Techno-economic Assessment of Solar-driven Polygeneration System for Agri-food Industries

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Abstract

This paper examines the technical, economic and environmental assessment of a solar-driven polygeneration system (SDPS) of a dairy industry located in Tauste, Zaragoza, Spain. The results showed that the proposed SDPS has a solar fraction of 64.3% with a lower cost and lower greenhouse gas (GHG) emissions than conventional system.

Introduction

Integrating solar thermal technologies in industrial energy systems is gaining popularity because of their low operation cost and diverse applications [1]. The integration of solar thermal technologies in industrial energy systems can provide sustainable energy services for temperature ranges above 90ºC [2]. SDPS can be a promising technology for heating, cooling and electricity production in industries. These systems are gaining interest in industries due to their installation convenience, high energy efficiency, interesting economic performance and environmental benefit [3]. Proper energy integration, considering the required operating temperatures, of cost-efficient technologies can be an effective solution to cater the energy demand in agri-food industries [4]. This paper examines the performance of an optimized SDPS providing the energy services (heating, cooling and electricity) of a dairy industry located in Tauste, Spain, producing annually 47,872,734 L of pasteurized milk [4].

Methodology

The dairy industry plant is open 16 hours per day for weekdays and 8 hours per day for weekends. The annual energy demand of cooling, heating and electricity are 22,932 MWh, 11,376 MWh and 2,328 MWh respectively. The peak demand of cooling, heating and electricity are 7,124 kW, 3,533 kW and 712 kW. The technologies considered in the proposed system, shown in Figure 1, include parabolic sky trough collector (SKY), cogeneration organic Rankine cycle (ORC), mechanical chiller (MC), auxiliary boiler (AB) and thermal energy storage (TES). The solar collector (SKY) produces high-temperature (320 °C) to drive the ORC, which operates in cogeneration mode producing electricity (for the electricity demands and the mechanical chiller) and heat (for the production of pressurized hot water). Excess solar heat can be stored in the TES unit or dissipated to the environment. Likewise, excess cogenerated heat from the ORC can be dissipated. Es and Ep represent the electricity sold and purchased by the system. The unit investment cost, technical specification, and associated carbon emission have been taken from previous work [5]. An electricity tariff-scheme corresponding to the year 2023, consisting of 6 pricing periods has been considered [6]. It is assumed that excess electricity can be sold to the grid at 80% of the purchase price. The natural gas price considered is equal to 0.11 €/kWh, which was a price value for the first semester of the year 2023 in Spain [7]. The pre-design of the SDPS has been made through a mixed-integer linear programing (MILP) model which has been developed by using LINGO software to minimize the total annual cost of the system. The model determines the capacities of SKY, TES and ORC. The installed capacities of MC (8,000 kW) and AB (4,000 kW) are fixed and have been sized to provide the energy demands when the solar system is not operative

Results and discussion

Figure 1 presents the annual results (energy flows) of the optimized system. Table 1 compares the conventional system with the SDPS. In a conventional system, solar energy is not considered, therefore electricity from the grid is used to drive the MC to produce cooling, and natural gas is used to drive the AB to produce heating. The results show that the optimized SDPS has a lower total annual cost (close to 30% lower) and also produces less carbon

emission (70% reduction) as compared to the conventional system with a solar fraction of 64.3%. The optimized system produced more energy than the conventional system because in the optimized system the excess energy is sold to the grid.

	Solar fraction %	Total cost €/yr	CO_2 emissions $tonCO_2eq/yr$
Conventional system	0	2,444,140	3,071
SDPS system	64.3	1,764,669	933

Conclusions

The study analyzed the performance of SDPS for a dairy industry located in Tauste, Zaragoza, Spain. Optimization results showed that the total annual cost and total annual carbon emission of the proposed system are lower as compared to the conventional system.

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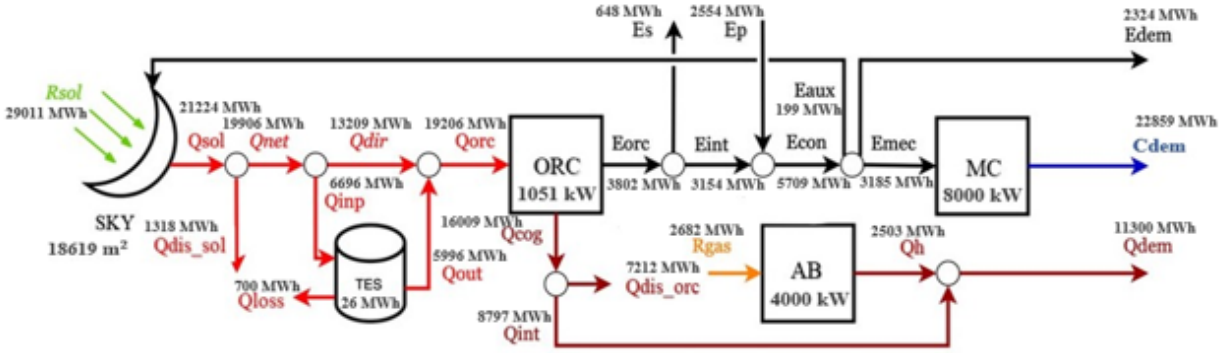

Figure 1 SDPS system – Annual energy flows