Energy Conversion and Management 74 (2013) 237–248

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Converting existing Internal Combustion Generator (ICG) systems into HESs in standalone applications

A.T.D. Perera, R.A. Attalage *, K.K.C.K. Perera, V.P.C. Dassanayake

Department of Mechanical Engineering, University of Moratuwa, 10400 Katubedda, Sri Lanka

ARTICLE INFO

Article history:
Received 20 October 2012
Accepted 12 May 2013
Available online 12 June 2013

Keywords:
Standalone systems
Hybrid energy systems
Multi objective optimization
Evolutionary algorithms
Lifecycle cost
Green house gases (GHG) emission
Initial capital cost
Power supply reliability

ABSTRACT

Expanding existing Internal Combustion Generator (ICG) systems by combining renewable energy sources is getting popular due to global concern on emission of green house gases (GHG) and increasing fossil fuel costs. Life cycle cost, initial capital cost (ICC), power supply reliability of the system, and GHG emission by ICG are factors to be considered in this process. Pareto front of Levelized Energy Cost (LEC)–Unmet Load Fraction (ULF)–GHG emission was taken in this study for four different expansion scenarios. Furthermore, Pareto front of ICC–LE–ULF was taken for three different expansion scenarios in order to analyze the impact of renewable energy integration. The results clearly depict that characteristics of the Pareto front varies with the scale of expansion and objectives taken for the optimization. A detailed analysis was conducted for a scale up problem with a 4 kVA ICG by using the Pareto fronts obtained.

Published by Elsevier Ltd.

1. Introduction

The capability to develop energy systems that are completely driven by renewable energy sources is an attractive opportunity [1]. Introduction of renewable energy sources into existing conventional energy systems can be taken a major step in this process. Such Hybrid Energy Systems (HESs) are becoming popular for off grid applications, where existing grids neither reached nor became economical [2]. Therefore, modeling, simulation and optimization of HES is a rich area of study due to a number of favorable characteristics of such HESs when compared to Internal Combustion Generator (ICG) systems [3,4]. Reduction of lifecycle cost, pollutant emission and maintenance can be taken as major advantages [5–7] of these systems which had resulted in number of applications as in rural electrification [8–10], desalination [11,12], tourism [13], telecommunication [14], etc. However, it is a challenging exercise to come up with the optimum design of such systems as these include energy sources with different characteristics.

Various techniques have been used to obtain optimum HES design and control strategy [3,4]. However, recent reviews on HES optimization suggest that heuristic methods are becoming increasingly popular to carry out this task [15–17]. At the same time, Pareto optimization is becoming popular due to its capability to evaluate conflicting objectives. Lopez and Agustín [18] introduced multi objective optimization into HES design by considering life cycle cost of the system and pollutant emission as objective functions which was extended later [19,20]. Moreover, Shi et al. [21] have highlighted the importance of optimizing renewable energy utilization efficiency along with life cycle cost and power supply reliability. Role of ICG in HES has been taken into discussion by Perera et al. [22] and Lopez et al. [23] by using multi objective optimization which portray the critical impact of ICGs in standalone energy systems. Recent reviews on HES design and optimization highlights the importance of adapting optimization techniques to match with real world application beyond the theoretical analysis [15].

Conversion of ICG systems into HESs is becoming popular for standalone applications. Previous studies on converting existing ICG systems into HESs emphasize the importance of maintaining a proper balance among the renewable energy sources in the expansion process [24,25]. A number of aspects need to be considered in this process including lifecycle cost, initial capital cost (ICC), power supply reliability and reduction in GHG emission where multi-criterion analysis is essential. Pareto multi objective optimization becomes an ideal technique to obtain alternative design solutions which can be analyzed subsequently. However, such detailed Pareto analysis has not been conducted for the conversion of existing ICG systems into HESs besides its timely importance which is taken to be the main objective of this study.

* Corresponding author. Tel.: +94 714964961; fax: +94 112650621.
E-mail address: raattalage@gmail.com (R.A. Attalage).

0196-8904/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.enconman.2013.05.022

In this research, multi objective optimization is used to derive the optimum HES design capable of catering timely varying electricity load demand (ELD) with a peak of 7.5 kW (Fig. 1). Pareto analysis is conducted considering conflicting objectives such as Levelized Energy Cost (LEC), ICC, power supply reliability and GHG emission by ICG. A detailed description of the mathematical model used for the analysis is given in Sections 2–4. A concise illustration about the optimization algorithm is given in Section 5. Finally, a detailed discussion is carried out in Section 6 based on the results obtained.

2. Energy flow modeling and simulation of HESs

A HES comprising wind turbines, Solar PV (SPV) panels, ICG, battery bank, AC–DC converters, DC–AC converters, and a battery charger was the subject of modeling and simulation (Fig. 2).

Hourly wind speed and solar insolation data are taken from the location where the system to be implemented, whereas power output from the wind turbines, and SPV panels are computed considering the conversion efficiencies. Energy requirement from dispatchable energy sources is computed based on the difference between ELD and renewable energy produced (Fig. 3). A detailed version of the system component modeling is exemplified in [22,25].

2.1. Mathematical modeling of renewable energy component

In order to compute the hourly solar energy element from SPV modules, hourly horizontal solar irradiation at Hambathota (06°07′N81°07′E) was taken (Fig. 4).

These values are converted to hourly tilted global solar irradiation (G_β) using Climed-2 [26] and Klucher [27] models. Efficiency of SPV modules are calculated using Durish model [28] (Eq. (1)).

$$\eta_{pv} = p\left[q\frac{G_\beta}{G_{\beta,0}} + \left(\frac{G_\beta}{G_{\beta,0}}\right)^m\right]\cdot\left[1 + r\frac{\theta_{cell}}{\theta_{cell,0}} + s\frac{AM}{AM_0} + \left(\frac{AM}{AM_0}\right)^u\right] \quad (1)$$

In Eq. (1), AM denotes the air mass value [29] and θ_{cell} denotes the cell temperature. Values for $G_{\beta 0}$, $\theta_{cell,0}$ and AM_0 are taken as $G_{\beta 0} = 1000\ W\ m^{-2}$, $\theta_{cell,0} = 25\ °C$, and $AM_0 = 1.5$. Parameters p, q, r, s, m, u for different SPV technologies are taken from [28].

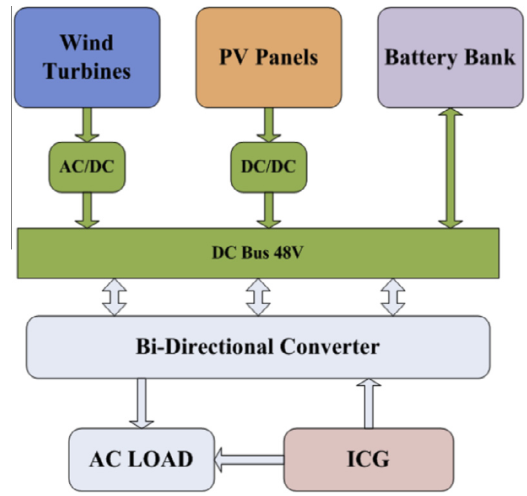

Fig. 2. HES configuration.

Finally, hourly power output of the SPV panels ($P_{SPV}(t)$) is calculated taking G_β, η_{pv} and panel area (A_{SPV}) according to the following equation:

$$P_{SPV} = G_\beta \eta_{pv} A_{SPV} N_{SPV} \eta_{spv\text{-}inv} \quad (2)$$

In Eq. (2), $\eta_{spv\text{-}inv}$ denotes the efficiency of the inverter and N_{SPV} denotes the number of SPV panels which is optimized using the optimization algorithm. Degradation of the performance of solar PV panels was assumed to be negligible.

Hourly wind speed at the same location was taken at an anemometer height of 12 m (Fig. 5) which is used to calculate the wind speed at wind turbine-hub level using power law approximation.

Power curve of a wind turbine is unique in itself, which provides the variation of wind turbine power with wind speed at hub level. Using a single mathematical model to demonstrate all the wind turbines conceals the individual characteristics built in them. Hence, the perfect method would be to use a separate mathematical model for each wind turbine, which however is an exhaustive task especially with large numbers of wind turbine

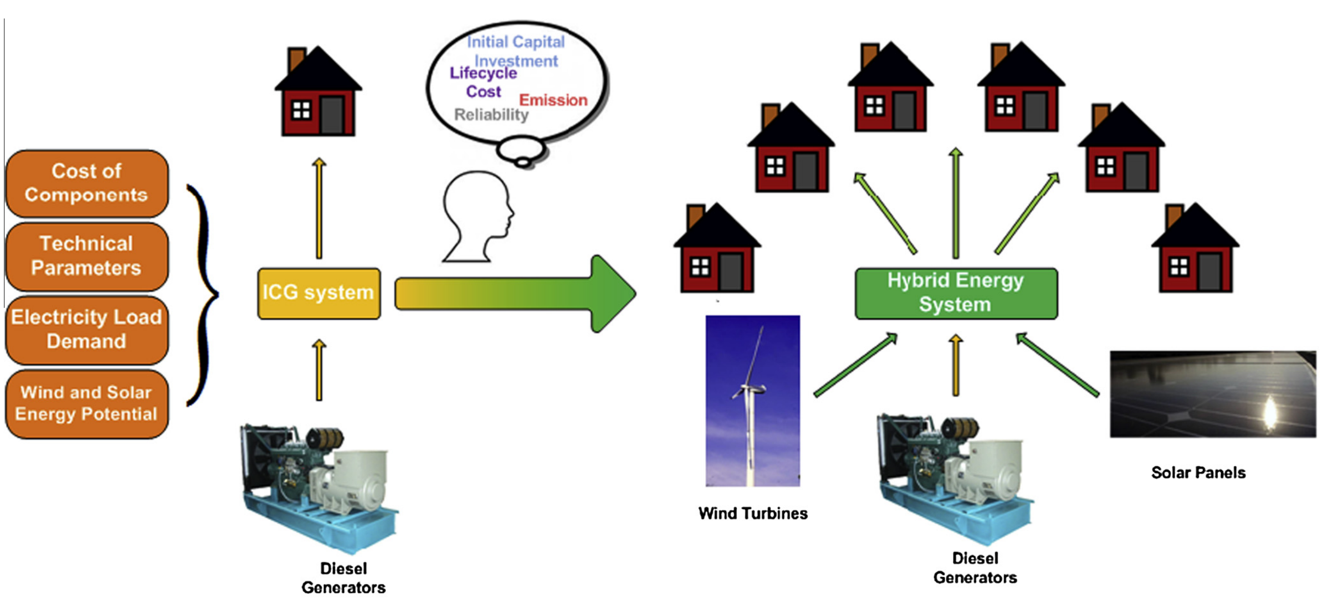

Fig. 1. Schematic representation of the problem addressed.