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Comparison between single-shaft and mutli-shaft gas fired 800 MWel combined cycle power plant

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ABSTRACT

Multi-shaft and single-shaft configurations allow customization to optimize plant performance, capital investment, construction and maintenance access, operating convenience, and minimum space requirements. Technical comparison between both configurations at partial loads has not been published before. This paper will primarily address a comparison between the two configurations based on thermodynamic simulation results for a gross power capacity of approximately 800 MWel at ISO conditions. This capacity has been chosen based on power market requirements. The analysis approach for each configuration is divided into three components: (1) Performance, (2) Plant configuration, and (3) Environmental impact. The first component dealt with plant gross power output, plant gross efficiency, plant auxiliary power demand, plant generator losses and plant shaft power. The second component dealt with space limitations and extension capability. The third component dealt with specific emissions of NO_x and specific emissions of CO_2. The thermodynamic simulations have been carried out using Thermoflow® at base load and part load respectively. The results show that the single-shaft configuration is more suitable with regards to performance, NO_x specific emissions, CO_2 specific emissions, start-up and extension possibilities. The multi-shaft configuration is more suitable with regards to space limitations, steam turbine shaft power, availability, and reliability.

1. Introduction

It is known from literature that many authors have discussed the principles of the Combined Cycle Power Plants (CCPP). However, many worldwide gas turbine manufacturers and combined cycle developers have mentioned only general nomenclature regarding their products (e.g. the recent examples from [1–3]). Until now, no publication has addressed a technical comparison between the two configurations of the CCPP from a non- manufacturers point of view. Depending on the combination of the turbines and generators, systems can be classified into two categories (single-shaft and multi-shaft configurations). With a single-shaft configuration, the gas turbine is directly coupled to a steam turbine with a single common generator, and with a multi-shaft configuration the steam turbine and a gas turbine are coupled to their own generators respectively. The signed Kyoto protocol which called for the reduction of CO_2 emissions would favor the execution of efficiency increasing measures for fossil fueled power generation [1]. The latest trend in CCPP configurations, high efficiencies of up to 60%, low air emission rates, and modest space limitations are the driving forces for the anlaysis this paper is to document. This evaluation will compare both combined cycle configurations for a gross power generation capacity of approximately 800 MWel (single-shaft and multi-shaft). Factors such as consideration of performance, environmental impact, availability, reliability, extension possibility, and space limitations will be considered for both configurations. An investigation of combined cycle configurations with F-series gas turbines (SGT5-4000F gas turbine, formerly known as V94.3A) was conducted. Commercial thermodynamic simulation software [4] was used to simulate the power plant performance under ISO conditions. The initial analysis approach of both configurations is briefly described below, including the design philosophy of each configuration option. Next, evaluation of the simulation results will be presented, and then overall findings and conclusions will be made.

2. Analysis approach

The analysis approach for both CCPP configurations is addressed in Table 1 as following:

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Table 1
Analysis approach for both CCPP configurations.

Approach	Investigated Items
Performance	Gross output
	Gross efficiency
	Auxiliary power demand
	Generator losses
	Availability and reliability
Plant Configuration	Space requirement
	Extension possibility
Environmental	Emissions of NO_x and CO_2

2.1. Design philosophy

The thermodynamic design and the performance calculations of the two configuration alternatives is based on the ISO conditions, Table 2:

Table 2
Design conditions.

Ambient air temperature	15 °C
Relative humidity	60%
Ambient pressure	1013 mbar
Fuel CH_4	
CH_4 (LHV) @ 25 °C	50047 kJ/kg
CH_4 (HHV) @ 25 °C	55533 kJ/kg

The steam turbine choice depends on the condenser back pressure, mainly influenced by the cooling condition [3]. A combined HP/IP, double flow LP, induction and condensing-reheat type turbine was selected for better performance with the desired low back pressure. In the induction part, additional power by means of low pressure steam was generated. The condensing part exhausted steam in a partially condensed state at the condenser back pressure. In the reheat part, steam flowed from the high pressure section of the turbine and was returned to the HRSG, where additional superheat was added. The steam then went back into the intermediate pressure section of the turbine and continued its expansion. The optimum bottoming cycle was selected to attain the maximum thermal efficiency by recovering the heat effectively from the turbine exhaust gases. Optimization of the plant cycle resulted in selection of a superheat/reheat and low pressure cycle or Triple Pressure System with double feeds to the steam turbine. The steam pressure and temperature were determined based on the limitation of the steam pressure requirement for natural circulation of the Heat Recovery Steam Generator (HRSG), and the erosion of the Low Pressure Steam Turbine (LPST) last stage. The high, intermediate, and low pressure steam conditions were: 125 bar/565 °C; 30 bar/565 °C; and 4.4 bar/235 °C. At part load the deaerator pressure will be kept above the atmospheric value to improve the overall efficiency and also to remove the dissolved gases from the feed water. Although supplementary firing is an effective means of increasing plant capacity, it significantly reduces the plant efficiency and therefore increases the emissions. No supplementary firing was considered to reach the best efficiency at the required output power. Based on the flow of exhaust gases, HRSG is categorized into horizontal type. The HRSG pinch points were optimized and selected based on the modern design of the CCPP. The HP, IP and LP Pinch points were optimized through multiple runs of the simulation software to get the highest process efficiency at a moderate HRSG surface. The cooling cycle was designed as a closed cycle system by means of a condenser with wet cooling towers. Wetness fraction of the steam was kept to less than 12% at 0.045 bar back pressure. This pressure could be achieved at ISO ambient conditions through an optimum design of the cooling system such as the water approach to wet bulb temperature was designed at 7 K with cooling water temperature rise in the condenser at 10 K at 3 K degradation. Common steam cycle components such as feed water pumps and deaerators for the two HRSGs were considered for the multi-shaft configuration. The exhaust system of the HRSGs included a by-pass stack by which steam from the HRSGs is fed into the multi-shaft configuration utilizing a common header to the steam turbine. In the single-shaft configuration, steam from each HRSG was fed to a separate steam turbine with no interconnection between the two steam cycles. The exhaust system for the single-shaft configuration did not include a by-pass stack, as only one of the single-shaft trains will be in operation and the second will be in an outage condition. A single reheat combined cycle system was considered to improve the thermal efficiency. In this system, steam is typically supplied from the steam turbine back to the HRSG, where it is then piped to the Intermediate Pressure steam turbine. Both are heated and returned to the steam turbine. This configuration does not exist with a single-shaft combined cycle, where one steam turbine and one HRSG receive heat from the gas turbine which is supplied directly from the one steam turbine to a single HRSG. However, application of a reheat steam cycle to a multi-shaft combined cycle has typically been restricted to a configuration in which cold reheat steam is distributed to each of only two HRSGs for reheating and subsequent return to the steam turbine. This restriction is a result of the complexity, expense, and operability problems that arise with multi-shaft configuration [5]. In other words, the distribution and collection of reheat steam requires more complicated design in terms of piping, valves, and other auxiliary equipment. For the single-shaft configuration hydrogen-cooled generators were considered, whereas for the multi-shaft configuration air-cooled generators were considered for the gas turbines and hydrogen-cooled generators for the steam turbines. The consideration of the generators types was made based on the output range limitations of both types. For increased flexibility in plant operation, the single-shaft configuration can be equipped with flexible couplings and/or synchronous-self-shifting (SSS) clutches. In this system the generator is located in the middle of the single-shaft train (between gas turbine and steam turbine), with one end connected to the cold end of the gas turbine and the other end to the steam turbine through the SSS clutch. It engages and disengages automatically during start-up and shut down of the steam turbine.

Table 3
Configuration options.

Option	Power Plant Configuration	HRSG Design	Steam Turbine Design
Option 1 $2 \times (1 + 1)$ Single-Shaft	2 CCPP trains, each consists of 1 GT of type SGT5-4000F, 1 HRSG plus 1 ST with mechanical draft cooling tower	Triple pressure HRSG with single reheat and no supplementary burners	Induction, Condensing-Reheat
Option 2 $1 \times (2 + 1)$ Multi-Shaft	1 CCPP block, consists of 2 GTs of type SGT5-4000F, 2 HRSGs plus 1 ST with mechanical draft cooling tower	Triple pressure HRSG with single reheat and no supplementary burners	Induction, Condensing -Reheat