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Modeling, Simulation, and Optimization of a Hybrid Power System for Techno-Economical and Environmental perspective

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Abstract: In the present paper the software Hybrid Optimization Model for Electric Renewables (HOMER) is used for modelling, simulation, optimal architecture and control strategy of hybrid solar/wind energy for a domestic power system which includes a grid connected solar photovoltaic (PV)/wind energy based power system along with battery storage to supply a residential load located in chennai, Tamilnadu (with latitude 13° 04'N and longitude of 80° 17' E respectively). It highlights the renewable hybrid power system which tends to obtain a reliable autonomous system with the balance between the components size and the improvement of the capital cost. The simulation results show that the hybrid system would be a feasible solution for distributed generation of electric power for grid connected applications.

Keywords: HOMER, Hybrid power system, Optimization, Residential load.

I. INTRODUCTION

With rapid increase of fossil fuel prices as well as sharp increase in the capital cost of new central generating plants, there is a attention on alternate generating system with energy use of higher efficiency. Under deregulation and restructuring of power systems, it becomes highly competitive. The main alternate energy sources include solar, wind, geothermal and hydro, and waste material. Solar power is used almost anywhere. In the new millennium many countries have taken serious initiatives to tap solar energy resources which are abundant and clean energy. These countries are hugely funding both in the research work and in the public awareness campaign for the protection of environment. High quality of research will bring down the cost of manufacturing as well as enhance the efficiency of the allied equipments for tapping solar radiation. Public awareness will increase the market demand of these equipments Thus the equipments will be sold at the economy of scale [1], [2]. Hybrid energy systems use solar, wind, and hydro energy sources, though most of the renewable energy available on earth consists of various forms of solar energy. A system of the combination of these various sources has the advantage of the stability and balance [3].The concept of photovoltaic (PV) is well clear and recently thousands of PV-based power systems are being showcased worldwide, for providing power to small, remote, grid-independent applications [4] . If the solar PV system is

producing excess electricity than the household, the excess electricity can be sold back to the grid. PV system should supply the electric power to the interrupted customers considering the discharge rate of batteries. Without storage, solar PV, typically, contributes less than 40% of its rating towards distribution capacity [5],[6],[7]. Photovoltaic and Wind generator (WG) generated electricity can be stored in batteries and can be retrieved during nights. Also use of Fuel Cell (FC) system with PV/WG/battery reduces battery storage requirement. Research conducted worldwide indicates that hybrid PV/Wind/battery system is a most reliable source of electricity [8, 9].

The optimal sizing of each component of hybrid system is required to make the system techno-economically feasible [10, 11]. More numbers of authors have used Hybrid Optimization Model for Electric Renewables (HOMER) for optimizing hybrid systems for various locations worldwide [12-13]. HOMER is found to be one of the most used software for the optimization and sensitivity analysis of hybrid systems [14]. The inputs required for the analysis are solar radiation, load profile, constraints, wind speed, temperature data, system control and economic factors [15].HOMER performs comparative economic analysis on a distributed generation power systems. Inputs to HOMER will perform an hourly simulation of every possible combination of components entered and rank the systems according to user-specified criteria, such as cost of energy (COE, US$/kWh) or capital costs. Furthermore, HOMER can perform “sensitivity analyses” in which the values of certain parameters (e.g., solar radiation or wind speed) are varied to determine their impact on the system configuration [16].

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II. SYSTEM MODEL

A. Research method

The proposed model consists of solar PV module of 17 kW PV system, a grid connected converter of 4 kW capacity with Trojan T-105 battery storage. The system is designed to have a life time of 25 years so the PV panels will not be replaced. The proposed system is shown in Fig.1.

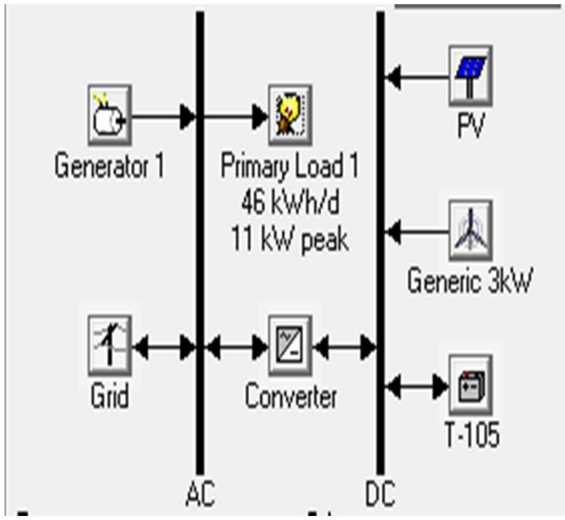

Fig.1. System configuration using HOMER

B. Daily load profile

A typical house in chennai is chosen for case study. The daily electrical load profile in the proposed area is based on basic demands of utilities such as refrigerator, television, lighting, etc. The load demand for the selected residential load is approximate 46kWh/d (i.e. 46000 Wh/day) (Table I) with 11kW peak. The average daily load profile data is shown in Fig. 2. The seasonal profile for the load is given in Fig. 3. Both these figures are prepared by the HOMER software based on the data of the daily load profile.

Table i. Total average energy consumption

Appliances	Quantity	Power(Watt)	Hours used per day (h/day)	Energy (Wh/day)
Refrigerator	10	80	12	9600
Television	10	90	3	2700
Fluorescent Lamp	40	40	2	3200
CFL	10	20	5	1000
Night lamp	20	10	8	1600
AC-ITON	10	1200	5	60000
Induction stove	10	1200	1	12000
Iron box	10	1000	1	10000
Washing machine	10	2500	1	25000
Computer with flat screen	10	70	2	1400
Micro Oven	10	1000	1	10000

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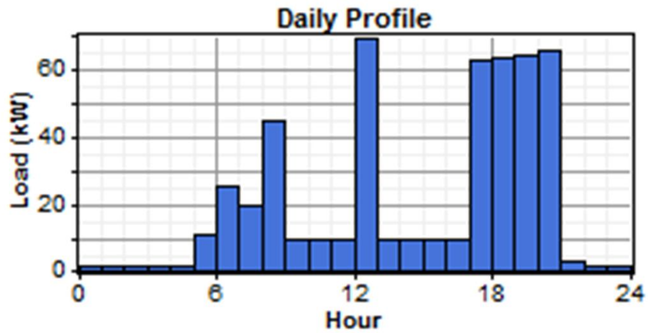

Fig. 2. Average load profile.

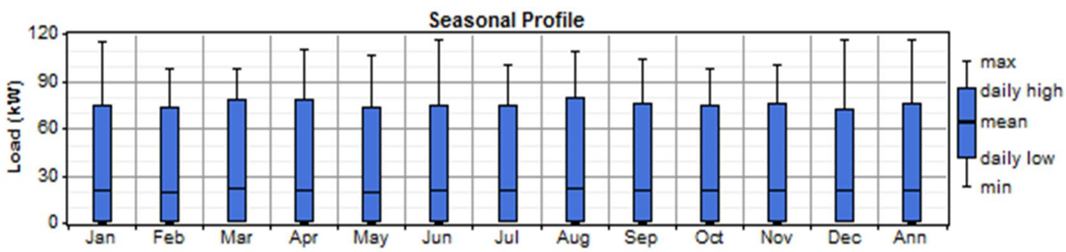

Fig. 3. Seasonal load profile.

C. Solar PV modules

Solar resource shows that the amount of global solar radiation that strikes earth's surface Solar radiation data for the study regions was obtained from Synergy Environmental Engineers (India) Private Limited web site. The Synergy Environmental Engineers (India) Private Limited has been monitoring solar radiation data in India at for the last many years. Monthly clearness index and radiation data is shown in table II [5]. R4.An average solar radiation of 5.08 kWh/m2/day and a clearness index of 0.523 are obtained for the study area (Table II). The clearness index is a measure of the clearness of the atmosphere which is then expressed by the fraction of the solar radiation then it is transmitted through the atmosphere to strike the surface of the Earth. The solar irradiation and Global horizontal radiations at Chennai are shown in Table II and Fig.4 respectively. The PV array modelled in HOMER gives DC output in direct proportion to incident solar radiation. The installation cost of PV array is taken $897/kW and replacement cost is relevant only if the project lifetime exceeds the PV array lifetime. Operation and maintenance (O&M) cost is practically zero and its lifetime is 25 years. For consideration of the degrading factors caused by temperature, soiling, tilt, wiring losses, shading, snow cover, aging etc. a derating factor of 80% is applied to each panel.

Table ii. Solar radiation and clearness index data for chennai

Month	Clearness Index Daily Radiation	(kWh/m2/day)
January	0.686	5.760
February	0.718	6.600
March	0.602	6.050
April	0.560	5.910
May	0.544	5.780
June	0.459	4.850
July	0.416	4.390
August	0.401	4.220
September	0.478	4.860
October	0.391	3.680
November	0.482	4.120
December	0.607	4.920

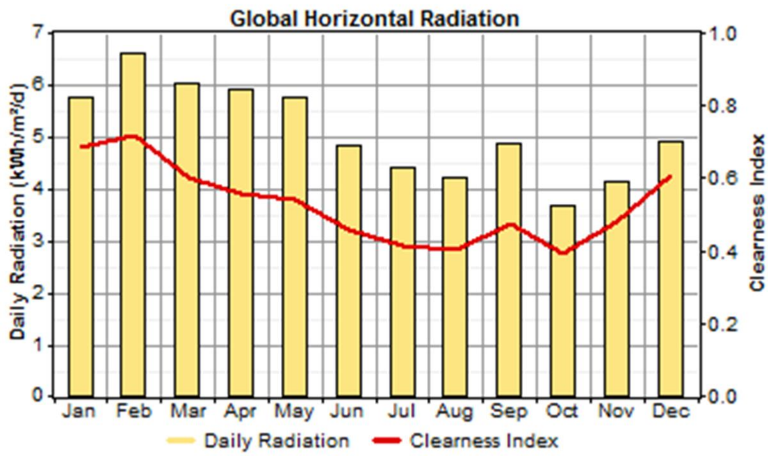

Fig. 4. Global Horizontal Radiation

D. Wind Resources

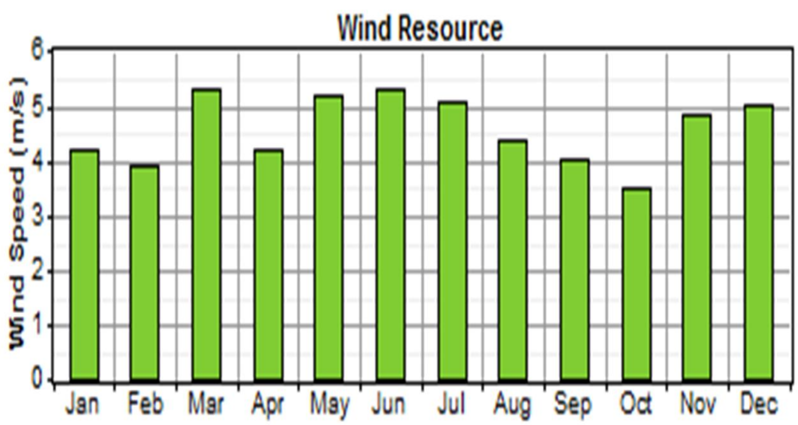

Fig. 5. Wind Resources

The wind speed data measured at 10 m height above ground is imported to HOMER in .txt format. The monthly Annual average wind speed at the site is found to vary from 4.570 m/s .The hourly average wind resource of the site shows that there are various periods during the year and various wind speed are shown in different colours. (Fig. 6). The duration curve of wind speed is shown in Fig. 5 which depicts that the hourly scaled data with respect to wind in a year. The wind powers during these intervals are very much enough to generate electric power with a wind. The main objective of this study is to understand the contribution of different wind speeds even of short duration for power generation at locations with average low speeds but occasionally high wind speeds during the year so as to utilize the wind resource for small applications.

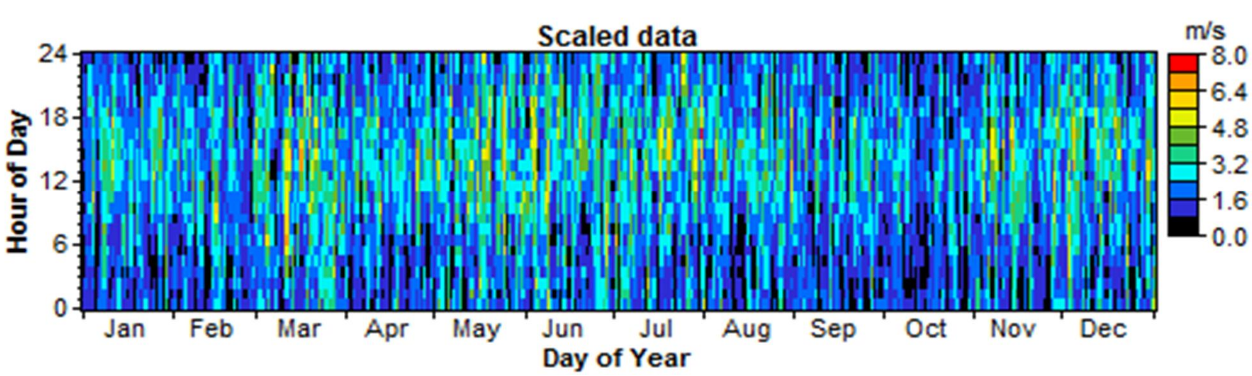

Fig. 6. Hourly scaled wind speed

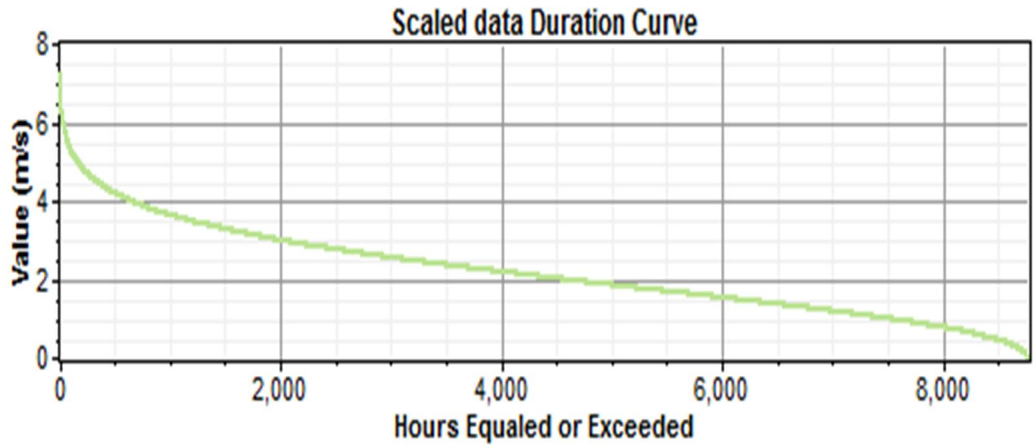

Fig. 7. Scaled data Duration curve

The scaled data duration curve in the above diagram Fig. 7. shows the changes in wind speed to the hours scaled or exceeded. It shows with respect to years. The Weibull shape and scale parameters are calculated as k = 2.29 and c = 2.35 m/. The Weibull shape parameter (k) which describes the stability of wind speed while scale parameter (c) indicates wind speed magnitudes. Autocorrelation factor (typically 0.80 and 0.95) is defined as the measure of hourly wind speed dependency on wind speeds in previous hours. The autocorrelation factor for this location is calculated as 0.85 which indicates wind speed is highly variable with time at this location.

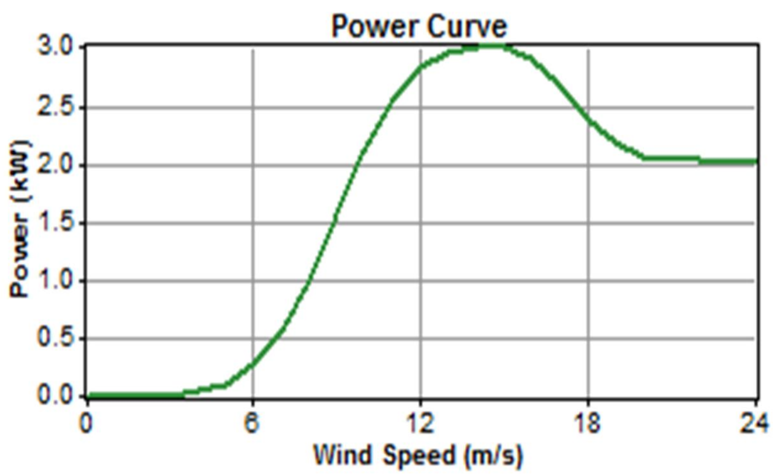

Fig. 8.Power curve

Fig 8 shows the graph between power and wind speed we can notice that when the wind speed is 12m/s the output power is 2.8Kw.From 0m/s to 4m/s there is zero output.There is no variation in output.

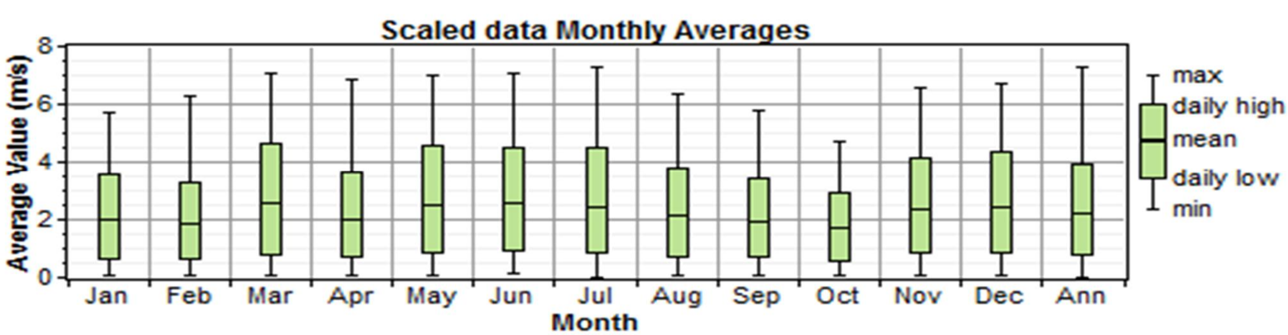

Fig. 9. Scaled data Monthly Averages

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Fig. 9 shows the monthly mean wind speed between 3.8m/s to 4.5 m/s. Similar to solar resource, wind resource also show more affluence in summer than winter.

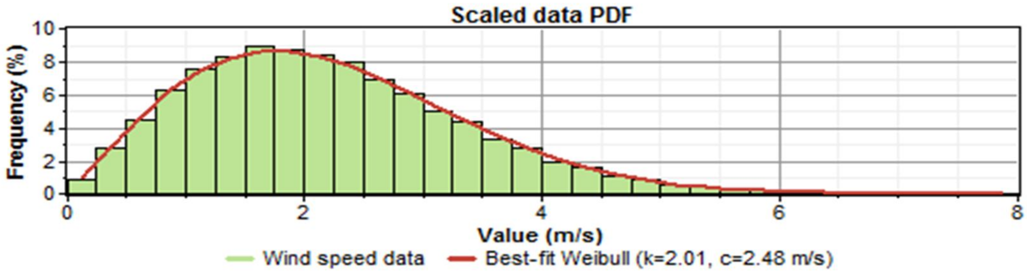

Fig. 10. Wind scaled data

Fig. 10 demonstrates the wind speed probability density function. In the above diagram we can see the best fit weibull is shown in red colour whereas is shown in y axis.

E. Diesel generator

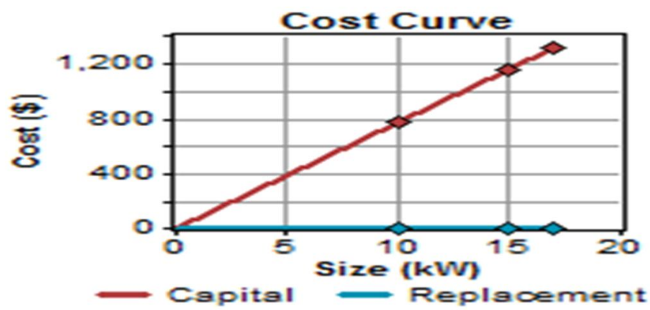

Fig. 11. Cost curve

Fig.11. shows the cost curve. The cost varies according to different size of generator. We can see that the cost curve is linear

Table iii. Technic al data and study of assumptions components

PV array	
Capital Cost	$15249
Derating Factor	80
Nominal Operating Cell Temperature	45
Lifetime	25
Tracking	No Tracking
Wind Turbine	
Technology	Generic
Power	3kW
Hub Height	10
Capital Cost	$5500
O & M Cost US$/year	$200
Lifetime	20
Diesel generator	
Capital Cost	$770
Minimum Load Ratio (%)	30

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Lifetime	15000 Hours
Battery	
Capacity	225Ah
Maximum Capacity	226Ah
Voltage	6V
Min. SOC	30%
Capital cost	103
O$M cost	30
Lifetime Throughput	845kWh
Lifetime	2 years
Converter	
Capacity	4kW
Capital cost	$651
Efficiency	80%
Lifetime	15years

IV. SIMULATION RESULTS

Several simulations have been made by considering different PV capacities and Wind generator (WG). The PV capacity has been allowed to vary from 15kW, 16kW, 17Kw, 18KW and the WG has been allowed 3Kw to 1kW. The battery storage size (kWh) considered include 0-6 load-hours autonomy (equivalent to 0-6 hours of average load). Also the diesel generator power has been considered to change from 15 to17 (kW). The simulation results for 5.08 (kWh/m2/d) solar radiations and 4.3 (m/s) wind speed are presented in table III. The first row shows the presence of PV modules of 17kW, 1Kw Grid, 10Kw generator and Battery (24V BUS) in hybrid system. It can be noticed from these results that the first system consist of PV/WG/Diesel Generator/Battery. Where the Net present cost is $58.346, Levelised cost of energy is $0.282/kWh, and the operating cost is $2.941/yr.

Table iv. Simulation results

	PV (kW)	G3	Label (kW)	T-105	Conv. (kW)	Disp. Strgy	Efficiency Measures	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Net Purchases (kWh/yr)	Ren. Frac.	Capacity Shortage	Diesel (L)	Lab (hrs
	17		10	24	4	LF	No	1	$ 20,744	2,941	$ 58,346	0.282	-809	0.71	0.09	3,279	1,5
	17	1	10	24	4	LF	No	1	$ 26,244	3,113	$ 66,036	0.319	-823	0.71	0.09	3,244	1,4
	17		10		4	CC	No	1	$ 20,650	4,383	$ 76,680	0.371	-662	0.64	0.09	5,104	2,6
	17	1	10		5	CC	No	1	$ 26,313	4,555	$ 84,537	0.409	-697	0.64	0.09	5,065	2,6

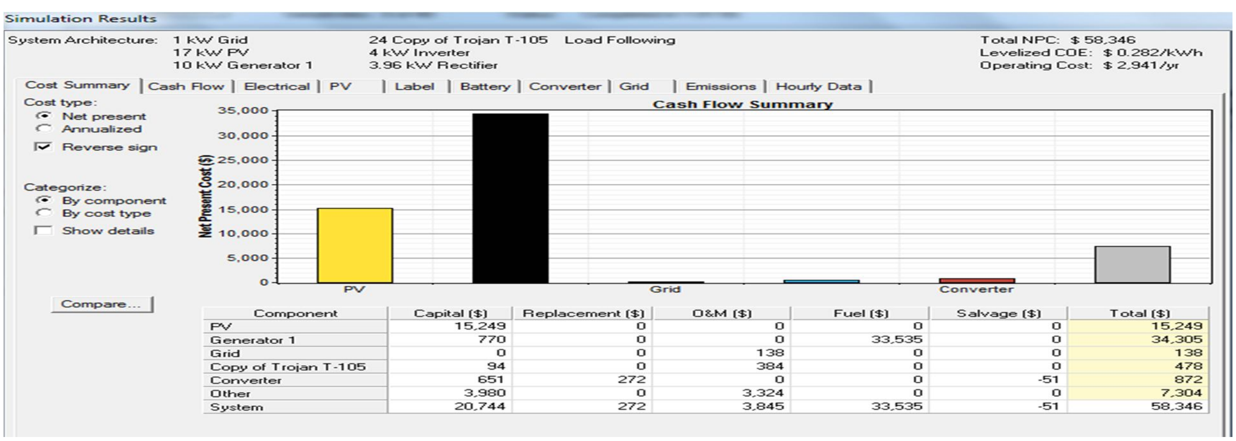

Fig. 12. Simulation-Cash flow summary

The Fig 21.shows the Net present cost changes according with the Resources given such as Solar, Wind, and Diesel generator. The cost such as capital cost, Replacement cost and Opeation and Maintenance cost can be seen in the above diagram

TABLE V. Annual Electric Energy Production

Production	kWh/yr	%
PV array	23,783	71
Generator 1	8,301	25
Grid purchases	1,473	4
Total	33,557	100

TABLE VI. Annual Electric Energy Consumption

Consumption	kWh/yr	%
AC primary load	16,191	88
Grid sales	2,282	12
Total	18,473	100

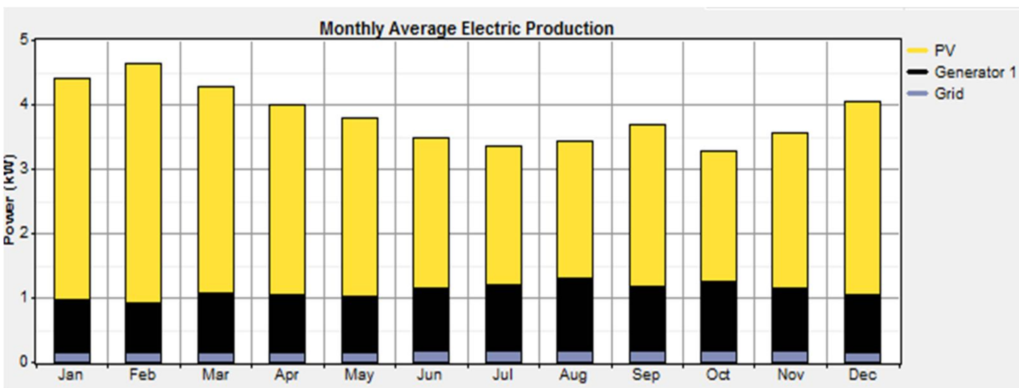

Fig. 13.Monthly Average Electric Production

The annual electric energy production and annual electric energy consumption is tabulated in table VI and table VII respectively. The production of power by individual renewable source is stated here as the percent fraction. Monthly average production of Photovoltaic, Generator, and Grid can be seen in the above diagram

Table vii. Annual emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	8,124
Carbon monoxide	21.3
Unburned hydrocarbons	2.36
Particulate matter	1.61
Sulfur dioxide	15.1
Nitrogen oxides	189

The annual emission of the hybrid system is tabulated in table VII. We all know there are different types of green house gases such as carbon dioxide, carbon Monoxide, etc.The emission with respect to pollutant gases are shown above.

V. COST OPTIMIZATION

The aim of this study is to achieve a Grid connected hybrid generation system, which should be appropriately designed in terms of economic, reliability, and environ-mental measures subject to physical and operational constraints/strategies [13,14,15].R2.The system cost is defined as sum of PV cost (*CPV*), WG cost (*CWG*), battery cost (*CBAT*), Diesel Generator cost (*CELEC GEN*), convertor cost (CCONV).

Csystem = Cpv + Cwg + Cbat + Celec Gen+ Cconv (1)

The cost for each element should be deducted:

Ci = Ni * [CCosti + RCosti * Ki + OMCosti] (2)

i = PV, WG, Battery, Converter, Diesel Generator

Where *Ni* is the number/size of the system component,*CCosti* is the capital cost, *RCosti* is the replacement cost, *Ki* is the number of replacement, and *OMCosti* is operation and maintenance cost through the system operation.

VI. CONCLUSION

The simulation results indicated that a hybrid power system comprising of 17(Kw) photovoltaic system together with 3 (kW) wind generator system, 10 (kW) Diesel Generator (DG), 1Kw Grid, 4kWConverter, 3.96Kw Inverter and battery storage .Battery is used as a standby system which would be a feasible solution for distributed generation of electric power and battery plays a vital role during power shortage though it is grid connected. The cost of generating energy from the above hybrid PV/WG/DG/battery system has been found to be 0.282 (US$/kWh). The hybrid PV/WG/DG/battery power system offers several benefits such as: Production is of PV generation is high; load can be satisfied in the optimal way with reliable power supply. The production of PV is 23,783kWh/yr and consumption is 16191 kWh/yr.Also it has been found that the unmet load was only 964 (kWh) per year and Excess electricity is 12,090 kWh/yr. The environmental friendly nature of the hybrid system can also be depicted from annual emission of the system.

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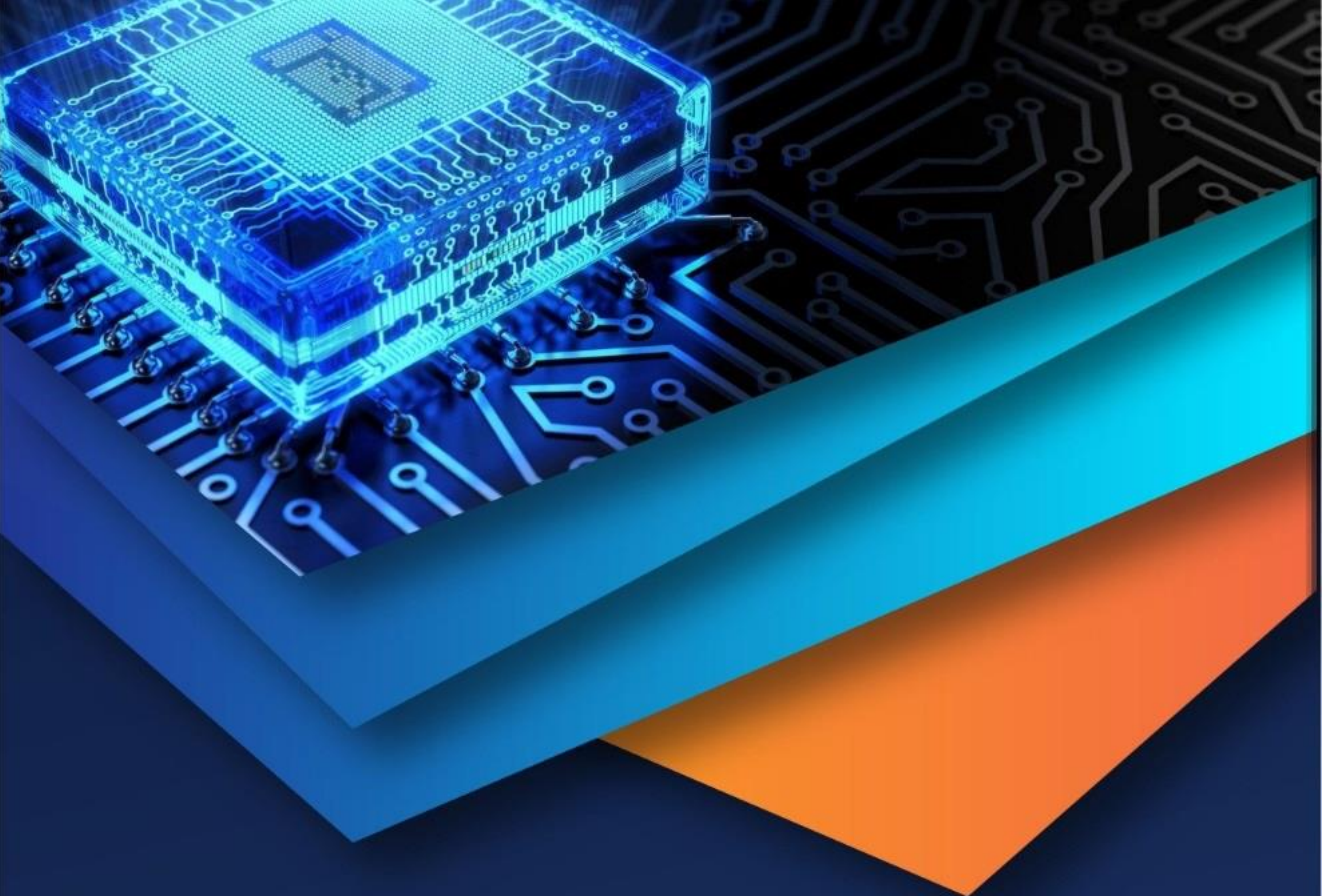

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