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Optimum design of hybrid renewable energy system through load forecasting and different operating strategies for rural electrification

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ABSTRACT

This paper demonstrates the optimum design and techno-economic assessment of hybrid renewable energy system (HRES) for rural electrification in the remote district of Korkadu, India. The renewable energy resources namely solar photovoltaic, wind turbine and bio generators are considered as the main sources because of its high potential in Korkadu district. This paper estimates the load forecasting for the selected district, which is a mixture of different load patterns namely residential, commercial, institutional and agricultural demands. The desired HRES has to meet the forecasted load demand for reliable electrification. The optimum design and techno-economic analysis of proposed HRES system is carried using powerful tool HOMER. This study also compares HRES's operational behavior with different operational strategies such as load following strategy, cycle charging strategy and combined strategy of the system. The outcome of the proposed dispatched strategy expressed the contribution of solar power as 86.8%, wind as 12.7% and bio gen power as 0.5% to meet out developed rural load pattern with 6.8% of battery bank losses and 1.78% of converter losses. This research work also illustrate the HRES based power generation can be a cost effective sustainable power alternative to the conventional grid extension system.

Introduction

Total power generation capacity of India was 340 GW as on March 2018, a major portion of which 65% was from fossil fuels such as coal, oil etc. whole the renewable energy, natural gases based energy generation contributed to 19.2% [1]. The research says that still 240 millions of India are living in dark without electricity and most of the electrified villages have poor quality of electricity especially during the peak demand period i.e., during summer [1,2]. Government of India has initiated several schemes, namely, Remote Village Electrification Program (RVEP), Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), Jawaharlal Nehru National Solar mission (JNNSM) etc., for addressing this issue and for ensuring electrification of the rural areas in India [1,3]. The main objective of these schemes is to ensure clean source of electricity generation for the electrification of un-electrified villages in India. Various researchers have proposed an attractive solution called the Renewable Energy based Hybrid Rural Electrification System (REHRES). But the main challenges in this proposed solution relate to system reliability, power management and economical cost of energy. In addition, wide variations are seen in the renewable energy availability and its potential depending on their geographical location. Hence the optimum sizing is considered as an important parameter for the development of an efficient and economical REHRES.

In recent years, various researchers have proposed the solution for REHRES worldwide such as Hydrogen fuel system based hybrid energy system has been deployed in Newfoundland [4], Solar/wind/hydrogen based HRE [5], solar/wind powered reversed osmosis system [6], PV/wind/battery based isolated island system [7] these study clearly expressed the issues related with HRE system sizing and necessity of performance optimization of the system.

Barsoum and Vacen et al. [8], Karakoulidis et al. [9], Giatrakos et al. [10], and Türkay and Telli [11] worked on the feasibility studies of optimizing the HRE component sizing. In Sri Lanka, a case study for realizing the cost effectiveness of standalone home energy system comprising of PV-diesel was analyzed by Lilienthal et al., [12]. Munuswamy et al., [13] have attempted a case study on decentralized energy system to serve rural health centre and concluded that the energy production cost of renewable energy is comparatively cheaper than conventional grid power. Bhattacharya et al., [14] have designed a micro-grid system to satisfy the electrical demand (5000 kwh/day) of a

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hypothetical rural community through renewable energy sources such as solar, wind, hydro and diesel resources with the optimal project cost. Siddharth Suman [15] has reviewed in detail about building the hybrid electrification system, which consists of renewable energy sources and nuclear reactor to manage base load management. Yashwant Sawle et al., [16] examined the socio-techno economic design of hybrid renewable system using different optimization techniques to find the optimal configuration parameters used in designing the energy system. Md Shahinur et al. [17] have studied the feasibility of combination of the hybrid renewable system with grid to meet the load demand of large commercial building, which results in 90% of reduction incarbon footprint. Laith M. Halabi and et al. [18] done the techno economic feasibility study on PV/diesel/Battery based hybrid system the author covers all the possibility scenarios expect the different load dispatch strategies consideration Larne olatomiwa et al. [19] were tried to implement the Hybrid renewable energy supply system for rural healthcare load fulfillments. Used different wind turbine and solar array based sensitivity analysis for health care load fulfillment but economic load dispatch based cost optimization not a clear shape in this article. Shezanarefin et al. [20] analyzed the wind /diesel based hybrid optimization in the terms of HRE components sizing and techno economic feasibility study. The further more of them articles [21–23] also examined the HRE applications with the different country regions such as Indonesia, Australia and Bangladesh. However the load dispatch strategy based economics beneficial was not addressed clearly.

Most of the earlier studies, did designing of the electrification system, but have not considered the different load patterns such as domestic load, commercial, irrigation, agricultural and community purpose load to meet the required electricity demand. In this paper, the author has attempted at designing an electrification system for a village in Puducherry region, India, through the availability of its renewable energy potential to realize the socio-economic development. Korkadu, a rural village in the union territory of Puducherry region, has an agricultural land of nearly 80 ha, Out of which 35 ha were of paddy and 45 of sugarcane producing 1.5 tons of agro-residues per day. It has also a cattle population of 150, which produces cattle dung of 80 kg/day (this information was obtained by site visit and survey conducted with the villagers). Presently, the villagers are burning the agro-residues and animal dungs, instead of utilizing it effectively.

Developed a RE based hybrid system from the RE based hybrid system from the resources available in Korkadu village that can meet the power demand in a reliable and sustained manner and to ascertain the cost effectiveness option. The assessment of power demand, potential renewable energy resource availability and the creation of a model composed of multiple combination of renewable energy are estimated using the HOMER software. The best system configuration selection, lower net present cost (NPC) and cost of electricity have been also studied using HOMER. The following are the contributions by this paper (i) past studies mostly considered solar, wind and diesel. But this research attempts to meet the energy demand using solar, wind and biomass/biogas for full utilization of the renewable energy resources. (ii) Operational strategy and reliability of HRES there has been no significant study of in the available literature. In this work this has been considered as the primary objective. (iii) The productive use of electricity in commercial, community, agricultural activities has been included in addition to domestic energy requirements, thereby extending the scope of the study.

The arrangement of this paper is as follows; Section 2 explains the problem statement and objective function formulation regards, Section 3 shows the selected methodology for solving rural electrification issues through RE component assessment and load assessment using forecasting techniques. Section 4 presents a case study relating to a rural electrification system using HOMER and Section 5 elaborates the results obtained from the study. Section 6 concludes the case study analysis with the best feasible solution in all aspects.

Problem formulation

The design and modeling of a remote hybrid renewable energy system which is consists of the Photovoltaic (PV) system, Wind Turbine (WT), Biomass power generator (BG-set) and Energy storage system (ESS) to meet out the village load demand. The main objective of the proposing HRE system is cost minimization. The minimization of annualized cost of the total system includes total capital cost, replacement cost, operational and maintenance cost. It can express as Eq. (1).

$$Min(AC) = [N_{PV}C_{PV} + N_{WT}C_{WT} + P_{SG}C_{BG} + P_{ESS}C_{ESS} \tag{1}$$

where AC is the annualized cost of the system, the total annualized cost of HRE components such as PV, WT, BG, ESS are asC_{PV} , C_{WT} , C_{BG}andC_{ESS}. The annualized cost of HRE consists of annualized capital cost, annualized operational and annualized replacement cost. The annualized capital cost of BG-set C_{BG}express as follows,

$$C_{BG} = C_{AC(Cap)}^{BG} + C_{AC(rep)}^{BG} + C_{f}^{BG} \tag{2}$$

where, the annual capital cost is as $C_{AC(rep)}^{BG}$, the annual replacement cost is represented as$C_{AC(rep)}^{BG}$, C_{f}^{BG}, is referred as operational fuel cost. Capital cost of HRE components in particular year of operation might be includes in the terms of capital recovery factor (CRF) for better accuracy in cost estimation, it can express as Eq. (3)

$$C_{AC(cap)}^{BG} = C_{cap}^{BG}\ CRF(a,\ b) \tag{3}$$

where α is the interest rate for capital in % and β is the project life span in years. The annual replacement cost of the BG set. The annualized value of total replacement cost [$C_{AC(rep)}^{MT}$] is expressed as follows,

$$C_{AC(rep)}^{MT} = C_{rep}^{MT}CRF(\alpha,\ \beta)\frac{1}{(1+\alpha)^{y}} \tag{4}$$

The mathematical equations for Net present cost and cost recovery factors are given in Eqn.5

$$M_{npc} = \frac{M_{ann,tot}}{CRF(i,\ R_{proj})} \tag{5}$$

where M_{npc} as the system net present cost in Rs., $M_{ann,Tot}$ as system annual total cost in $/yr. The factor CRF is a Capital recovery factor with '*i*' % interest rate and Rth year as project life time in year.

$$COE = \frac{M_{ann,tot} - M_{boiler}\ E_{thermal}}{E_{prim\ AC} + E_{prime\ DC} + E_{def} + E_{grid\ sales}} \tag{6}$$

Eq. (6) expressed the COE in the terms of annualized total cost ($/yr), marginal cost of the boiler ($/KWh) and different patterns of load served (KWh/Yr).

$$F_{ren} = \frac{P_{ren} + T_{ren}}{P_{Ta} + T_{Ta}} \tag{7}$$

where the renewable electrical production and thermal production are mentioned respectively as 'P_{ren}' and 'T_{ren}'. P_{Tot}, T_{Tot} is total generation of power and thermal in kWh.

Operational strategy and constraints

The proposed HRE system have the top priority of power utility from the PV panels and the WT over BG set Power due to environmental issues and cost effectiveness. The power management has derived as per following operational strategy. As a preliminary operational strategy, the developed load can be directly functioned by solar and the wind power when the power Production greater than load demand ($P_{PV}(t) \geqslant P_L(t)$ *and* $P_{WT}(t) \geqslant P_L(t)$) and the remaining power can be store for battery charging or meet out the deferrable load.

$$P_{Bu}(t) = (P_{PV}(t) + P_{WT}(t) - P_L(t) \tag{8}$$

$$P_d(t) = (P_{PV}(t) + P_{WT}(t) - P_L(t) - P_{Btt}^{\max} \tag{9}$$

The cost effectiveness based on dispatch strategy can be achieved through effective usage of Bio gen-set. It annual fuel coat can be expressed (Eq. (10)) in terms of feedstock consumed over a year.

$$C_f^{BG} = E_{BG} C_{BG} d(t) \tag{10}$$

where the price of BG fuel per kg is asC_{BG}, the total energy produced by BG-set in (kWh/yr) is represented asE_{BG}, the fuel consumed rate (kg/kW) by BG-set is referred as$\delta(t)$.

Methodology

Optimization of Hybrid renewable energy system was planned through set of procedure way of methodology. This methodology developed by three important stages such as (i) Assessment stage, (ii) Simulation stage, (iii) Evaluation stage. In the stage of assessment all the basic requirement procedure such as site study, load profile study and technology analysis were carried out. At simulation stage formulated objective function was executed through all the system operation constraints and user defined performance parameters. In the final stage proposed system's techno economic parameters were witnessed by different measuring quantitative and qualitative parameters such as technical performance, economic performance and environmental performance. This optimization procedure was clearly mentioned in Fig. 1.

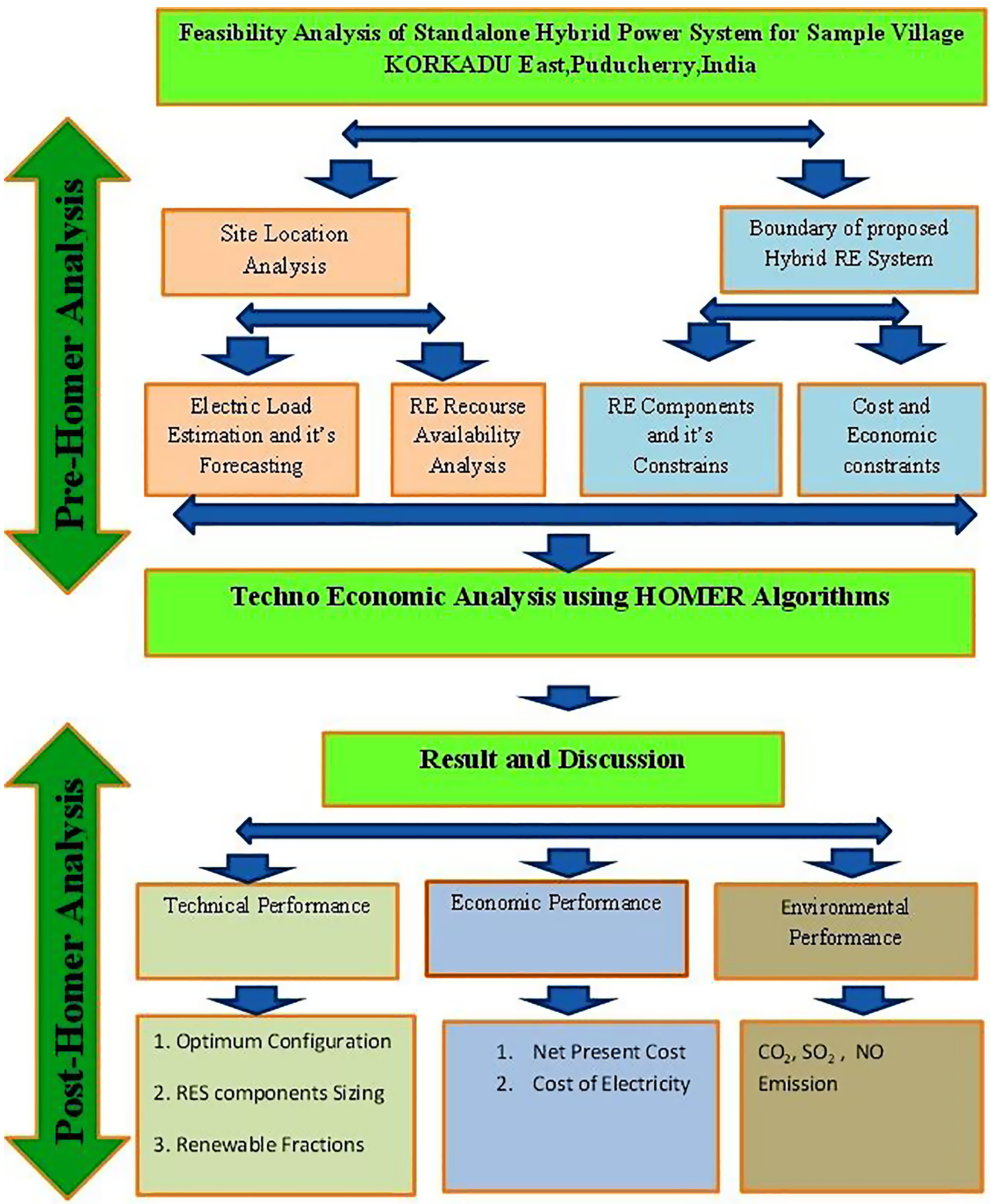


Fig. 1. Methodology of Hybrid RES design and implementation.

Site assessment

The selected village Korkadu, Villiyanur Commune, Union territory of Puducherry is located between latitudes 11.91′ N and 11.93′ North and longitudes 79.81′ and ′ 79.85′ East. This region is blessed with good solar energy density and a relatively high wind speed due to its vicinity to the sea coast. The daily average annual solar radiation and wind speed are 5.37 kWh/m^2/day and 3.81 m/s respectively. Korkadu village, Pondicherry has agricultural land area of approximately 35 ha of paddy crop which produces 1.5 tons of paddy husks on a daily basis [24,25]. The cattle population of the village is around 150 and the dung availability is 80 kg/day.

The economy of the villagers depends on agriculture and animal husbandry, which has the capability of producing a reasonable quantity of biomass. The availability and range of solar irradiation, wind speed and mass of biogas decides the suitability of the hybrid electrification system. Fig. 2 shows the geographical layout of the selected village Korkadu district.

Village load assessment

The load demand of the village is calculated by considering the domestic loads (light, fan, television, radio, refrigerators, and mixer/grinder), commercial loads (shops, community centre), agricultural and industrial loads (irrigation and well pumps, small-scale industry) and community load (medical centre, school, water pump and street light). Table 1 shows the load demand calculation for Korkadu village, UT of Puducherry. In this study, the village load demand was calculated cautiously by site survey and is also compared with the existing load profile data of similar village available from Pondicherry electricity board. The seasonal load variations seen in the village during summer and winter are shown in Table 2. The above explained loads are categorized into three load types based on installed power capacity.

Primary load

It covers the demand for the entire domestic and community loads. This load is considered as the top priority to provide power supply. The

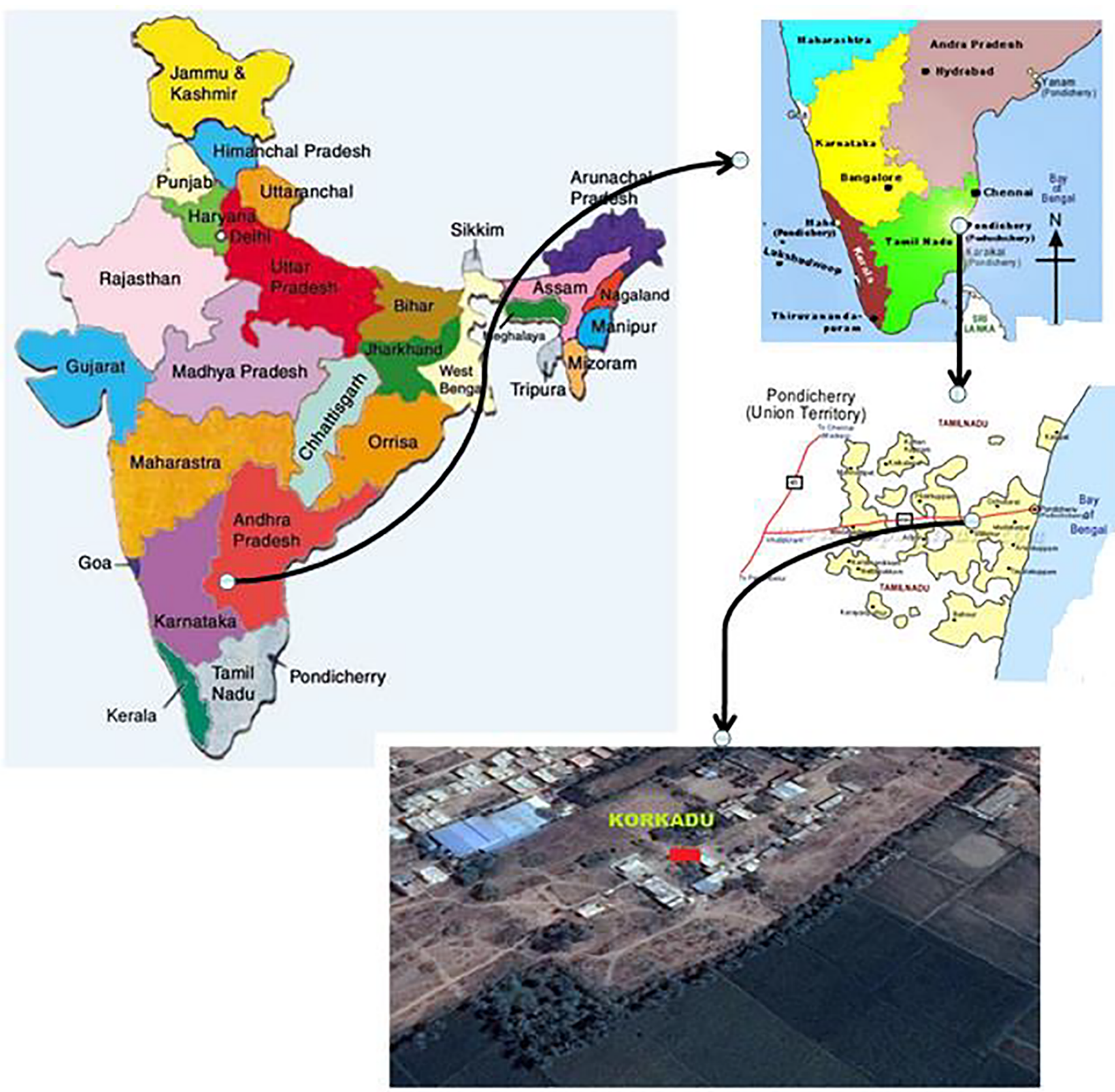


Fig. 2. Geographical layout of the selected village Korkadu, UT of Puducherry.

Table 1
Load demand calculation for Korkadu village, UT of Puducherry.

Sl. No	Load	Power (watts)	No. in use	Summer (May-Oct)		Winter (Nov-April)	
				Hrs/Day	watt-hrs/Day	Hrs/Day	watt-hrs/Day
Domestic Load							
1	Inner Light	20	3	6	360	7	420
2	Outer Lights	20	1	6	120	7	140
3	Fans	30	3	10	900	4	360
4	Radio	10	1	3	30	6	60
5	Mixer/ grinder	350	1	0.25	87.5	0.25	87.5
6	Refrigerat-or	100	1	24	2400	24	2400
7	Television	65	1	9	585	9	585
	TOTAL				**4482.5**		**4052.5**
A	**No. of houses**		**39**		**174817.5**		**158047.5**
Commercial Load							
1	Inner Light	20	8	6	960	6	960
2	Outer Lights	20	2	6	240	2	80
3	Projector	100	1	3	300	3	300
4	A/c system	1200	2	2 (Avg. in hr)	4800	0	0
5	Sound System	50	1	3	150	3	150
6	Fans	30	8	3	720	3	720
7	Shops (Avg.)	500	2	8	8000	7	7000
B	**TOTAL**				**15,170**		**9210**
Agri and Industry Load							
1	Irrigation Pumps	1492	2	6	17,904	4	11,936
2	well pump	746	2	3	4476	0	0
3	SS Industry	1200	2	8	19,200	8	19,200
C	**TOTAL**				**41,580**		**31,136**
Community load							
1	Panchayat (street lighting, water pump &off. Rooms)				12,095	8	12,695
2	Primary School (All lighting, fans& teaching aids)				2530	8	2100
3	Health Clinic (lighting ,fans, communication & medical aids)				26,845	8	26,715
D	**TOTAL**				**41,470**		**41,510**

estimated primary load demand is 176.321 kWh/day and the scaled annual average would be 19.56 kW.

Secondary load

This load covers other than top priority load. It is mainly concentrated on commercial type of load except the deferred load. It was observed that 12.214kWh/day as the scaled annual average, 4.2437 kW.

Deferred load

It includes a pumping station and agricultural irrigation loads [26]. It meets out the demands of any hours of a day, but not in peak demand hours. Scaled average demand per day is 5.1 kW, registered peak as 4.5 kW (which is the rated power of the pump). The pumped hour to necessary quantity of water is 3 h.

Load forecasting

The observed village load profile (obtained from survey) was treated using short term load forecasting techniques and mean average percentage error was found. This error value has been used in HOMER for estimating the day to day variations or hour to hour variations in the load profile. Load Forecasting is defined as the mechanism of the use of historical data in determining the movement of future trends. In the area of power system, electrical load forecasting was used for estimating the future power demand from consumers. Differnt short term load forecasting model with MAPE values are given in Table 3.

Future power demand was estimated on the basis of the historical load data (Figs. 3 and 4 shown historical data of day and monthly wise). The forecast model was used in processing the exogenous relation of the data provided, with the anticipated the future load demand. In this paper, load demand forecasting was done by averaging the model

Table 2
Sessional load demand of the Korkadu village.

Day Time	Summer demand (kW)			Winter demand (kW)		
	primary load	Secondary load	Deferred load	primary load	Secondary load	Deferred load
01:00 AM	6.95	0	0	3.53	0	0
02:00 AM	6.95	0	0	3.44	0	0
03:00 AM	6.95	0	0	3.44	0	0
04:00 AM	6.8	0	0	3.44	0	0
05:00 AM	6.1	0	1.49	3.53	0	1.49
06:00 AM	6.36	0.04	1.49	6.78	0	1.49
07:00 AM	14.64	0.5	1.49	16.89	0.05	1.49
08:00 AM	6.6	0.5	2.69	7	0	2.69
09:00 AM	7.06	1	1.95	6.82	1	1.2
10:00 AM	3.82	1.45	3.15	3.52	1.24	2.4
11:00 AM	4.01	1.5	3.15	3.74	1.4	2.4
12:00 PM	6.11	3.66	3.15	5.84	1.26	2.4
01:00 PM	5.81	2.71	0.75	9.74	0.31	0
02:00 PM	10.8	1.4	5.38	10.84	1.5	3.89
03:00 PM	6.98	1.16	5.38	7.04	1.16	3.89
04:00 PM	3.77	0.5	3.89	3.77	0.66	3.89
05:00 PM	5.33	0.5	3.89	8.9	0.5	3.89
06:00 PM	6.81	0.09	0.75	10.38	0.09	0
07:00 PM	15.21	0.04	0	16.77	0.04	0
08:00 PM	12.81	0.04	0	9.3	0	0
09:00 PM	12.65	0.04	0	9.18	0	0
10:00 PM	9.33	0.04	1.49	5.86	0	1.49
11:00 PM	6.95	0	1.49	3.44	0	1.49
12:00 AM	6.95	0	0	3.44	0	0

Table 3
MAPE values with different short term load forecasting model.

S. No	Name of the Models	Mean Absolute Percentage Error (MAPE)	
		Historical data	One day ahead
1	Neural Network model	4.07%	1.72%
2	Regression Trees model	4.77%	5.92%
3	Multiple linear regression Model	4.67%	5.81%
4	Curve fitting	4.93%	5.62%
5	averaging model	2.67%	3.07%

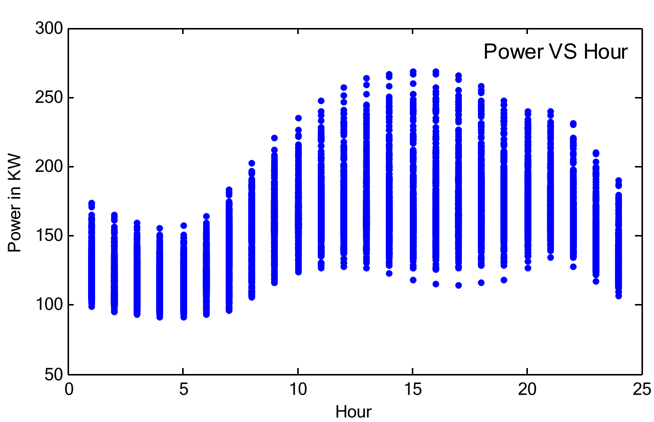


Fig. 3. Historical daily load demand.

which provides the combined advantages of four familiar forecasting methods namely, (Neural Network model, Regression Trees model, multiple linear regression Model and Curve fitting model) for getting the best results of mean average percentage error (MAPE eqn.11) those models are:

$$P(t) = Pn(t) + \sum_{i=1}^{N} \alpha_i \beta_i(t) + \varepsilon(t) \quad (11)$$

hear $P(t)$ is the forecast load at time t, $P_n(t)$ is the normal load at time t, $\alpha_i$is the estimated coefficient, β_i is the independent variable resulting from the weather effect, $\varepsilon(t)$is a white noise component and N is the number of observations. Figs. 5 and 6 shows the prediction demand of selected village in day and week ahead respectively. During the load assessments, the village load growth also considered in the terms of added realistic randomness values of MAPE. This mechanism used to allow the load profile with future growth noise on it.

Renewable resources assessment

Selected solar, wind and bio-diesel resources have been used in this model. The details of dates of the resource valuation are given below. The village solar resource was taken from NASA surface meteorology solar irradiation data (satellite image based derived data sets). It was crosschecked and evaluated with the National Institute of Wind Energy dataset (ground level measuring unit) since, the comparative analysis of the result between them showed the assessed global radiation from the proposed model having a better error range and fitted with ground measured data better than the satellite-derived data [27]. The selected area had the observation value of the annual average solar radiation as 5.37 kWh/m^2/day and the average clearness index as0.55. This solar radiation could be accessed throughout the year. Hence a considerable amount of PV power output could be obtained (see Fig. 7).

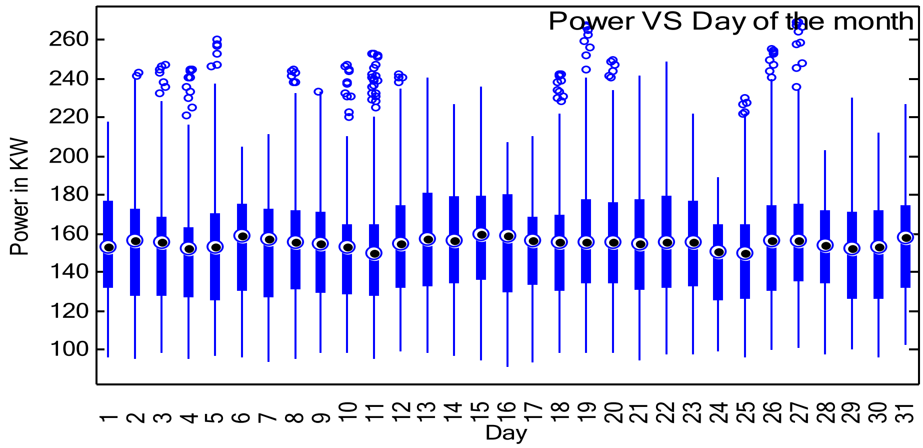


Fig. 4. Historical monthly load demand.

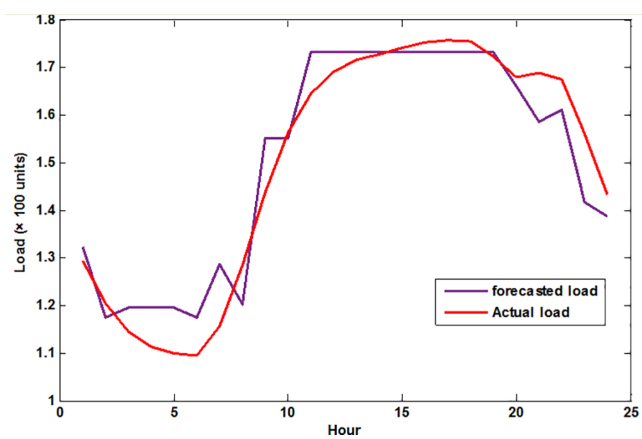


Fig. 5. Load forecasting one day ahead.

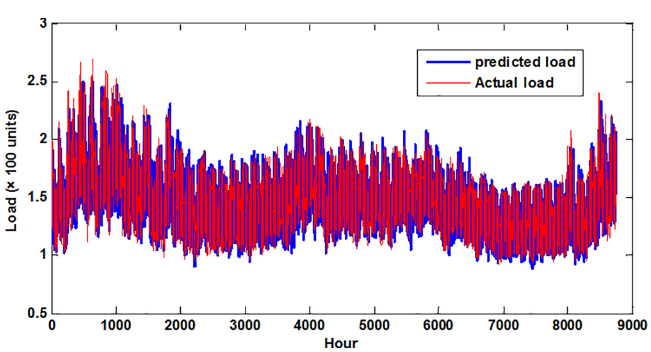


Fig. 6. Load forecasting one week ahead.

The monthly average wind resource data from an average was taken from the above NASA resource website based on the longitude and latitude of the village location. The annual average wind speed for the location is 3.81 m/s with hub height at 50 m (see Fig. 8). The wind speed probability and average monthly speed throughout the year were also observed. Assuming 0.036 m^3 biogas/kg [26] of animal dung yield,

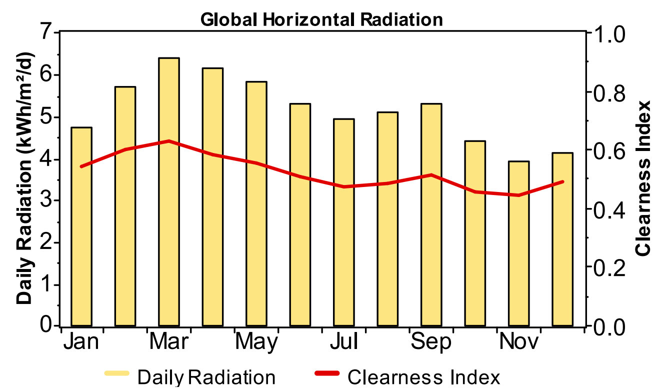


Fig. 7. Monthly wise solar resource availability at selected village location.

total quantity of biogas is 2.88 m^3/day available for power generation. This bio gas energy generation can be calculated by following Eqs. (12)–(14). The monthly wise biomass potential of the site location is expressed in Fig. 9.

RE components assessment

The general structure of a micro grid consists of renewable energy generators, storage elements, power converters and a power back up system as shown in Fig. 10 [28]. Two kinds of solar array systems are used for maintaining the good load factor of the system. One is the sun power X series brand of flat plate (DC form of output) solar panel with 21% of efficiency, 88% of De-rating factor and temperature co efficient of −0.300. The total rated capacity is assumes as 50 KW, capital investment is assumed as Rs. 60,000 and replacement cost is assumed as Rs. 60,000 [29] (for each KW equivalent). The life time of the panel is 25 years. Selected optimization sizing search space was 0,5, 10, 50. Another solar panel with inbuilt micro converter is considered for AC form of output power (ABB's Trio 50 model, efficiency 17.3%,88% of De-rating factor). Capital and replacement cost of each KW panel investment is calculated as Rs. 95,000. 0, 50, 100 are selected as search space for finding optimum configuration.

The performance and cost of each of the components of the system

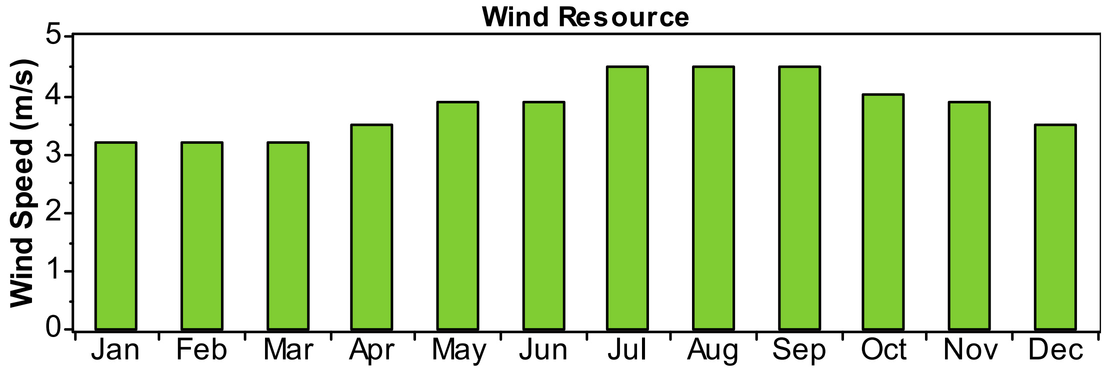


Fig. 8. Monthly wise Wind resource availability at selected village location.

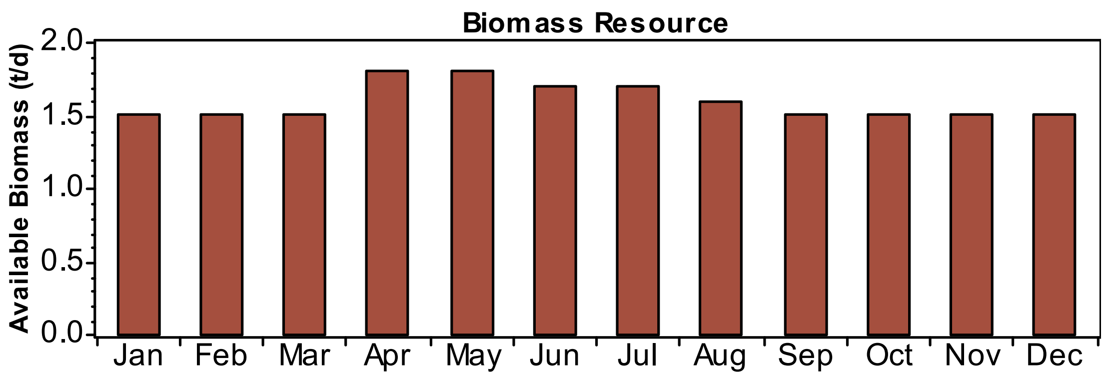


Fig. 9. Monthly wise Biomass potential at selected village location.

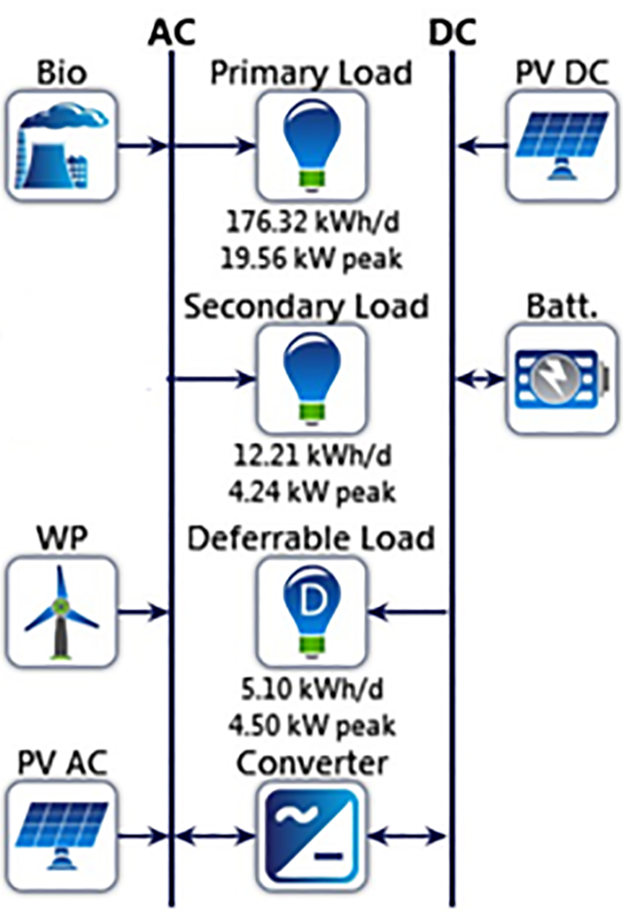


Fig. 10. Proposed structure of HRES based rural electrification system.

have influence on the total cost of the system. The panels did not have any tracking system and were modeled as stationary titled South at 11.73 N latitude with a slope of 45degrees. A generic 10 kW Vertical axes wind turbine has been considered. The amount of electricity generated by the wind turbine was based on the site wind speed. The G10 wind turbine selected provides 10 kW of AC output. The cost of one unit has been taken as Rs.1, 20,000, while the replacement and the maintenance cost have been considered as Rs.1, 20,000 and Rs.500/year respectively. The wind turbine has a hub height of 30 m and a lifetime of 20 years.

A Generic Biogas/mass power generator was installed with a capital cost of Rs.1, 70, 000 and O& M cost of Rs. 5000. The power production capacity has been assumed as 50 KW, Fuel lower heating value as 5.5 MJ/kg, density as 720 kg/m^3, Carbon content as 2%, substitution ratio as 8.5 (biogas/fossil), minimum fossil fraction as 20% and Derating factor as 70%. The system contains a converter at 30 KW, considering the inverter mode efficiency as 96% and rectifier mode efficiency as 95% with a life time of 10 years. The converter capital investment and replacement cost considered is Rs. 5000 per KW. The system has power storage provision through battery banks (Sonnen batteries eco16 model). 240v, 16KWh, 66A battery bank is connected with micro grid system with a fixed maximum charge/discharge current as 30 A. The total battery bank throughput is 160,000 KWh and assumed life time is 10 years considering capital and replacement cost as Rs. 120,000 and O & M cost as Rs 500 /year.

System sensitivity inputs

The key variables for the micro-power system are, however, often uncertain. This is the foremost problem seen in the designing of the system [30]. Here the uncertainties in the RES (wind, solar and Biogas/biomass) have been taken into account. The sensitivities are entered for the Biogas price (Rs/m^3) and Biomass price (Rs/kg) in 3% increment value.

Table 4
Village electrification system configurations.

	System Architecture						Economic Performance				Degree of Renewables		Resources Contribution in terms of Power				
S. No	PV DC (kW)	PV AC (kW)	Wind No.of Units	Bio (kW)	Battery No.of Units	Converter (kW)	COE (Rs.)	NPC (Rs. Million)	Operating Cost (Rs.Million)	Initial capital (Rs.Million)	Renewable Fraction (%)	Total Bio Fuel (Ton/yr)	Bio Power (kWh/yr)	PV DC Power (kWh/yr)	PV AC Power (kWh/yr)	Wind Power (kWh/yr)	Batt. Throughput (kWh/yr)
1	50		1		31	30	11.50	10.20	0.025	7.020	100.0	0.00	0	83430.52	0	12172.75	38996.87
2	50		1	50	28	30	11.73	10.71	0.030	6.825	99.4	0.88	400	83430.52	0	12172.75	38975.28
3	10	50	1		25	30	12.74	11.30	0.021	8.650	100.0	0.00	0	16686.1	86240.26	12172.75	38128.08
4		50	1		30	30	13.29	11.80	0.024	8.650	100.0	0.00	0	0	86240.26	12172.75	38743.41
5	**10**	**50**	**1**	**50**	**24**	**30**	**12.99**	**11.86**	**0.025**	**8.695**	**99.6**	**0.55**	**250**	**16686.1**	**86240.26**	**12172.75**	**38167.43**
6	**50**	**50**	**1**	**50**	**16**	**30**	**13.7**	**12.19**	**0.038**	**7.843**	**99.9**	**0.41**	**195**	**83431.1**	**86,250**	**12172.75**	**36648.1**
7	**50**	**50**	**1**	**50**	**17**	**30**	**13.72**	**12.50**	**0.018**	**10.300**	**99.6**	**0.49**	**332.29**	**83430.52**	**86240.26**	**12172.75**	**36658.94**
8		50	1	50	27	30	13.47	12.31	0.030	8.455	99.4	0.88	400	0	86240.26	12172.75	38721.36
9	50	50			21	30	14.30	12.69	0.017	10.450	100.0	0.00	0	83430.52	86240.26	0	42010.14
10	50	50		50	17	30	14.54	12.93	0.022	10.140	99.1	1275.93	600.46	83430.52	86240.26	0	41994.94
11		100		50	17	30	16.43	14.62	0.021	11.890	99.3	1083.06	509.02	0	142355.1	0	41825.48
12		100			22	30	16.59	14.72	0.019	12.320	100.0	0.00	0	0	142355.1	0	41848.34
13	50			50	37	30	19.43	17.28	0.073	0.779	94.8	7602.21	3581.1	83430.52	0	0	44412.92
14			1	50	6	30	131.99	117.42	0.899	0.119	0.2	146.10	68657.23	0	0	12172.75	49334.68
15				50	10	30	152.85	135.98	1.040	0.155	0.0	175.28	82569.59	0	0	0	56481.64
16	50	100	1	50		30	366.70	326.22	2.423	1.297	0.0	263.40	119,725	83430.52	142355.1	12172.75	0
17		100	1	50			371.26	330.28	2.479	0.982	0.0	269.56	122,525	0	142355.1	12172.75	0
18	50	100		50		30	374.11	332.81	2.475	1.285	0.0	269.06	122,300	83430.52	142355.1	0	0
19		100		50			379.70	337.78	2.538	0.970	0.0	275.99	125,450	0	142355.1	0	0
20	50		1	50		30	392.91	349.54	2.677	0.347	0.0	291.12	132,325	83430.52	0	12172.75	0
21	50			50		30	411.12	365.74	2.803	0.335	0.0	304.87	138,575	83430.52	0	0	0
22		100	1	50		30	514.53	470.10	3.559	0.997	0.0	386.98	175,900	0	142355.1	12172.75	0
23		100		50		30	534.33	488.20	3.700	0.985	0.0	402.33	182,875	0	142355.1	0	0

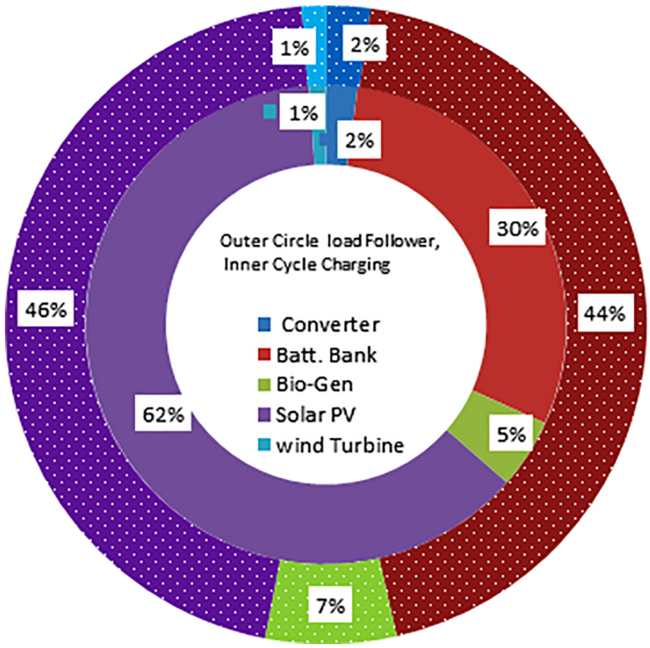


Fig. 11. Different dispatch strategy NPC comparisons.

Table 5
HRES system performance comparisons based on classical dispatch strategy [32].

Performance Optimization Parameter	Cycle Charge Strategy	Load Follower Strategy
Total Annualized Cost	Rs.9,70,285	Rs.9,17,786
Total Net Present Cost	Rs. 1,25,43,370	Rs. 1,18,64,690
Cost of Electricity	Rs.13.73	Rs.12.99
System architecture (Sizing of system)		
PV-DC	50 KW	10 KW
PV-AC	50 KW	50 KW
BIOGEN	50 KW	50 KW
Battery	17 no.	24 no.
Wind Turbine	1 no.	1 no.
Convertor	30 KW	30 KW
Production energy		
PV-DC Power KWh/yr	83,431	16,686
PV-AC Power KWh/yr	86,240	86,240
BioGen KWh/yr	232	250
Wind Turbine KWh/yr	12,173	12,173
Total Generation KWh/yr	182,076	115,349
Excess Electricity	1,03,718 KWh/yr	35,839 KWh/yr
Fuel consumption	500 L/yr	550 L/yr
Battery Annual throughput	36,659 KWh/yr	38,167 KWh/yr
Converter loss	1439 KWh/yr	1438 KWh/yr
Co2 emission	0.236 Kg/yr	0.259 Kg/yr
Nominal RE capacity / total nominal capacity	68.80%	58.30%
Total RE production	99.90%	99.80%

System's economic inputs

The selected hybrid optimization model for electric renewable system was simulated with the following economic inputs such as project life time has been taken as 25 years [29], annual discount rate of 6%, with no penalty for capacity shortage, Rs 5,00,000 considered as the system's of fixed capital cost and Rs 1,00,000 as fixed O&M cost. The system fixed capital costs include civil construction, logistics, wages, licences fees, administration and government approvals and other miscellaneous costs.

HOMER analysis

Analysis of the above Hybrid RE system has been made using micro-grid design software, with all design considerations. HOMER has been taken with sufficient iteration for finding the best fitness to solve the optimum performance objective function. Each iteration provided its own optimum configuration setup. Then all the configurations were arranged on merit based parameters, namely, least total net present cost (NPC) and the least cost of electricity (COE) [31]. This simulation was carried out for the classical load dispatch strategy parameters (cycle charging and load following). According to the location resources and developed load demand of particular village electrification system Configurations have been listed out in Table 4 on the basis of the location resources and the developed demand for the particular usage electrification system. (Least NOC and COE getting top priority).

Classical dispatch strategy with micro grid environment

A micro grid controller has the necessary mental capability to make important decisions on matter like how the day demand will be met with the available energy, battery operating power and duration and when the backup generator needs to be turned on. These decisions decide only the system performance in terms of optimization sizing and economic cost of generated power. The optimization decision to serve the developed load is concluded with a suitable dispatch strategy at each step of the operation. There are two classical dispatch strategies indicated in this study, namely, cycle charging and load following. Useful dispatch decisions are 1. Battery system alone met the net load 2. Net load was met by a generator system ramped up to charge the battery as much as possible.3. Net load was met by a generator running at a power sufficient only to serve the load. Fig. 11 shows the different dispatch strategy NPC comparisons.

Cycle charging strategy

In this mode the bio generator needs to be operated with full output power to assist the main priority load and surplus electrical production energies towards the further lower priority objectives, namely, charging the battery bank, secondary load and differed load. The basic constraints in the operation of this strategy were the Bio generator being ON to ensure the net-load demand and battery bank charge the prescribed SOC set point has been met [32]. It continues running for its prescribed minimum run time or the renewable power is sufficient to meet the load. Here generator will not operate to produce surplus power just to dump it as excess electricity. Battery wear cost is calculated through

$$M_{btt,WC(Rs/Kwh)} = \frac{M_{btt,Rc}}{Throughput^{*}\sqrt{n_{rt}{}^{*}\eta_{btt-load}}} \tag{12}$$

here $M_{btt,WC}$ –battery wear cost, $M_{btt,RC}$-Battery replacement cost, η_{rt}-round trip efficiency. Cycle charging cost is evaluated by

$$M_{cycle-charging} = M_{g,Fule(Rs/Kwh)} + M_{btt,WC}$$

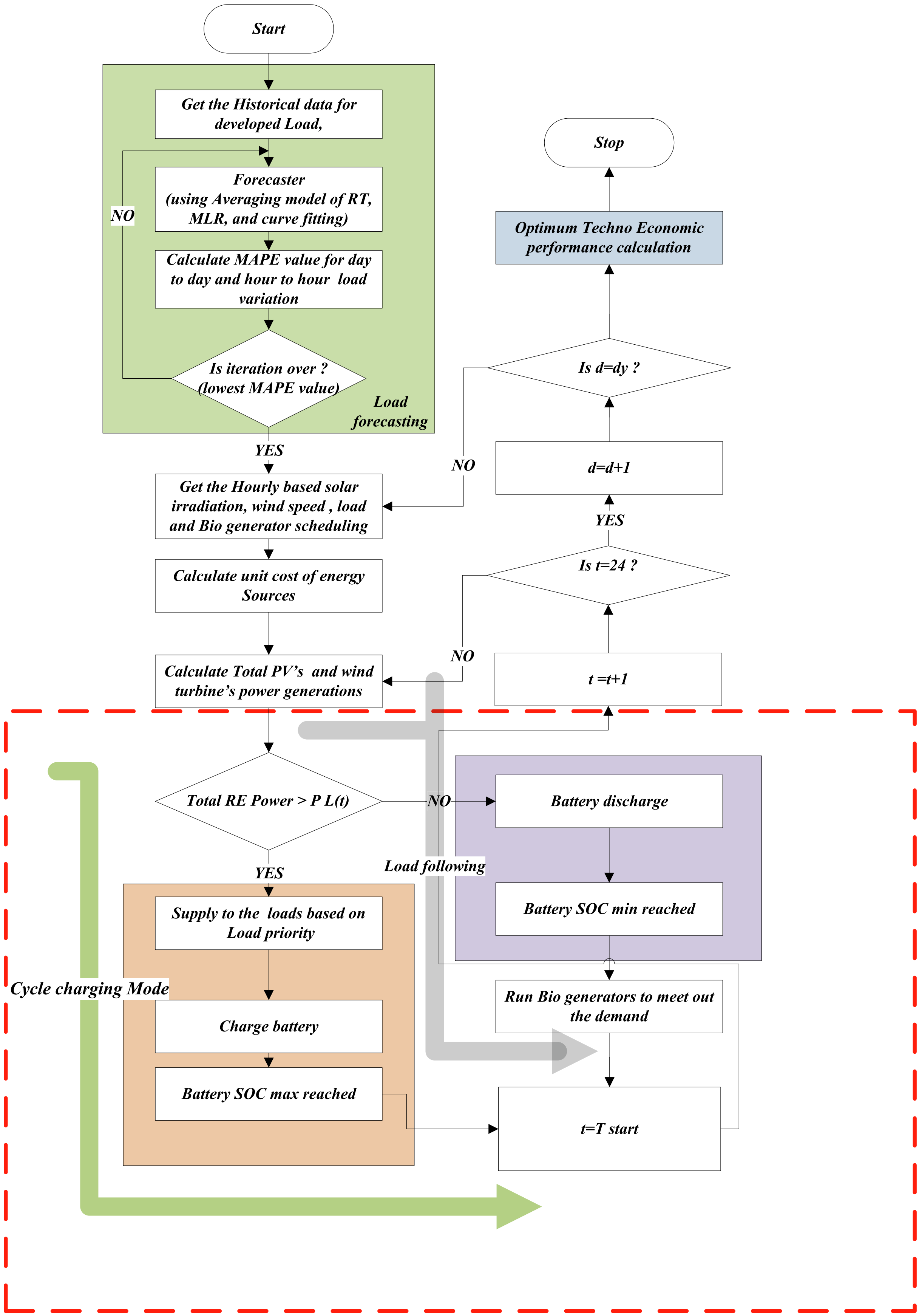
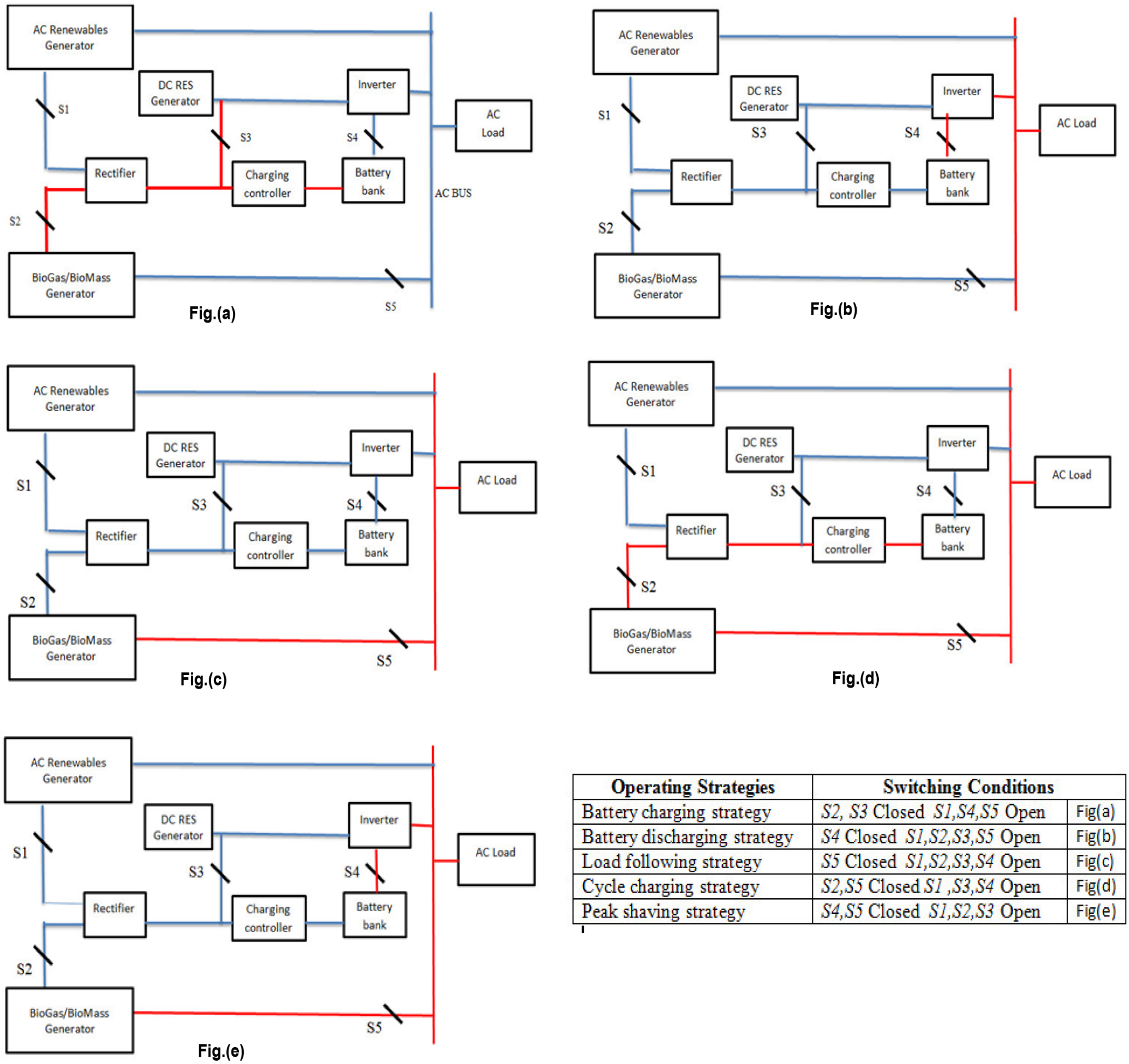


Fig. 12. Different dispatch strategy flow chart.



Operating Strategies	Switching Conditions	
Battery charging strategy	*S2, S3* Closed *S1,S4,S5* Open	Fig(a)
Battery discharging strategy	*S4* Closed *S1,S2,S3,S5* Open	Fig(b)
Load following strategy	*S5* Closed *S1,S2,S3,S4* Open	Fig(c)
Cycle charging strategy	*S2,S5* Closed *S1 ,S3,S4* Open	Fig(d)
Peak shaving strategy	*S4,S5* Closed *S1,S2,S3* Open	Fig(e)

Fig. 13. Implementation of different system operating strategies.

Table 6
. Improved HRES performance through proposed strategy over classical dispatch strategies.

System Performance Parameters		Classical approach		New approach
		Cycle charging	Load following	Combined dispatch
Economic performance	**NPC (Rs.in million)**	1.26	1.18	**1.21**
	COE (Rs./Kwh)	13.72	12.99	**13.71**
System operation Performance	Battery round trip loss (Kwh/yr)	5530	5755	**5528**
	Annual battery Throughput (Kwh/yr)	36,659	38,167	**36.648**
	Bio –Gen operating hour (hr/yr)	7	10	**5**
	Fuel requirement (kg)	500	550	**415**
Environmental Performance	CO_2 (kg/yr)	0.236	0.259	**0.196**
	CO (kg/yr)	0.150	0.165	**0.09**
	NO (kg/yr)	0.350	0.385	**0.291**

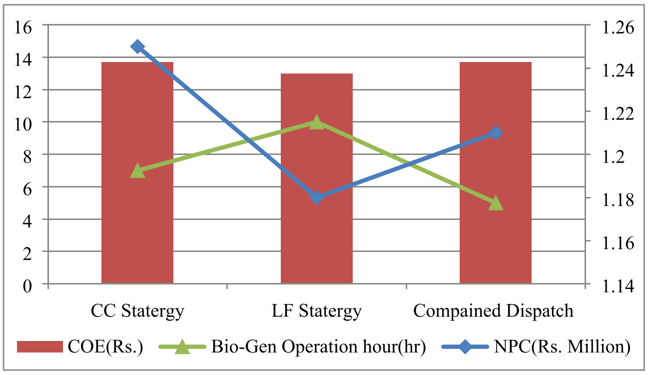


Fig. 14. Different Dispatch strategy comparisons in terms of economic parameters.

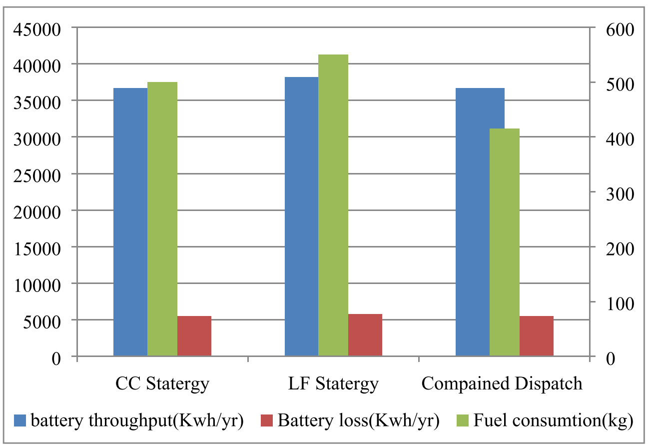


Fig. 15. Different Dispatch strategy comparisons in terms of system operating parameters.

$$M_{g,Fule(Rs/Kwh)} = \frac{S_{Fuelcurve}{}^{*}M_{fuel}}{\eta_{rt}} \tag{13}$$

here M_g –is the marginal cost of generator power S-slop of the fuel curve

Load following strategy

In this strategy, whenever Bio-generator operated to produce enough power to meet out the top priority load, the remaining priority objectives such as battery charge, differed load supply were left to renewable power resources. The main operating constrains for this mode has been assumed as no charge to the battery, no discharge from the battery. A minimum diesel run time is followed to avoid excessive start/stop frequency. Bio generator power cost is calculated by [32]

$$M_{Bg(Rs/Kwh)} = \frac{consumption_{(1/hr)} * M_{fuel(Rs/1)}}{Load_{served} * P_{bg(Kw)}} + \frac{M_{Bg,Rc(Rs/Kw)}}{Load_{served} * Lifetime_{Bg(hr)}} + \frac{M_{Bg,om(Rs/Kw)}}{Load_{served}} \tag{14}$$

where M_{Bgcost} of bio generator power, $M_{Bg,RC}$ generator replacement cost

According to the classical dispatch strategy operations, the load following trick gives the valuable performance outcome (Table 5) in terms of less COE value and lowest excess energy production values. Still there is a high possibility of performance improvement which can be achieved by a newly proposed combined dispatch strategy of HRES operation [33–41].

Proposed combined dispatch strategy

This strategy was created for energy flow management among the different components of the micro-grid electrification system. The control strategy was estimated as the battery SOC and net load at every time step of the simulation. These measured values were used for controlling generator ON/OFF and the power supply connectivity to the load. The system energy balance and SOC of battery were checked at every time step of the simulation to ensure achievement of the least operating hour of bio generator, less pollutant development from the system and reasonable cost of electricity.

Implementation of different system operating strategies

Different control strategies are implemented by specially designed control switches from S1 to S5 [33] as shown in Figs. 12 and 13.

Battery charging strategy. In this case if the renewable power is not enough to meet the load, then it supplies the power to charge the battery. When the SOC of the battery has reached 80% of its value then it is connected to meet out the required load. (S2, S3 switches are closed, S1, S2, S5 are open).

Battery discharging strategy. When the battery power is above 60% of SOC it is connected to meet out the required load and when it falls below the minimum SOC limit it is disconnected from the load and is

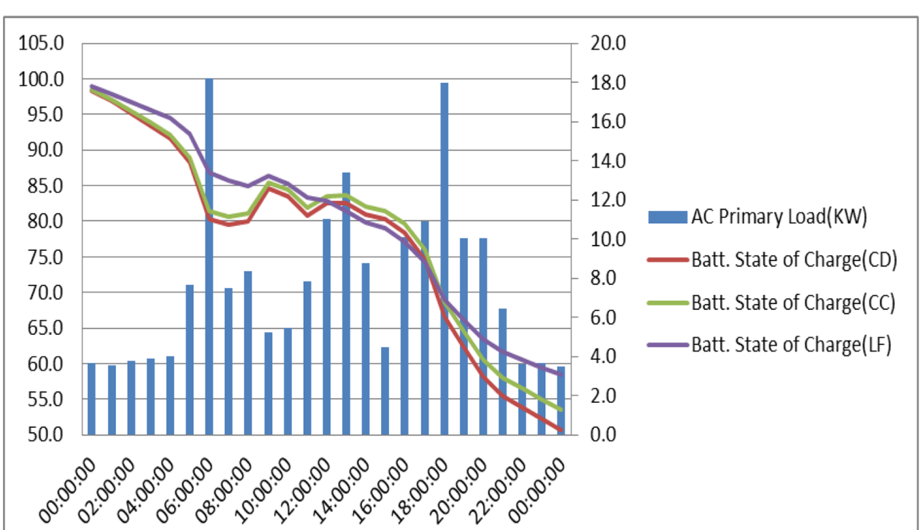


Fig. 16. Battery state of charge for different operating strategy.

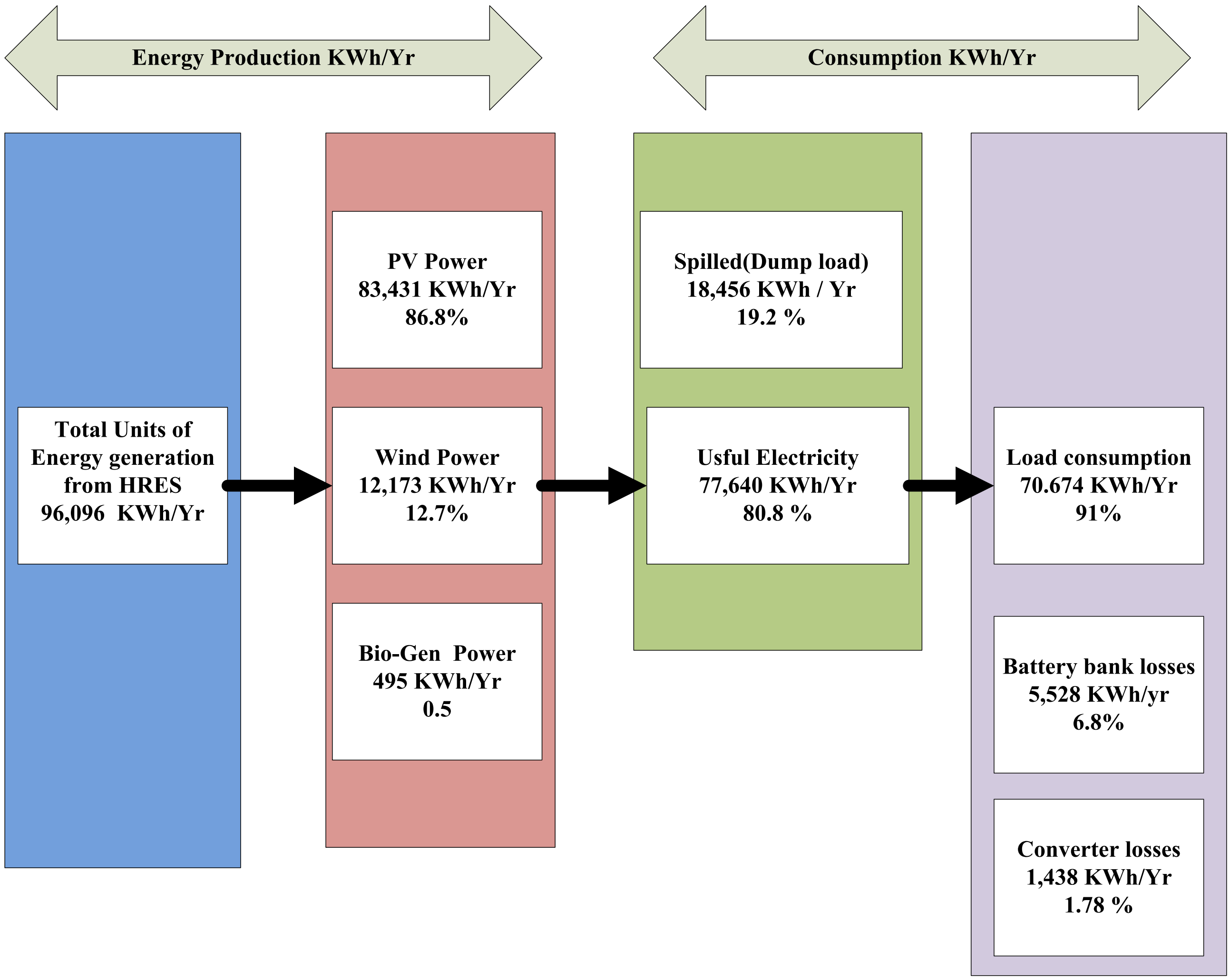


Fig.17. Energy flow summary during the simulated year.

about to charge to regain its saved power. (Switch S4 closed and S1, S2, S3, S5 are opened).

Load following strategy. In this case the bio generator is used to meet the required load demand. The entire power of the bio generator is used to meet out the connected load and it does not supply any power for charging or discharging the battery. The condition to be satisfied in this strategy is the bio generator operating time should be above the minimum run time. (S5 closed and S1, S2, S3, S4 are opened).

Cycle charging strategy. The Bio generator is run to meet out the load demand and charge the battery. The bio-gen is continued to run till its prescribed SOC set point is met. (Switches S2, S5 are closed and S1, S3, S4 are opened).

Peak shaving strategy. The Bio gen set is operated at full power. Battery power is used only for meeting buffer instantaneous variations around the net load. (S5, S4 are closed and S1, S2, S3 are opened)

Results and discussion

The following research challenges are fulfilled by the proposed dispatch strategy (Table 6).

Connected load is met out from renewable energy power and bio generator and this minimizes the charging and discharging losses of the battery thereby increasing the life span of the battery.
Possible simultaneous power generation and utilization are allowed with the system to achieve reasonable cost of electricity.
Once started the bio generator should run for a minimum time period (at least 20 min) of continuous operation. If operated for a minimum time period the wear and tear cost is increased and this increases the maintenance cost.
The Bio generator is not allowed to operate below a minimum power level to optimize the fuel efficiency.

Due to the proposed dispatch strategy, the sizing of the HRES system and annual throughput of battery bank becomes yield optimum, operation hours of the bio generator and its fuel requirement is reduced from 550Kg/year into 415 kg/year, environmental pollution level also reduced in to CO_2 as0.196Kg/year CO as 0.25 and NO gas into 0.291 Kg/year. Fig. 14 shows that the comparison analysis between different operating strategies and it is evident from that the combined dispatch is operated with the system in least bio gen hour with reasonable NOC (Rs.1.21 million) and COE as Rs.13.71 per KWh. Fig. 15 expresses the backup system performances comparison between different operating strategies of the HRES solution to the village. It is proved that the combined dispatch produces less environmental pollutant through least operating hours of bio gas/mass burning (415 Kg of fuel in the year with Total operating hour of 5 h per year) and optimum usage of

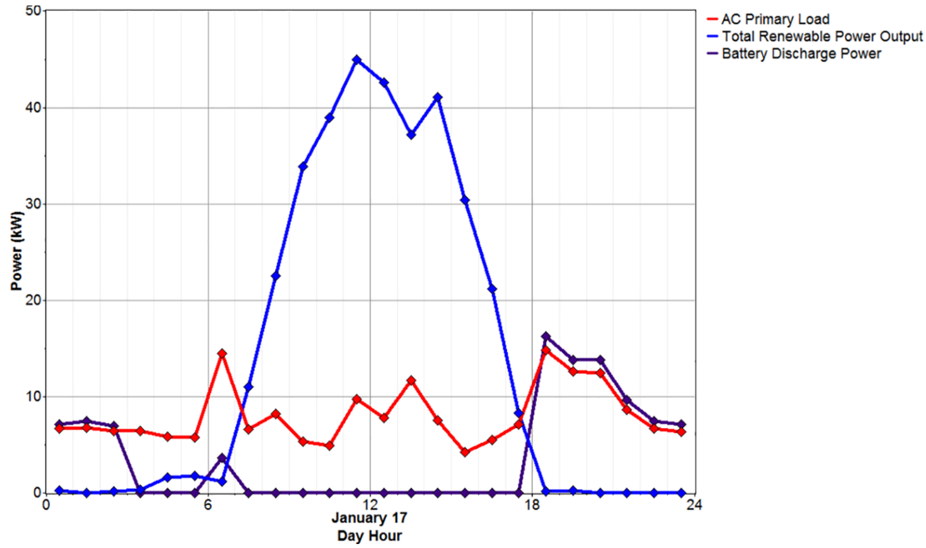


Fig. 18. Load Vs HRES system impacts in a sample day period.

Battery bank with its annual throughput is 36,648 Kwh/yr Fig. 16 strongly focuses on HRES battery backup system life span improvement. Combined dispatch takes too much care on battery through maintaining SOC levels with minimum percentage variation from 96% to 50%.

Energy flow summary of the proposed hybrid system

The table of the total electricity generation for the proposed system is 96,096 units per year. Out of this, PV generation is 83,431 (86.8%) units, wind powergenerationis12,173 (12.7%) units and the remaining 0.5% is from Bio gen-set arrangement. The total power consumption by the connected load is 91%, the remaining 9% are component losses. The proposed system has a renewable fraction of 0.998. The system has an unmet load of 0.0000666 and excess electricity of 18,456 units per year. This is shown in Fig. 17. The overall 8760 h performance prediction of duly designed PV, wind, Biomass/Biogas generation based combined dispatch strategy of Hybrid Renewable system characteristics are expressed in Figs. 18 and 19. In a sample day period of demand, major power share is from available renewable resources and the system is having less dependency on bio gen set with less quantity of excess energy generation due to compact architecture of the system.

Connected AC and DC loads are continuously meet out by the proposed HRES system. Figs. 18 and 19 shows the contribution of different components in meeting the demand. In due course charging and discharging status and corresponding SOC maintenance are also observed. Fig. 20 shows that AC/DC nature of operating capacity impacts in power generators production. The required capacity is fulfilled by the existing size of AC/DC power generators. Solar based DC power operating capacity is high due to the abundant solar potential on that selected village.

Conclusion

This paper has made a study of the hybrid renewable energy (PV/wind/biogen) based rural electrification system design and the analysis of its techno-economic performance. A mixture of different available load patterns of the village was considered and its day and time step variation was calculated using the short term load forecasting techniques. The feasible HRES configuration for Korkadu village electrification was obtained with the utilization of available village owned resources using the Homer optimization model. The selected finest configuration's techno economic performance was observed with the

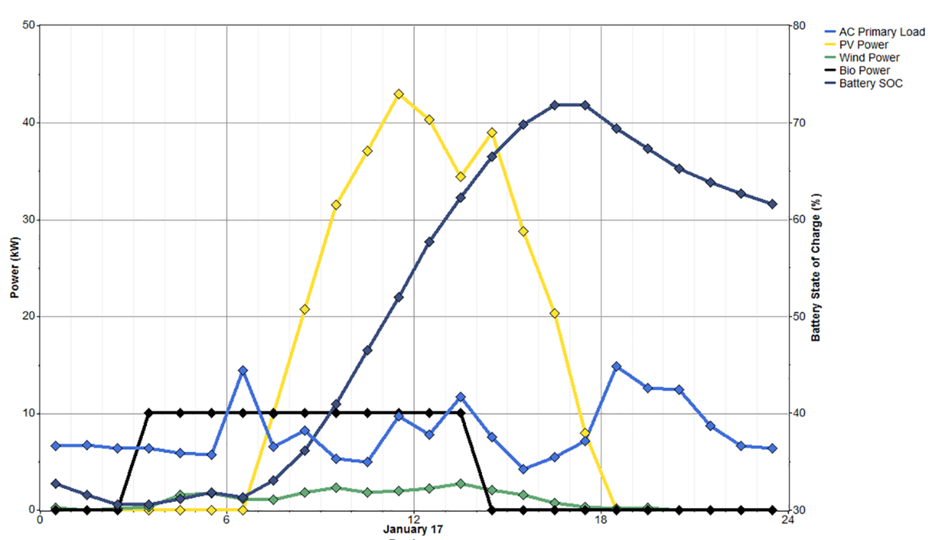


Fig. 19. HRES components performance in proposed system.

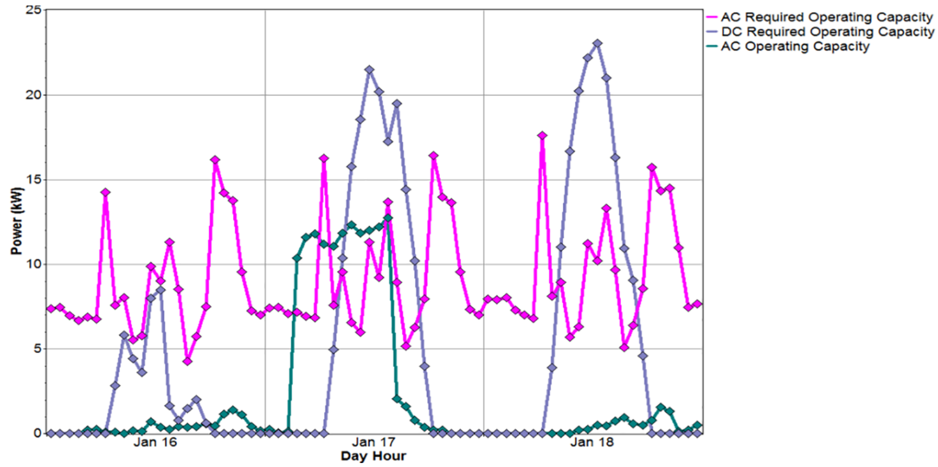


Fig. 20. AC/DC nature of operating capacity in proposed HRES system.

implementation of the operating strategies of various systems. The simulation results, showed the PV/wind/biogen based HRES system with combined dispatch strategy as the best fitted HRES solution for the Korkadu village, Puducherry state, India in terms of minimum buffer energy storage losses (5528 kwh/yr) with a reasonable net present cost of the system (Rs.1.21 million) and cost of energy (13.71 Rs/Kwh) over other dispatch strategies. This configuration with the proposed combined dispatch strategy was also found leading the system to a sustainable energy solution for the village electrification through reduced environmental hazards (Greenhouse gases emission) values such as carbon di oxide (CO_2) 0.196 Kg/yr, Carbon monoxide (CO) 0.25Kg/yr and Nitrous oxide (NO) 0.291 kg/yr. The further continuation of this work related to the artificial intelligence based HRE sizing optimization for the finest techno-economic configuration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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