Optimization of Cost of Energy of Real Time Renewable Energy System Feeding Commercial Load Case Study: A Textile Show Room in Coimbatore, India

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Abstract: Unsteadiness of electricity supply in India is an increasing problem, especially in the capital and other larger cities. Commercial users such as shopping malls, textile show rooms and hotels are looking for alternative solutions in order to deliver adequate standards to their customers. In this study we investigate and optimize combined Hybrid Photovoltaic – Wind System as a main electricity source for a textile show room. There is significant potential for the use of the photovoltaic solar energy in India which receives plentiful amount of solar radiation around the year; the current work aims to investigate the cost of energy of Real time Hybrid rooftop Photovoltaic - Wind energy system to produce 5 kWh/yr (2.22kW in solar and 2.7kW in wind) system of electricity for the textile show room in Coimbatore, India. The aim of this study is to find Cost of Energy (COE) and functional combinations between Photovoltaic and Wind turbine systems based on actual electricity consumption data of the textile show room with Hybrid Optimization Model for Electric Renewable (HOMER) developed by National Renewable Energy Laboratory.
[Balachander. K, Vijayakumar Ponnusamy. **Optimization of Cost of Energy of Real Time Renewable Energy System Feeding Commercial Load.** *Life Sci J* 2013;10(7s):839-847] (ISSN:1097-8135). http://www.lifesciencesite.com. 135

Keywords: homer; optimization; cost of energy; renewable energy system; net present cost

1. Introduction

Since time immemorial, people have been using conventional sources of energy for various purposes which ultimately cater to their energy needs and requirements. Little do they realize that the use of such resources not only limits the stock available for future generation but also cause serious environmental threats to the world in general. The cheap availability of these resources keeps their demand at an all time high. If this trend continues in future, we might have to face serious energy shortages because once gone, these resources cannot be renewed and otherwise would take millions of years to form again. The energy shortage would spiral up the fuel costs in future and the very characteristic of fossil fuels (Cheap, reasonable) would be violated.

Recent studies underscore that current global trends in energy supply and consumption are patently unsustainable – environmentally, economically and socially. It also went on to add that the situation can be changed if the supply of reliable and affordable energy is secured and a rapid transformation is made to a low-carbon, efficient and environmentally benign system of energy supply.

An analysis of the demand for the new renewable energy technologies, viz., solar photovoltaic, wind and biomass indicates a clear shift in global preference towards these technologies as sources of energy, especially in generation of electric power. Renewable technologies are likely to dominate global power plant construction in the decade from 2010 to 2020, exceeding the total for coal, oil, natural gas, and nuclear power combined. The continued rapid growth, primarily of renewable energy technology, despite the financial crisis and economic downturn, is a testament to the inherent attractiveness of the technology.

Most of the countries have been focusing on renewable energy systems as they resolve issues like continuous increase in crude oil price, deficit of crude oil, emission of CO_2, etc. In India, renewable energy sources (solar, wind) play the vital role in bridging the gap between energy supply and demand to the possible extent. Standalone PV system has increased more interests amongst researchers due to increasingly viable and cost-effective candidates for providing electricity to remote areas.

Wide studies have been done to evaluate the competitiveness of renewable energy system as alternatives. In literature, several papers have studied the design and planning of hybrid renewable energy system. The aim of this paper is to present optimum planning of real time hybrid PV and wind renewable system with battery backup and find out the cost of energy of an installed system based on resources and economics. The energy generating components data and load data are taken in a textile show room in Coimbatore, India. A detailed design, description, expected performance and cost of energy of the system are presented in this paper [15] [16] [17].

2. Study Location

The site of the integrated renewable electric system is located in a textile show room in Coimbatore, India (Latitude 11° 59' N, Longitude 76° 00' E, 411meter above Sea level).

3. Energy Generation System Components

The 2.2 kW solar photovoltaic panel (185W_p x 12 Nos.) and Alpha power 2.7kW wind turbine are installed on the roof top of the textile show room located at Coimbatore. These units serve as a backup power supply to the administrative office, canteen and staff room of a textile show room shown in Figure.1, 2, 3 and 4 respectively

Fig. 1. Photovoltaic Panel

Fig. 2. Alpha Wind Turbine System

Fig. 3. SOLIVIA 5.0 Solar Inverter

Fig. 4. Wind Mill Charge Controller

3.1 Technical Specification

The following components are installed in standalone PV-Wind hybrid power system in a textile show room located at Coimbatore. The below tables are shows a technical parameters of the components used for the Hybrid System.

Table 1. Photovoltaic module

Parameters	Unit	Specification
Nominal Power at STC (P_{max})	W	185
Power tolerance at STC (Min/Max)	%	±3
Voltage at P_{max} (V_{mp})	V	28.7
Current at P_{max} (I_{mp})	A	6.9
Open Circuit Voltage (V_{oc})	V	36.25
Short Circuit Current (I_{sc})	A	7.7
Maximum System Voltage (IEC/UL)	V_{dc}	1000/600
Operating Temperature	°C	-45 to +85
Temperature Co-efficient of P_{max}	%/K	-0.43
Temperature Co-efficient of V_{oc}	%/K	-0.344
Temperature Co-efficient of I_{sc}	%/K	0.11
Protection Level		IP65
Maximum Series fuse	A	6
Cell type	mm	Multi Crystalline
Cell Size	Inch	60 (10 x6)
Module Size	mm	1661(L) x 991 (W) x 40(T)
Weight	Kgs.	19.5
Maximum Static Load front and Back	P_a	2400

Table 2. Wind Turbine System

Parameters	Unit	Specification
Model - Alpha Power 2.7 with Charge Controller		
Capacity and Rated Power	kW	2.7
Rotor Diameter	M	4.5
Swept Area	Sqm/Sqft	3
Blade Material		Epaxy Resin PES Laminated
Number of Blades	Nos.	3
Generator		3Phase Alternator
Rated Wind	M/s	6.5
Peak Power at 12.00M/s	W	3000
Cut-in Wind	M/s	3
Tower Tip Weight	Kgs.	45
Lateral Thrust	Nm	950
Governor		Angular
Survival Wind Speed	M/s	61
Height	feet	30

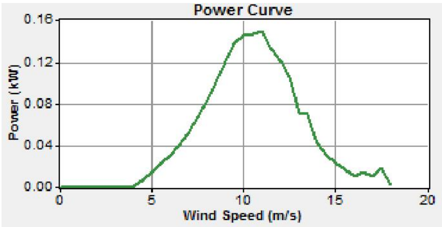

Fig. 5. Power Curve of an ALPHA Wind Turbine System

Table 3. Solar Inverter

Parameters	Unit	Specification
Model - SOLIVIA 5.0		
Input – DC		
P_v power (W_p)	W	6000
Nominal power	W	5500
voltage range	V	125…….540
MPP Range	V	150…….450
Full power MPP range	V	150……450
Nominal Current	A	17.2
Standby Power	W	<0.2
Output – AC		
Maximum Power	W	5240
Nominal Power	W	5000
Nominal Voltage	V	230
Voltage Range	V	210…..264
Nominal Current	A	22
Nominal Frequency	Hz	50
Frequency Range	Hz	48……..52
PF		>0.99 at Nominal Power
Total Harmonic Distortion		<4% Nominal Power
Operating temperature	°C	-25……….+60
Storage temperature	°C	-25……….+80
humidity	%	0……….98

Table 4. Exide Battery

Parameters	Unit	Specification
Model – Exide IT Tubular 12V/150AH		
String size	Nos.	1
Strings in parallel	Nos.	6
Batteries	Nos.	6
Bus voltage	Volts	12
Nominal capacity	kWh	10.8
Usable nominal capacity	kWh	6.48
Autonomy	hr	31.1
Lifetime throughput	kWh	190383
Battery wear cost	Rs./kWh	0.008
Average energy cost	Rs./kWh	0
Energy in	kWh/yr	943
Energy out	kWh/yr	757
Storage depletion	kWh/yr	0
Losses	kWh/yr	186
Annual throughput	kWh/yr	846

The Photovoltaic module uses high efficiency Poly Crystalline Silicon Solar cells having high transmitivity, Low iron content, tempered and toughened glass. The modules are fitted with IEC & UL approves IP65 rated terminals. The detailed technical data of a Photovoltaic module is shown in Table 1. Table 2, 3 and 4 shows the technical specifications of an energy generation components. Figure 5. Shows the Power curve of the wind turbine system.

4. Energy Generation Resources

The availability of renewable energy resources at study location is an important factor to generate the power for hybrid system. Many parts of the India solar and wind source are profusely available. Coimbatore is sanctified with renewable energy sources which can be effectively utilized for power generation. The sources which are used for power generation are given below.

4.1 Solar Resources

Hourly solar irradiation data and Clearness Index data for the year was collected from Energy environment web site (Table 5). The clearness index is a dimensionless number between 0 and 1 indicating the fraction of the solar radiation striking the top of the atmosphere that makes it through the atmosphere to strike the Earth's surface. The daily solar radiation in Coimbatore varies 3.71kWh/m^2 and 6.39 kWh/m^2. And Scaling of daily radiation is 4.97 kWh/m^2/d is shown in Figure. 6.

Table 5. Solar Data

Month	Clearness Index	Daily Radiation (kWh/m2/d)
Jan	0.633	5.46
Feb	0.634	5.94
Mar	0.63	6.39
Apr	0.562	5.93
May	0.508	5.35
Jun	0.371	3.87
Jul	0.355	3.71
Aug	0.389	4.08
Sep	0.473	4.83
Oct	0.475	4.54
Nov	0.531	4.65
Dec	0.597	4.99
Average	0.508	4.972
Scaled Annual Average (kWh/m^2/d)	4.97	

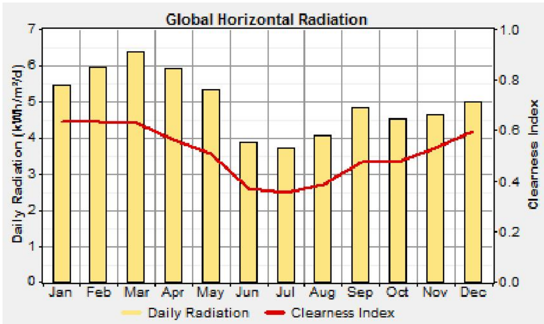

Fig. 6. Global Solar Radiation

4.2 Wind Resources

A monthly wind speed data were taken from synergy India website. The average wind speed is 3.935m/s and scaled annual average wind speed is 3m/s (Figure.7). This is an average of last ten years shown in Table 6.

Table 6. Wind Speed Data

Month	Wind Speed (m/s)
Jan	3.65
Feb	3.15
Mar	3.29
Apr	3.23
May	3.81
Jun	5.52
Jul	5.31
Aug	5.02
Sep	3.9
Oct	3
Nov	3.21
Dec	4.06
Average(m/s)	3.935
Scaled annual Average (m/s)	3

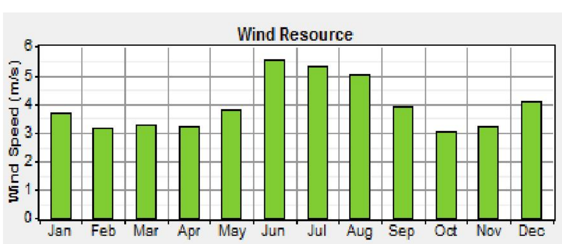

Fig. 7. Wind Resource

5. Load Profile

The load profile was taken in a leading textile showroom administrative office, canteen and staff room for a week and average hourly load profile was used in this study. A small base load of 1.225kw occurs throughout the day and night. A peak load of 4.725kW occurs in office hours 9.00AM to 5.00PM (Table 7). The load includes fluorescent tube, CFL, fan, CCTV and TFT monitor computer. The daily demand is approximate 5kWh/day and 551W peak show in fig. 8.

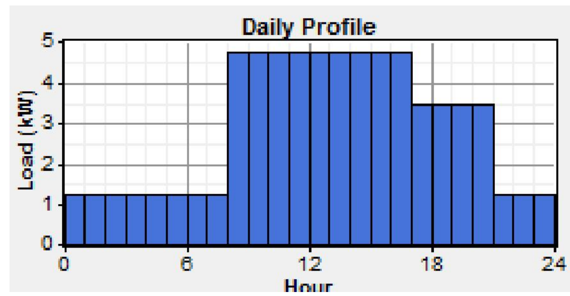

Fig. 8. Daily Load Demand

6. Cost Components

HOMER performs comparative economic analyses on a generation power system. The costs objective function is the Total Net Present Cost of the system, which includes the costs of the investments plus the discounted present values of all future costs throughout the total life of the installation. We assume that the life of the system is the life of the PV panels which are the elements that have a longer lifetime. In what follows the costs that have been considered are indicated. A detailed description of its calculation can be found in [6].

- Cost for purchasing the PV panels, the wind turbine, the batteries, the inverter, the charge regulator and the Diesel generator.
- Costs of replacing the battery charger throughout the life of the system.
- Costs of maintenance of the PV panels, the wind turbine and the batteries.
- Costs of replacing the batteries, the inverter, the wind turbine, the charge regulator and the Diesel generator throughout the life of the system.
- Costs of operation and maintenance of the Diesel generator throughout the life of the system.

Table 7. Show Room Load Demand

Time	Tube light (25W)	Tube light (40W)	CFL (5W)	CFL (18W)	Fan (100W)	Computer-TFT (200W)	CCTV (400W)	Load Average (W)
12			25				1200	1.225
1			25				1200	1.225
2			25				1200	1.225
3			25				1200	1.225
4			25				1200	1.225
5			25				1200	1.225
6			25				1200	1.225
7			25				1200	1.225
8			25				1200	1.225
9	1250	1000	25	450	500	300	1200	4.725
10	1250	1000	25	450	500	300	1200	4.725
11	1250	1000	25	450	500	300	1200	4.725
12	1250	1000	25	450	500	300	1200	4.725
1	1250	1000	25	450	500	300	1200	4.725
2	1250	1000	25	450	500	300	1200	4.725
3	1250	1000	25	450	500	300	1200	4.725
4	1250	1000	25	450	500	300	1200	4.725
5	1250	1000	25	450	500	300	1200	4.725
6		1000	25	450	500	300	1200	3.475
7		1000	25	450	500	300	1200	3.475
8		1000	25	450	500	300	1200	3.475
9		1000	25	450	500	300	1200	3.475
10			25				1200	1.225
11			25				1200	1.225

Some of the costs depend of the control strategy [6] selected amongst those possible. The proposed plan life time is considered to be 25 years with an annual interest rate of 8%. Individual cost of installed system components are shown in Table 8.

Table 8. Cost Review

Components	Rating	Quantity (Nos.)	Cost (INR*)
PV Panel	185W	12	350000
Wind turbine (Alpha2.7)	2.7kW	1	195000
Battery (Exide iT)	12V/150Ah	8	88000
Converter (Solivia 5.0)	96V/5VA	1	37500

*INR- Indian Rupee, 1$= 50 Rs. or INR

7. Research Methodology

A Photovoltaic-Wind hybrid system is the very best combination of renewable electric system and suitable of environmental changes. The installed hybrid renewable energy system includes PV panels, Wind turbine system, Battery and Inverter. These energy generation components are modeled using by HOMER simulation model for study purpose. The most important functions of HOMER are finding the lowest cost combination of components used in the generating system that meet electrical and thermal load, simulation of thousands of possible system combinations and optimization of the lifecycle cost and a sensitive analysis on most inputs.

HOMER simulates the operation of the system by making energy calculations for each of the 8,760 hours in the year. This model software compares the load demand in the hour to the energy that the system can supply in that hour and also decides for each hour how to operate the generators and whether to charge or discharge the batteries [4]. HOMER software is primarily an economic model. It can be used to compare different combinations of component sizes and quantities and explores how variation in resource availability and system cost in installing and operating different system design [4].

A case study has been analyzed in Coimbatore, India. By considering two power sources such as 2.22kW Photovoltaic, 2.7kW Wind turbine system, solar inverter and battery storage. Figure. 9 show the HOMER schematic diagram of the hybrid renewable electric system showing all components.

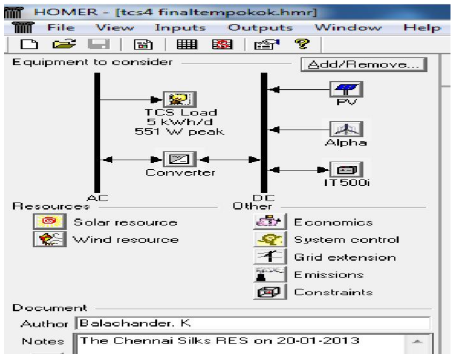

Fig. 9. HOMER Model

The software requires initial information such as energy resources, economical and technical constraints, energy storage requirements and system control inputs. Inputs like component type, capital, replacement, operation and maintenance costs, efficiency, life time, output current, slope for Photovoltaic arrays, hub height for wind turbine system, batteries per string, operational life, etc [5]. The absolute optimized system design is decided after performing the optimization process. In order to arrive at optimal number of system components, HOMER allows multiple values to be entered. These user supplied values are then shown in a table depicting called search space shown in Table 9. Sensitivity analysis of the HOMER is shown in the overall winner which shows that the most least cost and optimize hybrid system.

Table 9. Search Space

PV Array (kW)	ALP (Qty)	IT500i (Qty)	Converter (kW)
1	1	6	1
2		12	2
3		18	3
4		24	4
5		32	
6		40	
7			

8. Results and Discussion

A case study has been analyzed in Coimbatore, India and options for providing power to part of the textile show room. The analysis of this system considers three sensitive variables such as solar irradiation, wind speed and battery cost. For each of the sensitive values simulate all the system in their respective. An optimal system is defined as a solution for hybrid system configuration that is capable of meeting the load demand of the textile showroom staff room and administrative room.

8.1 Optimization Results

The optimization results of hybrid renewable energy system using HOMER are shown in Table 10. To calculate the NPC of the system to simulate it throughout its life time, obtaining the energy produced and consumed by the components, their own life time, the number of times in which the components must replaced, the operating and maintenance cost, fuel cost, etc. After simulating all of the possible system configurations, HOMER displays a list of configurations, sorted by net present cost, which we can use to compare system design options. HOMER recommended optimal combination is PV system, battery with converter produce 3355kWh by Photovoltaic panels (i.e. 100%) and, 0% by wind turbine system. The lowest total net present cost (NPC) at 8, 54,100 INR and cost of the energy of 43.85 INR per kWh.

Another second option given by HOMER is PHOTOVOLTAIC wind turbine system, converter with battery bank have total NPC at 11, 11,950 INR and cost of the energy of 57.65 INR per kWh. The energy produced by this combination is 3441kWh/Yr out of this total 98% meet by Photovoltaic arrays and 2% by wind (i.e. 86 kWh/Yr). Table 11 shows the total annualized cost of the system for both options.

8.2 Simulation Results

The simulation results for hybrid systems are presented below. Table 12 shows the optimum hybrid system components consisting of PV modules, Battery and Converter to meet the load demand. The cost of energy for purposed hybrid renewable energy system found to be is 43.85 INR. The annual electric energy production and annual electric energy consumption is tabulated in Table 13. Monthly energy production, PV Array output and PV Array performance illustrations are shown in Figure 10 and 11. From the simulation results standalone PV system is feasible option concern with energy production.

Table 10. HOMER Optimal Solution

Photovoltaic (kW)	ALP (Nos.)	IT 500i	Converter (kW)	Initial Capital (INR)	Operating Cost (INR/Year)	Total NPC (INR)	COE (INR/kWh)
2		6	1	8,03,600	4,750	8,54,100	43.85
2	1	6	1	9,98,500	11,650	11,22,950	57.65

Table 11. Total Annualized Cost of the System

Option 1					
Component	Capital Cost (INR)	Replacement Cost (INR)	O & M Cost (INR)	Fuel Cost (INR)	Total Cost (INR)
PV	700,000	0	0	0	700,000
Exide	66,000	36,600	12,800	0	115,400
Converter	37,500	11,800	0	0	49,300
System	803,500	48,450	12,800	0	864,750
Option 2					
Component	Capital (INR)	Replacement (INR)	O & M (INR)	Fuel (INR)	Total (INR)
PV	700,000	0	0	0	700,000
Alpha	195,000	41,850	53,350	0	290,200
Exide	66,000	36,600	12,800	0	115,400
Converter	37,500	11,800	0	0	49,300
System	998,500	90,300	66,200	0	1,155,000

Table 12. Optimal System Components

Component	Rating	Quantity
PV	2kW	1
Exide	12V/150Ah	6
Converter	1kW	1

Table 13. Simulation Results - Electrical

Production	
PV Array (kWh/year)	3,355
Total	3,355
%	100
Consumption	
AC Primary Load (kWh/yr)	1,825
Total	1,825
%	100
Excess electricity (kWh/yr)	1,141
Unmet electric load (kWh/yr)	0.00000194
Capacity shortage (kWh/yr)	0
Renewable fraction	1

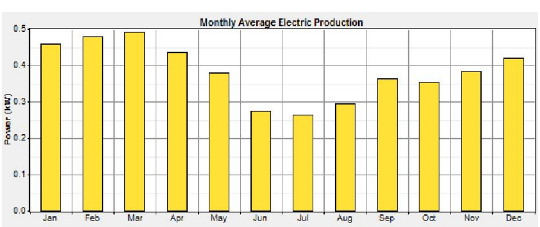

Fig. 10. Monthly Energy Production

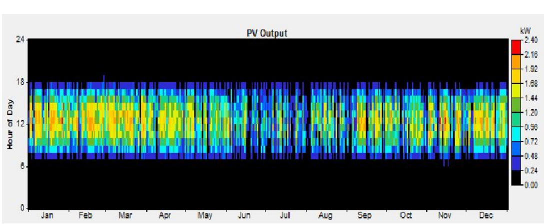

Fig. 11. PV Array Output

9. Conclusion

Renewable energy based systems can play indispensable role in bringing sustainable energy. In this real time study, an optimization and simulation of a Hybrid PV/Wind turbine system in a textile showroom has been presented. This study reveals that standalone Photovoltaic - Inverter with Battery is feasible for this load demand. The results are shown in Table 12 and Simulation results are shown in Table 13. But they installed 5 kW system (2.22kW in solar and 2.7kW in wind) which produces excess electricity of 1,141kWh/Yr with renewable fraction 1. It may be supplied to the grid or consumed by the user whenever the load demand rises. Even though the initial investment is quite high, it produces energy at least cost. The proposed system is suitable for the part of textile showroom load (5kWH/Day, 551W peak) located at Coimbatore, India and the cost of energy is 43.85INR/kWh.

Acknowledgement

The authors are thankful to The Chennai Silks, Coimbatore, India for allowing to visit the site and Load demand for this case study.

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6/14/2013