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Modeling and Performance Evaluation of Hybrid Renewable Energy System Considering The Ageing of System Components

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ABSTRACT

A new approach called ageing approach is presented in this paper while modeling and evaluation of the cost of the hybrid renewable energy system. The ageing effect of the system components directly affects the system performance which in turn affects the net present cost (NPC), generation cost (GC) and cost of energy (COE) of the hybrid system. Initially, the test system comprising hydro-wind-solar-fuel cell is considered without considering the ageing effect of the system components. The performance evaluation of the system is carried out with the help of an optimization technique called Bees algorithm (BA) and results of techno-economic feasibility analysis are presented. But this techno-economic analysis is not a true reflection of the real system because ageing of each component leads to the less efficient system. Therefore, system is again tested considering this ageing effect and modified results are reported. It is observed that the system performs with less efficiency and the cost of energy is high if ageing factor is considered. This result may lead to a real world implementation of the system more accurately and precisely.

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INTRODUCTION

Due to sparse availability of the fossil fuels and increasing energy demand, green energy is getting highest priority for energy production all over the world. There are many remote places where grid is not extended to provide the power supply. The extension of grid to the remote places may incur huge expenses and on the other hand conventional electrification will make the environmental more vulnerable to the pollution. Therefore, standalone renewable energy resources are thought to be a feasible option to mitigate the power scarcity as well as providing the carbon free environment. But the renewable energy resources are intermittent in nature and power cannot be produced continuously from these resources. In this scenario, hybrid energy system which is the combination of all or few of many may act as a feasible and reliable alternative to the conventional energy production system. But the performance of any hybrid renewable energy system primarily depends on the site under consideration. Geographical position and load characteristic of that particular site play a pivotal role in energy production from the renewable resources and the performance of the hybrid systems has a larger impact on the energy security and economics of any country in long run.

Therefore, hybrid system capacity determination, performance evaluation and economic assessment seek special treatment from the researchers and engineers.

Many works on system sizing and techno-economic feasibility analysis of hybrid system have been reported by the researchers all over the world and also many research findings have shown that different meta-heuristic optimization techniques are capable of providing solution for multi objective, non-linear, real world complex problems and different optimization techniques were applied for optimization of hybrid energy systems comprising of different combinations of energy sources (Erdinc and Uzunoglu, 2012; Mellit *et al*., 2009; and Banos *et al*., 2011). The most popular methods are genetic algorithm (GA) and particle swarm optimization (PSO) and their different modified versions (Fadaee and Radzi, 2012). Bilal *et al*. (2010) applied genetic algorithm to obtain optimal sizing of a hybrid solar -wind-battery system and investigated the influence of the load profiles on the optimal configuration. Techno-economic analysis of hybrid system was also carried out by Koutroulis *et al*. (2006, 2010), Yang *et*

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al. (2009) and Kalantar and Mousavi (2010) using GA. Optimal sizing of a stand-alone PV-fuel cell-battery hybrid system for powering street lighting system was presented by Lagorse *et al*. (2009). Hybrid Optimization by Genetic Algorithms (HOGA) was applied to obtain the optimal design of stand-alone hybrid system by Lopez and Bernal-Agustin (2005, 2008). Tudu *et al*. (2011) presented the hydro-wind-PV-fuel cell hybrid system configuration for a localized demand using GA and PSO. The optimization problem of hybrid system was addressed with the PSO techniques by Sanchez *et al*. (2010), Denghan *et al*. (2009) and Kaviani *et al*. (2009). Different hybrid system optimization problems were addressed by Tafreshi and Hakimi (2009), and Wang and Singh (2009). Basic version and improved version of PSO was implemented to obtain the optimal sizing and cost of hydro-wind-PV-fuel cell and PV-wind-battery-diesel system by Tudu *et al*. (2014, 2012). Apart from these techniques, many other techniques like differential evaluation (DE), simulated annealing (SA), bees algorithm etc. are used in the field of hybrid system optimization problem (Erdinc and Uzunoglu, 2012; Banos *et al*., 2011).

The research works published by many researchers including above mentioned works on techno-economic analysis of hybrid renewable energy system to find out the optimal sizing, cost and performance considering different parameters didn't address the impact of component ageing on the system performance apart from few works like Erdinc and Uzunoglu (2012) and Guinot *et al*. (2013).

The present work addresses the performance of the off-grid hybrid renewable energy system considering the ageing effect of the components. Initially, the hybrid system of hydro-wind-solar-fuel cell is optimized with the help of Bees algorithm optimization technique and results are presented obeying the power balance equation. The system total cost and cost of energy are reported with the optimal configuration. Then, optimal sizing and cost parameters are reported considering the ageing effect of the system components. A comparative analysis is done with these results. The results show that system performance degrades while we consider the effect and Bees algorithm performs satisfactorily for both optimization problems.

Hybrid Energy System:

The test hybrid system consists of micro hydro, PV, wind, and fuel cell. The system is modelled for a remote site far away from grid line and assuming availability of all the renewable resources. The solar irradiance, wind speed and load data for the specific site are obtained and hourly variations of these data are shown in Fig. 1 (Tudu *et al*., 2014). The load profile of that particular location is assumed to be increased by 10% over the lifetime of the project of 25 years.

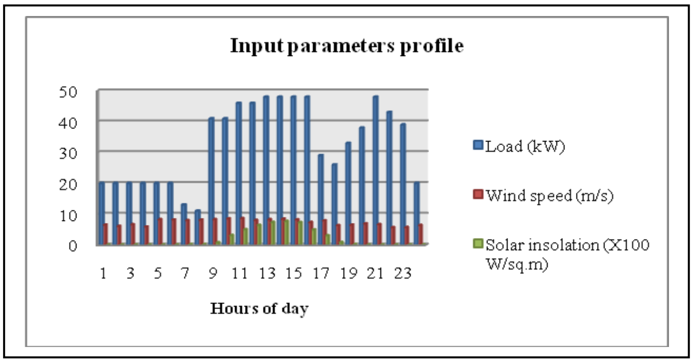

Fig. 1: Hourly load, solar insolation and wind velocity

The hybrid solar-wind-fuel cell system along with the micro-hydro plant is optimized for the total load of the site. Each hour load is met with the power provided by the hybrid system. The hourly output power from the wind turbines and solar modules depends on meteorological data of that particular site and hourly micro-hydro output depends on the hourly water flow. For any specific hour, if load is more than the combined power output from the wind, solar and micro-hydro plant, then fuel cells are operated to generate the required deficit power. The solar PV is connected to the inverter and DC power is converted to AC power required by the load by the inverter. The fuel cells are also connected to inverter to feed the AC load. If there is any excess power in any hour, it is utilized by electrolyzers employed in the system. The electrolyzers utilize this excess power to generate hydrogen which is stored in the hydrogen tank in compressed form. The stored Hydrogen is used by the fuel cells when the fuel cells are operated to cater the load. The stored hydrogen basically minimizes the need to buy additional hydrogen from market and this regenerative process gives the system more flexibility to operate and system performance and reliability is increased. The system AC bus feeds the required power to load and whole system arrangement is shown in Fig. 2.

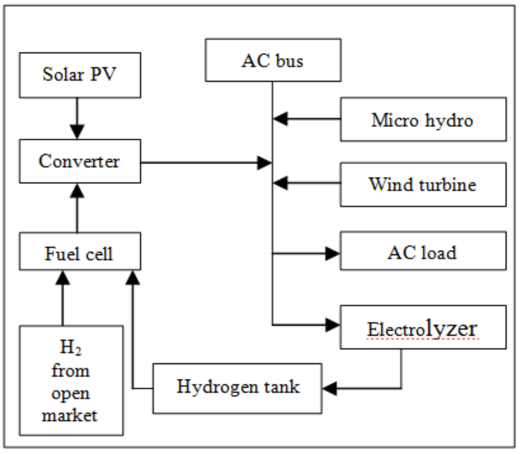

Fig. 2: Schematic diagram for integrated hybrid system

The System Cost and Objective Function:

The objective function of this optimization problem is the net present cost (NPC) of the hybrid system. The total annualized cost of the system is the summation of cost of each component. The different cost components of the system components are annualized capital cost, annualized replacement cost, annualized operation and maintenance cost as well as annualized fuel cost if any.

The net present cost of the system can be expressed as (Tudu *et al*., 2014):

$$C_{NPC} = \frac{C_{ann,\ tot}}{CRF_{proj}} \tag{1}$$

The cost of energy (COE) of the system is given by (Katsigiannis *et al*., 2010):

$$COE = \frac{C_{ann,\ tot}}{Total\ \ load\ \ in\ \ kWh} \tag{2}$$

Where $C_{ann,tot}$ is the total annualised cost of the system.

The generation cost (GC) is expressed as:

$$GC = \frac{C_{ann,\ tot}}{Total\ \ power\ \ generated\ \ in\ \ kWh} \tag{3}$$

When the power balance criteria is met, then the COE and GC will be same but if the system generates excess energy then values of two terms will be different. This work presents both the cost components of the hybrid system along with the system net present cost for two different cases.

Bees Algorithm:

Bees algorithm (BA) was introduced by Pham *et al*. (2005) in 2005 and it is a population based optimization algorithm which is based on the natural behavior of real bees in food foraging.

The bees have a certain process for food collection in real world. The scout bees travel in different direction in search of possible food. If they find the flower patches with more nectar and pollen then they fly back to the hive to inform other bees. Scout bees exchange this information with other bees by performing a special dance called ‘waggle dance’. The exchanged information includes the basic information of distance of the flower patches from the hive, direction of the flower patches, and quality of the nectar of the flower patches (Camazine *et al*.). Based on the information exchanged, scout bees along with other bees fly to the flower patches and number of bees accompanying the scout bees is decided depending upon the relative quality of the patches. The remaining bees then randomly travel to other search spaces in search of possible flower patches. This whole process of food collection helps bees to collect the food in easy and efficient way.

Multi-objective complex real world problems can be solved by the algorithm inspired by these behaviors of the bees. The operation of the BA is associated with different parameters tuning (Guney and Onay, 2010). These parameters are (a) number of scout bees, ‘n’, (b) number of best sites, ‘m’, (c) number of elite sites, ‘e’ out of ‘m’ sites, (d) number of bees employed for ‘e’ sites, ‘nep’ for neighborhood search, (e) number of bees employed for ‘m-e’ sites, ‘nsp’ for neighborhood search, (f) sizes of the patches, ‘ngh’ and (g) stopping criteria. The algorithm starts with the initialization of scout bees ‘n’ in search space with the random values. The fitness of each bee is evaluated for the visited sites according to objective function of Eq. (1) in step 2. The flowchart of the algorithm is given in Fig. 3 (Moradi *et al*., 2011).

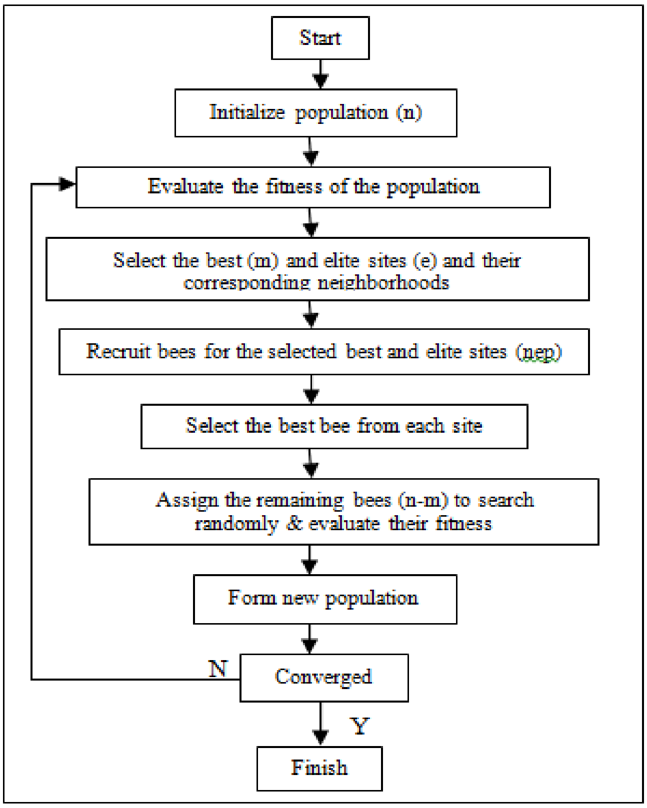

Fig. 3: Flow chart of bees algorithm (Moradi *et al*., 2011).

The algorithm is tested with different values of external parameters and number of iterations while performing the optimization of the problem. The final values of the parameters and number of iteration used in this algorithm are tabulated in Table 1. The unique feature of the algorithm is the neighborhood search along with random search which overcomes the problem of local optima and converges to global optimal value. The random value assigned to each bee is obtained by the equation below (Moradi *et al*., 2011):

$$X_i = X_{\min} + \alpha \times (X_{\max} - X_{\min}) \qquad (4)$$

Where α is random vector whose elements are between 0 & 1 and X_{min} & X_{max} are lower and upper limits of the solution vector (population) respectively.

The neighborhood search around best and elite sites of the solution vector is performed according to equation (Moradi *et al*., 2010):

$$X_{si} = (X_i - ngh) + 2 \times \alpha_i \times ngh \qquad (5)$$

Where X_{si} is the position of the recruited bee in the neighborhood search area around X_i with neighborhood radius (patch size) of *ngh* and α_i is the random number in the interval (0, 1).

Table 1: Different parameters considered for Bees algorithm

Bees algorithm parameters	Symbol	Value
Total number of population	*n*	100
Bees selected for neighbourhood search	*m*	20
Number of best sites selected out of selected m sites	*e*	3
Number of bees recruited for best e sites	*nep*	50
Number of bees recruited for best (m-e) sites	*nsp*	10
Initial patch size for wind	*ngh_w*	5
Initial patch size for Solar	*ngh_s*	15
Number of iteration (stopping criteria)	*g*	50

Ageing Approach:

There are many research works reported on the techno-economic feasibility analysis of the hybrid system but none of them included the effect of power output degradation issue due to ageing of the system components over the lifetime of the component. The requirement to perform the accurate and precise techno-economic analysis leads to the integration of degradation features of the components (Erdinc and Uzunoglu, 2012; Guinot *et al*., 2013). The degradation issue may be addressed with the help of two different models (Guinot *et al*., 2013). First model considers the feature by means of lifetime but with constant performance over the lifetime. The second model considers the degradation of performance over the time whereas lifetime remains constant. These models lead to a different optimal sizing of the hybrid system and cost of the energy. This consideration will impact the different economic indicators such as cumulated replacement, operation & maintenance cost etc. This may be incorporated considering the real time management of each component.

Therefore, the component performance (CP) can be expressed as (Guinot *et al*., 2013):

$$CP = 1 - \frac{V_c(t) - V_{c,new}(t)}{V_{c,end}(t) - V_{c,new}(t)} \quad (6)$$

Where $V_c(t)$ is control variable of the component, $V_{c,new}(t)$ is variable when the component is new and $V_{c,end}(t)$ is the variable when its lifetime ends.

Present work initially reports the optimal sizing and optimized cost of the hybrid system without considering the ageing effect of the components as case-I and then optimal sizing and optimal cost are presented considering the effect as case-II.

Results and Performance Study:

After modeling the system with different renewable resources, the optimal configuration and cost thereby are obtained by optimizing the system performance. The optimization of the system is obtained by formulating the MATLAB code in computer based on the BA optimization algorithm. Each position of the swarms in the search space represents the possible solution of the optimization problem. Each swarm represents the set of system control parameters. The merit of the solution is determined by the cost function given in Eq. (1). Algorithm is started with the random values generated for different independent parameters for pre-defined population. The position and velocity of each particle are updated according to Eq. (4) and (5) in each iteration and accordingly cost function changes. The optimal sizing obtained is presented in Table II for case-I.

Table 2: Optimal sizing obtained for the integrated hydro-solar-wind-fuel cell system (case-I)

Component	Optimal Sizing (No. of Units)	Capacity (kW)
Wind Turbine	12	120
Solar Panel	4	0.6
Converter	4	20
Fuel Cell	4	20
Electrolyser	12	12
Hydrogen Tank	4	4 kg.
Net Present Cost (NPC): Rs. 51230.92k		
Generation Cost (GC): Rs. 16.74/kWh		
Cost of Energy (COE): Rs. 12.14/kWh		

The optimal configuration of the system takes 12 numbers of wind turbines, 4 numbers of solar panels and 4 numbers of fuel cells without considering the ageing effect. The system is now again tested and optimal results are presented considering the ageing effect. The comparative results of the optimal sizing and cost of the hybrid system with and without ageing effect are presented in Fig. 4 and Fig. 5.

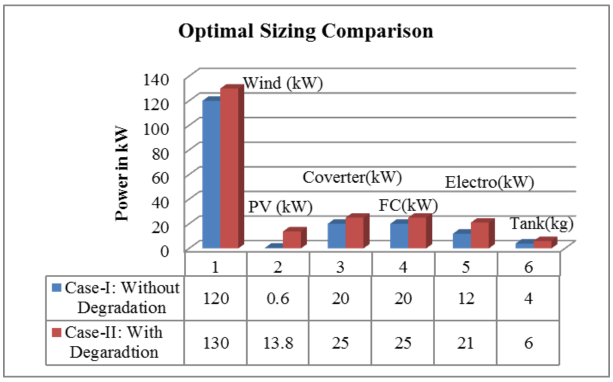

Fig. 4: The comparative results of system capacity for case-I and Case-II

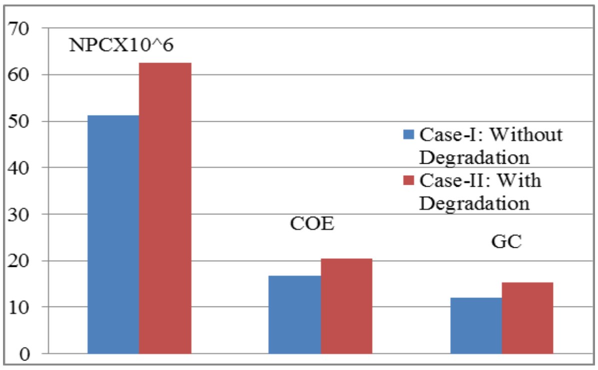

Fig. 5: The comparative results of different cost parameters for case-I and Case-II

From above table, it is seen that the optimal sizing for the hybrid system consists of 120 kW of Wind, 0.6 kW of solar PV, 20 kW of Converter, 20 kW of fuel cell, 12 kW of Electrolyzer and 4 kg of hydrogen tank. The optimal cost of energy and generation cost are Rs. 16.74 and Rs. 12.14 respectively. But in case-II, when degradation of the components is considered, the system optimal sizing as well as cost changes and for the same system power output is less and cost is more. Case-II chooses the hybrid system of 130 kW of wind and 13.8 kW of solar instead of 0.6 kW and accordingly costs change. The cost of energy for this second case is Rs. 20.46 per kWh while generation cost is Rs. 15.36 per kWh . The deficit energy supplied by fuel cell is high in case-II which reflects the more dependency on fuel cell. So a higher number of fuel cells and the converters are installed. Number of installed electrolysers is high emphasizing on the fact that the surplus energy production is also high. So the system cost increased accordingly.

The optimization technique plays a crucial role for obtaining the optimal configuration of the hybrid system and feasibility analysis of the system configuration. It is seen that Bees algorithm performs efficiently while optimizing the system. Fig.5 shows the net present cost vs. number of iteration graph for the algorithm.

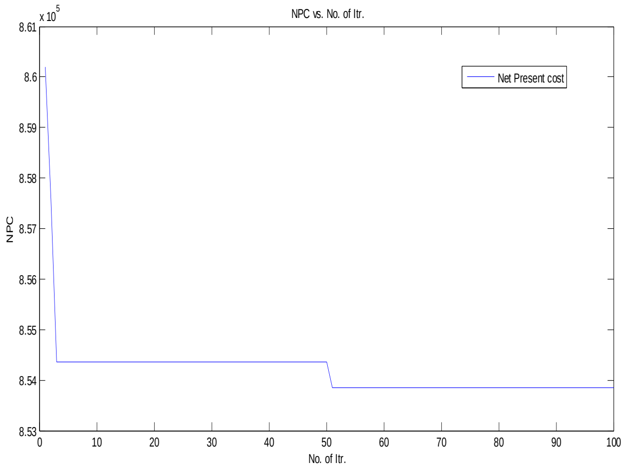

Fig. 6: NPC vs. iterations for Bees algorithm

Conclusions:

The present paper focuses on the design and optimal sizing of the hybrid system using Bees algorithm and system performance are presented with and without considering the ageing effect leading to degradation of the performance of the system components. The system is designed and optimized depending on the geographical position and load characteristic of the location. Characteristic of the designed system is analyzed closely under the two scenarios and it is observed that the system sizing changes if we consider the ageing effect and cost of the system is increased as well. This represents the real time scenario and it will help researchers and engineers to take right decision while implementing the system in real world.

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