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Optimal sizing of standalone PV/Wind/Biomass hybrid energy system using GA and PSO optimization technique

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Abstract

This paper presents the optimal planning of PV-Wind-Biomass hybrid energy system, which includes back up power sources as battery bank and diesel generator. The cost of energy (COE) or electricity price is minimized as objective function using GA and PSO. The optimal configuration of hybrid system is obtained on the basis of minimum COE. The optimal solution is consists with high reliability, maximum value of renewable fraction, less emission and low penalty cost according to minimum COE. The reliability is computed on the basis of loss of power supply probability (LPSP), which is assumed 2% maximum in this case study. This paper aim's to present the techno-economic feasibility of pv-wind-biomass hybrid energy system (HES) for a case study of remote area of barwani district, India. The optimization results are presented for load following and cycle charging strategy and also compared the results using GA and PSO optimization techniques.

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Keywords: Hybrid renewable energy system; dispatch strategies; COE; LPSP; penalty cost; pollutant emission

1. Introduction

In the present scenario use of diesel generator (DG) is not very effective alternative for power generation due to several issues like movement in fuel price, fuel transportation issues and high running expenditure. Furthermore diminution of the conventional resources (fossil fuel) and environmental issues, the renewable energy is the better alternative for power generation and it also prevents pollution emission. The configuration of different renewable energy sources like solar, wind, biomass etc with battery bank which increases the efficiency of the hybrid system and reliability [1]. The optimal solution of hybrid system is evaluated based on minimum total net present cost

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(TNPC) using various optimization techniques (analytical, probability, iterative etc). Dufo-Lopez et. al. [2] has design a multi-objective program for optimal solution and control techniques by using genetic algorithm (GA) and multi-objective evolutionary algorithm taking constrains as TNPC, unmet load and emission. For rural area, optimal solution of standalone hybrid system is evaluated through the GA [3]. PV panel, DG and battery bank combination is designed to fulfil the load demand of the consumer by using Homer software [4]. A proper technical methodological is needed for obtaining techno-economic analysis and better use of energy sources for integrated in hybrid renewable system. In this paper an off-grid PV/Wind/Biomass hybrid system for rural area Barwani, Madhya Pradesh, India is considered for best optimal solution and techno-economic comparative analysis with two different strategies(like load flowing and cycle charging) by using GA and PSO.

2. Unit Sizing of Hybrid Renewable Energy System

The proposed hybrid renewable energy model is used to design a PV/Wind/Biomass hybrid renewable energy system (HRES) with battery bank for storage purpose and diesel generator (DG) to maintain the supply and load demand. Dump load is used to dump excess power through the external resistor. The purpose of dump load is to maintain stability of hybrid system and dissipate the excess energy consciously, in the situation when minimum load limit of DG is lower as specified by company [23-24]. The optimal sizing and tech-economic analysis of the hybrid system is based on annual hourly average resource (PV/wind) data. Loss of power supply probability (LPSP) technique is used for reliability analysis. The optimal configuration of hybrid renewable energy system is ranked on bases of lowest COE of the system. To control the operation of the battery bank and diesel generator, despatch strategy is needed while there is not enough renewable power to satisfy required load demand.

2.1 Load Profile

The stand alone hybrid renewable energy system design location has less population so that electricity load demands also less. The regular assessment of daily energy consumption is 110.6kWh/day, peak load is 7.8kW and average is 4.61kW. The data was computed for the entire hour basis daily electrical load condition of a load demand for barwani district. The load profile for 23 hours of day is shown in Fig. 1.

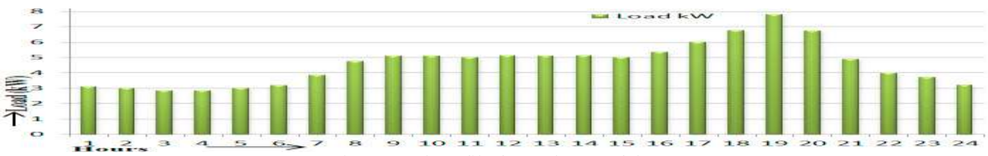


Fig. 1 Load profile for 24 hours of day

2.2 Wind Energy

In proposed work a small wind turbine with 1 kW rated power is considered for the design of HRES. The detailed description of particular wind turbine and wind speed monthly average is shown in table 1 & table 2. The wind power is calculated through equation 1. The design location of HRES has great potential wind system. The average annual wind speed is 4.5 m/s. The wind speed is not a constant value. It changes with hourly and seasonally [8]. The highest value of wind speed is gained in december, at this time performance of wind turbine maximum and gives maximum electricity output.

$$P^{T}_{WIND,each} = \begin{cases} 0 & V \le v_J \;\; or \;\; V \ge v_o \\ P_{Rw}\left(\frac{V - v_J}{v_R - v_J}\right) & v_J < V < v \\ P_{Rw} & v_r \le V < v_o \end{cases} \tag{1}$$

2.3 PV Energy

HRES is proposed for location of Barwani (has latitude 22.71 north and longitude 75.85 east) Madhya Pradesh, India [9]. Where Long-term average annual resource scaling of solar radiation is 5.531kW/m2. Solar radiation monthly average data is given in table 2. The PV panel output regarding to solar radiation is calculated through the following equation (1) [7]. The detail parameters of the PV panels used for proposed paper is given in Table 1.

$$P_{PV,each} = \begin{cases} P_{RS}\left(\frac{R^2}{R_{srs}R_{cr}}\right) & 0 \leq R < R_{CR} \\ P_{RS}\left(\frac{R}{R_{srs}}\right) & R_{CR} \leq R < R_{srs} \\ P_{RS} & R_{srs} \leq R \end{cases} \quad (2)$$

2.4 Biomass energy

The rice husk is taken in this paper as source of biomass energy. Rice a major cereal in India accounting for about 40 percent of food-grain production and over 30 percent of its cropped area. India share in world rice production is 21 percent. The design location Barwani daily produce of rice paddy is 460Kg. It is expected in the various study that the rice husk production is 25 percent of the paddy and immature paddy production is 3 percent of the paddy. So that the total biomass production of rice husk is 115 Kg/d [6]. The calorific value of rice husk has been reported in various literature is in range 12.1 to 15.2 MJ/Kg. The electricity production from the biomass energy can be calculated through the given equation [10].

Total available energy for electricity

$$P_{BM}\left(\frac{kWh}{yr}\right) = \left(\frac{Total\ rice\ husk\ available\left(\frac{t}{yr}\right)\times 1000 \times CB_{BIO} \times CV_{BIO}}{8760\times(operating\ hours\ /day)}\right) \quad (3)$$

2.5 Battery Bank

Battery is used for the purpose of storage, battery balance the power between supply and load demand. The input power of the battery can be negative or positive due charging and discharging process. Evaluation, state of charge with respective productivity and time consumption as:

a) $P_{PV}^{T} + P_{WIND}^{T} + P_{BIO}^{T} = P_{DEMAND}^{T}$ (4)

In this situation of the battery, capacity of battery, stable and not change.

b) $P_{PV}^{T} + P_{WIND}^{T} + P_{BIO}^{T} > P_{DEMAND}^{T}$ (5)

In this situation, Total hybrid (PV + Wind + Biomass) power of the system is more then to load demand.

c) $P_{PV}^{T} + P_{WIND}^{T} + P_{BIO}^{T} < P_{demand}^{T}$ (6)

In this situation, the total power generated by hybrid (PV + Wind + Biomass) system is less than to load demand.

2.6 Diesel Generator

The diesel generator work as back-up power supply when hybrid system generated power not fulfils the required load demand. The diesel generator increases the system reliability and makes the system more cost effective [11]. Diesel generator hourly fuel consumption and efficiency analysis according to given formula [12]:

$$F_{dsl}(t) = A.P_R + B.P(t) \quad (7)$$

2.7 Converter/Inverter

Electronic convert is needed to balance energy flow amongst the AC and DC elements. The converters/inverter converts the electrical energy from one form into another (converter AC to DC, and inverter DC to AC) with the desired frequency of the load. The efficiency of the inverter can be given as [24]:

$$\eta_{imv} = \frac{P}{P+P_0+kP^2} \quad (8)$$

$$P_0 = 1 - 99\left(\frac{10}{\eta_{10}} - \frac{1}{\eta_{100}} - 9\right)^2, k = \frac{1}{\eta_{100}} - P_0 - 1, \quad \text{And } P = P_{out}/P_n \quad (9)$$

Where, $\eta_{10}$and η_{100} are the efficiency of the inverter at 10% and 100% of its nominal power respectively, which are provided by the manufacturers.

3. Dispatch Strategies for Isolated

Hybrid system work properly to met load demand is directly connected with the dispatch strategy and control operation of system [20-21]. Battery bank and diesel generator maintain the operation of hybrid system and eliminate the issue regarding to reliability and variation in power supply. Dispatch strategy is utilized to control the operation of battery bank and diesel generator. Dispatch strategy is dependent on various factors such as nature of renewable energy resource, cost of fuel used, capacity of the battery and generator and quantity of renewable power in hybrid system. There are mainly two types of dispatch strategy is used for design of hybrid system such as: cycle charging strategy and load following strategy.

4. Optimization of Hybrid System Design Issues

4.1 Minimization cost

In this propose hybrid system design, objective function of the feasible design issue is to reducing the cost of energy (COE). The cost of energy is the ratio of total annual cost (the total annualized cost minus the cost of serving the thermal load). The hybrid system design issue is mention in equation and resolved by partial swarm optimization method.

$$M_{Total\ annual} = M_{AIC} + M_{O\&M} \tag{10}$$

Hybrid system is more optimal if the cost of energy is less [13]. Cost of energy is measure in cost per unit of electricity or constant price per unit of energy. It is calculated by the formula [27]:

$$\text{Minimization of } COE = \frac{M_{Total\ annual}}{\sum_{H-1}^{H-8760} P_L} \times C_{RF} \tag{11}$$

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is:

$$C_{RF} = \frac{I(1+I)^N}{(1+I)^N - 1} \tag{12}$$

The proposed hybrid system project lifetime is 20 year is considered. The lifetime of the battery and converter is ten year. The present worth factor calculation of the battery and converter(C&B) through the give formula:

$$P_{C\&B} = C_{C\&B} \times \left(1 + \frac{1}{(1+J)^{10}}\right) \tag{13}$$

4.2 Reliability model based on LPSP conception

Reliability is the main concern for any feasible hybrid system. Reliability is used to assess the quality of load supply. Reliability is defined in term of loss of power supply probability (LPSP) which is a statistical element [15]. LPSP indicate the power supply not a success to fulfil load demand either due to technical or lack of renewable resource. If LPSP value is zero means generated power supply full fill the required load demand and LPSP value is one its mean required load demand is not met. LPSP analysis evaluated by probabilistic methodology (intermittent nature of the renewable resource and the load demand, which remove require for time-series data) and chronological simulation (enumeration cumbersome, and requires the accessibility of data spanning a certain phase of time) [15-16].

$$LPSP = \frac{\sum\left(P_{LOAD} - P_{PV} - P_{wind} - P_{Bio} + P_{SOC_M} + P_{DISEL}\right)}{\sum P_{LOAD}} \tag{14}$$

4.3 Pollutant Emissions

Diesel generator is a conventional source of energy which produces emission of harmful gases contain carbon dioxide, carbon monoxide (g/L of fuel), unbumed hydrocarbons (g/L of fuel), particulate matter (PM) (g/l of fuel), proportion of the sulphur converted to PM (%) and nitrogen oxides (g/L of fuel) amongst all thus gases quantity of carbon dioxide is maximum. In the emission production, high quantity of carbon dioxide is considered for emission cost in this paper [19]. The cost value of carbon dioxide is calculated through the cost of tradable renewable certificate. In case of biomass generator, input fuel is rice husk which has high calorific value amongst all type fuel used. The biomass generator emission also produces harmful gases as like diesel generator accept carbon dioxide. In biomass generator maximum quantity of carbon monoxide (g/kg of fuel) amongst all harmful gases due to this reason only emission cost of carbon monoxide is considered.

4.4 Renewable Fraction

The renewable fraction is the fraction of the energy delivered to the load that originated from renewable power sources. In proposed hybrid system renewable fraction explain as limit of power supply as compared to non renewable energy source to renewable energy source. Ideal hybrid system which has hundred percent renewable fractions means total generated power supply to the load from renewable energy source. Renewable fraction is calculated by given equation. According to this equation if value of renewable fraction is zero means power supply through non renewable source (as PV, wind) is equal to supply of generator [18], [24].

$$\text{Renewable fraction} = \left(1 - \frac{\sum P_{diesel}}{\sum P_{pv} + \sum P_{wind}}\right) \times 100 \tag{15}$$

4.5 Result and Discussion

The optimal planning of PV-Wind-Biomass hybrid energy system with battery bank and diesel generator as back up are presented using GA and PSO optimization. The proposed work is carried out with MATLAB (2009a), with system configuration windows-8, Intel(R) Core(TM) i7-3370 CPU, 3.40 GHz and 4.0 GB RAM. The population and swarm size for GA and PSO are 30 for both and also the numbers of iterations are 50 in this case study. This section presents the design of optimal sizing of hybrid energy system for rural electrification in the remote location by using GA and PSO with two different dispatch strategies. The case study is carried out for optimal planning of PV-Wind-Biomass hybrid system of barwani, India.

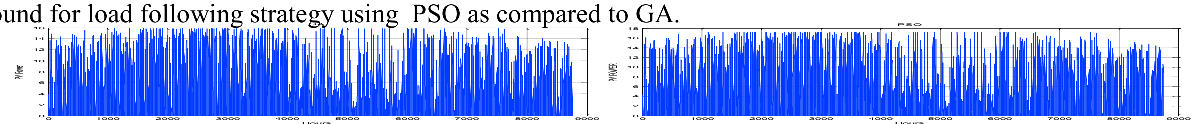
Table 1 specification of the Variables used in hybrid system

Variables	Values	Variables	Values
Annual interest rate (i)	6%	V_o	13 m/s
Life span of the system (n)	20 years	V_r	11 m/s
Solar panel price	468 $	P_{Rw}	1 kW
Solar panel installation fee	50% of the price	P_{RS}	260 W
Wind turbine price	1850 $/turbine	R_{cr}	150 W/m^2
Wind turbine installation fee	25% of the price	R_{srs}	1000 W/m^2
Unit cost of battery (C_{Batt})	150 $/kWh	O&M Diesel generator	0.008 $/kWh
Usage% of battery's rated capacity (g)	80%	O&M for Inverter/ Converter	0 $/kWh
Battery's rated capacity (S_{Batt})	8 kW h	O&M for Battery	50 Annual
Battery's life span	15000 cycles	Biomass price	500 $/kW
Unit time (D_t)	1h	Inverter/ Converter power	8 kW
O&M for PV array ($C_{Sol\ Mnt}$)	0.0 $/kWh	V_j	2.5 m/s
O&M for wind turbine ($C_{Wind\ Mnt}$)	0.02 $/kWh	O&M for Biomass	0.02 $/kWh

Table 2 resource data of renewable sources

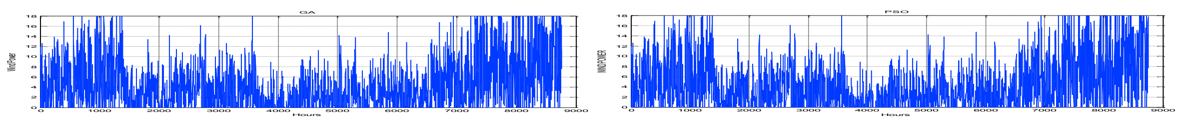
S.No	Months	Insolation (KWh/m^2/d)	Clearance index	Wind speed(m/s)
1	January	4.810	0.684	4.794
2	February	5.650	0.697	5.702
3	March	6.350	0.675	3.338
4	April	6.990	0.668	4.121
5	May	7.210	0.656	4.062
6	June	6.080	0.546	2.664
7	July	4.770	0.432	3.572
8	August	4.170	0.393	3.630
9	September	5.190	0.533	3.594
10	October	5.790	0.684	4.823
11	November	4.900	0.675	6.587
12	December	4.510	0.675	7.195
13	Average	5.531	0.598	4.500

The two different dispatch strategies namely as load following and cycle charging strategies are compared with respect to the optimal planning of PV-Wind-Biomass hybrid energy system using optimization techniques. These dispatch strategies have different impacts on the various optimized parameters of hybrid system. The results for optimal planning of PV-Wind-Biomass hybrid system for load following strategy using GA and PSO are given in figures 2 to 5 and table 3 respectively. The Figures 2-5 shows yearly PV output power, Wind output power, diesel Generator output power and Dump Load for load following strategy are effectively utilized using PSO as compared GA, which reveals that the PV output power is increased with PSO than GA. For example Fig. 2 indicates yearly PV output power which is more for PSO as compared GA which shows the good impact of PSO. Similarly the analysis for others parameters can be given, there is a some difference in hourly basis and better performances parameters are found for load following strategy using PSO as compared to GA.



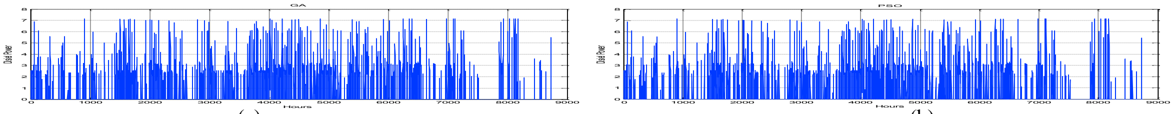
(a) (b)

Fig. 2 PV output power for load following strategy (a) GA, (b) PSO.



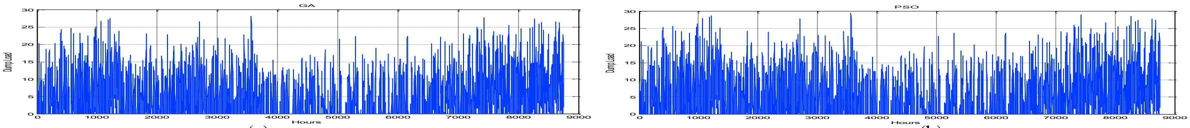
(a) (b)

Fig. 3 Wind output power for load following strategy (a) GA, (b) PSO.



(a) (b)

Fig. 4 Diesel Generator output power for load following strategy (a) GA, (b) PSO.

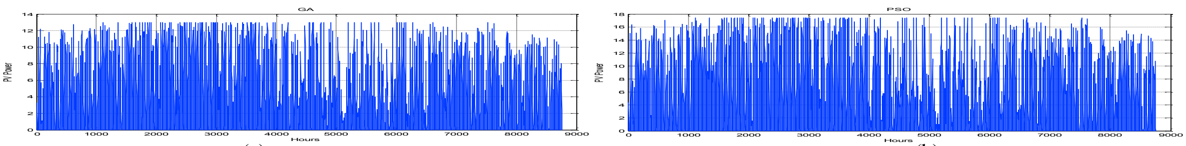


(a) (b)

Fig. 5 Dump Load for load following strategy (a) GA, (b) PSO.

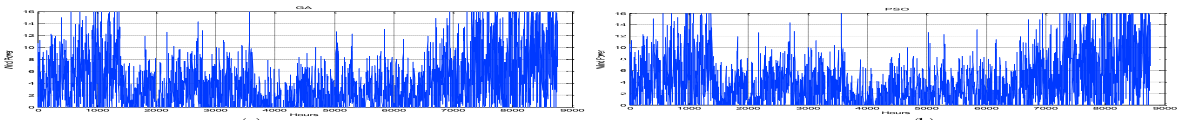
Table 3 demonstrates various parameters such as N_{PV}, N_{WIND}, price of electricity (COE), LPSP, renewable factor, pollutant emissions, cost, operating hours of diesel generator, PV power, wind power, biomass power, diesel generator power, reliability and algorithm running time for load following strategy as well as cycle charging strategy using GA and PSO. The N_{PV} and N_{WIND} for load following strategy are 61 & 18 with GA and 66 &18 with PSO respectively. The price of electricity (COE) for load following strategy is 0.2625 $/kWhr and 0.2617 $/kWhr using GA and PSO respectively. Similarly, LPSP, renewable factor, pollutant emissions, penalty cost, operating hours of diesel generator, PV power, wind power, biomass power, diesel generator power, reliability and algorithm running time for load following strategy using GA & PSO are 0.0172 & 0.0164, 0.9198 & 0.9237, 7.2668 ton & 7.2038 ton, 179.3397 $ &177.7828 $, 2127 hr & 2089 hr, 29497 kW & 31915 kW, 38739 kW & 38739 kW, 5693.3 kW & 5693.3 kW, 5925.6 kW & 5821.8 kW, 98.28% & 98.36% and 566.0706 Sec & 543.1537 Sec respectively.

The results of cycle charging strategy for optimal planning of PV-Wind-Biomass hybrid system using GA and PSO are given in figures 6 to 9 and Table 3 respectively. The PV output power, wind output power, diesel generator output power and dump Load for cycle charging strategy are techno-economically utilized using PSO than GA as given in Figures 6-9. Similarly the results for others parameters can be presented for cycle charging strategy, there is a comparable difference in hourly basis and better performances parameters are found for cycle charging strategy using PSO than GA. The N_{PV} and N_{WIND} for cycle charging strategy are 50 & 16 with GA and 67 &16 with PSO respectively. The price of electricity (COE) for cycle charging strategy is 0.2396 $/kWhr and 0.2393 $/kWhr using GA and PSO respectively. Similarly, LPSP, renewable factor, pollutant emissions, penalty cost, operating hours of diesel generator, PV power, wind power, biomass power, diesel generator power, reliability and algorithm running time for cycle charging strategy using GA & PSO are 0.01430 & 0.01409, 0.8659 & 0.8857, 8.9069 ton & 8.7027 ton, 219.8155 $ & 214.7755 $, 1078 hr & 1036 hr, 24178 kW & 32399 kW, 34435 kW & 34435 kW, 5693.3 kW & 5693.3 kW, 8624 kW & 8288 kW, 98.57% & 98.59% and 535.4624 Sec & 501.3572 Sec respectively. The above analysis clearly indicates that the PSO gives the better results for load following as well as cycle charging strategy with respect to the performance parameters of hybrid system.



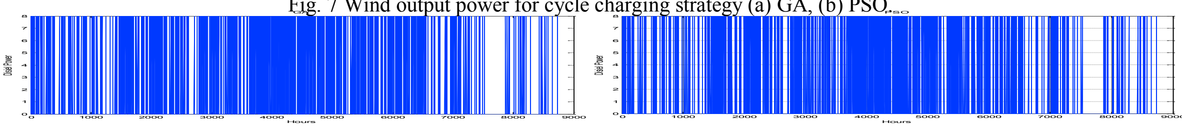
(a) (b)

Fig. 6 PV output power for cycle charging strategy (a) GA, (b) PSO.

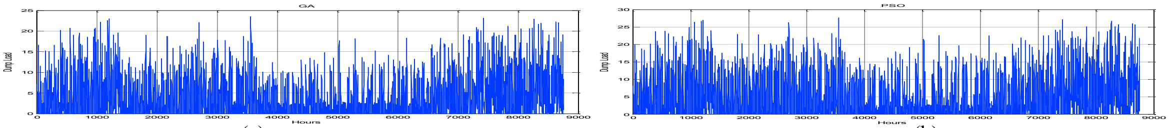


(a) (b)

Fig. 7 Wind output power for cycle charging strategy (a) GA, (b) PSO.



(a) (b)
Fig. 8 Diesel Generator output power for cycle charging strategy (a) GA, (b) PSO.

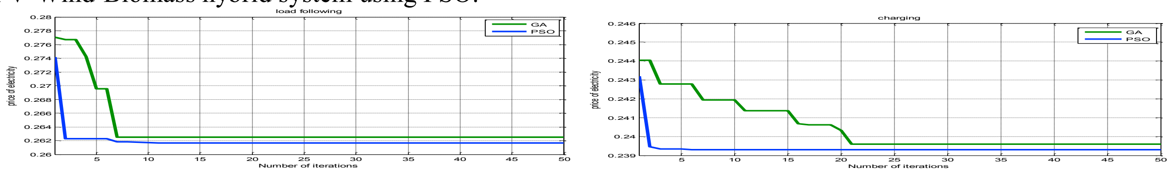


(a) (b)
Fig. 9 Dump Load for cycle charging strategy (a) GA, (b) PSO.

Table 3 Results for load following and cycle charging strategy using GA and PSO of hybrid system

Parameters	Cycle Charging		Load Following	
	GA	**PSO**	**GA**	**PSO**
N_{PV}	50	67	61	66
N_{WIND}	16	16	18	18
Price of electricity (COE in $/kWhr)	0.2396	0.2393	0.2625	0.2617
LPSP	0.01430	0.01409	0.0172	0.0164
Renewable Factor	0.8659	0.8857	0.9198	0.9237
Pollutant Emissions (ton)	8.9069	8.7027	7.2668	7.2038
Emission penalty cost ($)	219.8155	214.7755	179.3397	177.7828
Operating hours DG (hr)	1078	1036	2127	2089
PV Power (kW)	24178	32399	29497	31915
Wind Power (kW)	34435	34435	38739	38739
Biomass Power (kW)	5693.3	5693.3	5693.3	5693.3
Diesel Power (kW)	8624	8288	5925.6	5821.8
Reliability (%)	98.57	98.59	98.28	98.36
Algorithm Running Time (Sec)	535.4624	501.3572	566.0706	543.1537

The comparative results analysis of hybrid system for operating hours of DG, COE, pollutant emissions, reliability, algorithm running time including load following and cycle charging strategies using GA and PSO are shown in table 3. The table 3 shows that the operating hours of DG, COE, pollutant emissions, reliability and algorithm running time have comparable difference and better results are achieved by using PSO than GA for both load following and cycle charging strategies. The comparison of load following and cycle charging strategies can be given on the basis of optimum results obtained by each strategy as shown in table 3. These results indicates that the operating hours of DG, COE, algorithm running time are less and also reliability is higher for cycle charging strategies using GA and PSO. Hence, the overall effects are more efficient for cycle charging strategies using PSO. The optimal planning of PV-Wind-Biomass hybrid energy system including cycle charging strategy is more efficient and techno-economic than load following strategy; hence the cycle charging strategy is better for optimal planning of PV-Wind-Biomass hybrid system using PSO.



(a) (b)
Fig. 10 Comparison of Price of electricity (COE) using GA and PSO (a) load following strategy, (b) Cycle charging strategy.

5. Conclusion

The optimal planning of PV-Wind-Biomass hybrid energy system including cycle charging and load following strategies are presented for remote location case study situated in barwani district. The result shows that price of electricity (COE) for load following strategy are 0.2625 $/kWhr with GA and 0.2617 $/kWhr with PSO and also for cycle charging strategy are 0.2396 $/kWhr and 0.2393 $/kWhr using GA and PSO respectively. The analysis clearly indicates that cycle charging strategy gives better results using PSO. Hence the cycle charging strategy using PSO is the more economic option for optimum plan of PV-Wind-Biomass hybrid energy system. Similarly, the LPSP, renewable factor, pollutant emissions, penalty cost, operating hours of diesel generator, PV power, wind power, biomass power, diesel generator power, reliability and algorithm running time for cycle charge strategy using GA & PSO are more optimum as compared to load following strategy using GA & PSO. The table 3 shows that the operating hours of DG, COE, pollutant emissions, reliability and algorithm running time have comparable difference and better results are achieved by using PSO than GA for cycle charging strategies. The comparison of load following and cycle charging strategies can be given on the basis of optimum results obtained by each strategy. The optimal planning of PV-Wind-Biomass hybrid energy system including cycle charging strategy is more efficient and techno-economic than load following strategy; hence the cycle charging strategy is better for optimal planning of PV-Wind-Biomass hybrid system using PSO.

REFERENCE

[1] Diaf, Said, et al. "A methodology for optimal sizing of autonomous hybrid PV/wind system." Energy Policy 35.11 (2007): 5708-5718.

[2] Rodolfo Dufo-Lopez, José L. Bernal-Agustín, Multi-objective design of PV–wind–diesel–hydrogen–battery systems, Renewable Energy, Volume 33, Issue 12, December 2008, pp. 2559-2572.

[3] Papaefthymiou, Stefanos V., and Stavros A. Papathanassiou. "Optimum sizing of wind-pumped-storage hybrid power stations in island systems." Renewable Energy 64 (2014): pp. 187-196.

[4] Karakoulidis K, Mavridis K, Bandekas D, Adoniadis P, Potolias C, Vordos N." Techno-economic analysis of a stand-alone hybrid photovoltaic-dieselebattery- fuel cell power system". Renew Energy 011;36: pp. 2238-2244.

[5] Prakash, S. Lenin, M. Arutchelvi, and A. Stanley Jesudaiyan. "Autonomous PV-Array Excited Wind-Driven Induction Generator for Off-Grid Application in India." IEEE Journal of Emerging and Selected Topics in Power Electronics 4.4 (2016): pp. 1259-1269.

[6] Sawle, Yashwant, S. C. Gupta, and Aashish Kumar Bohre. "PV-wind hybrid system: A review with case study." Cogent Engineering 3.1 (2016): 1189305.

[7] J Park, Jeongje, et al. "A probabilistic reliability evaluation of a power system including solar/photovoltaic cell generator." 2009 IEEE Power & Energy Society General Meeting. IEEE, 2009.

[8] Yashwant- sawle and S. C. Gupta "A novel system optimization of a grid independent hybrid renewable energy system for telecom base station" International Journal of Soft Computing, Mathematics and Control (IJSCMC),Vol. 4, No. 2, pp. 49-57,May 2015.

[9] Yashwant Sawle, and S. C. Gupta. "Optimal sizing of photo voltaic/wind hybrid energy system for rural electrification." In Power India International Conference (PIICON), 2014 6th IEEE, pp. 1-4. IEEE, 2014.

[10] Gupta A. Modelling of hybrid energy system [Ph.D. thesis]. Roorkee: Alternate Hydro Energy Centre, Indian Institute of Technology; 2010.

[11] El-Hefnawi, Said H. "Photovoltaic diesel-generator hybrid power system sizing." Renewable Energy 13.1 (1998): 33-40.

[12] Ashari, Mochamad, and C. V. Nayar. "An optimum dispatch strategy using set points for a photovoltaic (PV)–diesel–battery hybrid power system." Solar Energy 66.1 (1999): pp.1-9.

[13] Kaabeche, Abdelhamid, Maïouf Belhamel, and Rachid Ibtiouen. "Techno-economic valuation and optimization of integrated photovoltaic/wind energy conversion system." Solar energy 85.10 (2011): pp.2407-2420.

[14] Luna-Rubio, R., et al. "Optimal sizing of renewable hybrids energy systems: A review of methodologies." Solar Energy 86.4 (2012): pp.1077-1088.

[15] Global Horizontal Irradiation (GHI). In: SolarGIS. GeoModel Solar; 2013. Available from: http://solargis.info/doc/71.

[16] Rajkumar, R. K., et al. "Techno-economical optimization of hybrid pv/wind/battery system using Neuro-Fuzzy." Energy 36.8 (2011): 5148-5153.

[17] Yang, H. X., L. Lu, and J. Burnett. "Weather data and probability analysis of hybrid photovoltaic–wind power generation systems in Hong Kong." Renewable Energy 28.11 (2003): pp.1813-1824.

[18] http://www.homerenergy.com

[19] S.C. Gupta, Dr.Y.Kumar, Dr. Gayatri Agnihotri "Reast: Renewable energy analysis and sizing tool"J. Electrical Systems 7-2 (2011): pp. 206-224.

[20] NPL (National Physical Laboratory), Delhi, India. URL: /http://www.nplindia. org/S.

[21] S.C.Gupta, Y.Kumar, G.Agnihotri, Techno-economical design of an autonomous photovoltaic wind hybrid energy system, IEEE Power India Conference(POWERCON)2008,New Delhi, India

[22] Barley, C. D., et al. Optimal control of remote hybrid power systems. Part 1: Simplified model. No. NREL/TP--441-7806; CONF-950309--3. National Renewable Energy Lab., Golden, CO (United States), 1995.

[23] A. K. Bohre, G. Agnihotri and M. Dubey, "Optimal sizing and sitting of DG with load models using soft computing techniques in practical distribution system," in IET Generation, Transmission & Distribution, vol. 10, no. 11, pp. 2606-2621, 8 4 2016.
[24] Maleki Akbar, Ameri Mehran, Keynia Farshid, "Scrutiny of multifarious particle swarm optimization for finding the optimal size of a PV/wind/battery hybrid system" Renewable Energy, 80, (2015): pp. 552-563.