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Performance improvement of distributed combined cycle plants through modification of structure

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Abstract

In this paper possible modifications of combined cycle power plants of electric power output below 50 MW are presented. The concept is based on modified configuration of a single pressure heat recovery steam generator and bigger number of system components. Alternative plant structures are examined theoretically using fundamental thermodynamic relations. Simulations were performed using the Engineering Equation Solver software package. Results show that there is a room for both efficiency and flexibility improvements. In the simulated cases the energy conversion efficiency of a combined cycle power plant increased from 49.9% up to 52.7%. In addition to this, design parameters such as gas turbine pressure ratio, combustion temperature, steam pressure are relatively low, in the range of values currently widely used in industry. The concept also assumes a bigger role of the ORC technology. Its share in the total power output increased from 5.5% in the reference case up to 12.6% in the configuration that achieves the highest value of energy efficiency.

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Keywords: Gas Turbines, Combined Cycle Power Plants, HRSG, ORC, cascade configuration.

1. Introduction

Recent trends in design of combined cycle power plant (CCPP) technology show that developers increase plant size and complexity of the system in order to reach high power generation efficiency at acceptable specific

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investment cost. Kotowicz et al. [1] presented that an increase in gas turbine efficiency leads to a greater growth of the overall CCPP efficiency than a corresponding increase in steam cycle efficiency. Moreover, the specific investment cost for the gas turbine installation is 4 to 5 times lower than for the steam cycle. As a consequence, the CCPP technology for a long time have been developed by means of increasing the turbine inlet temperature, improvement of aerodynamics and critical components cooling technology [2]. Nowadays, the highest power generation efficiency of modern CCPPs is at the level slightly above 60 %. This is however possible if power output of a plant that is at the level of 400 – 600 MW. On the other hand such plants basically run close to design load conditions [3]. This becomes a problematic issue in the context of the challenges that nowadays national energy systems face due to the use of energy from intermittent renewable energy sources.

Nomenclature

CO	Condenser
D	Drum
DSH	Desuperheater
E	Energy [kJ]
EV	Evaporator
GT	Gas turbine
h	specific enthalpy [kJ/kg]
H	Heater
HRSG	Heat Recovery Steam Generator
LHV	Lower heating value [kJ/kg]
m	Mass [kg]
NGT	Natural gas turboexpander
ORC	Organic Rankine Cycle
OT	ORC turbine
P	Electric power, Pump
SPH	Superheater
ST	Steam turbine
T	Turbine
TIT	Turbine inlet temperature [°C]

Greek symbols

η	energy efficiency [-]

Subscripts

ch	chemical
el	related to electricity
exh	related to exhaust gas
i	isentropic
in	inlet
NG	Natural gas
out	outlet
w	related to water
wf	related to working fluid

Flexibility of the energy system is becoming an important problem and a new criterion for design of energy conversion plants. In this light the distributed small and medium scale modular combined cycle plants can be an interesting alternative. According to Welch et. al. [4] distributed smaller, more flexible modular CCPPs, that are located closer to the actual loads, can help to improve system flexibility, reliability and security of supply as well as to reduce capital expenditure on capacity expansion/augmentation.

Traditional CCPP consists of gas turbine (GT), heat recovery steam generator (HRSG) and steam turbine (ST). The HRSG is the critical element integrating Brayton and Rankine thermodynamic cycles within the plant. There are many different configurations but the most common are: a) 1 GT + 1 HRSG + 1 ST; b) 2 GTs + 2 HRSGs + 1 ST. There are also configurations where 2 or more gas turbines are connected to a single HRSG. As common practice, the HRSG is tailored specifically for each gas turbine unit and for each specific plant [3]. Typically the improvement of HRSG and thus the entire CCPP performance is achieved by introduction of several water evaporation pressures and steam reheaters within the HRSG. Two or three-pressure steam cycles achieve better efficiency than the single pressure systems, but their installed cost is higher. They are the economic choice when fuel is expensive or if the duty cycle requires a high load factor [5]. In the case of low nominal power output of the plant single pressure HRSGs are used. Typical steam temperature is up to 540°C and pressure up to 140 bar. Consequently, although commercial offer for small-scale CCPPs of the power output below 50 MW is increasing the power generation efficiency of such plants is much lower than the one of modern large scale plants. Figure 1 presents power generation efficiency of CCPPs of the power up to 50 MW. The figure was elaborated using data presented in [6]. The most efficient plants are based on water injected aero derivative gas turbines.