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New operating strategy for a combined cycle gas turbine power plant

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ABSTRACT

The highly dynamic nature of power demand forces a combined cycle gas turbine (CCGT) power plant to often run at less-efficient part-load conditions. A new operating strategy called EGR-IGVC is proposed in this work to improve the part-load performance of a CCGT plant. The strategy partially recycles the flue gas from the heat recovery steam generator and manipulates the inlet guide vanes to regulate part-load operation and boost plant efficiency. It allows the CCGT plant to set its own acceptable gas turbine temperature limits at any time and thus maximize the plant performance. Our previous CCGT flow diagram in Aspen HYSYS [Liu and Karimi (2018)] is modified to accommodate EGR for evaluating EGR-IGVC. Then, using a case study CCGT plant, EGR-IGVC is compared in detail with the conventional inlet guide vane control (IGVC). The results show that EGR-IGVC improves the plant part-load performance significantly. It increases the plant efficiency by up to 1.2% (actual) and reduces the CO_2 emissions by up to 13.8 $kg\,MW^{-1}\,h^{-1}$. By enabling an effective utilization of low-temperature waste heat and reducing the propensity for NO_x formation, EGR-IGVC promises to be a better strategy for the part-load operation of CCGT plants.

1. Introduction

Gas turbines are widely used in the power industry due to their high thermal efficiency, super flexibility, short delivery time, and excellent regulation capacity [1]. The high-temperature exhaust from a gas turbine is normally utilized to produce extra power in a steam cycle that comprises a heat recovery steam generator (HRSG) and several steam turbines [2,3]. This serial coupling of a gas turbine followed by a steam cycle is called a combined cycle gas turbine (CCGT) power plant.

The thermodynamic analysis [4–6] and optimization [7–9] of CCGT plants have been addressed under design conditions. However, their operation under off-design (namely part-load) conditions is no less important, as the plants often run at lower than their design capacities during their lifetimes. For instance, a power plant in Nigeria produced only 64.3% of its design capacity from 2001 to 2010 [10]. Several factors are responsible for this part-load operation. First, the power demand is hardly steady and rarely equals the plant design capacity. Second, a power plant is required to maintain spinning reserves (surplus capacity) to meet unforeseen peaks in demands. Third, a power plant may often be overdesigned to buffer against demand uncertainties. Thus, the study of CCGT plants under part-load conditions is of practical importance. Under part-load conditions, the plant operation drifts away from its design conditions and thus the plant thermal efficiency decreases [11,12]. This wastes non-renewable fossil fuels and increases CO_2 emissions. Therefore, a proper operating strategy is needed for the part-load operation of a CCGT plant.

Kim and Hwang [13] investigated the part-load operation of recuperative gas turbines. They studied several operating strategies such as fuel flow control (FFC), variable speed control (VSC) and inlet guide vane control (IGVC) for the single-shaft configuration, and FFC and variable area nozzle control (VANC) for the two-shaft configuration. They found VSC and VANC gave better performance. Kim [14] analyzed the part-load performance of a combined cycle with different gas turbine design parameters under FFC and IGVC. They showed that the combined cycle exhibited superior performance under both operating strategies when the gas turbine pressure ratio and temperature were higher. Haglind [15,16] investigated the effects of variable geometry on the part-load performance of gas turbines and combined cycles and found the use of variable guide vanes and variable area nozzle improved their part-load performance. Jimenez-Espadafor Auilar et al. [17] and Cheng et al. [18] studied several operating strategies for a combined heat and power (CHP) plant and showed IGVC held the best regulation capacity and energy saving potential. Variny and Mieka [19] found that preheating the condensate and changing condensing pressure regulation strategy reduced the fuel consumption based on online monitoring data. Liu and Karimi [20] obtained an optimal operating strategy using a simulation-based optimization method to maximize the plant thermal efficiency at any part-load. Their optimal strategy struck a balance between FFC and IGVC to improve plant performance.

Several works have modified the basic cycle configurations to

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Nomenclature

Symbols

$\Delta\alpha$	IGV angle
PL	percent part-load
W	power, kW

Subscripts

d	design condition
max	maximum

Acronyms

BFD	block flow diagram
CCGT	combined cycle gas turbine
CCHP	combined cooling, heating, and power
CCP	combined cooling and power
CFD	computational fluid dynamics
CHP	combined heat and power
COMB	combustor
COMP	compressor
DESHT	desuperheater
ECON	economizer
EGR	exhaust gas recycle
EGRR	exhaust gas recycle ratio
EGRC	exhaust gas recycle control
EVAP	evaporator
FFC	fuel flow control
FGR	flue gas reinjection
GEN	generator
HP	high pressure
HPP	high pressure pump
HPST	high pressure steam turbine
HRSG	heat recovery steam generator
IATC	inlet air throttling control
IGVs	inlet guide vanes
IGVC	inlet guide vane control
IP	intermediate pressure
IPP	intermediate pressure pump
IPST	intermediate pressure steam turbine
LP	low pressure
LPP	low pressure pump
LPST	low pressure steam turbine
RHT	reheater
RP	recirculation pump
SPHT	superheater
TET	turbine exhaust temperature
TIT	turbine inlet temperature
TURB	turbine
VANC	variable area nozzle control
VSC	variable speed control

improve the plant part-load performance. Barelli and Ottaviano [21] added a variable speed compressor upstream of the gas turbine and changed its speed to maintain the main air compressor operation at its design point. Han et al. [22] installed a valve at the compressor inlet to reduce air flow via throttling and proposed an inlet air throttling control (IATC) for a combined cooling and power (CCP) system. They showed that IATC produced better part-load performance than FFC. However, it may cause the compressor to surge. Wang et al. [23] studied the effects of IATC and FFC on a combined cooling, heating, and power (CCHP) system and found that IATC reduced primary energy consumption, operating cost, and CO_2 emissions. They [24] also proposed to reinject the flue gas (Fuel gas reinjection or FGR) with air and combined FGR and FFC to improve the performance of the CCHP system. Liu et al. [25] combined thermal recuperation and inlet guide vanes (IGVs) to regulate the part-load operation of a partially recuperative gas turbine combined cycle. They found that the partially recuperative combined cycle gave a higher thermal efficiency, but a lower specific power output compared to the non-recuperative combined cycle.

Although exhaust gas recycle (EGR) as a concept has been studied

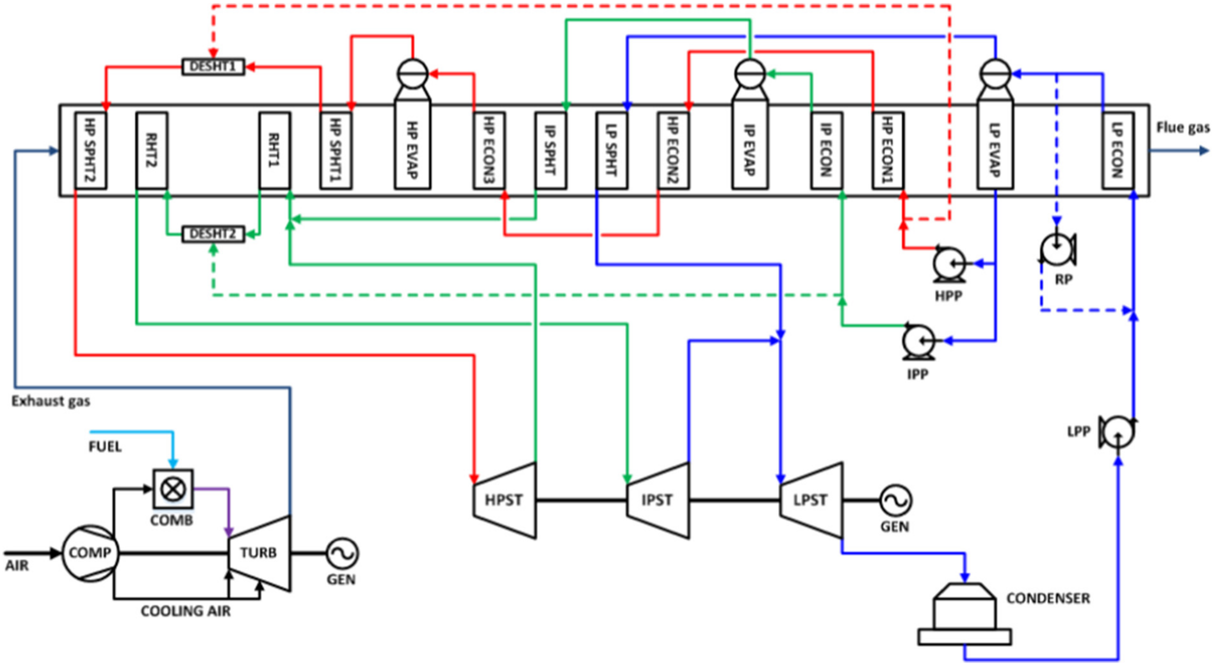

Fig. 1. Schematic of a triple-pressure reheat CCGT power plant.