International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 8, Number 2 (2015), pp. 145-159

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Simulation & Optimization of Solar-Wind Hybrid System for Remote Areas Using HOMER

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Abstract

This Paper presents a methodology to perform the optimal sizing of an autonomous hybrid PV/wind system with battery backup. The methodology aims at finding the configuration, among a set of systems components, which meets the desired system reliability requirements, with the lowest value of levelized cost of energy (LCE). This paper proposes the most feasible hybrid system configuration for a strategic remote village Umrikheda in Madhya Pradesh. The location is called strategic because of its location in the duct formed by two hill tops due to which wind speed is 40 percent more than the actual wind speed due to Bernoulli's effect. Actual survey of cooking and lighting load of the area has been done and based on the load requirements the hybrid system has been proposed by using HOMER on the basis of availability of solar and wind energy. This hybrid system is more beneficial to provide the electricity for the identified un-electrified remote area and economical for rural population .The study has been carried for hybrid system connected to grid (on-grid) and standalone (off-grid).

Keywords: HOMER, RGGVY, NREL, Photovoltaic, Bernoulli's effect

1. Introduction

The non-conventional sources are available free of cost and because of its pollution-free and inexhaustible nature mankind has used these sources from many centuries in propelling ships, driving windmills, pumping water, etc. Because of the poor technology then existing, the cost of harnessing energy from these sources was quite high and also because of uncertainty of period of availability and the difficulty of transporting this form of energy, to the place of its use were some of the factors which came in the way of its adoption or development [15]. India is a developing country, there are total 6, 38,596 villages in India, of which 5, 93,732 villages are inhabited and number of un-electrified villages in India is 12,468 [33]. India has achieved 44% electrification to rural households only [32]. In India rural area receives only 5-10% of electricity to meet their demand therefore most of villagers are using traditional sources of energy for lighting and cooking for fulfill the daily needs [28]. Indian populations are increasing day by day and so is their energy needs. Energy prices, supply un certainties, and environmental concerns are driving the India to rethink its energy mix and develop diverse sources of clean, renewable energy.

The nation is working towards generating more energy from domestic resources and renewable sources to fulfill the nation requirement for energy that can be cost-effective and replaced or renewed without contributing to climate change or major adverse environmental impacts. Using hybrid renewable energy (solar-wind combination) is one of the best alternatives to supply the electrical energy at remote areas [28].

2. Identified Areas Description

The Indian government is implementing a programme for providing financial support for electrification of those remote un-electrified census villages and un-electrified hamlets of electrified census villages where grid-extension is either not feasible or not cost effective and is not covered under Rajiv Gandhi Grameen Vidyutikaran Yojana. Such villages are provided basics facilities for electricity/lighting through various renewable energy sources [21] [29].

In India most of the population lives in villages and they are isolated from main city. In which some villages suffers scarcity of electricity supply therefore they use the different sources of energy. The survey of lighting fuel and cooking fuel usage of some villages have been conducted to assess the requirement of load.

A. Selection of site

The selection of study site is on the basis of survey of different families using different sources of energy for cooking & lighting used by the villagers which is shown in below table 1& table 2.

Table: 1 Survey of Cooking Fuel Used Area wise

Cooking Fuel	Cowdung	Wood	Charcoal	LPG	Kerosene	Electricity	Bio gas	Solar	Total
Umrikheda	63	60	1	80	58	9	12	0	146
9th Mile	56	41	0	52	37	0	3	0	189
Datoda	68	68	0	57	32	2	4	0	231
Arsawad	59	59	2	38	54	0	36	0	248
Badikima	65	66	17	49	50	0	51	0	298
Shiv Nagar	30	27	0	30	23	0	1	0	111
Malikhedi	100	100	8	79	76	61	67	32	523

Table: 2 Survey of Lighting Fuel Used Area wise

Lighting Fuel	Candle	Battery	Lantern	Kerosene	Electricity	Generator	Solar	Biogas	Total
Umrikheda	42	23	77	64	24	2	0	0	232
9th Mile	30	3	33	43	56	0	0	31	196
Datoda	31	0	56	59	22	9	0	0	174
Arsawad	55	25	29	60	67	7	8	6	257
Badikima	57	20	65	62	61	4	0	0	269
Shiv Nagar	20	3	29	11	30	1	0	5	99
Malikhedi	90	35	92	101	105	0	0	2	423

On the basis of above survey data, we selected the village Umrikheda as a study area because this location is between two hill tops (as shown in satellite view below) and during the condition of less wind speed, as the location is in the duct formed by the two hill tops and due to Bernoulli effect the speed of wind in the identified location increases by 40 percent. The population of study area village Umrikheda is 500. The geographical location of study area village Umrikheda is 553 meters above the sea level with Latitude 22°43" North, Longitude 75°49" East and time zone GMT+5:30 Indian Time producing an average daily radiation of 5.43 kWh/m²/d, and average wind speed 2.998 m/sec.

Fig.1 A Satellite view of study area village Umrikheda (M.P.) India

Here actual wind speed is Poor but good solar radiation due to this situation the solar-wind hybrid system is connected to grid for economic point of view [11].

B. Load Estimation

The study area village Umrikheda is isolated from main city and availability of electricity is only for 8 hours.The villagers many time suffer from scarcity of electricity supply for their daily needs.The primary load for study area village Umrikheda is selected to be residential with some load for stores, and school. There is no industrial or commercial load demand in the selected location.

The load is composed of the household devices such as lights, fans, radios, TVs and computers. Survey of 100 houses, plus 2 stores and 1 school is done for the proposed work. It is assumed that the houses are divided into three categories i.e. small, medium and large houses. The estimated energy consumed by each of the categories is shown in Table 3. The table 3 shows the estimation of each appliance's rated power, its quantity and the hours used by each houses, stores and school in a single day [22][20].

Table 3 Load Type and Estimation

Houses Category	*Load Type*	*Rated Power (Watts)*	*Quantity*	*Hours*	*Energy Wh/day*	*Total Energy KWh/day*
67 Small Houses	*Light*	*10*	*67*	*5*	*3350*	***11.12***
	Radio	*15*	*17*	*4*	*1020*	
	Fan	*75*	*15*	*6*	*6750*	
24 Medium Houses	*Light*	*20*	*24*	*5*	*2400*	***30***
	Radio	*15*	*20*	*6*	*1800*	
	Fan	*75*	*24*	*6*	*10800*	
	TV	*200*	*15*	*5*	*15000*	
9 Large Houses	*Light*	*30*	*9*	*5*	*1350*	***15.71***
	Radio	*15*	*7*	*6*	*630*	
	Fan	*75*	*9*	*7*	*4725*	
	TV	*200*	*9*	*5*	*9000*	
2 Stores	*Light*	*20*	*2*	*12*	*480*	***3***
	Light	*15*	*2*	*5*	*150*	
	Radio	*15*	*2*	*4*	*120*	
	Fan	*75*	*2*	*7*	*1050*	
	TV	*200*	*2*	*3*	*1200*	
1 School	*Light*	*15*	*2*	*11*	*330*	***2.13***
	Computer	*100*	*1*	*3*	*300*	
	Fan	*75*	*5*	*4*	*1500*	
			Total Load (KWh/Day)			***61.96***

The total daily electric load of the village (EL) = 61.96 $kW\text{h}/day$

The designed load of solar-wind hybrid system must be higher than the total electrical load of the study area because at the time of operation load fluctuations and power losses are occurs in the hybrid system [19][20].

The designed load for the hybrid system (ED) = 1.5 $*$ EL

The estimated hourly load of the study area village Umrikheda during whole year, based on the information given in above table 3, are given by fig. 2 below.

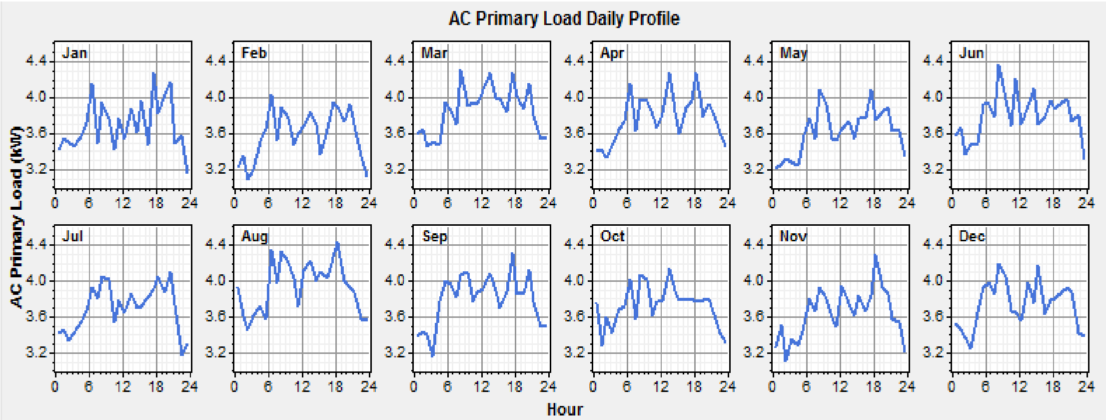

Fig. 2 ***Approximate average load demand for 24 hours during whole year (Jan.-Dec.)***

Source: The load data of study area is provided by MPSEB Head office Polo ground, Indore

The total estimated peak load is not actual peak load that will calculated by the system, because all the loads connected for a certain time period might not be switched on at the same time. The above hourly load profile for the whole year is created by the HOMER on hourly estimated load for different months [2].

3. Assessment of available renewable resources

A. Wind Power

Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface. Seasonal variations in the energy received from the sun affect the strength and direction of the wind. The wind turbine captures the winds kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture [3].

The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time [7]. That is

$$P_{air} = \frac{1}{2}(\text{Air mass per unit time})(\text{Wind velocity})^2$$

$$= \frac{1}{2}(\rho A V_{wind})(V_{wind})^2$$

$$= \frac{1}{2}\rho A V_{wind}^3 \qquad \text{eq. --> 1}$$

Where *Pair* is the power contained in wind (in watts) , ρ is the air density (1.225 kg/m3 at 15°C and normal pressure), A is the swept area in (square meter), and V_{wind} is the wind velocity without rotor interference, i.e., ideally at infinite distance from the rotor (in meter per second) [16].

Although eq.1 gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient, Cp

$$C_p = \frac{P_{windturbine}}{P_{air}}$$

$$P_{windturbine} = C_p \times P_{air} = \frac{1}{2} C_p \rho A V_{wind}^3$$

A maximum value of Cp is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum Cp values in the range 25-45% [8] [12].

B. **Solar Power**

The solar modules (photovoltaic cell) generate DC electricity whenever sunlight falls in solar cells. The solar modules should be tilted at an optimum angle for that particular location, face due south, and should not be shaded at any time of the day [14]. Data of solar –wind provides by synergy Environ professional services company for every province in India [23]. Table 2 shows the average solar radiation and wind speed data for selected study site.

Relation between the current and voltage may be determined from the diode characteristics equation [9]:

$$I_{ph} = I_{pv} - I_s(e^{qv/kT_c} - 1) = I_{pv} - I_d \qquad \text{eq.->2}$$

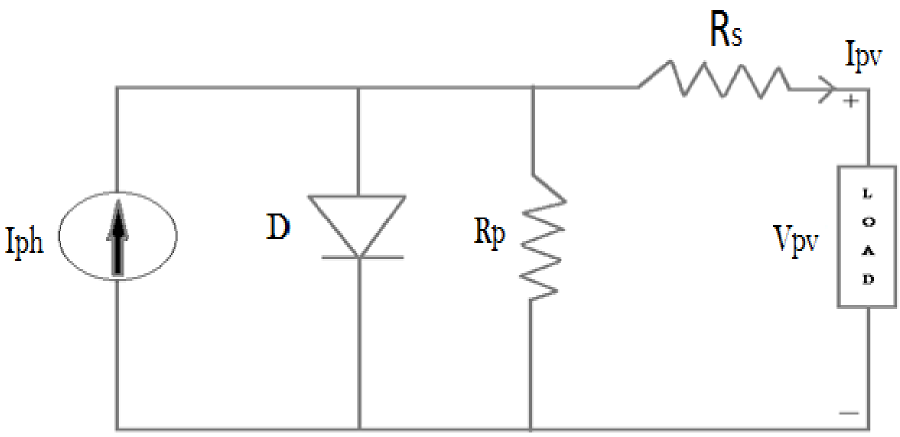

Fig. 3 Equivalent circuit of a solar cell

Where q is the electron charge, k is the Boltzmann constant, I_{pv} is the photocurrent, I_s is the reverse saturation current, I_d is the diode current and T_c is the solar cell operating temperature [16] [18].

Table 4 Average Monthly Solar-Wind data

Month	Average isolation KWh/m²/day)	Wind (m/s) Wind Speed (m/s) Speed (m/s) after Bernoulli effect
January	4.18	2.57 3.59
February	5.65	2.89 4.04
March	6.35	2.86 4.00
April	6.99	3.38 4.73
May	7.2	4.11 5.75
June	6.08	4.3 6.02
July	4.77	3.06 4.28
August	4.12	3.27 4.57
September	5.19	4.3 6.02
October	5.79	3.06 4.28
November	4.7	3.27 4.57
December	4.21	2.36 3.30

It is obvious that the site has good solar resource and whereas the wind resource is poor, therefore for uninterrupted power supply. We design a solar-wind grid connected hybrid system on economical and power supply point of view [5].

4. Unit Sizing and Optimization

HOMER software make solar-wind hybrid model on the basis of input data as electric load, solar data, wind data, converter data and battery data as model shown in fig.4 below.

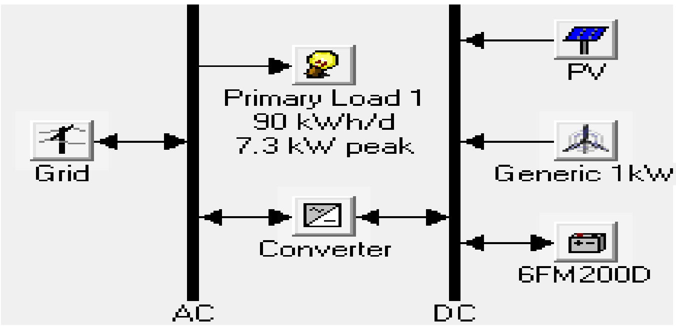

Fig.4 On-grid solar-wind hybrid model

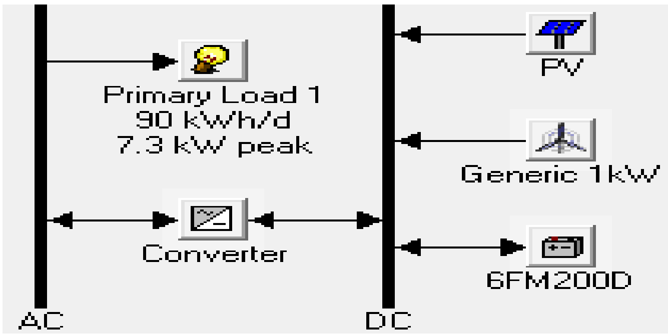

Fig.5 Off- grid solar-wind hybrid model

The Hybrid Optimization Model for Electric Renewable (HOMER) is a micro power optimization software developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA, which can useful for evaluating designs by simplifying the given task for both off-grid and grid-connected power systems for plenty of applications. It also provides the cost benefit analysis for hybrid energy system. In designing any power system, the decisions about the configuration of this system needs to be analyzed, like components and its specification for the system design, size of that all components, the availability of energy resources and technological options, and the cost of each available technology, all these information are difficult to achieve HOMER simulates the different combinations of these power sources and provides the optimal combination [17].

The HOMER simulation output includes the capital cost, net present cost, and energy per KWh. The characteristics of each source and component are explained in the following sections [30].

Table 5 Equipments Cost & Ratings

S.No	Equipment	Rating	Cost in Dollar	Cost in Rupees
1	Solar panel	1 KW	2200	132000
2	Wind turbine	1 KW	1700	102000
3	Converter	1 KW	208	12500
4	Battery	112V, 200 Ah	166	10000

(A)Battery Storage

Battery storage is considered in the system so that when the load demand is less than the available renewable energy, the excess energy can be stored in batteries. Batteries will supply stored energy when the load demand increases in the system. However, HOMER will analyze the system with different combinations and provide the optimal solution. The 6FM200D battery type is selected which has nominal voltage of 12 V and nominal capacity 200 Ah (917 kWh). The capital, replacement and operation and maintenance costs associated with each battery are $166, $150 and $25/year respectively [21] [4].

(B)Photovoltaic system

PV arrays costs vary based on their technology. In general, a PV costs $1.60/W. The capital costs of a PV system include: the PV array cost and other costs such as labor, installation and structure costs. Different PV array costs were investigated and finally a 1kW PV array cost was assumed to be $1600 [23]. Civil work also contributes a significant portion of the capital cost and it is assumed to be $600/kW. The replacement cost is almost equivalent to the capital cost. [15] Operating and maintenance costs are not high for a PV system; we assume $5/kW per year. The system is designed with no tracking and a range of sizes is considered from 0 to 100 kW. HOMER will simulate the system within the given range and will give the output with the optimal size of PV [25] [27].

(C)Wind Turbine

Wind turbine cost varies based on the technology used and tower height. Costs of civil work and installation of wind turbines also vary based on site condition and turbine size [15]. The wind turbine that is chosen to be installed in the system is 1 kW; it is included in the HOMER database. The wind turbine costs about $872 and it includes 30-m. guyed lattice tower kit, inverter and tower wiring kit [24]. Installation costs of the turbine range between $1700 and $19,00 at the selected site. Therefore, capital cost is considered to be $15, 00 for turbine with $200 for installation. The replacement cost is considered to be $ 1500 and the operating and maintenance costs are assumed to be $50 per year unit. The numbers of wind turbine units are considered to be 0 to 10 units. HOMER will simulate the system with given range and the output will the optimal number of wind turbines in the system [1] [26].

(D) Hybrid Renewable System

Intermittent energy resources and energy resources is the most important reason to install a hybrid energy supply system. The Solar PV wind hybrid system suits to conditions where sunlight and wind has seasonal shifts [10]. As the wind does not blow throughout the day and the sun does not shine for the entire day, using a single source will not be a suitable choice.

A hybrid arrangement of combining the power harnessed from both the wind and the sun and stored in a battery can be a much more reliable and realistic power source [13].

Hybrid power system consist of a combination of renewable energy source such as wind generators, solar etc. of charge batteries and provide power to meet the energy demand, considering the local geography and other details of the place of installation [6]. India is potentially one of the largest markets for solar energy in the world. The estimated potential of power generation through solar photovoltaic system is about 20 MW / Sq.km in India [31].

Depending on the environmental conditions, required energy for the system can be supplied either separately from the wind or solar systems or using these two resources at the same time is shown in Fig. 6 [18].

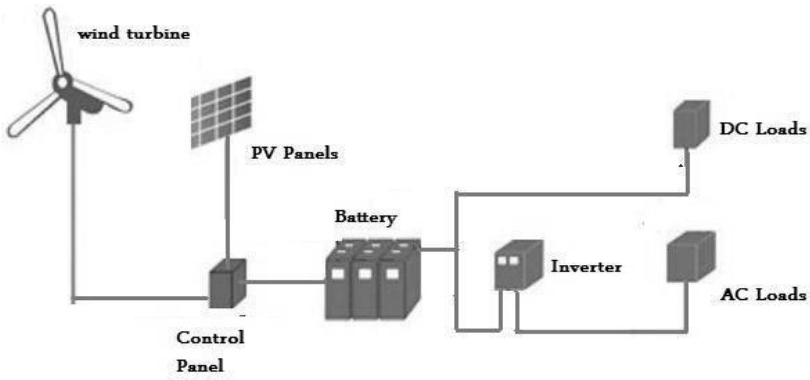

Fig.6 Solar-Wind Hybrid System

A. First Condition (On-Grid)

In first condition when hybrid system is grid connected, the individual system cost is given as input which by using simulation software operating cost per year, cost of energy(COE) ,total net present cost is calculated as shown in figure 7 :-

	PV (kW)	G1	6FM200D	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	10	10	80	10	10	$ 47,550	2,605	$ 80,855	0.168	0.45
	10	10	80	10	5	$ 47,550	2,608	$ 80,883	0.169	0.45
	10	10	80	20	10	$ 48,100	2,637	$ 81,806	0.170	0.45
	10	10	80	20	5	$ 48,100	2,639	$ 81,834	0.171	0.45
	10	10	80	5	5	$ 47,275	2,762	$ 82,586	0.185	0.41
	10	10	80	5	10	$ 47,275	2,767	$ 82,646	0.184	0.41

Fig.7 Simulation and optimized result of ON-Grid solar-wind hybrid system

In on-grid solar-wind hybrid system with grid connection 10 PV panel (1KW), 10 wind turbine (1 KW) 80 battery rating 12 V, 200 Ah, 2.8 kWh, 10 converter (1KW) and grid connection of 10 KW are used to provide the electricity for lead 90 KWh/day.

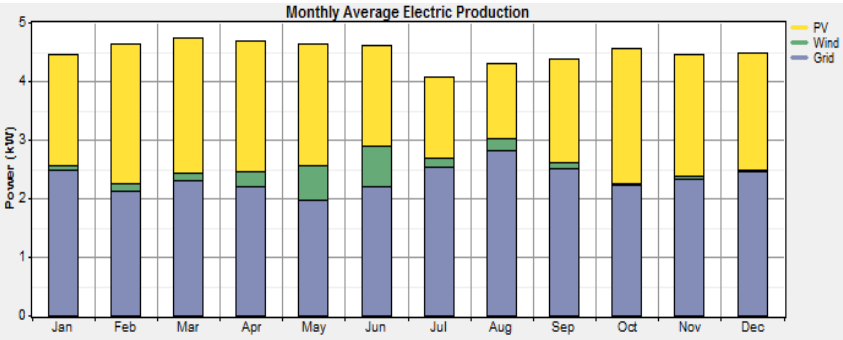

Fig.8 Representation of electrical production of on-grid solar and wind hybrid system

In above monthly average electrical production of solar-wind hybrid system the output of PV and wind vary according to solar radiation and wind speed and according to their output power purchased and sale out to grid. Solar output is good but wind speed is poor but Bernoulli Effect improves the wind speed.

Table 6 Electrical production and Cost summery of On-grid system

Production	kWh/yr	%	Consumption	kWh/yr	%	Quantity	kWh/yr	%
PV array	17,060	43	AC primary load	32,741	87	Excess electricity	30	0.08
Wind turbines	1,817	5	Grid sales	4,823	13	Unmet electric load	0	0
Grid purchases	20,601	52	Total	37,564	100	Capacity shortage	0	0
Total	39,478	100						
Total NPC : $ 80,855			**Levelized COE: $ 0.168/kWh**			**Operating Cost: $2,605/yr**		

In grid connected hybrid system AC primary load is 32,741 kWh/yr , according to load PV array output 17060 kWh/yr, wind turbine output 1817 kWh/yr but this production is less than primary load requirement therefore in grid connection for continue supply power is purchased from grid.

B. Second condition (Off-grid)

In second condition standalone hybrid system is designed, the individual system cost is given as input which by using simulation software operating cost per year, cost of energy(COE) ,total net present cost is calculated which is shown in figure 9:-

PV (kW)	G1	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
40	10	240	10	$ 129,550	3,772	$ 177,766	0.425	1.00
40	10	240	20	$ 130,100	3,805	$ 178,742	0.427	1.00
40	10	240	30	$ 130,650	3,838	$ 179,717	0.429	1.00
40	10	240	40	$ 131,200	3,872	$ 180,693	0.432	1.00
40	20	240	10	$ 146,550	4,272	$ 201,158	0.481	1.00
40	20	240	20	$ 147,100	4,305	$ 202,133	0.483	1.00
40	20	240	30	$ 147,650	4,338	$ 203,109	0.485	1.00

Fig.9 Simulation and optimized result Off-Grid solar-wind hybrid system

In off-grid solar-wind hybrid system 40 PV panel (1kW), 10 wind turbine (1 kW) 240 battery rating 12 V, 200 Ah, 2.8 kWh, 10 converter (1kW) are used to provide the electricity for lead 90 kWh/day.

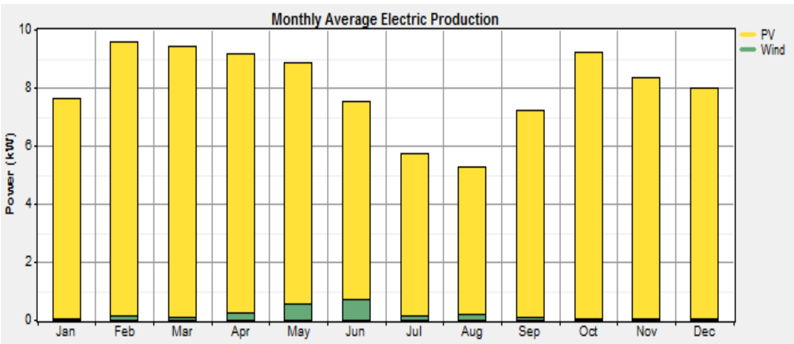

Fig. 10 Representation of electrical production off-grid system

Table 7 Electrical production and cost summary of off-grid system

Production	kWh/yr	%	Consumption	kWh/yr	%	Quantity	kWh/yr	%
PV array	68,239	98	AC primary load	32,741	100	Excess electricity	28,745	41.2
Wind turbines	1,604	2	Total	32,741	100	Unmet electric load	3.91	0.0
						Capacity shortage	5.48	0.0
Total	69,443	100						
Total NPC : $177,766			**Levelized COE: $0.425/kWh**			**OperatingCost:$3772/yr**		

In grid connected hybrid system AC primary load is 32,741 kWh/yr , according to load PV array output 68,239 kWh/yr, wind turbine output 1604 kWh/yr but this production is greater than primary load requirement therefore excess electricity is 28,745 kWh/yr.

5. Comparison between on-grid and off-grid solar-wind hybrid system

In grid connected solar-wind hybrid system after feeding the input data in HOMER software, a software on the basis of feeding data simulate the solar-wind hybrid model using different combinations of solar panel, wind turbine, converter, battery etc. In number of simulation results the software give us the optimized result, which is the best result among all simulation results as shown in fig. 7 the optimized COE (cost of energy) is $ 0.168/(kWh)[Approx 10.08 Rs/Unit]. In on-grid system the total production of electricity by solar and wind hybrid system is 18877 kWh/yr and 20601 kWh/yr electricity is purchased from grid in poor production by hybrid system. There is only 0.08% excess of electricity which can be saved and used by increasing further no of storage i.e. battery.

The simulation results obtained for Off-Grid (solar-wind) hybrid system as shown in fig. 9, the optimized COE (cost of energy) is $ 0.425/(kWh)[Approx 25.5 Rs/Unit] for above described load and designed system.

In off-grid hybrid system the total production of electricity is 70057 kWh/yr and unmet electric load and capacity shortage is 0% achieved as shown in figure 9. There is only 41.2% excess of electricity which can be saved and used by increasing further no of storage i.e. battery.

6. Conclusion

Overall conclusion: By comparing simulation result of on-grid and off-grid solar-wind hybrid system, it is clear that grid connected system is much better then off-grid hybrid system for VILLAGE UMRIKHEDA, INDORE, M.P. because in off-grid hybrid system Cost of energy is approximate 25 Rs./Unit and system installation cost is $ 80,855 (Approx. 50 lakhs) but in on-grid hybrid system Cost of energy is approximate 10 Rs./Unit and system installation cost is $ 177766 (Approx. 1 crore).

In on-grid system the excess power is sale back to grid this is benefit of on-grid system but in off-grid hybrid system excess power is totally losses and in low generation condition the consumers suffer black out of electric power cut.

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