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Numerical cost optimization and irreversibility analysis of the triple-pressure reheat steam-air cooled GT commercial combined cycle power plants

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ABSTRACT

Steam-air cooling of the gas turbine (GT) and optimization are important methods for enhancing the efficiency and power of the combined cycle power plants. A steam-air cooled GT uses less air for GT cooling; thus, allows more air to be available for the combustion process and increases output power significantly. In this paper, the commercial triple-pressure reheat steam-air cooled GT combined cycles (The GE Stage 107H and Mitsubishi M501H commercial combined cycles) were presented, optimized relative to its operating parameters, and the irreversibilities of the components were analyzed to identify the magnitude and locations of such irreversibilities and discuss its causes. Constraints were set on many operating parameters such as air pressure ratio, the ratio of the cooling steam flow to the maximum available flow for steam cooling, and stack temperature. The net revenue and cycle efficiency were optimized at 10 different maximum values of turbine inlet temperature (TIT) using two different methods: the direct search and variable metric. The optimized cycles had better performance and lower irreversibilities for the main components than that for the commercial cycles. Optimizing the net revenue could result in an annual saving of about 29.2 million US dollars for a 400 MW power plant.

1. Introduction

Increasing TIT enhances the efficiency and power of the combined cycle power plants, but it also increases NO_x emissions so that advanced designs for combustors [1,2] have been developed to keep NO_x emissions within the permissible limits. Such designs apply some techniques to reduce NO_x emissions, including steam and water injection and using some of the compressor air to either quench the flame prior to the combustor discharge entering the GT or to cool the walls of the combustor. In order to increase the combustion temperature to 1600 °C, an enhanced Thermal Barrier Coating (TBC) was introduced, the effectiveness of the turbine blades cooling process was improved, and a new technique to reduce NO_x emissions was applied in the design of M501J GT, developed by Mitsubishi Heavy Industries (MHI), Ltd [3]. Such a technique applies steam cooling for the combustor walls and also quenches the flame prior to the combustor discharge using the compressor air [3]. The M501J combined cycle GT has not been delivered for commercial operation. Future increases in TIT will be limited to the technology of developing combustors that are capable of keeping NO_x emissions below the permissible limits at the increased TIT; therefore, alternative methods to increase the efficiency and power of the combined cycle are sought.

One of these alternative methods is optimizing the combined cycle, which has been the subject of many investigations. Some investigators have focused on optimizing the thermal performance using different techniques [4–14] whereas others optimized an objective function of the net revenue or total cost. Casarosa *et al.* [15] minimized the total cost of the exergy loss of the HRSG for a combined cycle using the Simplex method, which can be used only when the objective function and constraints are linear [16]. Thermoeconomic optimization of the HRSG was also performed by Rovira *et al.* [17]. The optimization was based on off-design conditions and the results were compared with that of a thermoeconomic model based on the design conditions. Valdes *et al.* [18] maximized the annual cash flow of a combined cycle gas turbine

Abbreviations: AC, air compressor; CC, combustion chamber; D_i, the steam drum number *I*; EG, electrical generator; GT, gas turbine; H-P ST, high-pressure steam turbine; HRSG, heat recovery steam generator; I-P ST, intermediate-pressure steam turbine; L-P ST, low-pressure steam turbine; Regular 107H Cycle, the triple-pressure reheat steam-air cooled GT combined cycle shown in Fig. 1; Regular M501H Cycle, the triple-pressure reheat steam-air cooled GT combined cycle shown in Fig. 3; Optimized-revenue Cycle, the optimized-revenue triple-pressure steam-air cooled GT combined cycle; Optimized-efficiency Cycle, the optimized-efficiency triple-pressure steam-air cooled GT combined cycle; Steam-air cooled GT, a GT cooling system in which the first two stages of the GT blades are cooled using a steam closed loop; the third stage is cooled using an open loop of air, and the fourth stage is uncooled.

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