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A Novel Biomass-Driven Cogeneration System for Zero-Energy Buildings

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ABSTRACT: This study proposes and evaluates a new cogeneration system for zero-energy buildings. The proposed system is comprised of a biomass gasifier, an internal combustion engine, a double-effect lithium bromide-water absorption chiller, a backup boiler for hot water production, a gas storage tank, a hot water storage tank, and two heat exchangers. The system is supposed to provide the building with the electricity, hot water, heating and cooling requirements over the year. Besides presenting a functional strategy for the proposed system, this study evaluates the sensitivity of the objectives of the system (i.e., annual actual benefit) to some main decision variables, including the capacity of engine, chiller and boiler, the volume of hot water tank, the start-up time of the internal combustion engine. The results demonstrate that an increase in the input power of the engine helps to achieve the goal of zero-energy buildings. It is observed that the system is most economical when the cooling capacity of the absorption chiller approaches the heating and cooling demands of the building. The results also indicate that the start-up time of the combustion engine would be more influential in the case of high electricity demand conditions.

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1. Introduction

Ijaz Dar et al. [1] introduced two types of energy systems using a heat pump and a heat storage unit. These systems were analyzed using four control strategies. Lu et al. [2] investigated due to the periodic and uncontrollable behavior of renewable energy sources, the efficiency of zero energy houses can be unpredictable. Good et al. [3] examined various solar energy systems for a model residential building in Norway and converting this building into a nearly Zero Energy Building (nZEB). Sotehi et al. [4] studied the feasibility of using a combined solar cell and solar collector system (PV/T) to achieve ZEB as well as pure water. Al Ajmi et al. [5] focused on changing a typical building to a zero energy building. The solar energy was used in their project. Hirvonen et al. [6] studied the economic point of view, as well as the electrical generation by solar energy and energy requirements for a single-family building in Finland. Marta and Panao [7] introduced a new function termed Overall Energy Renewal Rate (OREF) for use in the ZEB analysis. This is a generalized function of the consumed energy rate (OEF) in site, which includes renewable energy generated off-site. Shen et al. [8] addressed the application of thermoelectric technology in NZEBs.

In this study, the system's operational strategy for all building demands, including electricity, cooling and heating is described. Considering the lack of utilization of biomass in renewable energy sources in achieving the goal of a building with zero energy consumption in previous studies, a hybrid biomass based system, a time dependent strategy and sensitivity analysis of the system to various design parameters and objectives and innovations of this research are provided.

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2. Introduction of System

In Fig. 1, the Combined Cool, Heat and Power (CCHP) system is shown along with a biomass gasification. The system is divided into two sub-divisions: the biomass gasification system and the CCHP system.

3. Operational Strategy

This section, describes the functional strategy of the system. For this purpose, a year is divided into three periods of cooling, heating and without cooling/heating seasons. In all these seasons, gasification generates gas during the early days of the morning, when the demand for building is low, and the engine generates electricity after being switched on at a specified time. In addition to generating electricity, the engine also produce hot water. Also, the exhaust gases from the engine are also used to produce cooling or heating in the chiller.

4. Sensitivity Analysis of the System

In order to sensitivity analysis of the system, firstly, should determine objective functions. Here, the objective functions

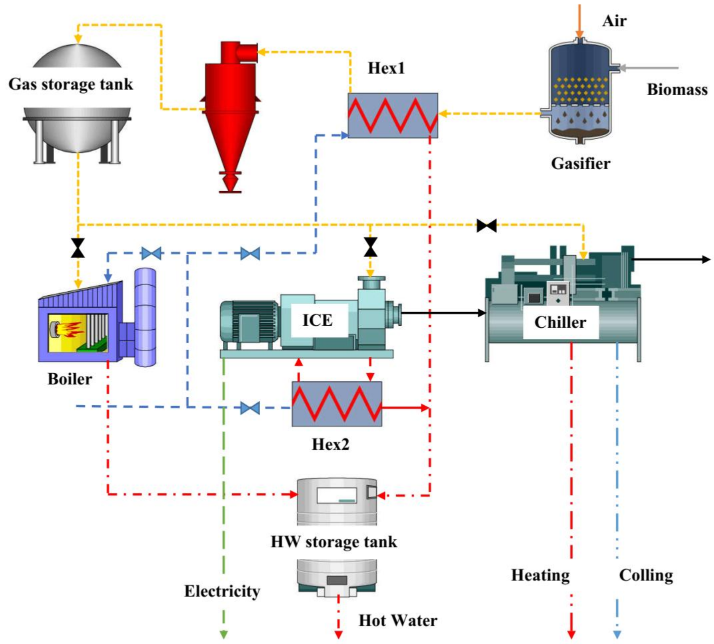

Fig. 1. Cogeneration system connected to biomass gasifier

of the output and input power balance (PBalance), annual actual benefit (AAB) [9] are investigated. The electric energy balance function shows the difference between the electrical input of an annual input to the building through the electricity distribution network (PImport) and the energy exported from the energy system to the distribution network (PExport).

$$P_{Balance} = P_{Im\ port} - P_{Export} \quad (1)$$

5. Results and Discussion

In order to sensitivity analysis of the system with changes in the design variables, results were obtained which are discussed below. For each design variable, a default value is considered and sensitivity analysis is performed based on this value.

Fig. 2 shows the variation of the balance function in terms of engine power variation. As can be seen, this function will decrease with increasing engine power. This is because that

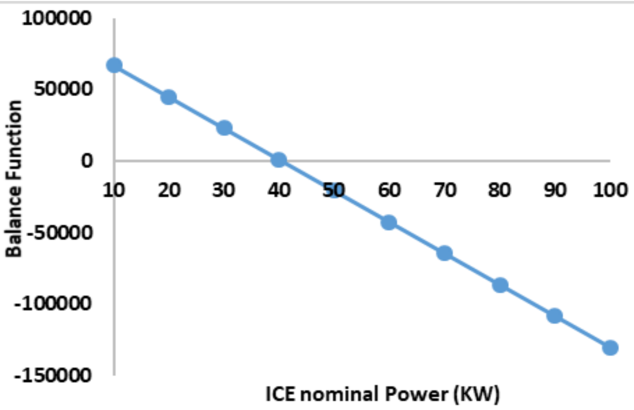

Fig. 2. Changing the balance function in terms of change in engine nominal power

with increasing engine power, the amount of excess electricity will increase on the building demands, so the electricity transmitted to the distribution lines will also increase, which will reduce the balancing function.

Fig. 3 shows the cooling effect changes of chiller on the annual actual benefit function. As can be seen. First, this function increases and then decreases. This is due to the fact that, until the cooling or heating demands of the building are reached, the cooling capacity of the chiller increases with the increase of chiller nominal power, thereby increasing the system profits.

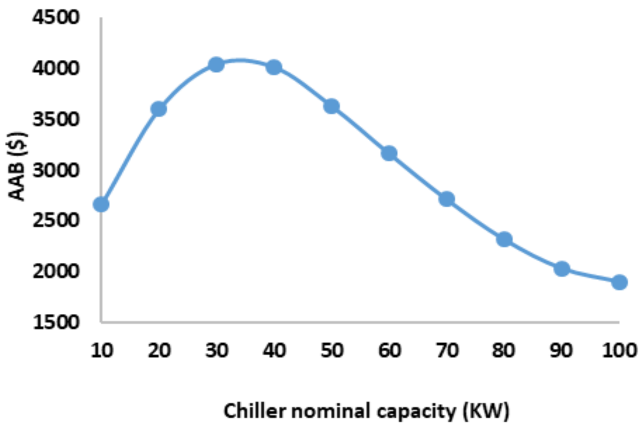

Fig. 3. Changes in annual actual benefit of the system in terms of chiller nominal power

6. Conclusions

In this research, a synchronous generation system designed to achieve a zero-energy building has been designed. By defining the design variables including internal combustion engine power, chiller power, supporting hot water boiler power, hot water tank volume and engine start-up time, the sensitivity of the system by changing these variables has been investigated. The results showed that by increasing the engine input power, the function of the electricity balance will be reduced, which can help achieve the goal of the building with zero energy consumption.

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