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Research Article

Optimal Planning of Solar PV/WTG/DG/Battery Connected Integrated Renewable Energy Systems for Residential Applications using Hybrid Optimization

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Abstract

Nowadays, energy becomes the basic need of each and every human being. Most of the energy demands are met by the conventional energy sources like coal, oil, natural gas, etc., which are going to exhaust one day and cause severe energy demand in future. Renewable energy sources become the alternative for meeting the energy demand, among which solar and wind energy resources are most commonly used. Because of the intermittent nature of solar and wind energy sources, Hybrid/Integrated renewable energy systems are evolved in the recent years. This paper discusses about the economic analysis and the optimal selection of solar PV, Wind, Diesel Generator and Battery connected hybrid energy systems for residential applications. For the analysis purpose, a small middle class family in Perundurai, Erode District, Tamil Nadu has been considered in the present work. Also, a suitable Hybrid Optimized Model has been developed and the results have been discussed based on their Net Present Cost (NPC) and Cost of Energy (COE) and Green House Gas (GHG) emissions.

Keywords: Cost of energy; Net present cost; Integrated renewable energy systems; GHG emissions; Renewable energy fraction; Hybrid energy systems.

Introduction

Energy demand is growing day by day due to the increase in population, urbanisation and rapid industrialization. Most of the peoples rely on the conventional energy based electricity production for meeting their daily needs. These conventional energy sources emit greenhouse gases, when the fuels are being burnt. Since the oil crisis in late 1970s, renewable energy has been considered as an alternative way of generating electrical power for meeting their needs. Various industrial sectors and even general public and government organisations are also turning their attention towards renewable energy based energy production for meeting their energy demands [1]. The Government of India is also trying to maintain the energy balance between the energy demand and the source availability. Nowadays, hybrid energy systems are being mostly preferred rather than depending on single source for supplying the electric power in urban, rural and remote areas due to the intermittent nature of solar and wind resources. Due to the integration of renewable energy based systems, it results in high cost, complexity and several factors have been considered for integration [2,3].

As on 31st March 2014 (Renewable Energy Status Report 2014), the installed capacity of renewable energy has reached 32,269.6 MW (12.95%) of the total potential available (2,49,199 MW) in India. The Ministry of New and Renewable Energy (MNRE) has set down a target of 41,400 MW, as the total installed capacity by the end of 2017. Even though there is a considerable growth in power generation, the demand for the electric power has been growing at a rapid rate, whereas the opportunities for electricity production are very high. The Government of India is trying to bridge the gap between energy demand and power production by providing the funds to the research projects and development of Ultra Mega Power Projects (UMPPs) by making use of renewable energy systems.

Usually, Renewable energy sources are of single energy based systems and multiple energy based systems or Hybrid/Integrated

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energy systems [1]. In case of single energy based systems, it uses only one source along with energy storing devices and power electronic systems, whereas in case of multiple energy based systems, it utilizes two or more renewable energy sources along with DG sets, storage devices and power electronic devices. Several hybrid energy system combinations can be used for generating power depending upon their requirements. Hybrid energy systems are more advantageous compared to single energy based systems because they are highly reliable and more efficient. But, a proper design and better solution has been considered, in order to find the economic and most feasible solution. (i.e.), it should be neither oversized nor undersized.

The present work clearly discusses about the economic analysis of Solar PV/Wind/DG/Battery connected Integrated Renewable Energy Systems for residential load applications. For the study purpose, a small middle class family and their energy demand have been considered in Perundurai, Erode District, Tamil Nadu. A Hybrid Optimization Model has been developed and a better optimal solution with proper design has been found out from the several possible combinations based on the energy calculations like Net Present Cost (NPC), Cost of Energy (COE), Excess Energy (EE), etc.

The concept of Integrated Renewable Energy Systems was first introduced by Ramakumar in the 1980's, where he worked on evaluating the design scenarios of IRES. Later, he formulated the designs for integrating the renewable energy sources from the existing, freely available sources in which a remote village had been chosen and the versatility of IRES–KB has been discussed [2-4]. Later, in the late 1980's, a linear programming approach had been developed for integrating the renewable with the aim of minimizing/reducing the total annual cost using the concept of Loss of Power Supply Probability, in terms of power and energy calculations. The main aim of the IRES model proposed by Ramakumar in linear programming approach was to minimize the total annual cost per year subject to the energy produced. Many computer based simulation models are available in order to design and evaluate the techno – economic analysis of the renewable energy based systems [5-8]. The hybrid optimization model is one of the powerful tool which is mostly used by the researchers for designing and analysing the hybrid power systems, which contains a mix of conventional generators, combined heat and power, wind turbines, solar photovoltaic panels and so on [9-14].

Methodology of the Proposed Hybrid Energy System

Study area

Based on the village electrification report by MNRE released during May 2014, only few of the villages are fully electrified. Most of the villages remain unelectrified/ partially electrified even though they are ready to pay for the electricity and having a plenty of energy availability. Among the various states, some of the states like Meghalaya, Odisha and Arunachal Pradesh facing these problems. Even in some other states, a few of the villages which are located at a remote site, where the electrical power transmission is highly complex and involves huge investments. In those cases, IRES based systems may provide the better solution for rural electrification. Fig. 1 shows the geographical location of the study area on the map. The study area has the latitude of 11.270000 and a longitude of 77.580000 and has the DMS latitude and longitude of 11°16'12.0000"N and 77°34'48.0000"E respectively as shown in Fig. 2, wherein their load demand profile is shown in Table 1.

Fig. 1. Geographical location of the study area

Fig. 2. DMS latitude and longitude of study area

Table 1. Load demand profile

Sl. No.	Name of the appliances	Power rating, W	No. of hours used	Load Demand, W
1.	CFL lamp	25	10	250
2.	CFL lamp	40	10	400
3.	Television	250	8	2000
4.	Fans	50	19	950
5.	Computer	200	6	1200
6.	Radio	20	3	60
7.	Refrigerator	700	24	16800
8.	A.C.	3.516 k	10	35160
9.	Washing machine	500	2	1000

Modelling of the proposed system

A suitable system has been developed using the Hybrid Optimization Model, which consists of Solar PV, Wind Turbine Generator, Diesel Generator set, Battery along with the Power Electronic Conversion Systems as shown Fig. 3.

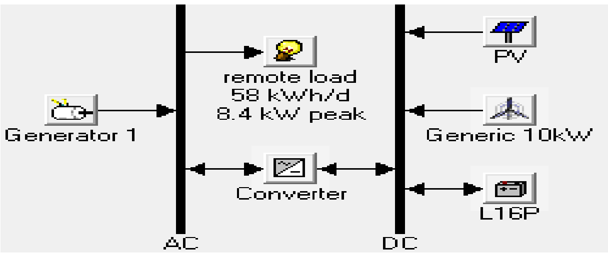


Fig. 3. Proposed system model

Fig. 4 shows the load profile data of the selected site location for a single day, wherein there will be a maximum load of nearly 5kW during the evening hours. The D map shows the monthly average report of the selected site from January to December and also the annual scaled report given at the last.

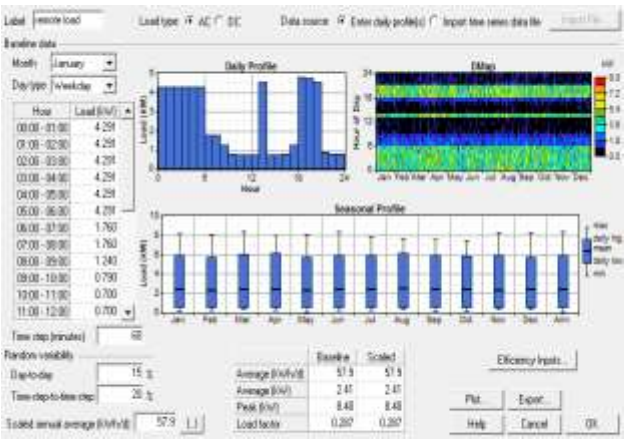


Fig. 4. Monthly load profile data

Availability of solar energy resources

The Monthly average values of the solar and wind speed data related to the case study location is shown in Fig 1. It is observed that the solar radiation of this city reaches its minimum of 4.7 kWh/m^2/day in the month of November and it is having the maximum of 6.6 kWh/m^2/day in the month of February. Also, the average of daily radiation in the whole year is about 5.46 kWh/m^2/day. Fig. 5 shows the solar and wind resources with the clearness index values along with the daily solar radiation, wind speed for the selected study location.

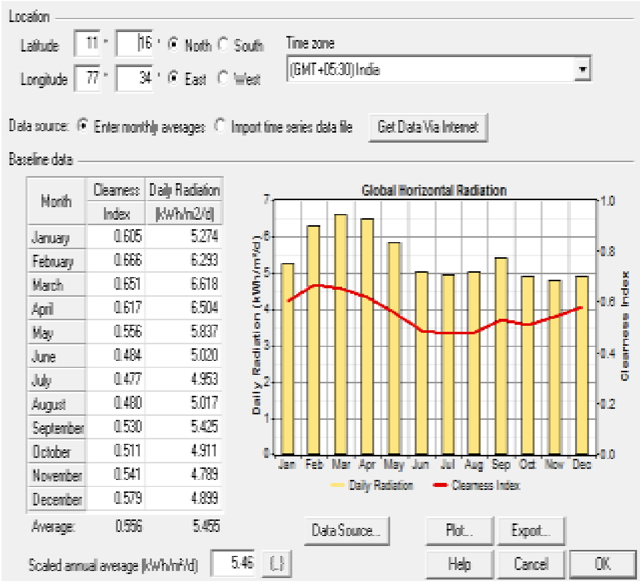


Fig. 5. Average solar radiation data over a year

Availability of wind energy resources

Although the proposed Hybrid Optimization model has the capability to generate the wind data, once if the user defines the four parameters which are Weibull parameter value, autocorrelation factor, diurnal pattern strength and hour of the peak wind speed. The average wind speed is calculated as 2.17 m/s. The availability of wind energy sources is shown in Fig. 6.

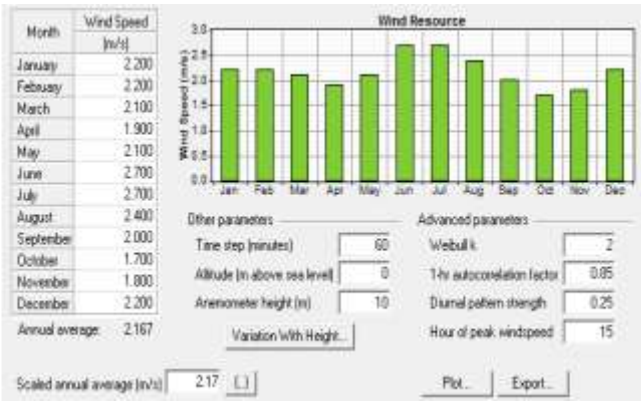


Fig. 6. Average wind speed data at a selected study location

Energy storage devices

Lead acid batteries are included in the proposed model for storing the energy. Super capacitors and hydrogen cells may also be considered for the same purpose. But, the cost of electrolysers in hydrogen cell is very high.

Power electronic converters

A power electronic converter is used to maintain the flow of energy between the AC and DC buses. A suitable converter design is essential in order to convert AC-DC, DC-AC, DC-DC and AC-AC voltages.

Results and discussion

For the single residential load of the selected study area, various combinations are obtained from solar PV, WTG, Fuel cell, PE converter, DG, Battery by using this proposed optimization model as shown in Fig. 7 and 8. When the developed model is simulated, the possible combinations of DG's are listed out and ranked according to their Cost of Energy (CoE) and Net Present Cost (NPC). Sensitivity analysis can also be done by the proposed system model by eliminating the unfeasible model and rank the feasible and economical combinations alone.

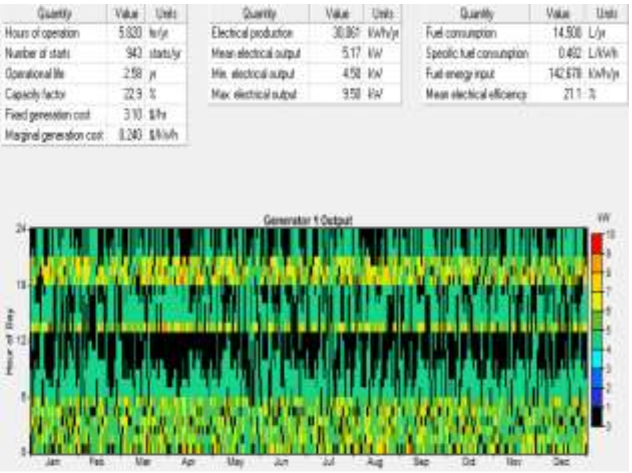
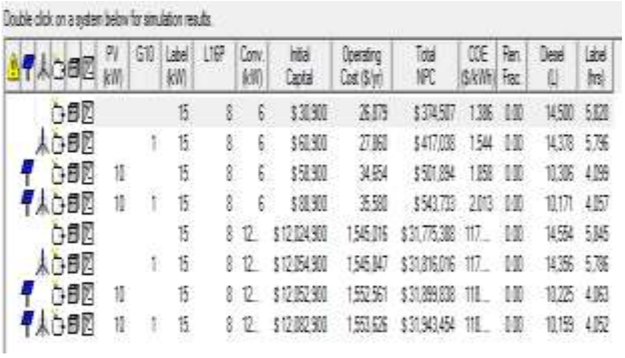


Fig. 7. Annual electricity production of diesel generator



Double click on a system below for simulation results.

	PV (kW)	G10	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
			15	8	6	$ 30,900	26,879	$ 374,507	1.386	0.00	14,500	5,828
		1	15	8	6	$ 60,900	27,860	$ 417,038	1.544	0.00	14,378	5,796
	10		15	8	6	$ 58,900	34,854	$ 501,894	1.858	0.00	10,306	4,099
	10	1	15	8	6	$ 88,900	35,580	$ 543,733	2.013	0.00	10,171	4,057
			15	8	12	$ 12,024,900	1,545,016	$ 31,775,388	117...	0.00	14,564	5,845
		1	15	8	12	$ 12,054,900	1,545,847	$ 31,816,016	117...	0.00	14,356	5,786
	10		15	8	12	$ 12,052,900	1,552,561	$ 31,899,838	118...	0.00	10,225	4,063
	10	1	15	8	12	$ 12,082,900	1,553,526	$ 31,943,454	118...	0.00	10,159	4,052

Fig. 8. Optimization results

The most economic system in each category is chosen and can be used based on their ranking order. From the simulation results, it is observed that there are 8 feasible combinations based on their NPC and CoE values. From the simulation results, it is observed that the most feasible and economic solution with a minimum Net Present Cost of about $374,507 and the Cost of energy is about $1.386/kWh can be obtained by running the diesel generator.

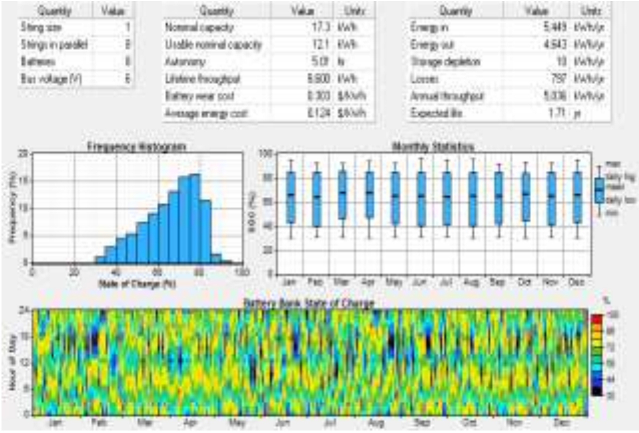


Fig. 9. State of charge of battery

From Fig. 9, it is found that the wind + diesel is the economically viable system next to the diesel generator of 15 kW independently, with the net present cost of $417,038 and a COE of $1.544/kWh. From the discussion, it was inferred that for the load demand of 4300 W, the economically feasible and technically viable solution is found to supply the load either by the stand alone diesel generator or the mix of wind + diesel generator, whose rectifier outputs and cash flow summary are shown in Fig. 10 and 11.

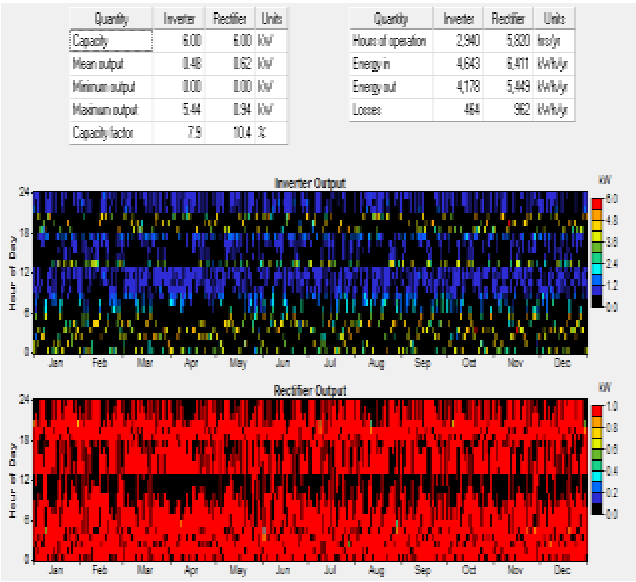
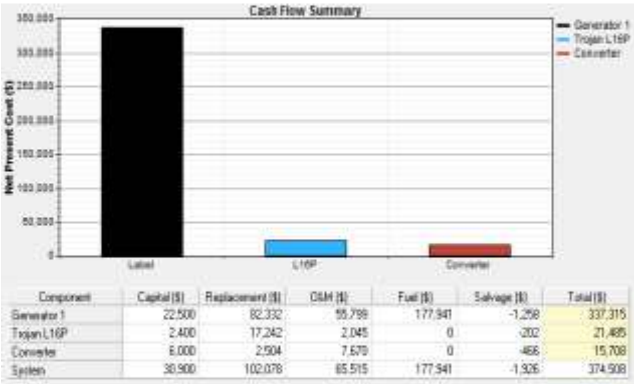


Fig. 10. Rectifier and inverter outputs



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generator 1	22,500	82,332	55,799	177,941	-1,258	337,315
Trojan L16P	2,400	17,242	2,045	0	-202	21,485
Converter	6,000	2,504	7,670	0	-466	15,708
System	30,900	102,078	65,515	177,941	-1,926	374,508

Fig. 11. Cash flow summary

Conclusion

An optimization model consisting of solar, wind, battery and a conventional diesel generator has been developed and simulated for the selected study area. The model developed has been found to be very useful for the Rural Electrification of Perundurai in Erode District, as it offers a 'n' number of possible combinations for the study area. This proposed model optimizes the different renewable energy systems based on their net present cost, renewable fraction, cost of energy, fuel emissions, etc. In this work, a diesel generator has been considered in order to keep the constant output in spite of the fluctuating power outputs from solar and wind energy resources. Simulation results present the economic analysis of the integrated renewable energy systems for the selected study area. It implies that the IRES based system has the advantages of long term availability and flexibility.

Conflicts of interest

Authors declare no conflict of interest.

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