profile. The hybrid energy system should suffice the energy demands of the load throughout the year without the support of utility. The realistic climate data obtained from the NASA website for the location Manipal (13.347° N, 74.75° E).

The Figure 1 shows proposed system contains a solar system, wind system with DG with a battery storage system for storage of excess generated electricity. Converter system connected between AC and DC link and grid system is used here only for excessive power feeding not taking from the grid. The Solar power is the major supplier of energy to this system and the variation of solar power with time. The DG and battery banks are used as a back-up electricity source. The HOMER software determines the optimal cost and sensitivity analysis of the proposed system. The size of the energy system consists of 2200 kW Solar power, 800 kW DG, Wind power 750 kW, 800 Battery Cycle Charging, and 2000 kW AC/DC converter. The lifetime of the project is estimated at 25 years. The three different configurations considered for optimization are as follows:

1. Hybrid system with PV, Wind, Diesel, and Battery
2. Hybrid system with PV, Diesel, and Wind
3. Hybrid with PV and Diesel

2.1. Load Profile of Site Location

The Powerhouse-I contains a load profile involving 5 major academic buildings and is currently supplied by 10 feeders from the grid. The power supply is given to the load profile using three transformers (800 kVA, 800 kVA and 1250 kVA). The demand is met using a DG when there is a shortage. Figure 2 shows the single line diagram of Powerhouse I. The daily load profile data is collected for the whole year from the grid supply. Also, the DG supply and fuel consumption is also considered for optimization of the sources and feasibility study of the Renewable energy sources in this study.

The average estimation of daily energy consumption is 13 MWh/day, peak load is found to be 1408 kW and the average load is 537 kW. Base load is from evening 11 PM to morning 6 AM this is interior and outdoor lighting load. The information was computed for the entire hour bases daily electrical load conditions of a demand for an MIT Campus (five major buildings). The daily load profile with the respective 24 h of the day is shown Figure 3. The net present cost (NPC), capital cost and cost of energy are calculated and the solution with the least cost of energy is considered for the implementation of hybrid energy sources.

2.2. Availability of Resources

Solar global horizontal irradiance (GHI) the solar irradiation data collected based on the monthly average value that is geographically available at the location of the MIT Campus where PV cells to be devised. This input parameter is extracted from National Solar Radiation Database of National Renewable Energy Lab based on the latitude and longitude of the location. The Clearness Index value is also counted since the effective utilization of the solar energy by the PV cells depends on the Solar GHI which involves both Clearness Index and the solar radiation as shown in Figure 4. The clearness index value varies between zero and one. The monthly average wind speed and temperature as shown in Tables 1 and 2 http://eosweb.larc.nasa.gov.

2.3. Fuel Consumption (for DG)

The monthly consumption data is collected for 1 year. The monthly consumption data will change based on wind/PV/DG/Battery combination. When the Wind/PV Combination is present, so that, it is useful in calculations related to the DG. This data is especially useful for the application of Linear Programming method.

Figure 1: Proposed hybrid system

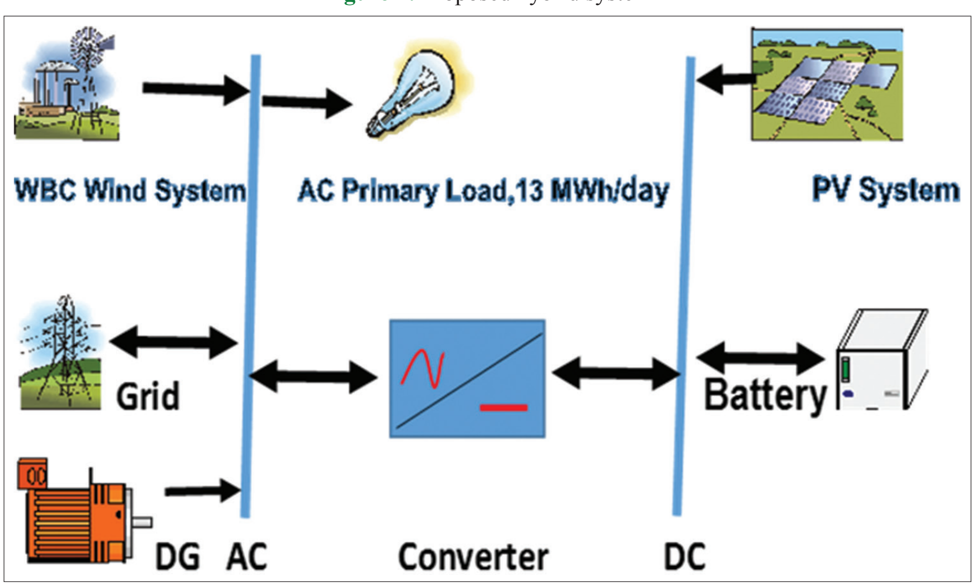
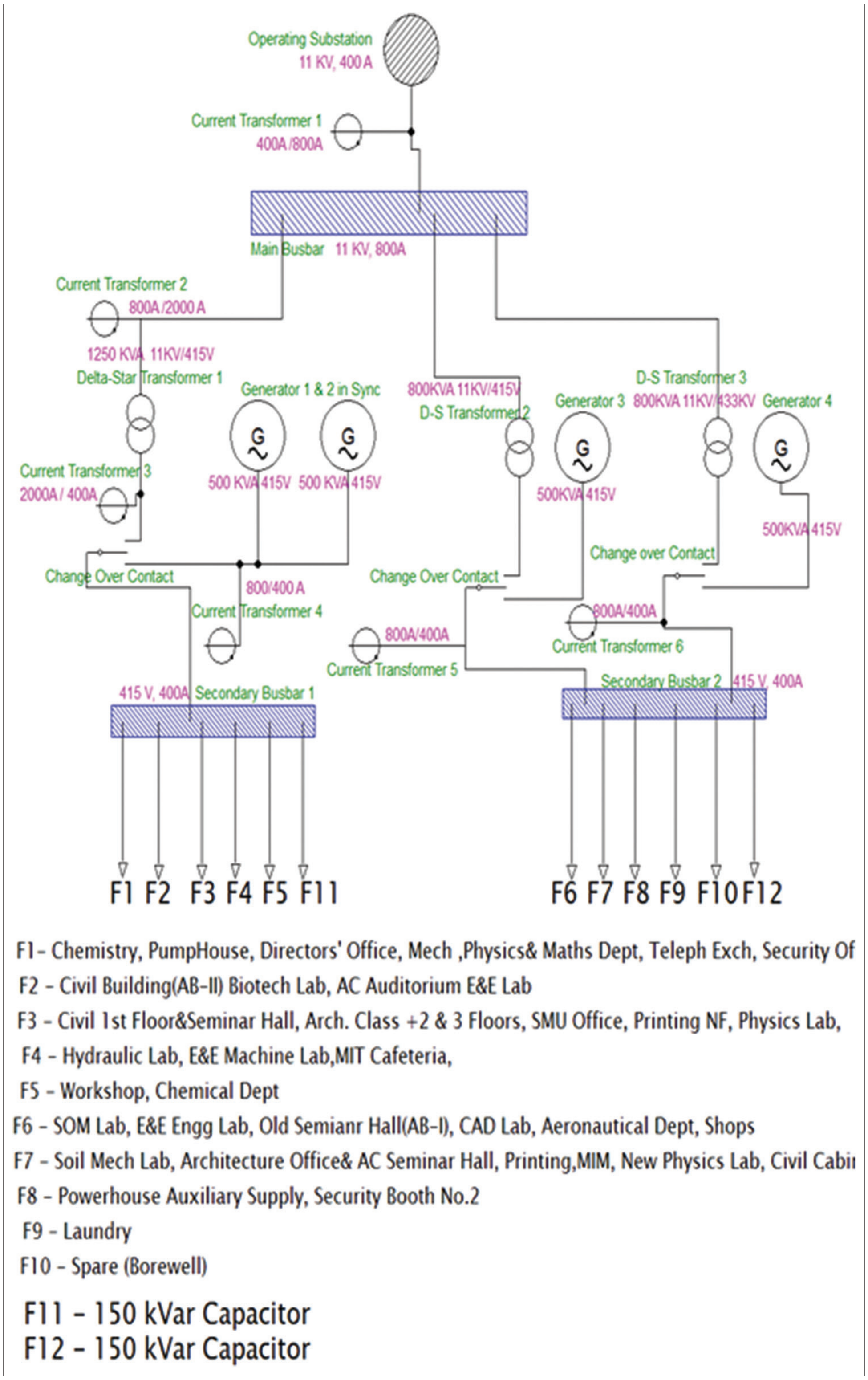


Figure 2: Single line diagram of power house I



3. COST AND SIZE OF HYBRID SYSTEM COMPONENTS

An optimal sizing method is required efficiently and economically in utilizing the energy sources. The optimum sizing method can help for a minimum investment with full use of the system components. The life cycle cost (LCC) is signified by the NPC. The NPC is a combination of initial cost, replacement cost, operation, and maintenance cost of the system components.

3.1. PV System

Here the generic flat plate PV is chosen since the complications of tracking is not necessary, as its collectors absorb energy in every direction above absorbers. The details of the Generic flat plate PV panel and its cost details are given in Table 3.

3.2. Wind Turbine System

In this work Generic 10 kW (BWC Excel 10) Wind Turbine is used, as it has very low cut in speed which is best utilized for the low sea level terrain like Manipal, where Wind Speed is not high always. Another best feature of the Bergy is that it is able to operate by itself even in adverse weather conditions like the rainy season when it is very important for the wind turbine to generate electricity. It also can work in extreme temperature conditions starting from −40 degree to 60 degree. It has low maintenance and high reliability. The parameters of the Wind Turbine and its costs are listed in Table 4 and Figure 5 shows the power curve of the wind turbine.

3.3. DG model

The DG has low capital cost but involves a high operating cost since the fuel price is elevating in the current days. The Diesel fuel cost is Rs. 61 at present. The Hybrid Energy system configured to the best level when the Auto size DG set is included, it benefits the lower heating value and the selection of different capacities. The Specifications are mentioned in detail in Table 5.

3.4. Storage System

The generic lead acid battery is chosen in this work. For back up sources, the battery bank system is required. When the DG, solar and wind power system is inadequate for the load demand, the battery bank system can operate. There is 800 number of batteries with nominal voltage 12 V, the nominal capacity of 200 Ah (2.4 kWh) are used. The capital cost, replacement cost and operation and maintenance cost are Rs. 23,725, Rs. 19,500 and Rs. 260. The cost curve of the batteries is shown below Figure 6. This battery can operate between −20°C and 55°C. The parameters related to the battery are given in Table 6.

3.5. DC-AC Converter

In this study, the DC-AC converter is used based on the primary load. Converter Specifications and it's cost curve as shown in Table 7 and Figure 7.

3.6. Grid

To avoid the corresponding capital investment, the grid can be attached to the Hybrid System for optimization so that the

Figure 3: Daily load profile

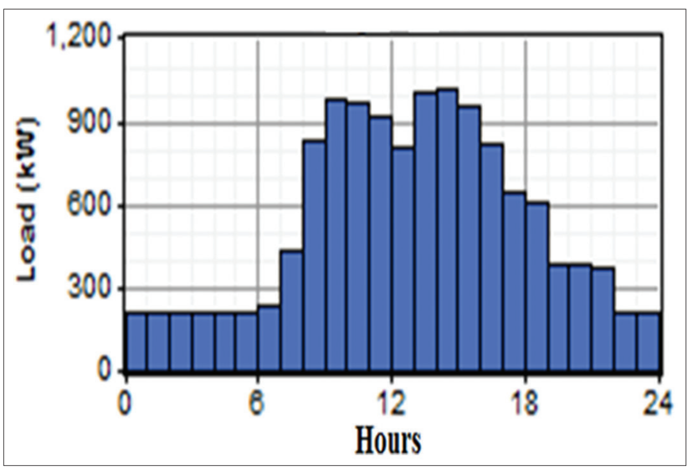


Table 1: Monthly average of temperature at location

Month	Temperature (°C)	Month	Temperature (°C)
January	25.73	July	25.15
February	26.25	August	24.83
March	26.91	September	25.3
April	26.87	October	25.30
May	26.58	November	26.07
June	25.76	December	26.00

Table 2: The monthly average wind speed

Month	Average wind speed (m/s)	Month	Average wind speed (m/s)
January	3.8	July	6.95
February	3.73	August	6.59
March	4.18	September	4.78
April	4.26	October	3.68
May	4.83	November	3.77
June	7.01	December	4.56

Table 3: Parameter specifications of PV panel

Parameters	Specifications
Rated capacity	1 kW
Capital cost	Rs. 56,875/kW
Replacement cost	Rs. 0
O&M cost	Rs. 650/year
Derating factor	80%
Lifetime	25 years
MPPT	No
Manufacturer	Generic

Figure 4: Monthly average solar radiation data along with clearness index

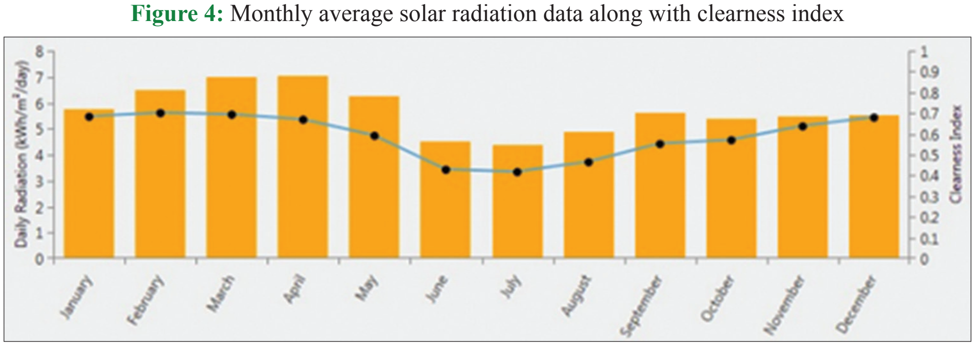


Figure 5: Wind speed-generated power curve

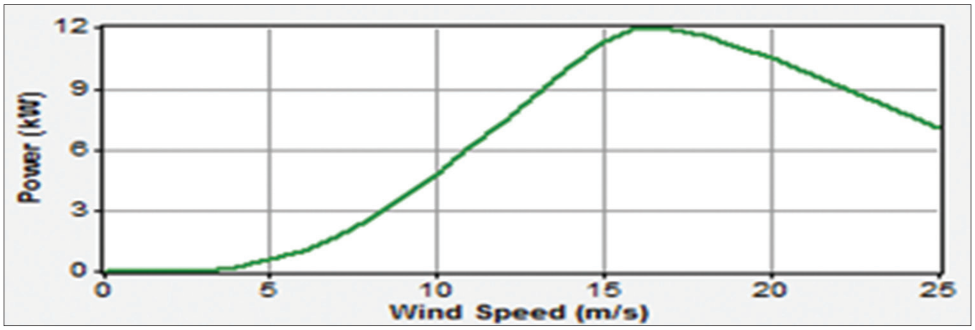


Table 4: The parameter specifications of wind turbine

Parameter	Specification
BWC Excel-s	10 kW, AC
Life time	25 Years
Hub height	50 m
Capital cost	Rs. 2,015,000
Cut out speed	12 m/s
Cut in speed	2.5 m/s
Rotor diameter	7 m
Temp range	−40°C-60°C
Generator	PMSG

Table 5: Parameter specifications of selected diesel generator

Parameters	Specifications
Capacity	10 kW (AC)/Greaves
Capital cost	Rs. 1,56,000
Replacement cost	00
O&M cost	Rs. 60/h
Lifetime	15,000 h
Specific fuel consumption	0.414 L/KWh

Table 6: Battery bank parameters

Vision 6 FM 2000	10 Amp
Nominal voltage	12 V
Nominal capacity	200 Ah, (2.4 kWh)
Initial cost	Rs. 23,725
Replacement cost	Rs. 19,500
O&M cost	Rs. 260/year
Depth of discharge	60%
Efficiency	80%
Life time	10 years

Table 7: Converter specifications

Capacity	6 kW
Initial cost	Rs. 37,635
Replacement cost	Rs. 31,999
Life time	15 Year
Efficiency	93%

excessive energy can be wheeled into it and the energy can also be transferred to fulfill the load demand at peak conditions instead of increasing the capacity of the system with the proper metering.

4. OPTIMIZATION AND COST ANALYSIS

Renewable and non-renewable power sources normally have drastically unique cost characteristics. Renewable sources of

Figure 6: Cost curve of the battery bank

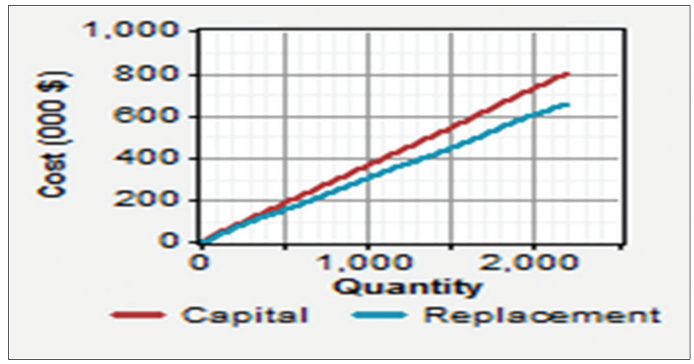
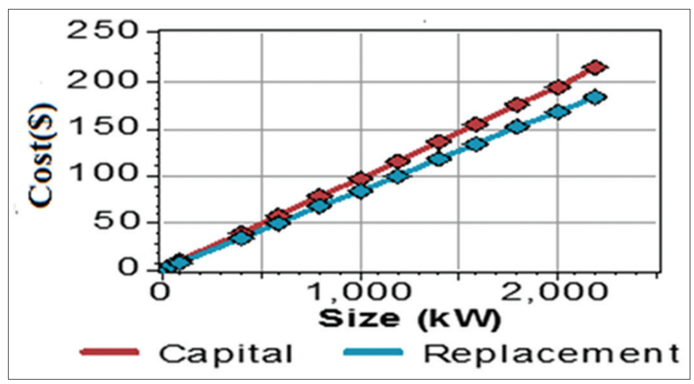


Figure 7: Cost curve of the inverter



energy have a tendency to have high initial capital expenses and low working (O&M) costs, while ordinary non-renewable sources have a tendency to have low capital costs and high operating expenses. In its optimization procedure, HOMER should regularly analyze the financial matters of an extensive variety of system configurations containing different amounts of renewable and non-renewable resources. To be fair, such correlations must be validated for both capital and working expenses. LCC analysis, includes all costs that happen within the life span of the whole Hybrid System.

The total NPC is calculated by using the following equation Kamel and Dahl, 2005; Sandeep and Vakula, 2016).

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,R_{proj})} \quad (1)$$

Where $C_{ann,}$ the tot is the total annualized cost, "i" the annual real interest rate (the discount rate), R_{proj} is the lifetime of the project and CRF is the capital recovery factor, which is given by the equation:

$$CRF(i,N)=\frac{i(1+i)^N}{(1+i)^N-1} \quad (2)$$

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

HOMER uses the following equation to calculate the Levelized cost of energy:

$$COE=\frac{C_{ann,tot}}{E_{prim}+E_{grid,sales}} \quad (3)$$

Where $C_{ann,tot}$ is the total annualized cost,
E_{prim} is the total amounts of primary load,
$E_{grid,sales}$ is the number of units sold to the utility every year. The denominator of the above equation is an outflow of the aggregate sum of useful power that the Hybrid System generates every year. The levelized cost of electricity is hence the normal cost per Kilowatt-hour of valuable electrical energy delivered by the system.

4.1. LCC Analysis

An LCC analysis gives the total cost of the system, including all expenses incurred over the life of the system. There are two reasons to do an LCC analysis: (i) To compare different power technology options and (ii) to determine the most cost-effective system designed by Amer et al. (2013).

LCC= P1+P2+P3

P1= Initial cost of the system (IC)
P2 = Operation and maintenance cost of the system (O&M)
P3 = Replacement cost of the system

$$\text{Levelized cost of energy}=\frac{\text{Life cycle cost}}{\text{Annual energy production}} \quad (4)$$

Here the cost of energy of the 1 kW PV and 10 kW wind system is considered.

For Solar

Initial cost of PV module: Rs. 56,875
Initial cost of inverter and cables: Rs. 24,000
Initial cost of 12 V, 200 Ah battery system: Rs. 24,000
Total initial cost is=Rs. 104,875
Interest rate or discount rate is considered (i) 8%, inflation rate is (f) :6% and "n" is the number of years, n=25 years
LCC=Initial cost+Present worth of operating cost+Present worth of replacement cost

Present worth of annuity factor for 25 years)

$$PAF=\frac{(1+d_r)^{n-1}}{d_r(1+id_r)^n}\text{; discount rate } d_r=\frac{(i-f)}{(1+f)}\text{; PAF=19.83;}$$

$d_n = 0.0186$
Present worth of operating cost= 5% IC $\frac{(1+d_r)^{n-1}}{d_r(1+d_r)^n}$ IEEE Std. (1995) (5)

=5243.75×19.83

=Rs. 103983.57

Present worth of replacement or installation cost

Future worth factor, 6% inflation, 5 years = $(1 + f)^n = (1+.06)^5$ = 1.338

Present worth factor 8% discount, 5 years $=\frac{1}{(1+i)^n}=\frac{1}{(1+0.08)^5}$ =0.680

Future worth factor, 6% inflation, 10 years = $(1 + 0.06)^{10}$ = 1.790

Present worth factor 8% discount, 10 years $=\frac{1}{(1+0.08)^{10}}$ = 0.468

Future worth factor, 6% inflation, 15 years =$(1 + 0.06)^{15}$ = 2.396

Present worth factor 8% discount, 15 years $=\frac{1}{(1+0.08)^{15}}$ = 0.315

Future worth factor, 6% inflation, 20 years =$(1 + 0.06)^{20}$ = 3.207

Present worth factor 8% discount, 20 years $=\frac{1}{(1+0.08)^{20}}$ = 0.2145

Present worth of 5th, 10th, 15th, and 20th years replacement = (36800 × 1.338 × 0.680)+(36800 × 1.790 × 0.468)+ (36800 × 2.396 × 0.315)+(36800 × 3.207 × 0.2145)=1,17,399
Total LCC = 104,875 + 117,399 + 103983.57 = Rs. 326257.57

$$LCE=\frac{326257.57}{47486}=Rs.6.9$$

For wind:
10 kW wind turbine
Initial cost of wind turbine and Inverter = Rs. 2,015,000 + Rs. 97,500 = Rs. 2,112,500
Initial cost of rectifier and tower and cables and energy meter = 1,300,000 + 65,000
Here considered the O&M cost is Zero
Replacement cost or installation cost.
(97,500 × 1335 × 0680)+(97,500 × 1.78 × 0.463)+ (97,500 × 2.396 × 0.315)+(97,500 × 3.207 × 0.214)=Rs. 310,015
LCC = Rs. 3,787,515
Energy produced per year is = 539777 units

Energy production of 10 kW per year $=\frac{539777}{50}$ =269888 units

$$LCE=\frac{\text{Life cycle cost}}{\text{Total energy production}}=Rs.\ 14$$

$$P_{PV}=f_{PV}Y_{PV}\frac{I_T}{I_S}$$

Where,
P_{pv} = Mean output power of PVthe system
f_{PV} = Is the PV derating factor,
Y_{PV} = The rated capacity of the PV array (kW),
I_T = The global solar radiation (beam plus diffuse) incident on the surface of the PV array (kW/m^2).
I_S = Is 1 kW/m^2, which is the standard amount of radiation used to rate the capacity of the PV array.

$$P_{pv}=0.89\times 2200\times\left(\frac{5.82}{1}\right)=11395.56\,kWh/day$$

Mean output energy per day = 11395.56 kWh/day

Total energy production per year = 11395.56×365 = 4159379 kWh/year

4.2. Optimization Using Linear Programing

The optimization using Linear Programming for Hybrid Energy System and the flow chart is given below Figure 8 (Acakpovi et al., 2015; Huneke et al., 2012).

5. OPTIMIZATION RESULT

5.1. The Case I – PV, Wind, DG and Battery Combinations, System is Connected to Grid

The optimization solutions obtained using HOMER software displays three different configurations from the finest to poorest as follows:

1. Hybrid PV, Wind, DG and Battery system
2. Hybrid PV, DG, and Wind system
3. Hybrid PV and DG

5.2. The Case I – PV, Wind, DG and Battery Combinations, System is Connected to Grid

In this case, four different combinations meet the load profile is considered. According to the optimized model contains Solar, Wind, DG, and Battery hybrid system for the site (MIT Manipal). It Consists of Solar 2200 kW, AC wind generator of 750kW output power, Inverter Capacity 2000 kW, DG capacity 600 kW and 800 number of batteries of 12 V and 200Ah capacity are configured. The estimated cost of the hybrid system as shown in Table 8. The initial capital cost of the system is Rs. 317,135,000, operation and maintenance cost is Rs. 12,801,490, the NPC is Rs. 48,07,80,690 per year and cost of Energy is Rs. 7.99/kWh Consider the renewable fraction of 77%. The annualized cost of the individual system is shown in Figure 9.

The monthly average electricity profile of the system is shown in Figure 10. The solar system supplying the electricity is more than that of a DG and wind system in the whole year. The PV supplying 65%, wind supplying 13% and DG supplying 22% Electricity. Energy consumption and production is shown in Table 9.

The hourly power production on March 21st is shown in Figure 11. One sample day is taken for discussion. The combination of PV, Wind, DG, and Battery operated system connected to the grid is considered. Morning up to 7 AM power generated by the solar system is zero and wind power generation is minimum during this time. DG system and battery are supplying the power to the load. From 8 AM to 5 PM DG system is off. During this time solar and wind generate more power than the load demand, so, excessive power is selling to the grid. After 6 PM wind contribution is too low and Solar also stops to generate the power. Thus DG and Battery operate to meet the load demand. In Table 10 the Individual system power Generation and its unit Cost are shown. The grid energy rate summary is shown in Table 11.

5.3. Case II-Hybrid PV, Wind and DG

In this case there are three different combinations to meet the load profile. The HOMER optimized model contains the configuration

Figure 8: Optimization using for linear programing

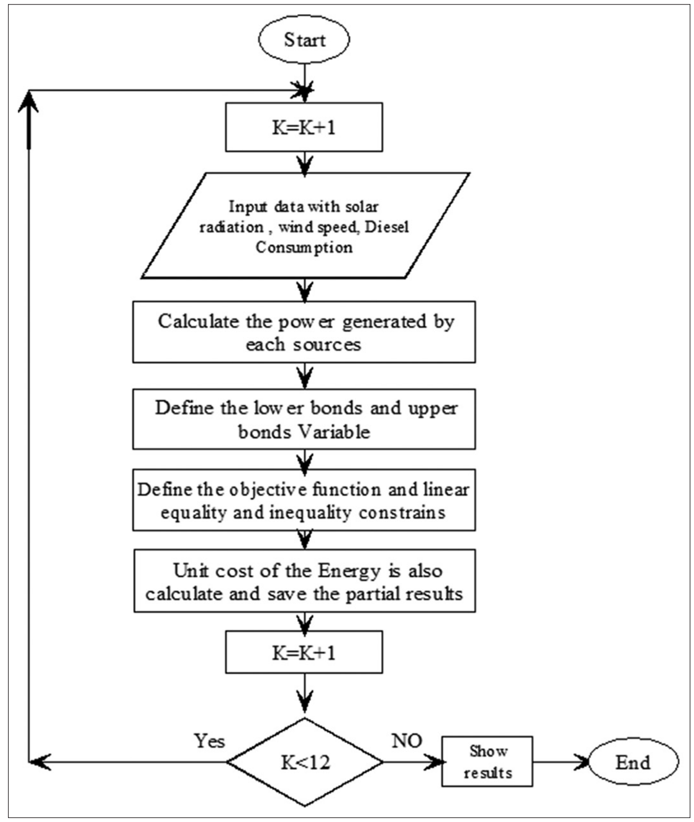


Figure 9: Annualized cost

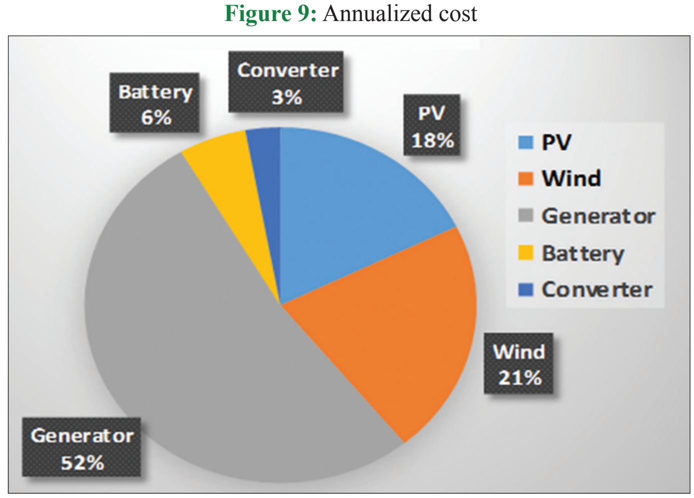


Table 8: Optimization results of PV, wind, DG and battery system

The cost in Indian Rupees											
PV system (kW)	Wind (kW)	DG set (kW)	Battery (6FM200D)	Converter (kW)	Initial cost (Rs.)	O&M cost (Rs.)	Total net present cost (Rs.)	COE Rs./kWh	Net purchase (kWh/year)	Renewable fraction	Battery life (year)
2200	750	600	800	2000	31,710,000	12,800,000	480,780,690	7.99	−88,234,575	0.77	7.7

PV: Photovoltaic, DG: Diesel generator

Figure 10: Monthly average electricity production

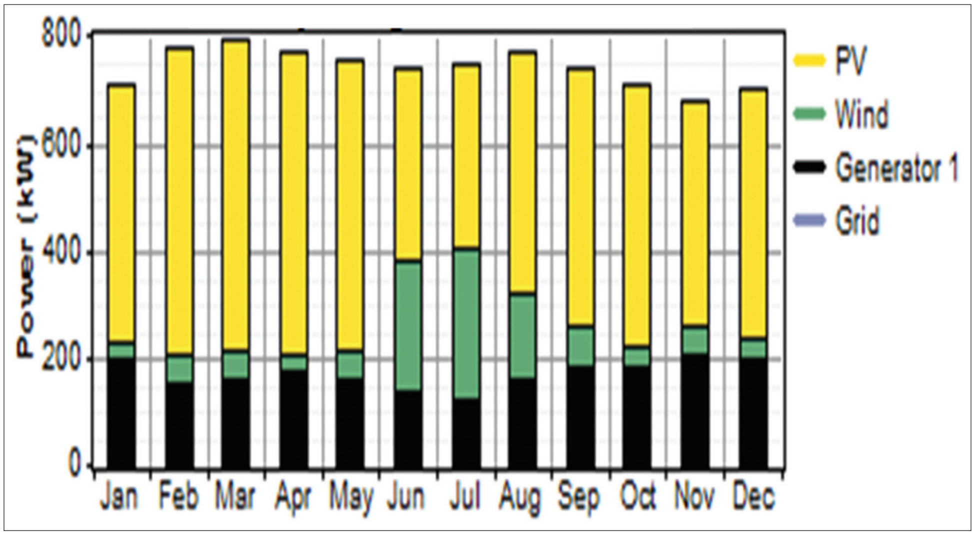


Table 9: Energy consumption and production

Load	Consumption (kWh/year)	Fraction
AC Load	4,706,765	78%
Grid sales	1,357,455	22%
Total	6,064,216	100%
Renewable fraction	-	77
Excess electricity	94,474	1.46
Unmet load	1,368	0.03
Component	**Production (kWh/year)**	**Fraction**
PV array	4,178,807	65%
Wind turbine	809,663	13%
Generator 1	1,488,267	22%
Grid Purchases	0	0%
Total	6,476,737	100%

Table 10: System power generation and unit cost

Quantity	Solar system	Wind system	DG system
Rated size (kW)	2200	750	600
Average output power (kW)	477	92.4	293
Total energy production (kWh)	4,178,807	809,663	1,488,267
Unit cost (Rs.)	8.58	14.62	11.37
Hours of operation (h/year)	4441	8015	5088

Table 11: Grid energy rate summary

Month	Energy purchased (kWh)	Energy sold (kWh)	Net purchases (kWh)	Energy rate (Rs.)
January	0	102,469	−102,469	1,332,110
February	0	131,256	−131,256	1,706,315
April	0	126,639	−126,639	1,646,320
May	0	128,749	−128,749	1,673,750
June	0	112,548	−1,12,548	1,463,150
July	0	125,111	−125,111	1,626,430
August	0	116,803	−116,803	1,518,465
September	0	104,817	−104,817	1,362,595
October	0	96,047	−96,047	1,248,585
November	0	83,157	−83,157	1,081,015
December	0	92,982	−92,982	1,208,740
Annual	0	1,357,455	−1,357,455	17,646,915

of Solar 2200 kW, AC wind generator of 500 kW, and DG capacity 1000 kW. The inverter Capacity 2000 kW is considered. The estimated cost of the hybrid system is shown in Table 12. The initial capital cost of the system is Rs. 254,020,000, operation and maintenance cost is Rs. 28,673,255, the NPC is Rs. 620,560,005 per year and cost of Energy is Rs. 10.34/kWh, consider the renewable fraction of 65%. The annualized energy production of the individual system are shown in and Table 13 and system power and unit cost as shown in Table 14.

The monthly average electricity profile of the system is shown in Figure 12. The solar system supplying the electricity is more than that of a DG and wind system in the whole year. The PV supplying 58%, wind supplying 7% and DG supplying 35% electricity. The battery system is not used here, because DG system is supplying more power than case I.

The hourly power production for 21st March is shown in Figure 13. One sample day is taken for discussion of PV, Wind and DG operated system connected to the grid. Solar system power generation is zero up to7 AM and maximum from 12 PM to 2 PM. During this time DG system and wind system are supplying power to the load. From 10 AM to 2 PM DG system is off, and during this period solar and wind are generating more power than the load demand, excessive power is selling to the grid. After 6 PM wind contribution is too low and solar stops to generate the power so DG and wind are operated to meet the load demand.

5.4. Case III - Combination of PV and DG System

The optimization of third solution (case III) considers PV and DG grid-connected system for the site (MIT Manipal). Which Consists of Solar 2200 kW, Inverter Capacity 2000 kW, and DG capacity 1200 kW. The estimated cost of the hybrid system is shown in Table 15. The initial capital cost of the system is Rs. 15.63,9000, operation and maintenance cost is Rs. 40,735,500, the NPC is Rs. 677,126,255 and cost of Energy is Rs. 11.245/kWh, consider the renewable fraction of 58%. The Tables 16 and 17 shows the power consumption and production of the system.

The monthly average electricity profile of the system is shown in Figure 14. The solar system supplying the electricity is more than that of a DG. The PV supplying 58% and DG supplying 42% electricity are shown in Figure 15, DG system is supplying more power than the Case I and Case II, in this case, wind and battery system is not considered.

The hourly power production for 21st March is shown in Figure 16. One sample day is taken for discussion of PV, and DG operated system connected to the grid. Morning up to 7 AM power generated by the solar system is zero, so, only the DG system is supply's the power to the load. Solar system generates maximum power from 12 PM to 2 PM. Thus from 11 AM to 2 PM DG system is off, during this period solar generates more power than the load demand and excessive power is selling to the grid. After 6 PM Solar stops to generate the power and again DG is operated to meet the load demand.

6. LINEAR OPTIMIZATION RESULTS

6.1. The Case I: PV, WIND and DG System

In this case, the combination of Solar-wind–DG and Solar-DG are validated using linear programming. The Figure 17 shows

Figure 11: Hourly power production and consumption for case I (photovoltaic, wind, diesel generator, and battery)

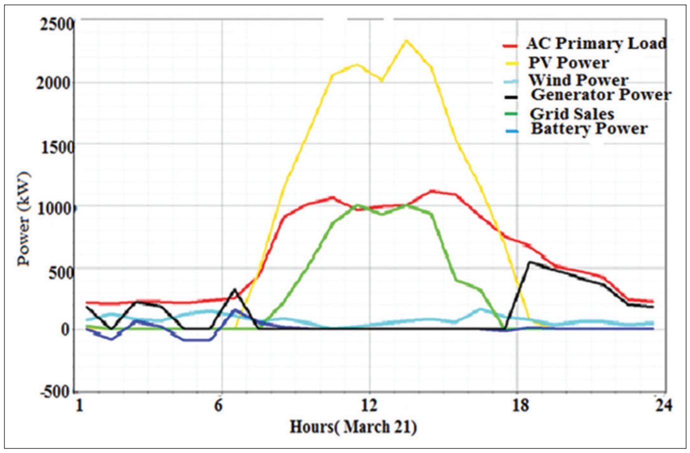


Figure 12: Monthly average energy production of photovoltaic, diesel generator and wind

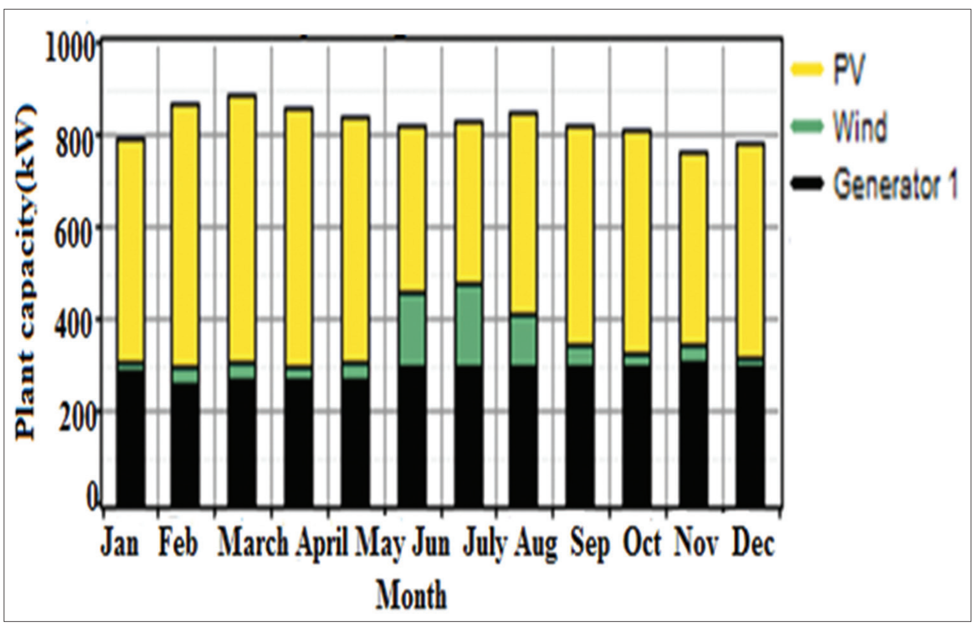


Table 12: Optimization results (PV, wind and DG)

PV system (kW)	Wind (kW)	DG Set (kW)	Grid	Converter (kW)	Initial cost (Rs.)	O&M cost (Rs.)	Total net present cost (Rs.)	COE Rs./kWh	Net purchase (kWh/Year)	Renewable fraction
2200	500	1000	00	2000	254,020,000	28,673,255	620,560,005	10.34	−140,416,900	65%

PV: Photovoltaic, DG: Diesel generator

Table 13: Annualized energy production

Component	Production (kWh/year)	Fraction
Solar	4,178,807	58%
Wind turbines	539,777	7%
Generator 1	2,509,140	35%
Grid purchases	0	0%
Total	7,227,724	100%

Table 14: System power generation and unit cost

Quantity	Solar system	Wind system	DG system
Rated size (kW)	2200	500	1000
Average output power (kW)	477	61.6	337
Total energy production (Kwh)	4,178,807	539777	2509100
Unit cost (Rs.)	8.58	13	11.01
Hours of operation (h/year)	4441	8015	7450

Table 15: Optimization results of PV and DG, system

PV system (kW)	DG Set (kW)	Converter (kW)	Initial cost (Rs.)	O&M cost (Rs.)	Total net present cost (Rs.)	COE Rs./kWh	Net purchase (kWh/Year)	Renewable fraction
2200	1200	2000	156,390,000	40,735,500	677,126,255	11.245	139,439,820	58%

PV: Photovoltaic, DG: Diesel generator

Figure 13: Hourly power production and consumption for case II (photovoltaic, wind and diesel generator system)

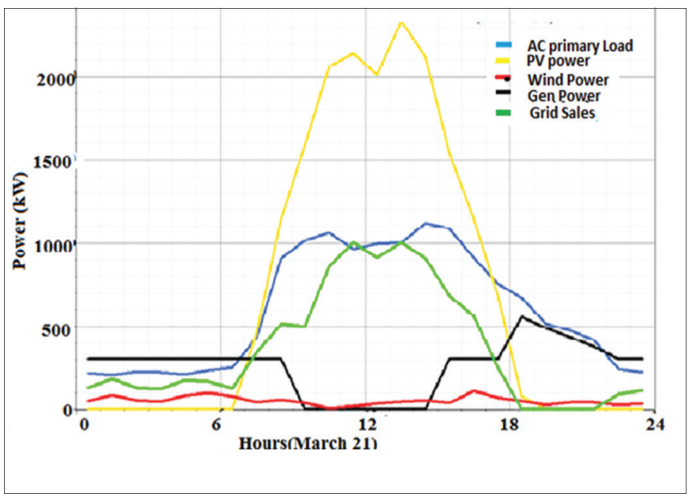
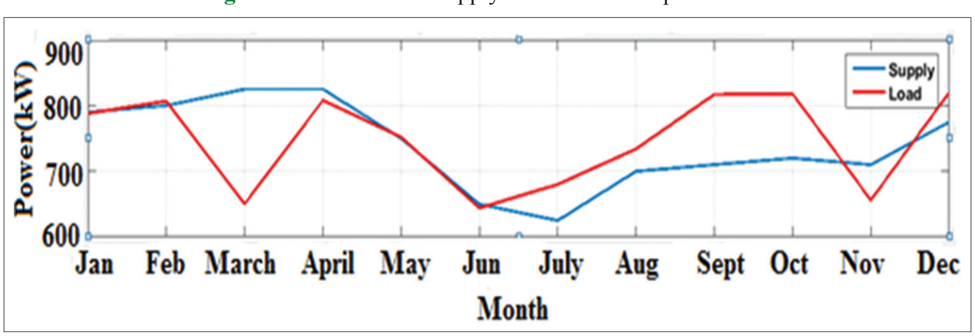


Figure 14: Load versus supply-demand linear optimization



monthly average electricity production obtained from the proposed linear optimization algorithm. It is observed that the involvement of the solar plant has been used for all months. This is suitable since the generation cost of solar is minimum compared to the DG and the wind. The per unit cost of electricity calculated by the linear programming is "Rs. 8.72/kWh," "Rs. 14.82/kWh," Rs. 13.1/kWh respectively for the PV, wind and DG system. It is also noticed that in this location, the wind energy comes in third

Figure 15: Monthly electricity production

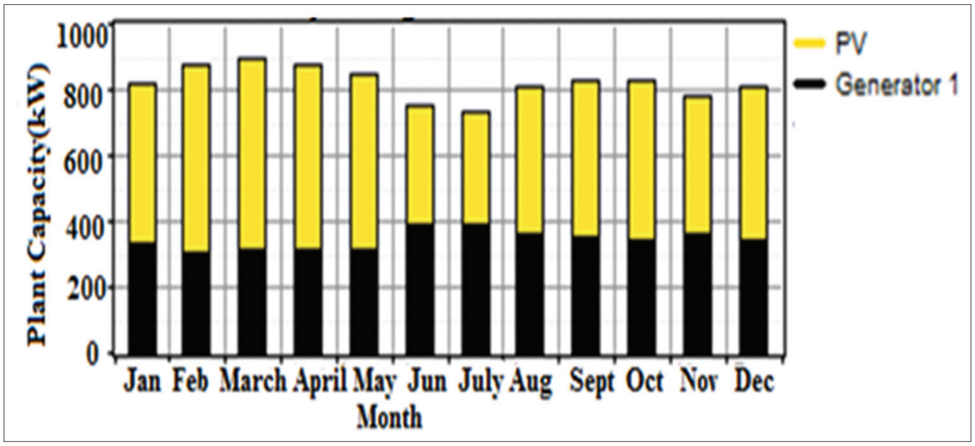


Figure 16: Hourly power production and consumption (photovoltaic and diesel generator system)

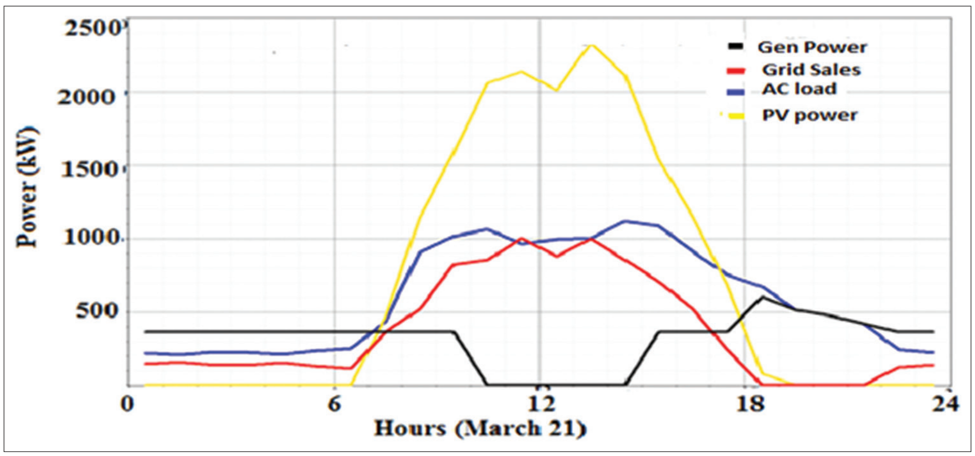
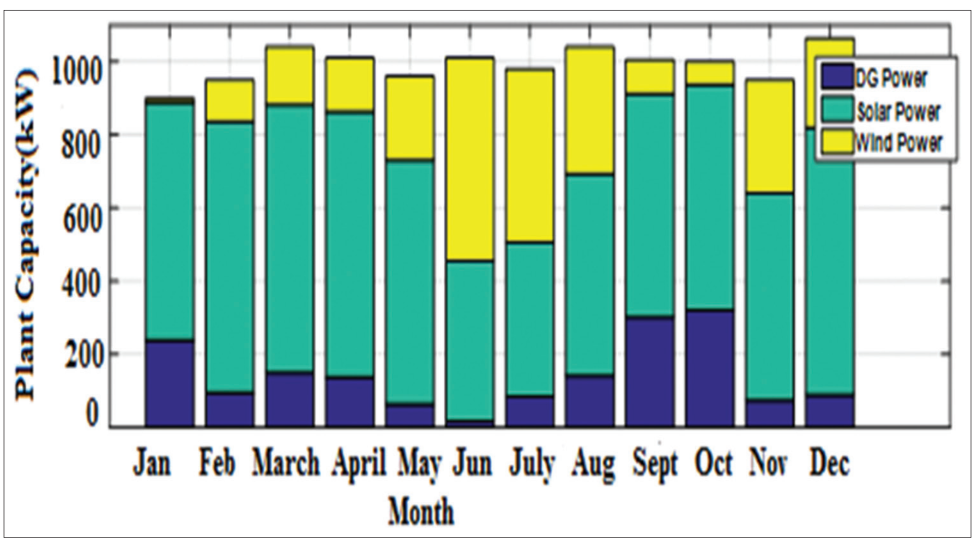


Figure 17: Monthly average electricity production obtained by using linear optimization (photovoltaic, wind and diesel generator)



position when cost concerned, it is higher than the solar and DG with respect to the linear programming technique. However, wind velocity is too low in this location, therefore, making the wind power generation is minimum. When wind generation is too low, DG contribution is more in the month of May, June, July, and November.

Figure 18 shows that the average unit cost of electricity of PV, Wind, and DG is around Rs. 10.8/kWh with a peak of Rs. 12.025/kWh for the month of June-July. For these months solar radiations are too low and wind can generate more power. In general, the cost calculated by the developed algorithm is more than the one estimated by the HOMER for the same conditions.

Figure 18: Unit cost of hybrid electricity linear optimization method (photovoltaic, wind and diesel generator)

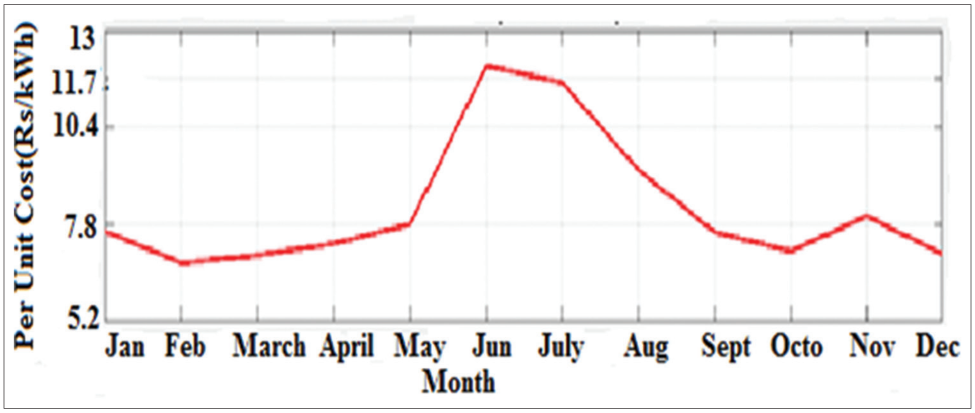
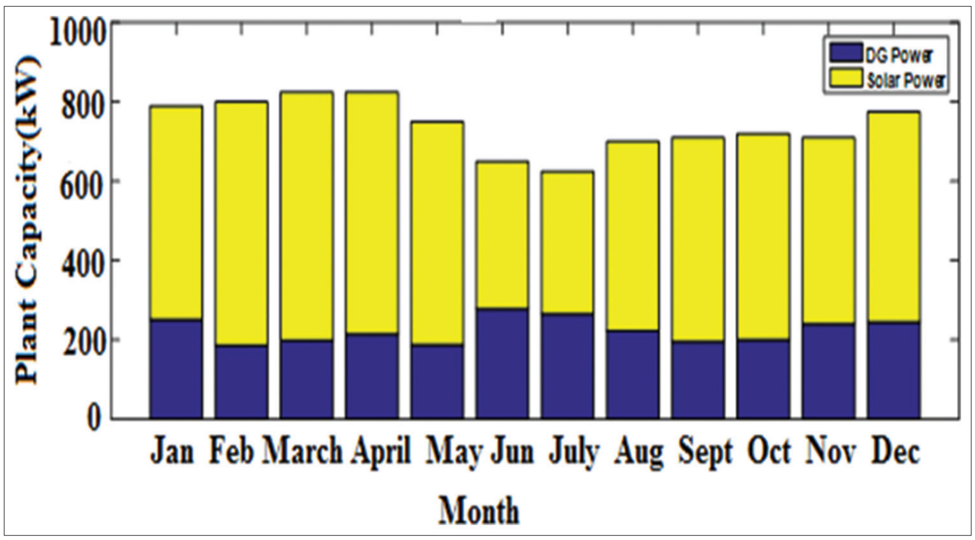


Figure 19: Monthly average electricity production obtained by using linear optimization (photovoltaic and diesel generator)



This can be more useful for the investors to reduce the 'payback period 'of the system. The cost summary and capacity of the individual systems of the Solar/Wind/DG Hybrid Energy system by using both Linear and Homer optimization method are shown Tables 17-20. The Figure 14 shows the Load versus Supply-demand by using linear optimization method.

6.2. Case II PV and DG System

The Figure 19 shows monthly average electricity production obtained from the proposed linear optimization algorithm. The DG contribution is more for the month of June, July, and August because solar radiations are too low in this location. Almost in all the months solar and DG power are contributed.

From the Figure 20, the average unit cost of electricity of PV and DG system is around Rs. 11.9 kWh with a peak of Rs. 12.35/kWh during the month of June-July. For these months solar radiations are too low so DG system should operate more number of hours. In general, the cost calculated by the developed algorithm is more than the one estimated by the HOMER for the same conditions. This can be more useful for the investors to reduce the 'payback period 'of the system. The Figure 14 shows the load versus supply-demand by linear optimization method. The Tables 21 and 22 shows the per unit cost using linear optimization and homer optimization method.

7. CONCLUSION

This paper presents a relative analysis of cost optimization of hybrid energy system consisting of PV, wind, and DG using a linear optimization algorithm and the "HOMER" optimization software. The COE estimated for different combinations and validated the results with linear optimization. Though the analysis it is found that the DG, PV and wind system is gives better performance in terms of COE. This system performance is better than individual solar and wind scheme because if any fault occurs in the solar system or in wind energy conversion system, then, the generator can minimize this problem and also it can reduce the unit cost of power generation from the hybrid energy systems. For this location wind, energy contribution is too low in all the months, excepts June, July, and August so that wind energy system is not recommended for this location. When the unit cost of energy is considered, the combination of the PV, Wind, Battery and the DG systems is better. However, when the availability of resources is considered, the PV and DG system is better even though there is an increase in the per unit cost.

Figure 20: Unit cost of hybrid electricity linear approach (photovoltaic and diesel generator)

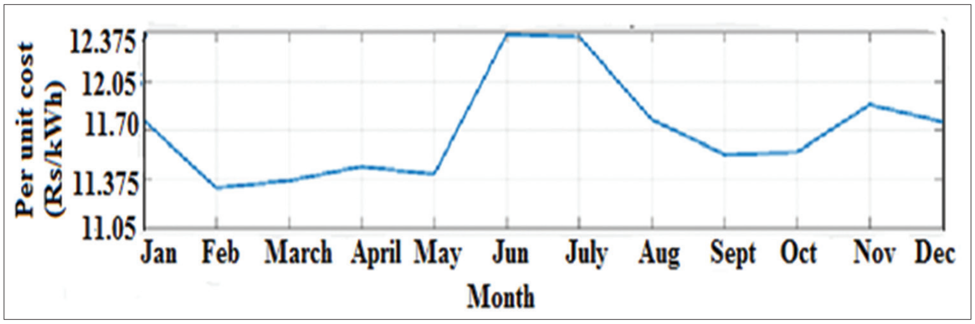


Table 16 : Power consumption of the system

Load	Consumption (kWh/year)	Fraction
AC primary load	4,708,134	69%
Grid sales	2,145,228	31%
Total	6,853,361	100%
Renewable fraction	0.581	-

Table 17: Energy production

Component	Production (kWh/yr)	Fraction
PV array	4,178,807	58%
Generator 1	3,010,403	42%
Grid purchases	0	0%
Total	7,189,210	100%

PV: Photovoltaic

Table 18: Power generation of solar and DG system

Quantity	PV system	DG System
Rated size (kW)	2200	1200
Average output Power (kW)	477	396
Total energy production (kWh)	4,178,807	3,010,403
Unit cost (Rs.)	8.45	13.91
Hours of operation (h/year)	4441	7595

PV: Photovoltaic, DG: Diesel generator

Table 19: Per unit cost of energy using linear optimization method (PV/Wind/DG)

Plant	Capacity (kW)	Per unit (Rs./kWh)	COE of the system (Rs./kWh)
PV	2200	7.82	10.8
Wind	50	13	
DG	1000	11.2	

PV: Photovoltaic, DG: Diesel generator

Table 20: Per unit cost of energy using HOMER optimization method (PV/Wind/DG)

Plant	Capacity (kW)	Per unit cost (Rs./kWh)	COE of the system (Rs./kWh)
PV	2200	8.58	11.31
wind	50	14	-
DG	1000	11.96	-

PV: Photovoltaic, DG: Diesel generator

Table 21: Per unit cost of energy using linear optimization method (PV and DG)

Plant	Capacity (kW)	Per unit cost (Rs./kWh)	COE of the system (Rs./kWh)
PV	2200	10.57	11.9
DG	1200	13.18	-

PV: Photovoltaic, DG: Diesel generator

Table 22: Per unit cost of energy using homer optimization method (PV and DG)

Plant	Capacity (kW)	Per unit cost (Rs./kWh)	COE of the system (Rs./kWh)
PV	2200	8.45	11.24
DG	1200	13.91	-

PV: Photovoltaic, DG: Diesel generator

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