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Techno-economic Performance Analysis of a Hybrid Concentrated Photovoltaic/Thermal Combined with Organic Rankine Cycle (CPV/T-ORC) system for Simultaneous Generation of Power and Heat

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Abstract

Using the solar concentrating systems leads to an increase in the solar power radiation hitting the Photovoltaic (PV) panel surface which in turn increases the power generated by PVs. However, the concentrated radiation, on the other hand, raises the PV panel temperature, decreasing its operational efficiency. Cooling techniques (usually water) are used in these systems to reduce the PV operating temperature. In this way, the temperature of the operating fluid rises after cooling the PV panel and its heat can be used for heating purposes in cold seasons and to generate electricity in hot seasons through Organic Rankine Cycle (ORC) technology, which significantly increases the overall efficiency of the combined system. This paper aims to investigate the technical and economic aspects of a hybrid Concentrated Photovoltaic Thermal / Organic Rankine Cycle (CPV/T-ORC) system for simultaneous generation of power and heat in the summer and winter seasons. The results of the analysis show that for the ORC investment cost of 2000$/kW, the return on investment is 3.58 years and for the ORC investment cost of 3500$/kW, the return on investment is 5.81 years.

Keywords: Solar energy, techno-economic analysis, organic Rankine cycle, renewable energy

1. INTRODUCTION

Rising electricity demand and concerns about rising environmental pollutants are the main factors that make the use of alternative energy sources more necessary. Among renewable energy sources, solar energy has considerable potential as a safe and available alternative [1]. One of the technologies that can be used to use this huge amount of energy is photovoltaic cell technology. Solar concentrators are used to increase the incident radiation on the photovoltaic panels .Solar concentrating systems consist of large mirrors or lenses to focus sunlight over a small area of solar cells. To use concentrators, uniaxial or biaxial solar trackers are used to track the maximum solar power during the day and year [2].

Zhang et al. [3] designed a small-scale concentrating photovoltaic system coupled to a small-scale organic Rankine cycle. Zhao et al. [4] thermodynamically evaluated an organic Rankine cycle system coupled with a concentrated photovoltaic system. Calise [5] designed a similar system and evaluated it economically and energetically.

Due to the importance of this topic, in this paper, a hybrid concentrated photovoltaic system coupled with an organic Rankine cycle is evaluated from a technical and economic point of view. In this regard, the first and second laws of thermodynamics are very important. For modeling the system, constants and assumptions are used, which are described in the methodology section. After a complete description of the methods, the results of the system evaluation are presented. In this regard, system performance parameters such as production capacity and annual production energy, sensitivity analysis, and finally the economics of the system are examined.

2. MATERIAL AND METHOD

The detailed schematic model of the proposed system including the concentrated photovoltaic and organic Rankine cycle is shown in Fig. 1. The general function of the system is that the first part of the concentrated solar radiation in the photovoltaic panel is converted into electrical energy. The rest of the energy is thermal, part of which is conveyed by convective heat transfer and radiation from the system to the environment, and the rest of the heat is transferred from the PV panel to the organic Rankin cycle by the working fluid. A noteworthy point in this system is the use of heat behind the panel as thermal energy for heating applications in cold seasons. According to the amount of incident radiation on the PV panel, the output power of the panel is calculated according to the following equation:

$$P_{pv} = Q_{pv} n_{pv} n_{inv} \tag{1}$$

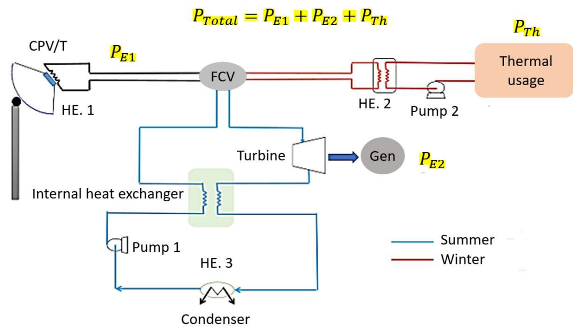

Figure 1. Scheme of the proposed system

where P_{pv} is the PV output power (W), Q_{pv} is the radiation on the PV panel (W), n_{pv} is the PV nominal efficiency (%), and n_{inv} is the inverter efficiency (%). The power consumption of the pump and the power generated by the expander are calculated by the Eqs. (2) and (3), respectively [6]:

$$P_{Pump} = \dot{m}_{orc} \frac{h_5 - h_4}{\eta_{Pump}} \tag{2}$$

$$P_{Expander} = \dot{m}_{orc}(h_1 - h_2)\eta_{Expander}\eta_{Gen} \tag{3}$$

where P_{Pump} is the pump consumption (W), $\dot{m}_{orc}$ is the fluid mass flow rate (kg/s), η_{Pump} is the pump efficiency (%), $P_{Expander}$ is the expander power production (W), $\eta_{Expander}$ is the expander efficiency (%), and η_{Gen} is the generator efficiency.

3. Results and Discussion

Table 1 shows the values of the performance parameters of the system at solar radiation of 1000 w/m^2, wind speed of 2 m/s, and ambient temperature of 25 °C.

Table 1. Values of performance parameters

Parameter	Unit	Value
PV power	kW	3.30
Turbine power production (summer)	kW	3.44
Pump power consumption (summer)	kW	0.12
Thermal power	kW	26.22

For the economic analysis of the system, the payback period index is used. In the dynamic method, the value of this index is calculated through the following equation:

$$\sum_{j=1}^{n_p} \frac{S_j - C_j}{(1+f)^j} - I_0 = 0 \tag{4}$$

Figure 2 shows the payback period chart for different prices of the ORC. According to the figure, the minimum payback period occurs at a cycle price of 2,000 $/kW, which equates to 3.58 years. The highest payback period occurs at a cycle price of 35,000 $/kW, which equates to 5.81 years.

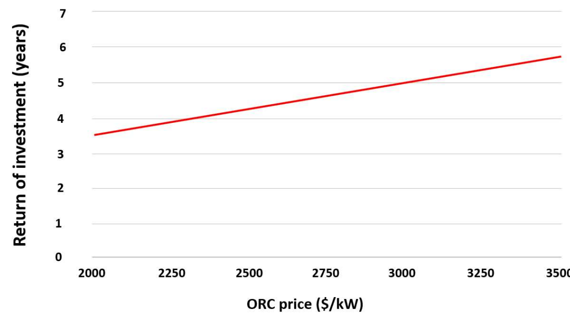

Figure 2. The payback period for different ORC prices

4. Conclusions

In this paper, a novel photovoltaic hybrid system with a concentrator combined with an organic Rankine cycle is simulated thermodynamically and economically for generating electricity and heat simultaneously. The system simulation was performed based on the mass and energy conservation model and a dynamic model based on the payback period was used for economic analysis. The results showed that the payback period for ORC prices between 2000 to 3500 $/kW varies between 3.58 and 5.81 years.

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