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Parametric multi-objective optimization of an Organic Rankine Cycle with thermal energy storage for distributed generation

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Abstract

This paper focuses on the thermodynamic modelling and parametric optimization of an Organic Rankine Cycle (ORC) which recovers the heat stored in a thermal energy storage (TES). A TES with two molten-salt tanks (one cold and one hot) is selected since it is able to operate in the temperature range useful to recover heat from different sources such as exhaust gas of Externally Fired Gas Turbine (EFGT) or Concentrating Solar Power (CSP) plant, operating in a network for Distributed Generation (DG). The thermal storage facilitates a flexible operation of the power system operating in the network of DG, and in particular allows to compensate the energy fluctuations of heat and power demand, increase the capacity factor of the connected plants, increase the dispatchability of the renewable energy generated and potentially operate in load following mode. The selected ORC is a regenerative cycle with the adoption of a Heat Recovery Vapour Generator (HRVG) that recovers heat from molten salts flowing from the Hot Tank to the Cold Tank of the TES. By considering the properties of molten salt mixtures, a ternary mixture able to operate between 200 and 400 °C is selected. The main ORC parameters, namely the evaporating pressure/temperature and the evaporator/condenser pinch point temperature differences, are selected as variables for the thermodynamic ORC optimization. An automatic optimization procedure is set up by means of a genetic algorithm (GA) coupled with an in-house code for the ORC calculation. Firstly, a mono-objective optimization is carried out for two working fluids of interest (Toluene and R113) by maximization of the cycle thermal efficiency. Afterwards, a multi-objective optimization is carried out for the fluid with the best performance by means of a Non-dominated Sorting Genetic Algorithm (NSGA) in order to evaluate the cycle parameters which maximize the thermal efficiency and minimise the heat exchanger surface areas. Toluene results able to give the best trade-off between efficiency and heat exchanger dimensions for the present application, showing that by with respect to the best efficiency point, the heat exchange area can be reduced by 36% with only a penalty of 1% for the efficiency.

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Keywords: ORC; Organic Rankine Cycle, thermal energy storage, molten salts, optimization; genetic algorithm, distributed generation

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1. Introduction

Due to the current environmental needs, the European Commission has set for 2030 new targets aiming at improving the energy efficiency and reducing the greenhouse gas emissions [1]. In order to achieve these targets, the spreading of renewable energy plays a central role, together with the continuous improving of component efficiency [2]. The intermittency characteristic of renewable sources (such as solar, wind) introduces the need of managing the energy production by means of energy storage devices. Thus, in the last years the development of TES coupled with CSP represents a key topic in the scientific community [3], [4]. Indeed, CSP with TES devices are suitable to be integrated in distributed generation (DG) networks composed by different power blocks that can supply heat, power or both, as described in Figure 1. In this paper, the CSP plant is supposed to be integrated by an Externally Fired Gas Turbine (EFGT) fed by biomass. A potential candidate for recover energy from the thermal energy storage and convert it in electric energy is the ORC technology (Figure 2). To convert most efficiently the thermal input of the TES in electric power, we assume that the ORC generates only electric power. However, note that all the methodologies applied to this system can be easily extended to a different configuration that includes also heat generation.

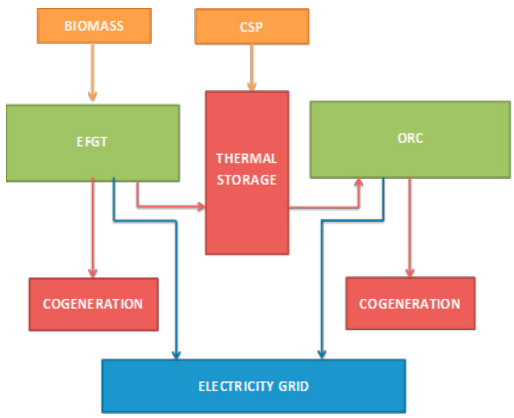

Figure 1 - Power blocks of the distributed heat and power plant

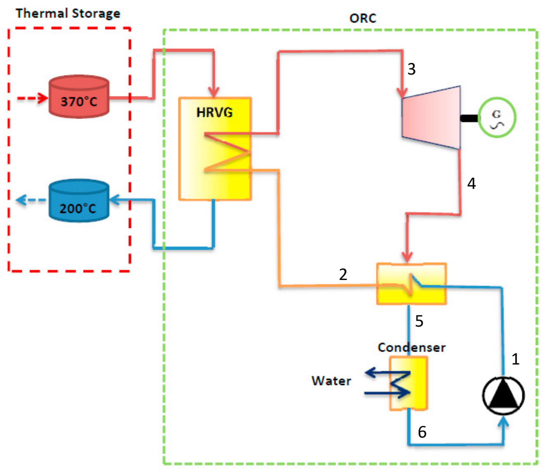

Figure 2 - ORC plant connected to TES

In ORC applications, the choice of the cycle parameters is of importance for improving the thermal efficiency and the exploitation of the thermal source. On the other hand, the expander and heat exchanger sizes influence the overall cost of the plant and a trade-off study for increasing efficiency and minimizing costs should be carried out. In this framework, the multi-objective optimization has gained interest as an efficient tool able to evaluate the best parameter configuration in the assigned design limits. Especially, the Non-dominated Sorting Genetic Algorithm (NSGA) [5] has been implemented in several thermo-economic analysis and parameter selection for ORC applications. Muhammad et al. [6] performed a multi-objective optimization of an ORC evaporator for low temperature geothermal heat source by minimizing the costs and the pressure drop. Aiming to improve the performance of the HRVG, numerical simulation of the flow through the banks can give a significant contribution [7]. The primary geometrical parameters of evaporator were selected as decision variables which included length, width and plate spacing. Muhammad et al. [8] showed the results of a thermo-economic optimization for a regenerative ORC for waste heat recovery applications. Maximum thermal efficiency and minimum specific investment cost were selected as objective functions and relative increase in thermal efficiency and cost were analyzed. In the mono-objective optimization framework, Wang et al. [9] applied a genetic algorithm to improve the system performance of an ORC for different working fluids, whereas Xi et al. [10] examined the performances of