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Part-load analysis of gas turbine & ORC combined cycles

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ABSTRACT

Organic Rankine Cycles (ORC) are considered to be effective solutions for low and medium temperature heat recovery for power production. In such applications where the temperature of waste heat is in the 300–450 °C range, they stand as a more interesting option to enhance system performance than the more complex steam cycles typically used in heavy duty combined cycle plants.

In this paper, the rated and part-load performances of combined cycles formed by a topping gas turbine and a bottoming ORC are analysed. To this aim, five commercial gas turbines are used in combination with an ORC bottoming cycle in lieu of a conventional steam cycle, with the goal of maximising the overall efficiency of the plant at part-load. These operating conditions are typical of power stations operating in load-following mode.

During the analysis of part-load operation, different control strategies are studied in order to recuperate as much heat as possible from the gas turbine exhaust. It is observed that keeping the live vapour conditions in the bottoming cycle as constant as possible produces maximum power at any operating conditions, compensating for the poor performance of the gas turbine engine at part-load.

The interest of this work is twofold. First, it confirms the interest of merging gas turbines and ORC units for efficient power generation under variable operating conditions. Second, the work is based on commercial gas turbines, thus trying to analyse the real potential of state-of-the-art technology in the application proposed.

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1. Introduction

For mid-scale variable-load power generation and mechanical drive applications (gas pipelines), gas turbines of the aeroderivative type allow for fast start-up and flexible operation. For instance, the General Electric LMS 100 PA engine (100 MW rated output) achieves full load in just 10 min from ignition and is able to perform several starts/stops along the day without significant incidence on its maintenance schedule; the Rolls Royce TRENT 60 unit performs cold starts or starts after tripping in 10 min as well. On the other hand, for heavy duty power generation, gas turbine engines are commonly found today in combined gas and steam power plants, where the exhaust gases from the gas turbine unit are used to produce steam that is eventually expanded through a steam turbine to produce additional power. Presently, these power plants are the most efficient amongst the fossil fuel based and achieve total efficiencies in the range of 60% running on natural gas [1–3]. Numerous works analyse both on and off-design performance and component design of such power plants.

One of the most investigated individual components in combined cycle power plants is the heat recovery steam generator HRSG which recuperates heat from the gas turbine exhaust. Works like [2,4,5] analyse the influence of this element and its design on the global efficiency of the power plant. On the same basis, the present work shows that when the exhaust gases of the gas turbine are at low temperature, it is beneficial to use an Organic Rankine Cycle. In this case, as opposed to conventional steam Rankine cycles, the working fluid of choice that optimises the performance of the power plant is project specific, therefore depending on the application as previously shown by the authors in [6,7]. As a general rule of thumb, the efficiency of bottoming steam cycles is reported to be low for waste heat (exhaust gases) below 370 °C [3], even though applications for lower temperatures are found in open literature [8–11].

Following the reported interest in gas turbine and ORC combined cycles and due to the importance of part-load control in the performance of gas turbine based power plant, this work analyses the part-load performance of combined GT–ORC power plants. In this regard, it complements a previous work by the authors [6] oriented to the economic analysis at on-design (rated)

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