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Research Paper

Application of R-curve analysis in evaluating the effect of integrating renewable energies in cogeneration systems

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HIGHLIGHTS

- R-curve tool is used to evaluate the effect of integrating renewables in cogeneration systems.
- Based on the operating conditions, this integration can improve or deteriorate the efficiency.
- A new benchmarking tool is proposed to account for the effect of renewable integration.
- 13 MW of renewable power can cause either 4 or 53 MW of energy saving based on the integration scenario.

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ABSTRACT

Because of their higher efficiency, cogeneration systems are widely used in many industrial plants. Moreover, due to concerns about environmental issues, replacing conventional fossil fuels with clean and sustainable energy resources seems inevitable. In This paper, the effect of integrating renewable energy resources in cogeneration systems is investigated. As will be demonstrated, integration of these resources can either improve or deteriorate the performance of the cogeneration system. Therefore, R-Curve tool is used for a detailed analysis on the effect of integrating renewable energies on the performance of the cogeneration system. Different scenarios for integration of solar and wind power as well as solar heat are investigated. Also, a new benchmarking index is proposed as a comparison tool for integration of renewables into total site utility systems. Finally, three cases are studied using the proposed concepts. As the results suggest, with the same renewable system, there is a considerable difference between savings for different scenarios of integration. Accordingly, as an example, integration of a 13 MW solar power plant can be associated with either 53 or 4 MW of fuel saving in the same cogeneration system based on the operating state.

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1. Introduction

Today, operation costs, carbon production and reliability of the site utility system are among the most important parameters in design, evaluation and optimization of industrial plants. In addition, fuel cost is a major contributor to the total operational costs of many chemical, petrochemical, food and other industries. Accordingly, in past few decades, researchers and engineers have been trying to find methods for reducing the energy consumption of site utility systems. Generating power and thermal energy from the same fuel source is among the most highly regarded concepts of these efforts. The so-called "cogeneration systems" offer a more reliable production, less energy consumption, less emissions and reduce the grid congestion [1]. Large industrial cogeneration systems often consist of several steam mains, a complex network of back pressure and condensing turbines, boilers, let-down stations and other components. Therefore, they have high degrees of freedom for optimization [2]. Accordingly, besides tools proposed for cogeneration targeting such as site utility grand composite curves, several methods have been developed for optimization of existing designs [2]. Top level analysis and R-curve methods are both considered as practical tools for optimization of cogeneration systems [3]. R-curve is a powerful method which is used to identify the current operating state of the system, scope for improvement, comparison between different options, identifying promising options for debottlenecking and proper direction for energy retrofit [4]. The concept of R-curve was first proposed by Kenny in 1984 and was further developed by Zhu and Kimura [4,5]. Later, other modifications were made on R-curve in order to extend its applications. These modifications include proposing new methods for modeling turbines and other components [6–8] and introducing the concept of environmental and economic R-curves [9,10].

In addition to developing methods for reducing the energy consumption of industrial plants, replacing the conventional fossil fuels

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with a more clean and sustainable alternative is considered as the other path toward a low cost and emission free production. Therefore, besides efforts on optimization and improvement of site utility systems, integrating renewable energies into industrial plants has also been considered by many researchers [11]. These efforts were made on a single process as well as the total site utility system. Feasibility studies on integrating renewable energies into industrial plants suggest a promising outlook. As an example, the results of Lauterbach et al. suggest that Germany has the potential of saving 16 TWh/year of energy by applying solar heat in industrial plants [12]. Kalogirou and Beath have also investigated the feasibility of using solar heat in Mediterranean region and Australia and reported that both of these regions have a great potential for integration of solar heat in their industrial plants [13,14]. Besides these feasibility studies, several efforts have been made on optimization of solar heat integration. As an example, the integration of solar heat into process and its optimization were investigated by Baniassadi et al. and Atkins et al. [15,16]. In addition, Schnitzer et al. have considered the application of solar heat into process in order to minimize the emissions [17]. Also, the concept of power pinch has been developed for process integration of hybrid power systems. Design, targeting and integration of such systems have been dealt with in works of Wan Alwi et al. and Rozali et al. [18–20].

Efforts on integration of renewable energies in total site systems include algorithmic targeting of renewable energy integration in total sites [21] and dealing with the varying nature of such systems [22,23]. Based on efficient heat transfer, integration of renewables into total sites was optimized in the work of Varbanov and klemes [24]. In another research work, the concept of Biomass-solar cogeneration has been developed by Angrisani et al. [25]. Moreover, Beretta et al. have developed a general method for allocating resources and products in a multi-product/multi resource plants [26].

While the anticipated result of integrating renewable resources in all fuel consuming systems such as residential utility systems, transportation vehicles and power plants is reducing the fuel consumption, cogeneration system offer a further susceptibility for improvement. By applying renewable energies in power plants or residential water heating systems, the fuel consumption is solely reduced by replacing it with another source of energy. In contrast, since the performance of cogeneration systems is highly dependent on their operating state and integrating renewable energies will alter this state, when integrated with renewable energies, the efficiency of these systems can change drastically. In this paper, R-curve tool is used to evaluate the effect of integrating renewable energies into the total site utility system. Solar heat, solar power and wind power are considered as the renewable resources for integration. Also, a new benchmarking index is proposed for the effect of integrating renewables on the cogeneration efficiency. Finally, by applying the presented concepts, three different cases of integrating renewable energies into total site utility systems are investigated.

2. Cogeneration and renewable resources

Cogeneration systems provide power and heat demand of processes within the site. The heat is often transferred via steam with different levels of pressure and temperature. Steam and gas turbines generate the power which is mostly consumed on site. However, there are possible interactions with the national or local grid. In most systems, there is a great potential for optimization and improvement of the performance [2]. In addition, renewable resources can provide a clean and cheap energy input which ensures sustainable production (Fig. 1).

As mentioned earlier, compared to other fuel consuming systems, cogeneration systems offer more susceptibility for improvement by integration of renewables. This feature can be exploited to further enhance the performance of the system. In order to investigate this feature of cogeneration systems, the effect of integration of solar heat, solar power and wind power are investigated. It should be noted that although biomass is also a renewable resource which is used in many modern utility systems [11], it is still considered as a fuel. Accordingly, unlike solar and wind energy which are directly converted to useful heat and power, biomass simply replaces a portion

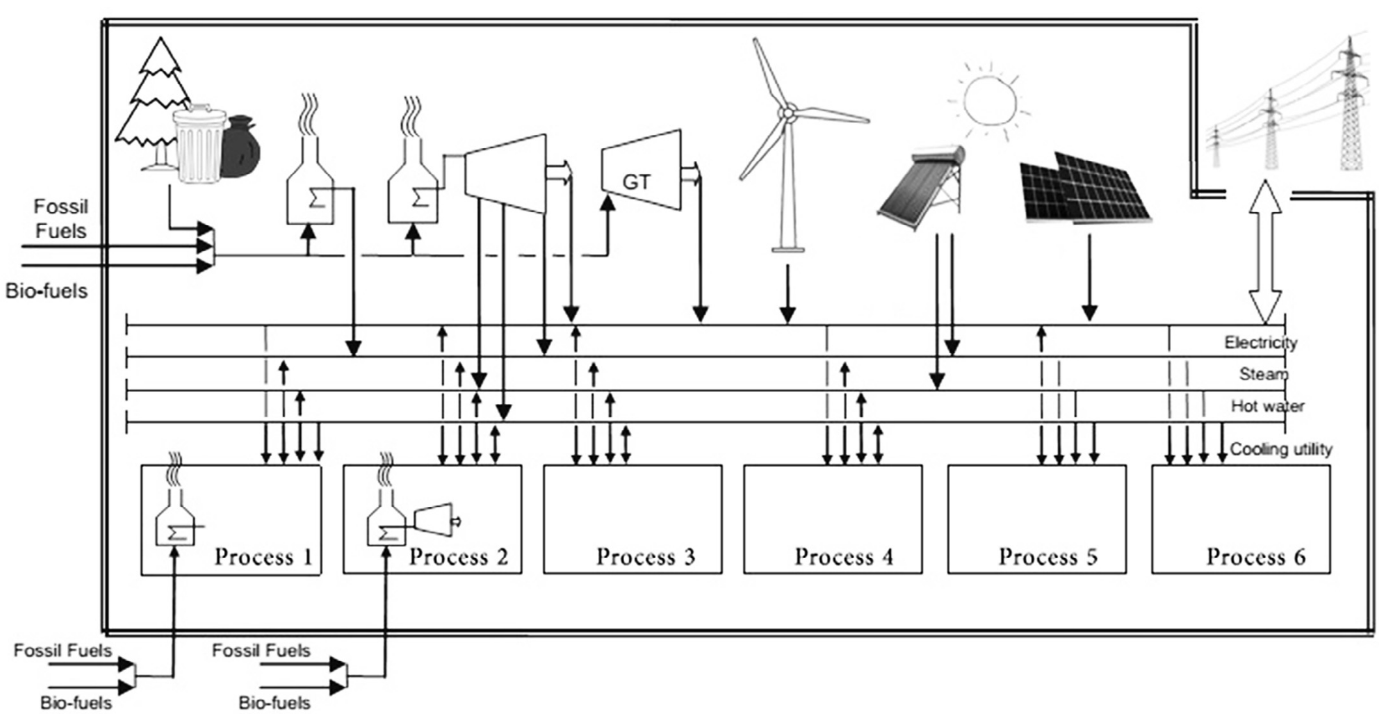

Fig. 1. Integration of renewable resources in total sites [24].

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