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Techno-Economic Analysis of a Grid-Connected Hybrid System in Portugal Island

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Abstract— The present scenario describes that there are some untouched areas in the world, which are electrified but from pollution-generating energy sources. Since pollution generating energy sources provide the advantage of continuity of power supply so they are used especially in different islands of the world as compared to individual renewable energy sources. Most of these islands have huge possibilities for renewable power generation. Thus renewable energy based hybrid system is the only option that can replace these pollution generating energy sources. A hybrid system uses multiple energy sources for generating electricity due to which it helps in maintaining the continuity of power supply. However, the most significant thing is that the system should be cost-effectively attractive. In this paper, the optimization study of the hybrid system is done using the HOMER Pro software. This work investigates an optimum combination of grid-connected solar, wind and bio-generator based hybrid system, which can supply electricity in Portugal Island at an affordable price with an acceptable level of reliability. The main objective of the present study is to utilize the available solar, wind and biomass resources at the selected location to meet the demands of residential load, telecom tower load and water pump load in Portugal Island. The result of the study indicates that the system is a cost-effective system as well as it successfully satisfies the load demand by generating a large amount of energy every year.

Keywords—*Hybrid System, Renewable Energy, Global Warming, Solar Energy, Wind Energy, Converter, Grid, Bio-generator*

I. INTRODUCTION

In the present scenario, the whole world is moving towards renewable energy use in order to reduce the increasing air pollution in the environment. Increasing air pollution affects the environment by increasing global warming and also increases health problem. And due to which it is better to locate those places in the world that have a high possibility of renewable power generation and use it to for renewable power generation. One such place is Portugal Island. This type of generation not only promotes clean energy but also helps in earning money by selling the excess power to other users for their profit. A hybrid system uses multiple energy sources for generating electricity due to which it helps in maintaining the continuity of power supply [1]. The hybrid system not only helps to fulfill a major part of the electricity demand of a particular place but also helps if they are built more at different suitable places and connected to each other in order to fulfill the electricity needs of other areas. Islands like Portugal can use its capability of renewable power generation for reducing the air pollution. Also, help to reduce the air pollution in other countries by selling their renewable power to them for the betterment of nature because still the whole world is dependent upon the non-renewable energy sources for its maximum power generation.

In this work, the optimization analysis of the hybrid system is done using the HOMER Pro software. This work investigates an optimum combination of grid-connected solar, wind and bio-generator based hybrid system, which can supply electricity in Portugal Island at an affordable price with an acceptable level of reliability. The main objective of the present study is to utilize the available solar, wind and biomass resources at the selected location to meet the demands of residential load, telecom tower load and water pump load in Portugal Island. The result of the analysis shows that the system is a cost-effective system as well as it successfully fulfills the load demand by generating a large amount of energy every year. The sections of the paper are organized as follows: Section I contains the introduction of the paper. Section II contains the description of the related work of the hybrid system. Section III contains the system data description of the proposed hybrid model where different types of loads and different resources are described. Section IV explains the methodology. Section V contains the explanations of the simulation model and its different components. Section VI explains the optimization results and finally, in section VII, the conclusion is given.

II. RELATED WORK

In the paper [2], the author has done an optimization case study of a hybrid energy system based charging station for an electric vehicle on Mettur, Tamil Nadu. The hybrid model mainly consists of the PV power plant, wind farm, battery storage, grid connection, hydroelectric power plant, and thermal power plant. The proposed hybrid system reduces the dependency from the thermal power plant as well as maintains the continuity of power supply. The design and optimization of proposed hybrid model based electric vehicle charging station using real-time data have been done in HOMER software. The optimization results show that the on-grid hybrid system easily stores a large amount of power in the battery for electric vehicle charging, satisfy the required load demand, and sells extra power to the grid [2]. In [3], the author had done a case study of Sri Lanka. In this study, they identified that the PV-diesel hybrid system is more cost effective as compared to a standalone small solar home system (50 W PV with battery). An individual household base load of 5 W with a peak load of 40 W is considered in this case study, leading to a daily load average of 305 watt-hours. After doing many simulations, it is found that the PV-diesel hybrid system becomes cost effective as the demand increases. However, the aim of this study is to focus only on the basic needs as such and it does not include the generation and use of energy [3]. In the paper [4], the author conducted a case study of Nakalawaka, Fiji. This paper presented an optimization study of both on-grid and off-grid solar wind biomass hybrid power plant in Fiji. The hybrid model has been designed and optimized by using Homer Pro (Hybrid Optimization of Multiple Energy Resources) software. From the optimization result, it is clear that the proposed hybrid system is more profitable in on-grid as compared to off-grid and it can easily satisfy the fixed portion of load demand for selected area and it sells a large amount of power in grid every year and purchase a comparatively low amount of power from grid every year [4]. In the paper [5], the author designed and implemented an efficient renewable energy system for household users in Khartoum, the capital of Sudan. An individual household and a group of 10-25 households are considered for the simulations. The cost of energy provided from a wind-PV combination for a group of households was less as compared to PV-battery for singular users [5]. In the paper [6], the author has designed the off-grid Wind-Diesel generator hybrid system to supply energy in the hot coastal regions of Dhahran. In this paper, the author considers the providing of energy basically from wind energy for a 100 typical two-bedroom residential building. In order to design and analyze the hybrid system, there is a need for the data of natural resources like solar irradiance, temperature and wind speed. These resources data has been As we know that wind resources is an intermittent source of energy and therefore the wind-diesel-battery hybrid energy system is a solution for the fluctuation of supplying energy, as described in the paper [6]. A feasibility study is conducted in the paper [7] for a solar-wind based hybrid standalone system for supplying electricity for remote areas in Ethiopia. The simulation model of PV-wind-diesel and battery is built for analyzing. A model community of 200 households, consisting of approximately 1000 to 1200 people in total is considered for the simulations. The techno-economic analysis in this study was done by using HOMER software. The most cost-effective combination from the hybridizing of diesel generator-battery and converter is showed in this paper where the renewable fraction is zero. Another cost efficient combination of diesel-generator-PV and converter is also presented in this paper and the dispatch strategy applied in this case was the load following strategy [7]. In this paper [8], the author designed an intelligent controller of hybrid system that combines two renewable energy sources with a conventional energy source for maintaining the continuity of power supply in order to charge electric vehicle battery. The two renewable energy sources are solar and wind energy source. The conventional energy source is a thermal power plant. In this paper, the hybrid system tries to minimize the usage of the thermal power plant. The main aim of this study is to reduce air pollution by increasing the use of an electric vehicle. The hybrid system has designed in MATLAB/SIMULINK software. This paper also includes a case study analysis using real-time data of solar irradiance and wind speed of Delhi, India. All these works mainly aim to reduce the use of pollution-generating energy sources by increasing the use of renewable energy sources using the hybrid system.

III. DESCRIPTION OF THE SYSTEM DATA

A grid-connected Hybrid System designed using National Renewable Energy Laboratory's (NREL) HOMER Pro software. HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a free software application and developed by the National Renewable Energy Laboratory in the United States. It is used for designing and evaluating technically and financially the options for on-grid and off-grid power system especially for stand-alone, remote and distributed generation applications. The proposed hybrid system uses solar power, wind power, and bio-generator power. The hybrid system has been analyzed for Portugal Island. Figure 1 shows the geographical location of the study area with 31°11.4'W (latitude) and 39°26.6'N (longitude). This location is found out by using HOMER Pro software.

taken from NASA Prediction of Worldwide Energy Resources (power.larc.nasa.gov, 2018).

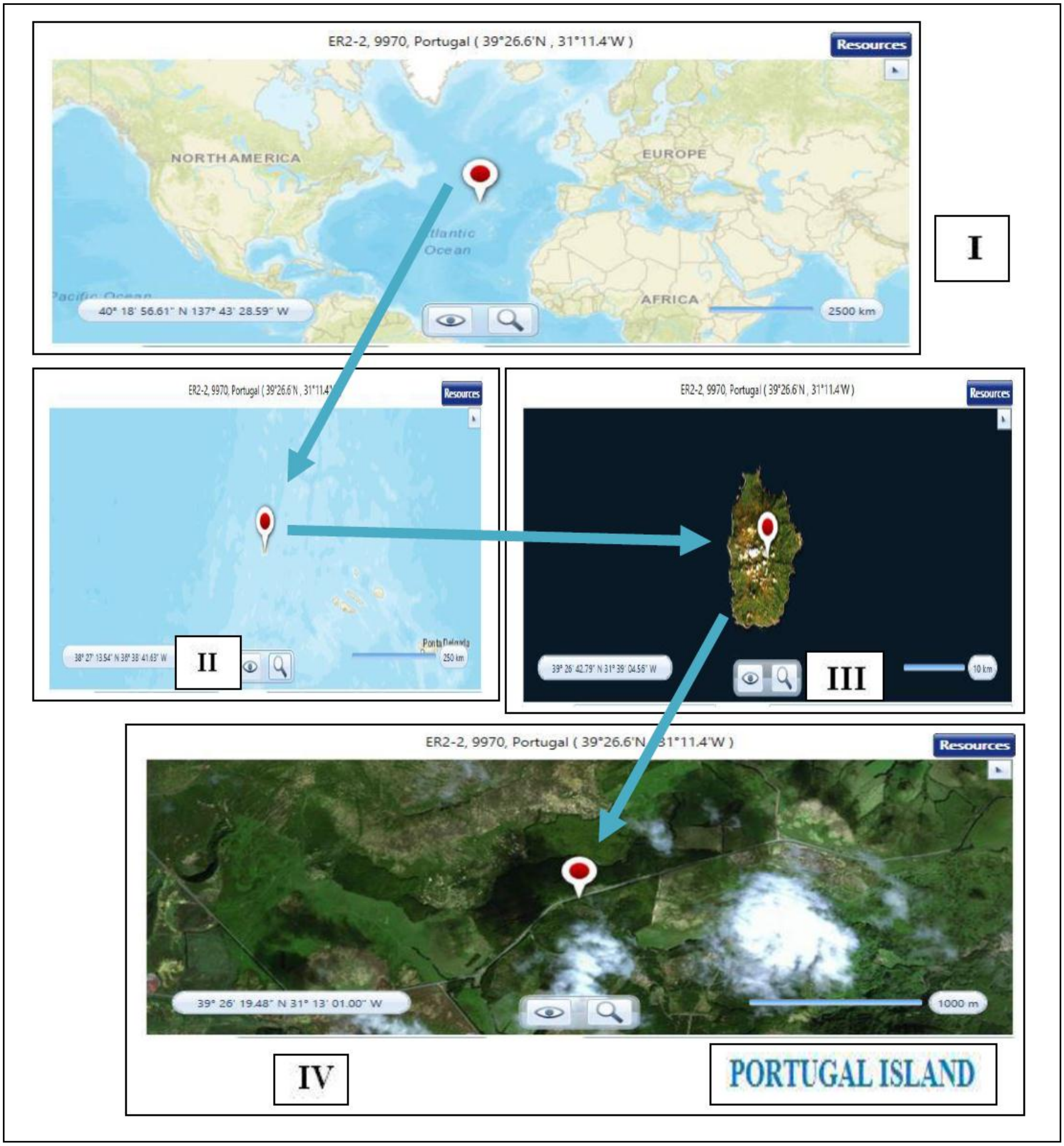

Fig.1 Location of study area

Electric Load Data Information

Different types of load such as Residential Load, Telecom Tower Load, and Water Pump Load are considered in this hybrid system in order to analyze the feasibility.

Residential load

Here, the average electric load for Portugal Island is considered to be 60 kWh/day. Figure 2 shows the daily load profile. Figure 3 indicates the average load in months where the peak load found to be 9 kW. Figure 4 shows the yearly load profile where the load factor is 0.28 and the average load is 2.5 kW.

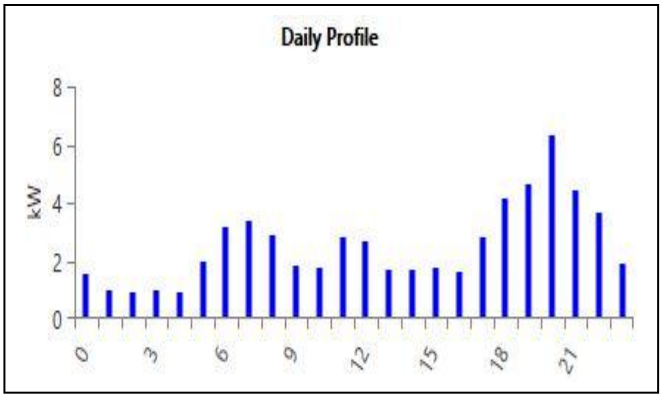

Fig.2 Daily profile of hourly load of Portugal Island

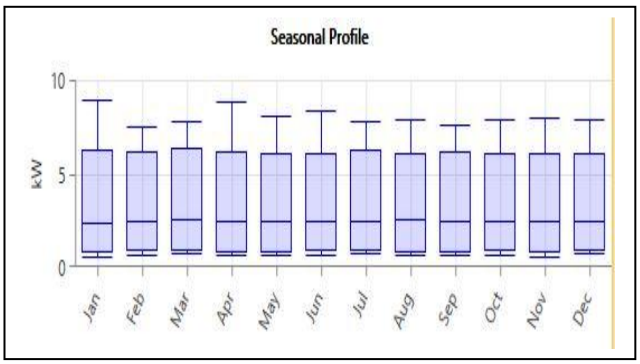

Fig.3 Seasonal Profile of Monthly Load of Portugal Island

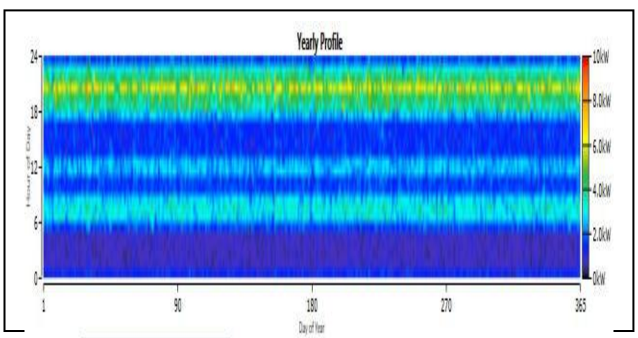

Fig.4 Yearly Load Profile of Portugal Island

Telecom Tower Load

The average energy consumption of Telecom Tower Load at the selected location is 120 kWh/day. Figure 5, 6, 7 indicates the daily, seasonal and yearly load profile of telecom tower. The peak load found to be 5.78 kW. The average load of the telecom tower is 5 kW and the load factor is 0.86.

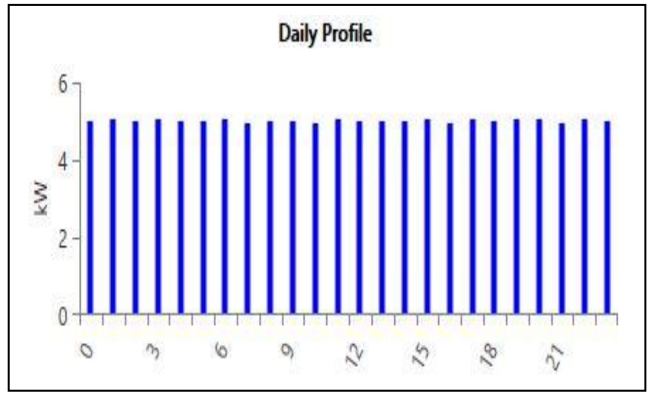

Fig.5 Hourly Load Profile of Telecom Tower

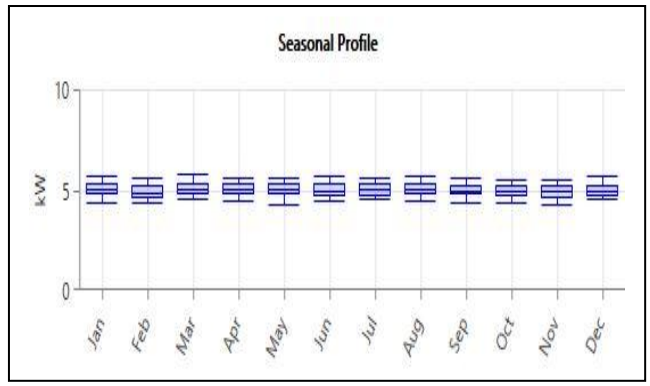

Fig.6 Monthly Load Profile of Telecom Tower

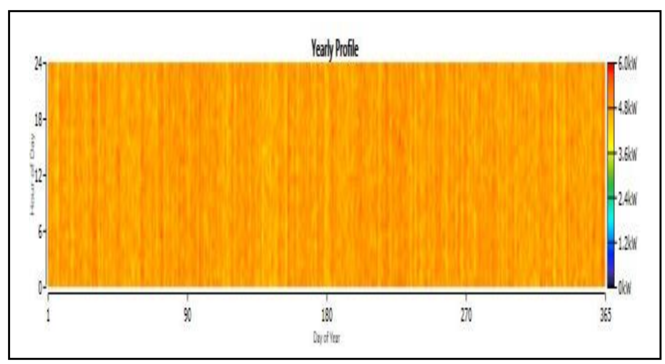

Fig.7 Yearly Load Profile of Telecom Tower

Water Pump Load

For this hybrid model, the water pump is expected to require 1.5 kWh of energy per day, and the water tank is capable of storing up to 4 days of water (i.e. 6 kWh of energy). The pump is expected to require 0.75 kW of power to run and must be at 100% of that power to operate. Figure 8 indicates the monthly load profile of the water pump.

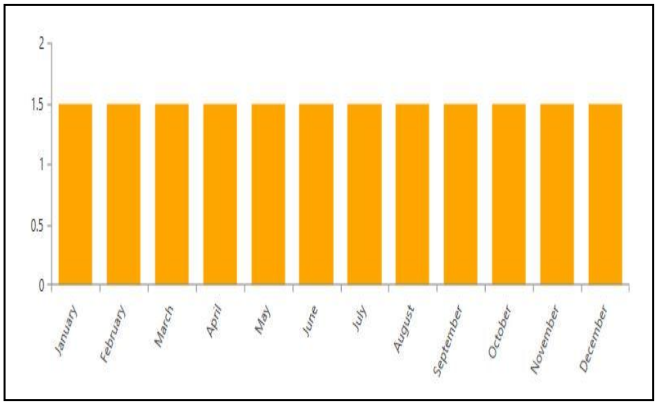

Fig.8 Monthly Load Profile of Water Pump

Solar Resource

The solar irradiance data obtained from NASA surface meteorology and solar energy. The annual average solar radiation in selected location is 4.23 kWh/m2/day with its highest radiation in the month of July and lowest in the month of December. Figure 9 shows the daily radiation and clearness index of the selected area over a one year period where it can be seen that the solar radiation ranges from 1.640 kWh/m2/day to 6.760 kWh/m2/day and the clearness index ranges from 0.419 to 0.624.

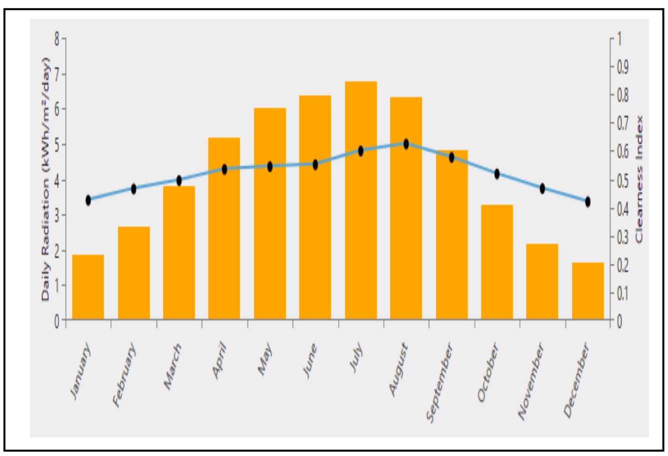

Fig.9 Monthly Average Solar Radiation Data and Clearness Index of Portugal Island

Wind Resource

All the data regarding wind speed has been downloaded from (National Aeronautics and Space Administration) NASA surface meteorology. The annual average wind speed is 7.69 m/s with highest in the month of January and lowest in the month of July. Figure 10 shows the monthly average wind speed data, where it can be seen that the wind speed ranges from 5.140 m/s to 9.860 m/s.

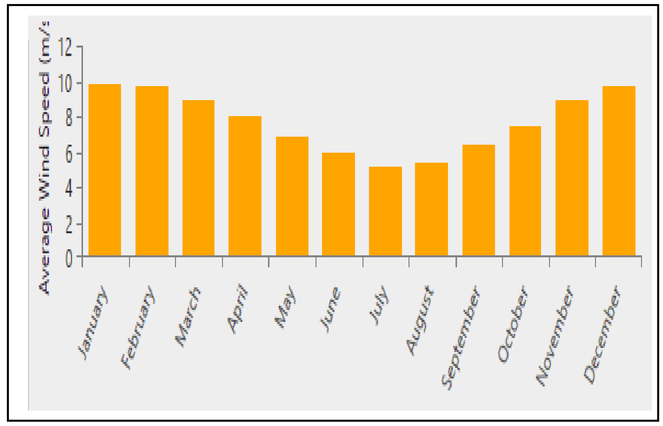

Fig.10 Monthly Average Wind Speed Data of Portugal Island

Temperature

The Temperature Data has been downloaded from (National Aeronautics and Space Administration) NASA surface meteorology. Figure 11 shows the range of the temperature which is from 14.950°C to 21.880°C. The average annual temperature found to be 17.83°C with highest in the month of August and lowest in the month of March.

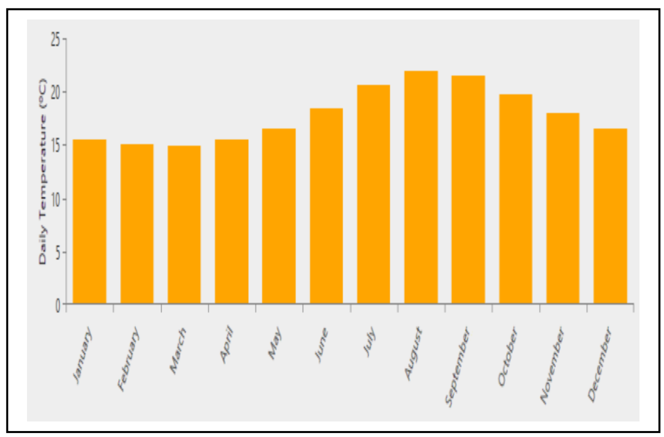

Fig.11 Temperature Data of Portugal Island

Biomass Resource

Here, the annual average biomass is 45.75 tonnes/day with its highest biomass in the month of May and lowest in the month of December. The carbon content is 5.00 % and the gasification ratio is 0.70. The Lower Heating Value (LHV) of biogas is 5.50 MJ/kg. Figure 12 shows the monthly average biomass data where the range of biomass is 35 tonnes/day to 60 tonnes/day.

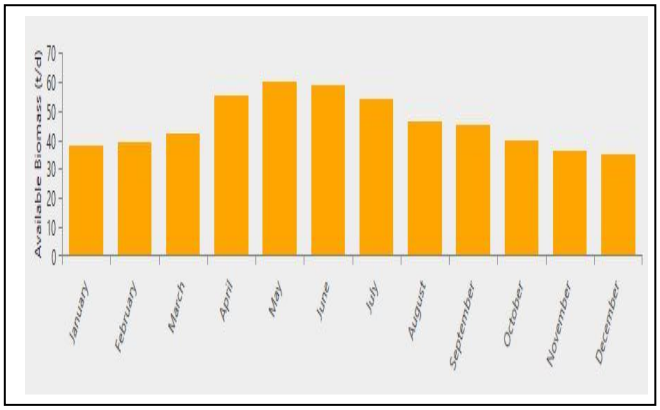

Fig.12 Monthly Average Biomass Data of Portugal Island

IV. METHODOLOGY

About HOMER Pro Software

Dr. Peter Lilienthal developed the HOMER software in National Renewable Energy Laboratory (NERL) in the United States of America (USA) [9]. In October 2014 HOMER software was developed into HOMER Pro version [10]. HOMER Pro software is used to optimize, design and analyze hybrid system which mainly uses renewable [11].

Analysis of Cost by using HOMER Pro Software

Total Investment Cost

Total investment cost is the cost that involved in executing the hybrid system which includes the cost of delivery and transportation, the cost of components and materials, building cost, installation cost, power distribution cost and consultation service cost [12].

Operating and Replacement cost

The operating cost is the cost that is required for the operation of the hybrid system and replacement cost is the cost of those components of the hybrid system which need to be replaced after a fixed amount of time.

Net Present Cost

The initial capital cost, replacement cost, annual operating and maintenance cost, as well as fuel costs, are known as Net Present Cost (NPC). This cost is calculated for the system throughout its lifetime.

The formula for NPC is [13]: NPC = TAC / CRF (i, Rprj).

Here, TAC is the Total Annualized Cost in terms of $. CRF is the Capital Recovery Factor. i is the rate of interest in terms of %. Rprj is the lifetime of the project in terms of the year.

Total Annualized Cost

The cost comprising of the addition of the cost of all equipment used in power system which comprises of capital cost, operation cost, maintenance cost, replacement, and fuel cost calculated annually is known as Total Annualized Cost (TAC) [13].

Capital Recovery Factor

It is the factor that calculates the present value of a series of equal cash flow annually in the ratio is known as the Capital Recovery Factor (CRF). The formula for CRF is [13]:

$$\mathbf{CRF = \{I \times (1+i)^{n}\} / \{(1+i)^{n-1}\}}$$

Here, n is the number of years. i is the real interest rate calculated annually.

Annual Real Interest Rate

The Annual Real Interest Rate represents the nominal interest rate as a function. The formula for Annual Real Interest rate is [13]:

$$\mathbf{I = (i^{r}-F) / (1+F)}$$

Here, i is the real interest rate. i^r is the nominal interest rate. F is the annual inflation rate.

Cost of Energy

The average cost in cost/kWh of the system producing electrical energy which is useful in practice is known as Cost of Energy or COE. The formula for COE is [13]:

$$\mathbf{COE = TAC / (L_{prim,\,AC} + L_{prim,\,DC})}$$

Here, Lprim, AC is the primary AC load and Lprim, DC is the primary DC load.

V. SIMULATION MODEL

The design of the simulation model has been done by choosing different components from HOMER Pro software. The model consists of a PV power plant, wind farm, bio-generator, power converter, residential load, telecom tower load, water pump load, grid connection, as shown in figure 13.

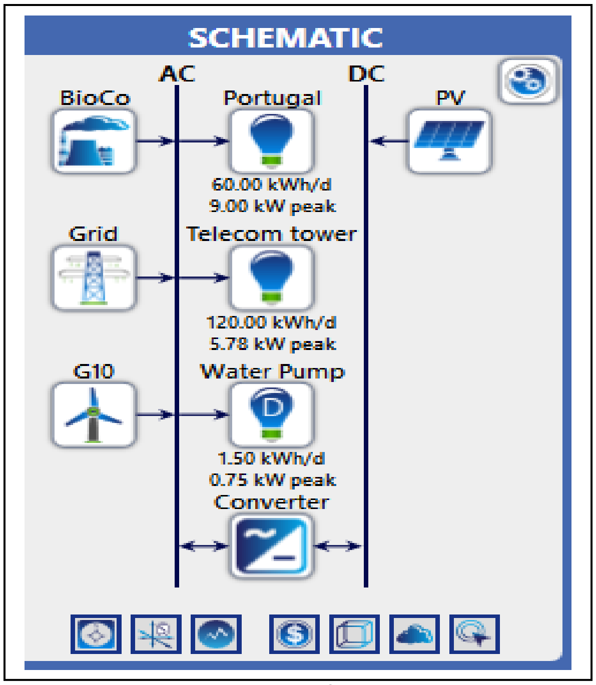

Fig.13 HOMER Pro Model for Hybrid Power Plant of Portugal Island

Photovoltaic (PV) System

The name of the PV system is Generic flat plate PV manufactured by Generic. The panel is of flat plate type with rated capacity 800 kW. The operating temperature of the panel is 47°C and its efficiency is 13%. The capital cost of the PV panel is 500 $/kW along with operation & maintenance (O&M) cost of 50 $/year. The lifetime of the panel is 15 years.

Wind Turbine

Generic 10 kW wind turbine has been used in this paper which is manufactured by Generic. The rated capacity of each wind turbine is 10 kW and the number of wind turbine used is 10. The capital cost for each wind turbine is $ 24,000 and the O&M cost is 400 $/year. The hub height is 24 m and the lifetime of the turbine is 20 years.

Converter

System Converter has been used in this paper manufactured by Generic. The size of the system converter is 860 kW. The capital cost is 300 $/kW with the O&M cost of 10.0 $/year. The efficiency of the converter is 95% and the lifetime is 15 years.

Combined Biogas and Diesel Generator

The Generic manufactured Bio-Generator has a size of 100 kW. The capital cost is 40000 $/kW with O&M cost of 2 $/op. hr. The minimum load ratio of the bio-generator is 25 % and the Lower Heating Value of the generator is 43.2 MJ/kg. The lifetime of the biomass generator is 15,000 hours. It uses both the biogas and diesel as a fuel with minimum fossil fraction is 20%. Biogas co-fired substitution ratio (biogas/fossil) is 8.5.

Grid

In general grid connection used either to give excess power to the grid or to consume power from the grid. When after satisfying the load demand of an area, there is an excess of power, then that excess power can be a sale to the grid. On the other hand when there is a shortage of power from the Renewable Energy Sources then power can be consumed from the grid. The purchase price of energy from the grid is 0.1500 $/kWh and the sell back price is 0.1200 $/kWh.

VI. OPTIMIZATION RESULTS

This section presents the simulation results from HOMER software and discussion of the results. After proper analysis of the optimization results of different configuration on the basis of continuity of power supply and cost, one configuration is selected as the most suitable configuration. Figure 14 shows all the possible configurations of the proposed hybrid system with their initial cost, operating cost ($/yr), total NPC (Net Present Cost), COE (Cost of energy in $/kWh), renewable fraction, energy production (kWh), operation and maintenance cost. From figure 14, it is clear that the last configuration is the most suitable configuration in terms of both the continuity of power supply and cost. This configuration uses all the power sources as well as its overall cost show that the system is economical to use. The total net present cost of this configuration is $1,217,192.00. The levelized cost of energy is 0.0448 $/kWh. The operating cost is 16,521 $/yr. This configuration has a renewable fraction of 82.8. These results indicate that the configuration is economical to use. The net present cost of an optimized hybrid power plant is shown in figure 15 and the annualized cost of the hybrid system is shown in figure 16.

Configurations	Initial Capital	Operating Cost($/yr)	Total NPC	COE($/kWh)	Ren. Frac.	Total Fuel(L/yr)	Production(kWh)	O&M Cost
PV(kW), Grid(kW) & Converter(kW)	$726,001	-$40,627	$206,646	$0.0127	97.4	0		
PV(kW), Wind(kW),Grid(kW) & Converter(kW)	$966,001	-$35,818	$508,125	$0.0311	97.6	0		
PV(kW), BioCo(kW), Grid(kW) & Converter(kW)	$766,001	$11,712	$915,713	$0.0339	82.7	102,422	876,000	17,520
PV(kW), Wind(kW), BioCo(kW), Grid(kW) & Converter(kW)	$1.01M	$16,521	$1.22M	$0.0448	82.8	102,422	876,000	17,520

Fig.14 Different Configurations of Hybrid Energy System

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 10 kW	$ 240,000	$ 51,133	$ 62,361	-$ 34,950	$ 0.00	$ 318,545
Generic 100kW Genset with Biogas Cofire	$ 40,000	$ 223,964	$ 286,926	-$ 3,728	$ 1.51M	$ 2.05M
Generic flat plate PV	$ 400,000	$ 511,334	$ 0.00	$ 0.00	$ 0.00	$ 911,334
Grid	$ 0.700	-$ 3.16M	$ 0.00	$ 0.00	$ 0.00	-$ 3.16M
PV Dedicated Converter	$ 68,000	$ 543,293	$ 28,374	-$ 5,281	$ 0.00	$ 634,385
System Converter	$ 258,000	$ 109,937	$ 107,654	-$ 20,038	$ 0.00	$ 455,553
System	$ 1.01M	-$ 1.72M	$ 485,315	-$ 63,997	$ 1.51M	$ 1.22M

Fig.15 Net Present Cost Summary of Hybrid System

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 10 kW	$ 18,774	$ 4,000	$ 4,878	-$ 2,734	$ 0.00	$ 24,919
Generic 100kW Genset with Biogas Cofire	$ 3,129	$ 17,520	$ 22,445	-$ 291.63	$ 117,785	$ 160, 588
Generic flat plate PV	$ 31, 291	$ 40,000	$ 0.00	$ 0.00	$ 0.00	$ 71,291
Grid	$ 0.0548	-$ 246, 843	$ 0.00	$ 0.00	$ 0.00	-$ 246,843
PV Dedicated Converter	$ 5,319	$ 42,500	$ 2,220	-$ 413.14	$ 0.00	$ 49.626
System Converter	$ 20,182	$ 8,600	$ 8,421	-$ 1,567	$ 0.00	$ 35,636
System	$ 78,696	-$134,223	$ 37,965	-$ 5,006	$ 117,785	$ 95, 217

Fig.16 Annualized Cost Summary of Hybrid System

The production summary data is shown in Figure 17, where it can be seen that the total renewable energy generated is 2,188,333 kWh/yr. The consumption summary data is shown in Figure 18, where it can be seen that the AC primary load is 65,700 kWh/yr. This shows that the hybrid energy system easily satisfies the load while generating an excess of load. Figure 19 indicates how much emissions are occurring in the hybrid system. The emissions summary is less of this system because of renewable dependency.

Component	Production (kWh/yr)	Percent
Generic flat plate PV	1,301,207	59.5
Generic 100kW Genset with Biogas Cofire	876,000	40.0
Generic 10 kW	11,125	0.508
Total	2,188,333	100

Fig.17 Production Summary of System

Component	Consumption (kWh/yr)	Percent
AC Primary Load	65,700	3.09
DC Primary Load	0	0
Grid Sales	2,057,025	96.9
Total	2,123,272	100

Fig.18 Consumption Summary of System

Pollutant	Quantity	Unit
Carbon Dioxide	447,381	kg/yr
Carbon Monoxide	4,380	kg/yr
Unburned Hydrocarbons	177	kg/yr
Particulate Matter	17.5	kg/yr
Sulphur Dioxide	316	kg/yr
Nitrogen Oxides	350	kg/yr

Fig.19 Emissions Summary of System

Figure 20 shows the grid purchase (kWh) per month and grid sales (kWh) per month data, where it is seen that grid purchase of the hybrid system is zero, on the other hand, grid sale is very high and quite a large amount of power is injected into the grid. It shows that the hybrid system is profitable in the selected area and it will benefit the proposed project by earning a lot of money which is very good for a business proposal.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	0	134,235	-134,235	0	-$ 16,108	$ 0.00
February	0	135,011	-135,011	0	-$ 16,201	$ 0.00
March	0	170,128	-170,128	0	-$ 20,415	$ 0.00
April	0	184,793	-184,793	0	-$ 22,175	$ 0.00
May	0	202,373	-202,373	0	-$ 24,285	$ 0.00
June	0	200,197	-200,197	0	-$ 24,024	$ 0.00
July	0	213,243	-213,243	0	-$ 25,589	$ 0.00
August	0	214,050	-214,050	0	-$ 25,686	$ 0.00
September	0	182,286	-182,286	0	-$ 21,874	$ 0.00
October	0	157,970	-157,970	0	-$ 18,956	$ 0.00
November	0	135,037	-135,037	0	-$ 16,204	$ 0.00
December	0	127,702	-127,702	0	-$ 15,324	$ 0.00
Annual	0	2,057,025	-2,057,025	0	-$ 246,843	$ 0.00

Fig.20 Grid Purchase (kW) per month and Grid Sales (kW) per month of Hybrid System

Case Study

Figure 21 shows the plot between the solar irradiance in kW/m^2 and PV power output in kV (without MPPT). Figure 22 shows Generic flat plate PV power output (kW) and PV dedicated converter power input (kW) (with MPPT). Figure 23 shows the plot between wind speed in m/s per month and wind turbine power output in kW. Figure 24 shows the plot between biomass resource (kg/hr) and bio-generator power output where the bio-generator used both biogas and diesel as a fuel also. Figure 25 shows the grid purchase (kWh) and grid sales (kWh) data of Portugal Island. And from this figure, it is clear that the grid purchase is zero and the grid sale is very high.

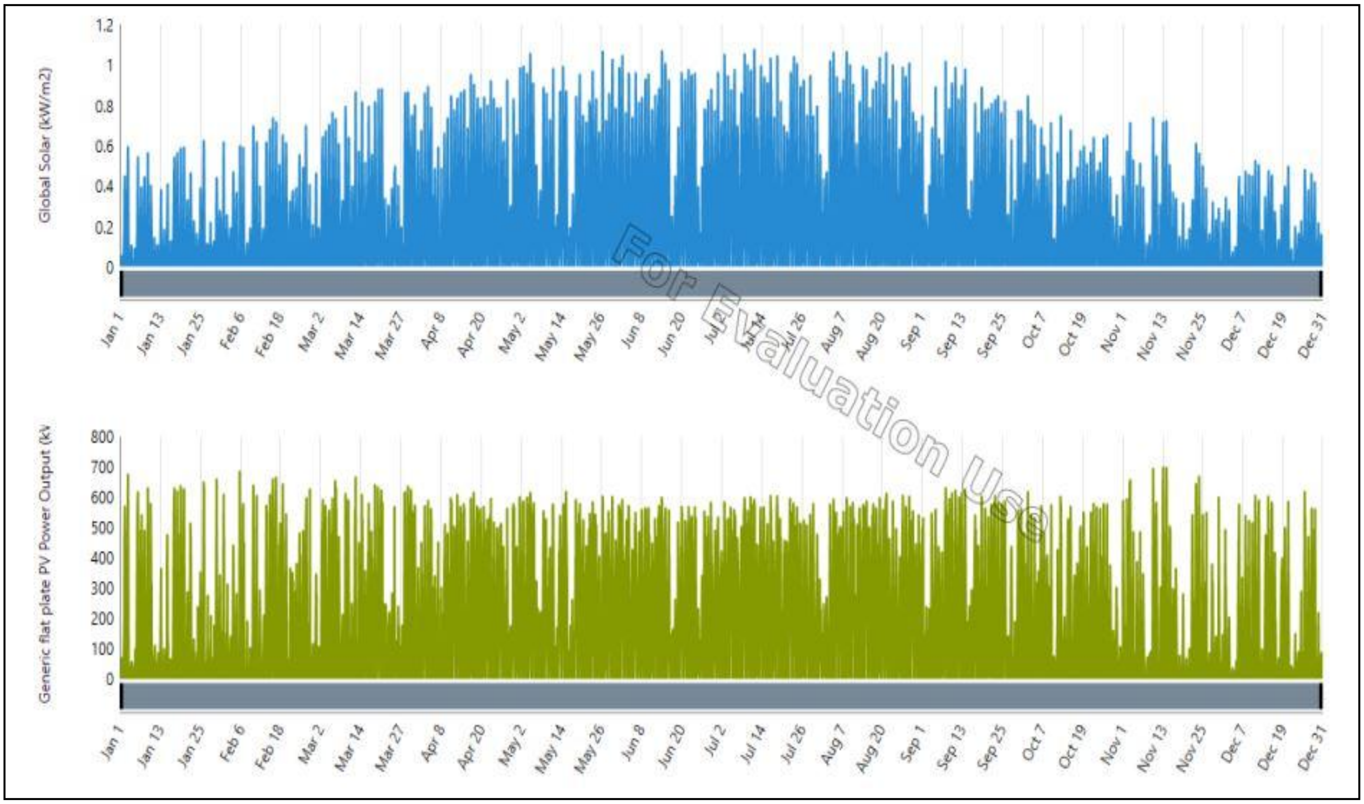

Fig.21 Global Solar (kW/m2) and Generic Flat Plate PV Power Output (kW) of the Hybrid System of Portugal Island

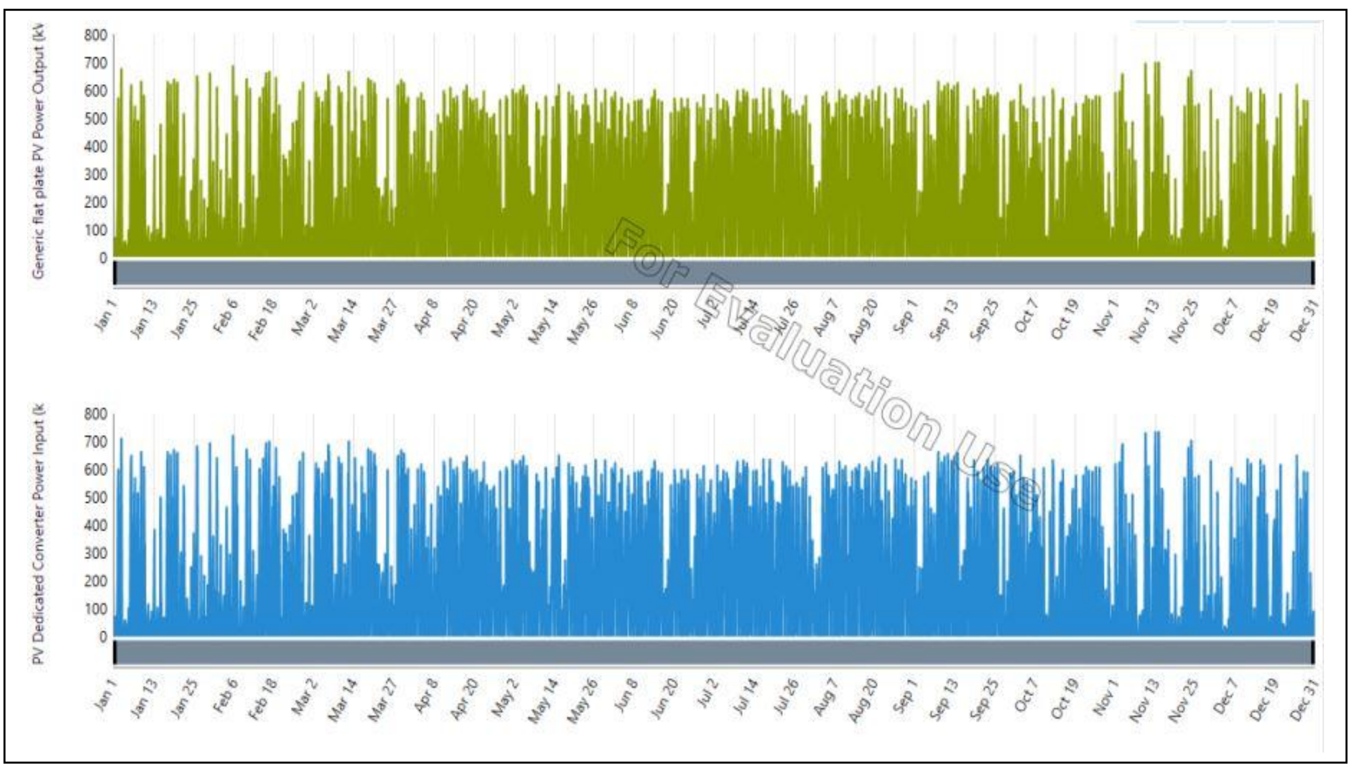

Fig.22 Generic flat plate PV Power Output (kW) and PV Dedicated Converter Power Input (kW) of Hybrid System

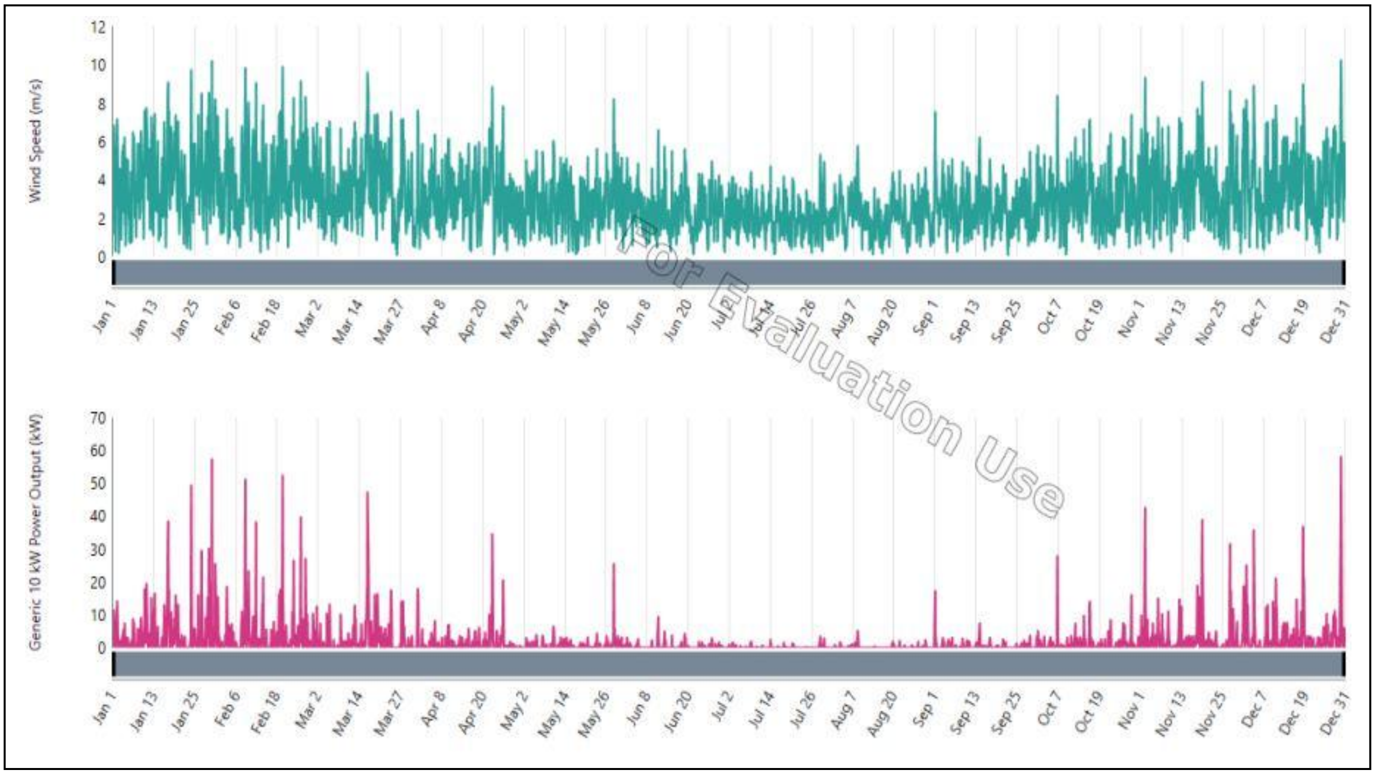

Fig.23 Wind Speed (m/s) and Generic 10 kW Power Output (kW) of Hybrid System of Portugal Island

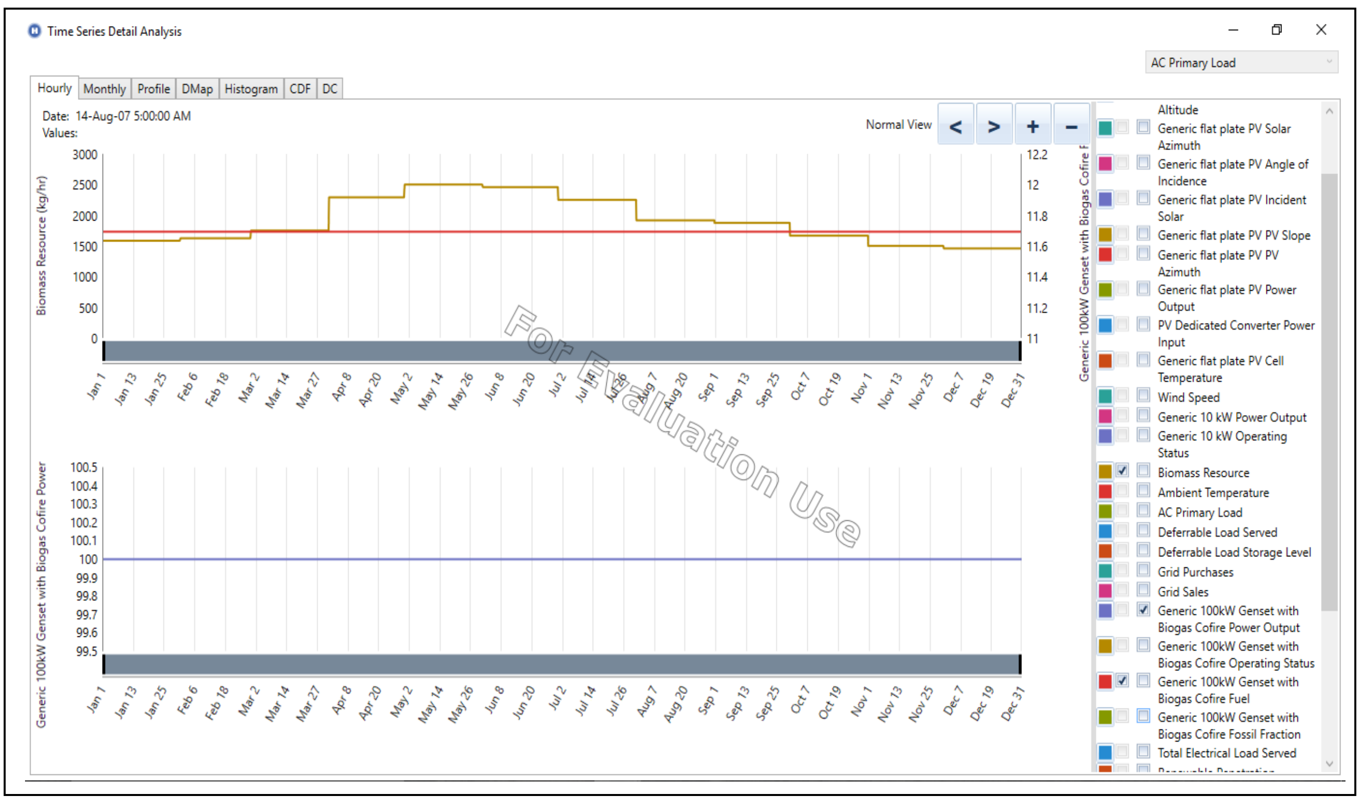

Fig.24 Biomass Resource (kg/hr) and Generic 100kW Genset with Biogas Co-fire Power Output and Generic 100kW Genset with Biogas Co-fire Fuel of Hybrid System of Portugal Island

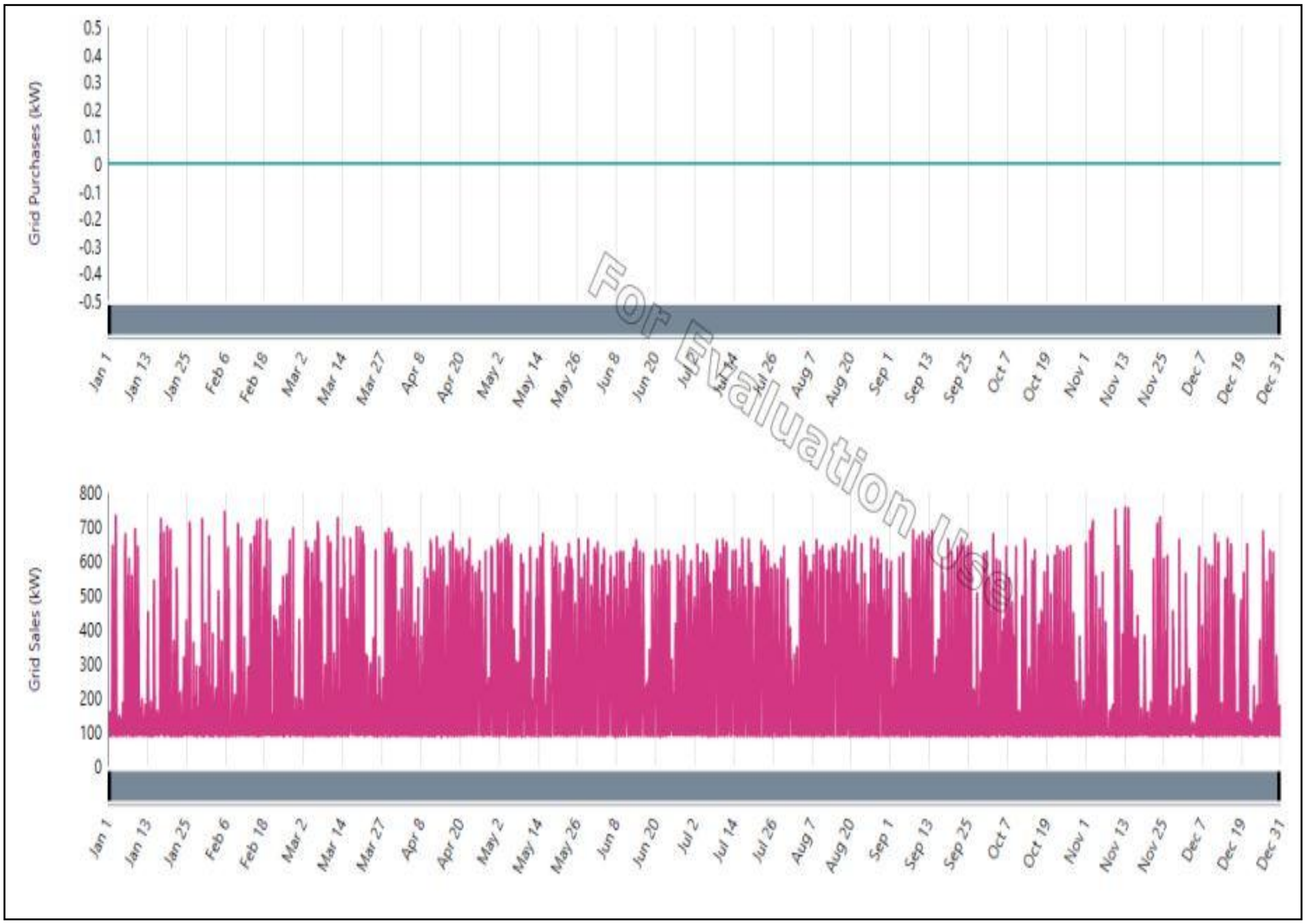

Fig.25 Grid Purchase (kW) and Grid Sales (kW) of Hybrid System of Portugal Island

VII. Conclusion

The overall conclusion of this analysis is that the hybrid system is profitable since it sells a large amount of power in the grid every year and purchase a zero amount of power from the grid every year and it provides an effective control strategy as well as business plan in reducing pollution, energy management, and electric demand fulfillment. This study helps us to explain the scope of renewable power generation in Portugal Island is very good as well as it can generate a large amount of extra power which can be used for selling. If such kind of hybrid system built at more suitable places by making contracts agreements in between different countries of the world then such hybrid system at a very large scale solve the problem of pollution from thermal power plants to a very large extent.

This research presents a technically feasible and cost-effectively viable hybrid solution for grid electricity supply to the selected region in a least-cost combination of solar PV, wind turbine, and bio-generator that can satisfy the load demand in a dependable manner at a cost of $0.0448/kWh. However, there are some emissions which we found after analyzing the hybrid system using the real-time data of the selected location due to the use of the generator to maintain the continuity of power supply in the required conditions. This hybrid energy system generates less emission due to the usage of renewable energy sources on a large scale. This study proves that the renewable-energy based hybrid system is a more cost-effective option for Portugal if appropriately supported by the government.

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