IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

ISO 3297:2007 Certified

Vol. 5, Issue 3, March 2017

Design and Development of Optimal Sizing of Integrated Renewable Energy Systems for electrifying the rural areas in Nilgiris District

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Abstract: A large proportion of the world's population lives in remote rural areas that are geographically isolated and sparsely populated. This paper discusses the efficient system of sustainable renewable energy for domestic use and its total cost for the off-grid area; taking Pykara as model which is in Ooty town of Nilgiris district. Method of this paper is collecting the basic data of solar radiation, wind speed and other required input data, and then hybrid optimization. Simulation model was developed using the HOMER energy modelling software. Simulation model has been used to find out the best technically viable renewable based energy efficient system for different numbers of household. Results have been presented as the most efficient economic way for electrifying the area.

Keywords: Hybrid optimization model of renewable energy (Homer), Pykara, Domestic and agricultural power consumption, Cost analysis**.**

I. INTRODUCTION

Hybrid systems compromises of two or more renewable energy sources for the generation of electrical power so that the deficit of power generation from one source can be easily compensated by the other source available in order to maintain the reliability of power supply. Comparatively the efficiency of the power generated from renewable sources are less than that of power generated from conventional resources, thus employing hybrid systems for renewable resources can be efficient and reliable solution for the generation of electrical power. It can be designed to achieve desired attributes at the lowest acceptable cost which can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and/or economics.

II. NECESSITY OF HYBRID ENERGY SYSTEM

Hybrid system is considered as one of the most efficient means to access electricity from locally available renewable energy resources where the access to national grid is quite impossible and also not economic. People of several places are out of reach of electricity also because of its geographical landscape and conditions where providing electricity from a centralized power plant through some sorts of transmission lines is not possible[1]. The people residing in such kind of place can be highly benefitted by the means of hybrid system. Also depending upon conventional sources of energy is becoming harder day by day due to its rising prices and limited availability. Thus developing countries burdened by the high costs of imported fuel can benefit from small, sustainable renewable energy system that use a combination of a solar, wind and micro-hydro technologies to electrify rural, villages[2][3]. In addition to facilitating livelihood development and reducing fossil fuel dependence "Hybrid" system aids the development of carbon credits and funding options to subsidize clean renewable energy projects. easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it[4][5].

III.SUMMARY OF THE PROJECT SITE

The name of the project site is Pykara which lies in Ooty town of Nilgiris district. (Latitude: 11.4064° N, Longitude: 76.6932).It's one of the non grid-connected areas of Pykara and about 50 families live here. It is surrounded by hilly areas and most of the people living here are dependent upon agriculture for their livelihood. The people of this region experience the continuous daylight throughout the year although the solar radiation of winter season remains comparatively low than that of summer season[6]. The average solar isolation intensities of about 4.758kWh/day with average sunshine hour of 5.8hours/day of about 300 days of sun a year is available in this region. The wind speed of this area is quiet high; mostly below the optimum level (5 m/s). But during the months May-July it gets a favourable wind speed (max 4.3m/s); for some low power generation but enough to meet the demand of irrigation system during that dry season. It will reduce the overall cost for electricity generation for this particular area. So combining both solar

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energy, hydro energy and the wind energy to produce power, it's possible to meet the current demand[7][8][9]. Even though the potential of renewable sources are moderate, the application of renewable generators as standalone units will not be sufficient to provide a continuous power supply due to seasonal and non-linear variation of renewable resources [10][11].

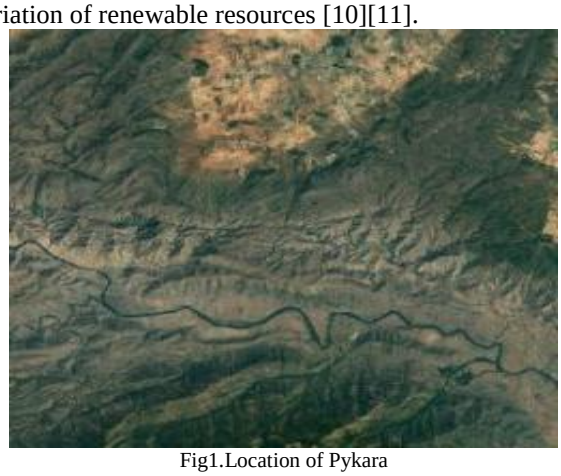

Fig1.Location of Pykara

To ensure a balance and stable power output it needs to be integrated with a diesel generator. Here in our study we have developed a hybrid system for this area which consists all the load demands using Solar PV, Wind turbine and a Diesel Generator.

IV. LOAD ESTIMATION

A. Loads (Per Day)

Electricity demand for each family

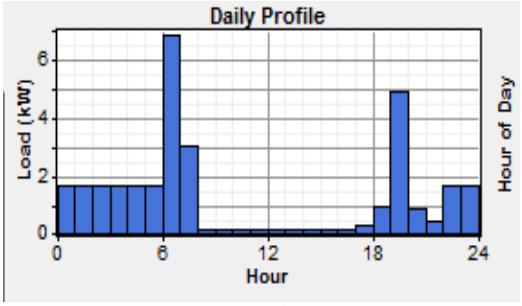

Fig2.Load Profile results

V. COMPONENTS OF THE PROPOSED SYSTEM

Considering our project site we have designed our hybrid system with power source of Wind Energy, Solar isolation and diesel. Solar isolation is the most abundant green energy source here when necessary wind speed for power generation will only be available for 2-3 months. So a diesel generator is taken for continuous supply of power. Hence the components of our systems are:

1. Wind Turbine
2. Solar Photovoltaic system
3. Diesel Generator
4. Storage device
5. Biomass

VI. INPUT PARAMETERS

A. Wind Turbine scheme:

Wind speed varies throughout the year and the exact wind speed for a particular area in different seasons is not available. Fortunately for us our project site and recently a study based on this area's wind speed is done by LGED (*Local Government Engineering Department)*.Although they have marked the area as low potential wind site but for low power generation considering a low populated site like *Pykara* it can be taken into consideration. The wind speed data for each month is given below in Table 1.

TABLE I
WIND SPEED THROUGHOUT THE YEAR

Month	Wind Speed(m/s)
January	3.1
February	2.7
March	2.8
April	2.8
May	3.3
June	4.7
July	4.5
August	4.3
September	3.3
October	2.6
November	2.7
December	3.5
Average	3.364

B. Solar PV Scheme:

Location of the site: Pykara in Ooty
Latitude 11'4064° North
Longitude: 76'6932° East
Time Zone: [GMT+05:30] India year in *Pykara* is shown in Table 2.The solar radiation data for various months throughout the year.

TABLE II

Solar radiation throughout the year.

Month	Clearness Index	Daily Radiation ($kW/m^2/d$)
January	0.633	5.640
February	0.634	5.940
March	0.630	6.390
April	0.562	5.930
May	0.508	5.350
June	0.371	3.870
July	0.355	3.710
August	0.389	4.090
September	0.473	4.830
October	0.475	4.540
November	0.531	4.650
December	0.597	4.990
Average	0.508	4.971

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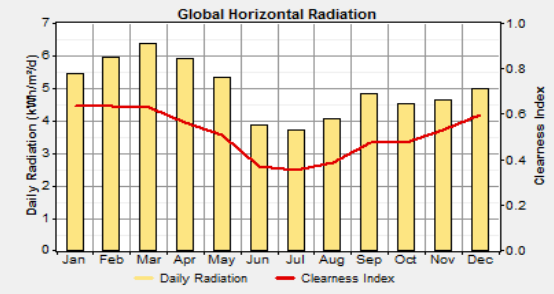

Fig 3.Solar PV Scheme Results

The solar radiation for each month was obtained where it was found that the maximum solar radiation was found for the month of February and March with daily radiation of 6.390kWh/m^2/day whereas the minimum radiation was found for the month of July with daily radiation 3.710kWh/m^2/day .The average radiation throughout the year was 4.971kWh/m^2/day.

C. *Diesel Generator:*

For uninterruptable power supply we have used a 15kW diesel generator. Only for this scheme a traditional fossil fuel source (diesel) is used. When Wind-PV will unable to fulfil the load demand than the generator will operate. Some specifications of the diesel generator are:-

Limit consumption: 10000L/yr
Lower heating value: 43.2MJ/Kg
Density: 820KG/m3
Carbon content: 88%
Sulphur content: 0.33%
At present the price of diesel: 0.905$/L (litre).

D. Biomass:

For uninterruptable power supply, we have used a biomass generator. Only for this scheme a traditional fossil fuel source (biomass) is used. When Wind-PV will unable to fulfil the load demand than the generator will operate. The biomass data for various months throughout the year in *Pykara* is shown in Table 3.

TABLE III

Biomass availability throughout the year.

Month	Available Biomass(Tonnes/day)
January	0.462
February	0.490
March	0.452
April	0.380
May	0.580
June	0.391
July	0.386
August	0.367
September	0.0416
October	0.478
November	0.410
December	0.425
Average	0.437

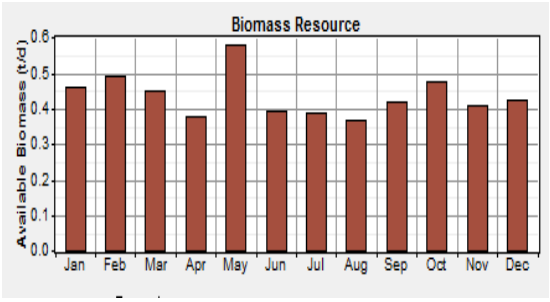

Fig4.Biomass Scheme Results

The biomass for each month was obtained where it was found that the maximum biomass was found for the month of May of 0.580tonnes/day whereas the minimum biomass was found for the month of August of 0.386tonnes/day. The average radiation throughout the year was 0.437tonnes/day.

E. Storage device:

The hybrid system compromises of Solar PV thus storage device is also modelled so that the energy from solar panels can be stored in battery and it can be used whenever the solar radiation is weak or when the generation is not feasible from solar cells, such as during cloudy days, rainy days. The storage device can also be used as the source of energy during the period of night. The battery is usually employed as a storage device for the hybrid system. This battery is only used by a solar cell to store excess energy so that it can be accessed during unavailability of Sun. The description of storage device i.e. battery is given below:

Name of Battery: Hoppecke 6 OPzS 300
Abbreviation: H300
Nominal Capacity: 300Ah
Nominal Voltage: 2V
Round trip Efficiency: 86%
Minimum State of Charge: 30%
Minimum Battery Life: 20yrs
Lifetime throughput: 1014kWh
Suggested value: 1012kWh
Maximum charge rate: 1A/Ah
Maximum charge current: 60A

F . Input unit cost of equipments:

Its need to be noted that the price listed in Table 3 is taken as the unit price of the equipments used in our system for simulation. It's done by collecting data from local market for the individuals.

TABLE IV

Unit price of components for simulation input

Equipment	Size (kW)	Capital ($)	Replacement ($)	O&M
Wind Scheme	10	765	700	4/yr
Diesel	0.5	969	400	0.050/yr

DOI 10.17148/IJIREEICE.2017.5330

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Generator Scheme				
Solar PV Scheme	1	596	550	2/yr
Storage Device	1	300	150	20/yr
Converter	3	1200	1000	100/yr
Biomass	0.5	250	100	100/yr

VII. MODELING OF HYBRID ENERGY SYSTEM

The complete model of hybrid system consisting of Wind, Solar PV and Diesel generator as the individual generating schemes contributing for hybrid operation, storage device and converter for storing and conversion of power produced from solar panel is shown in Fig. 5. Here, by the HOMER software the simulated peak demand of primary load is 12kW and total energy consumption is 32kWh/day where calculated peak demand is 6 kW and total energy consumption is 33kWh/day. Simulated result is low from the calculated result as we given balanced input load to the HOMER software of different hours of a day. The hybrid system consists of three individual generating units where the output from Wind turbine and Diesel Generator units are alternating in nature hence they are tied to AC bus-bar. Solar PV is tied to DC bus-bar because the output from solar panel is DC. The battery is also tied to DC bus-bar so that it can store the power delivered by solar panel when there is excess solar radiation during peak sun hours and deliver the required amount of power when the solar panel is not in operation that is during period of night, cloudy and rainy days etc. The converter is tied between AC and DC bus-bar.

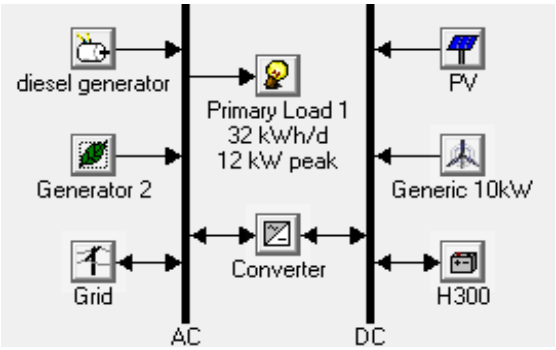

Fig.5: Complete Model of Hybrid System

Converter converts the DC outputs of the PV system and battery into AC. The loads are considered to be AC loads.

VIII. SIMULATION RESULTS OF THE PROPOSED HYBRID ENERGY SYSTEM:

The hybrid system was designed in HOMER by placing the appropriate input resource parameters for each individual scheme. After simulation different type of scheme has generated with their different energy system. Among them the hybrid system with 10kW Solar PV, 1pcs WES (10kW) wind turbine, 8kW diesel generator, 11 pieces Hoppecke 6 OPzS 300 battery and 15kW converter scheme is most cost effective from other different hybrid schemes as the levelized cost (COE) is only 0.227$/kwh, which is comparatively low from other schemes.

A . Electrical Results of the Hybrid System:

The production of electricity by individual scheme in hybrid system is given below in Table

TABLE V
Electrical output of the system

Production	Kwhr/yr	%
PV array	22,354	63
Wind Turbine	3,591	10
Generator	0	0
Bio Mass	9,371	27
Total	35,253	100

It is seen from above Table that PV array accounts for total of 63% of hybrid system production whereas Diesel Generator accounts for only 20% and Wind turbine accounts for 10% of total electrical energy produced by the hybrid system. Since the electricity produced by Solar PV scheme is more than any other scheme participating in the hybrid system thus is considered as the base load of the hybrid system. The monthly average electric production of hybrid system compromising of Solar PV, Diesel Generator and Wind is represented in a graph given below in Fig.6 which is obtained as a result after the simulation.

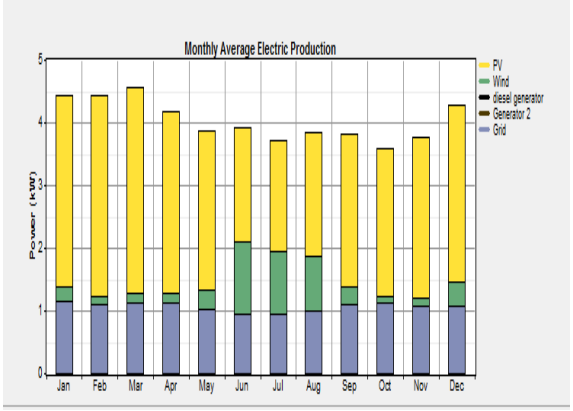

Fig.6: Complete Model of Hybrid Energy System

The consumption of electrical energy by AC primary load is 31965.82 kWh/yr which is 77% of the total electrical energy produced by the hybrid system. The excess electricity available from the system is about 3,632 kWh/yr.

B .Simulation Results for Solar Photovoltaic System:

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Electrical, Electronics, Instrumentation and Control Engineering

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The solar PV system participating in the hybrid system delivers 61.2 kWh/day of power to the load when operating in a hybrid system. The simulation results obtained for Solar PV is given below in Table 5.

TABLE VI
PV scheme results

Quantity	Value	Units
Rated Capacity	15.0	Kw
Mean Output	2.6	Kw
Mean Output	61.2	Kwh/d
Capacity Factor	17.2	%
Total Production	22,354	Kwh/yr
Rated Capacity	15.0	Kw
Minimum output	0.0	Kw
Maximum Output	14.7	Kw
PV Penetration	191	%
Hours of Operation	4,413	Hr/yr
Level Zed Cost	0.0366	$/kwh

From above Table it is seen that maximum output from solar PV is 14.7 kW when solar insulation is fully available and minimum output is 0 kW when the panel didn't get enough solar insulation to produce electricity. The total production of electricity from Solar PV system is 22,354 kWh and total hour of operation is 4,413hrs per year. The levelized cost only of this schee is 0.0366Tk.

C .Simulations Result for Wind Turbine System:

The Wind turbine system participating in the hybrid system has nominal capacity of 10kW with mean output of 0.41kW. The different simulation results obtained for Wind Turbine system while operating in hybrid manner with other system is given below in Table

.

TABLE VII
PV scheme results

Quantity	Value	Units
Total Rated Capacity	10.0	kW
Mean Output	0.41	kW
Mean Output	0	kWwh/d
Capacity Factor	4.10	%
Total Production	3,591	kWh/yr
Minimum output	0.01	kW
Maximum Output	7.98	kW
PV Penetration	30.7	%
Hours of Operation	5,341	Hr/yr
Level Zed Cost	0.0230	$/kWh

It is seen from the above figure that maximum output from wind turbine is 7.98kW when wind speed is maximum and minimum output is 0.01 kW when the wind turbine didn't get enough wind speed to create rotational force to the rotor .The total production of electricity from wind turbine system is 3,591 kWh and total hour of operation is 5,341hrs per year. The Level zed cost only of this scheme is 0.0230TK.

C. Simulation Result for Diesel Generator System:

The Diesel generator system participating in hybrid system has nominal capacity of 12kW with means electrical output of 2.19kW with electricity production is 1,863kWh and total hour of operation is 851hrs per year. The marginal generation cost only of this scheme is 15.3TK. The different simulation results obtained for Diesel Generator system while operating in hybrid manner with other system is given below in Table

TABLE VIII
Diesel Generator System scheme results

Quantity	Value	Units
Hours of Operation	0	Hr/yr
Number Of Starts	0	Starts/yr
Operational life	1,000	Yr
Capacity Factor	0.00	%
Fixed Generation Cost	6.81	$/hr
Marginal Generation Cost	2.26	$/kwh
Electrical Production	0.00	Kwh/yr
Mean Electrical Output	0.00	Kwh
Min. Electrical Output	0.00	Kwh
Max. Electrical Output	0.00	kwh

D. Simulation Results for Storage Device:

Battery was used as storage device for the hybrid system. The capacity of each battery was 1800Ah. The simulation result for battery is given in Table.

TABLE IX
Storage Device results

Quantity	Value	Units
Nominal capacity	3.60	kWh
Usage nominal capacity	2.52	kWh
Autonomy	1.89	hr
Lifetime throughput	6.084	kWh
Battery wear cost	0.160	$/kWh
Energy in	0.000	kWh/yr
Energy out	0.00	kWh/yr
Storage depletion	-1	kWh/yr
Losses	1	kWh/yr
Expected life	20	yr

IX. COST SUMMARIES:

The cost summary of hybrid system in terms of Net Present cost by component size and cost type obtained after simulation is given below in Fig. 7 and Fig. 8 respectively

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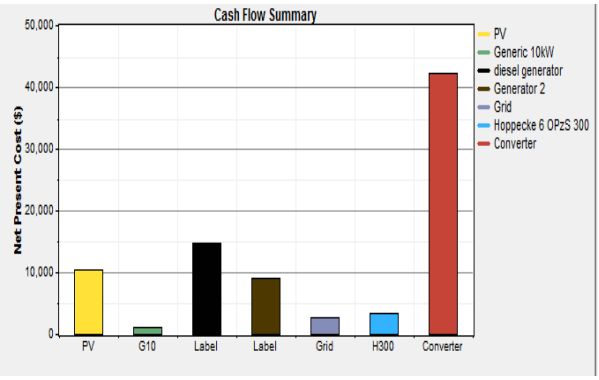

Fig 7: Cost summary by component type

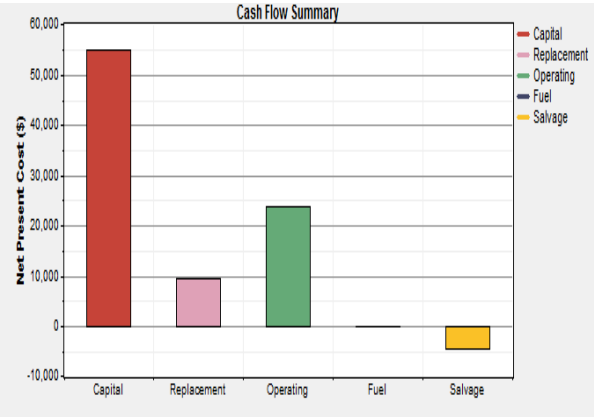

Fig. 8: Cash Flow Summary by Cost type

The economics of hybrid system is represented above where the overall costs associated with the system is given in individual manner of each participating scheme as well as the overall system considered as a whole. The costs associated with hybrid system is given in both component type and cost type.

X. SUMMARIZED RESULT

Renewable energy systems are very much site specific and designing such a system is complicated. Solar and wind system are most suitable for electrification of isolated remote areas in developing countries like India.[14] Our study deals with the design of hybrid power system for one of the rural remote place named Pykara of Ooty and also observe the economics associated with designed hybrid system. In this study, each of the individual scheme participating in hybrid system i.e. Wind, solar PV and Diesel generator, Biomass was modelled separately by defining real input parameters for each of the scheme. The economics associated with hybrid system was analyzed so that the cost of energy (COE) produced from hybrid system would be affordable for the people living in that region. From HOMER simulation we obtain minimum per kWh cost (COE) of Hybrid system is 25.198$/kWh

Here, Total Net Present Cost (NPC): 83,804$
Levelized Cost of Energy (COE): 25.0145/kWh
Operating Cost: 2,253/yr.
If the capital amount of money will be loaned from a bank with interest rate then cost will be,
Initial Capital cost of the system = 17,254$
At 6% interest rate, system fixed capital cost = 1,02640$
Total initial capital cost of the system = 18,1330$

XI. CONCLUSION

Using of hybrid power generations came forward due to high prices of generating power from oil and also due to the limited availability of such kind of non-renewable sources. Hybrid system can optimize the power supply especially in off-grid rural areas. However it is still considered expensive and difficult to combine various energy sources together .The expense is only for one time with a life span of about 20-25 years. So it can easily be considered. The simulated hybrid system for Pykara can be used in any off grid area of Ooty for electrification as solar radiation is used as primary source of energy which is abundant throughout the country; with level zed cost (COE) of 0.0366$/kWh.

ACKNOWLEDGMENT

The authors wishes to thank the Principal and Management of Kongu Engineering College, Erode, Perundurai for providing the support to complete this work as an initiative of electrifying the rural areas through the use of hybrid energy systems in remote rural areas.

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