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Research Paper

Operational analysis of natural gas combined cycle CHP plants: Energy performance and pollutant emissions

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HIGHLIGHTS

- Operation analysis of natural gas combined cycles units connected to DH network.
- Good system performances in a wide range of operation conditions.
- High pollutant emissions during start-up and shut-down phases.
- Non-optimal generation when operating in electricity markets with high variability.

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ABSTRACT

The natural gas-fired combined cycle (NGCC) plants are among the best technologies for power production, especially when operating in combined heat and power (CHP) generation feeding a district heating (DH) network. Even if usually designed to operate with very high utilization factors, thus satisfying mainly the base load, nowadays these plants are often used also as backup power. This is due mainly to the necessity to compensate the non-programmable renewable energy sources (RES) production, and it can be done, thanks to the good flexibility of these plants. However, in off-design conditions, the energy performance and the pollutant emissions may not be as good as the expected nominal ones. In this paper, the real operation of three NGCC units has been analysed in detail by considering mean hourly data over several years. A gas turbine efficiency curve at partial loads has been obtained, showing a decrease of conversion efficiency at lower unit loads. The CO emissions during the start-up and shut-down procedures of the plant reached values that are some orders of magnitude higher than in normal operation. This criticality should not be forgotten when using these units for frequent on-off operations.

1. Introduction

The efficiency of the energy conversion plants is among the main topics discussed in EU energy policies [1]. Various advantages are related to an increase of the conversion efficiency, from climate change mitigation to decrease of overall fossil fuels consumption, with both environmental and geo-political concerns [2]. Considering fossil fuels, the natural gas-fired combined cycle (NGCC) plants are currently among the best available technology in terms of conversion efficiency [3], especially when operating in combined heat and power (CHP) mode [4]. The cogeneration in NGCC plants often requires the connection to a district heating (DH) network, as the connection to industrial users is often hindered by the large size of these units, resulting in high available heat. This configuration is among the most efficient solutions for providing heat to buildings [5]. A state-of-the-art NGCC plant can reach up to 58% of electrical efficiency and 90% of global conversion efficiency [6].

Due to these reasons, a number of NGCC have been built in the last decades, resulting in an increase of the electricity production efficiency from natural gas. However, the operation of these plants is currently facing significant transformations, mainly due to the increase of the share of electricity production from renewable energy sources (RES) [7,8]. The EU targets on RES production by 2020 [9] resulted in a spread of RES electricity plants, especially photovoltaics, wind and biomass plants. The increase of RES share in Italian Power Market (IPEX), up to 38% of national electricity production in 2014 [10], resulted in a global decrease of average market prices [7,11]. This situation had a significant impact on fossil-fuel based generation, as the plants that were not able to cope with the new prices have been shut down. Considering NGCC, the ones coupled to a DH network can mitigate the electricity price decrease, thanks to the heat sales incomes. Anyway, the new units' commitment cannot leave aside the new market scenario, and alternative commitment models need to be studied and developed [12,13].

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Table 1
Main technical components and data of the three analysed units (data from References 14, 15 and 16).

Plant component	Value	Moncalieri plant		Torino Nord plant
		2GT	3GT	TON
Gas turbine	**Nominal gross electric power (MW)**	270	260	270
	Fuel	natural gas	natural gas	natural gas
Heat recovery steam generator (high / medium / low pressure stages)	**Pressure (bar)**	94 / 28 / 4,6	104 / 28 / 3,5	125 / 30 / 4,5
	Temperature (°C)	542 / 542 / 225	550 / 560 / 250	550 / 550 / 237
Steam turbine	**Nominal gross electric power (MW)**	141	138	119
District heating heat exchangers	**Nominal thermal power (MW)**	260	260	220
	Inlet temperature (°C)	70	70	70
	Outlet temperature (°C)	120	120	120
Condenser	**Cooling fluid**	Water	Water	Air
Combined cycle operation (ISO conditions on site)	**Net electric power (MW)**	395	383	390
	Global efficiency (-)	58%	57%	56%
Combined cycle + cogeneration operation (ISO conditions on site)	**Net electric power (MW)**	340	322	340
	Thermal power (MW)	260	260	220
	Global efficiency (-)	90%	87%	87%

Another significant aspect of the new market situation is the high variability of production conditions: solar and wind power are intermittent and non-programmable, possibly resulting in very different energy mixes in the same day. A significant amount of backup power is then needed to guarantee the network stability: as a result, NGCCs are often chosen as backup plants rather than simple power generation plants, thanks to their quick start-up and shut-down. However, these transitory operations may have an impact on energy performance and pollutant emissions. An operation analysis needs to be carried out with detailed time step, to consider the real conditions of the generation plant, which can significantly differ from the nominal conditions and have steep and quick variations that could not be highlighted when using time-aggregated data.

In this paper, an operational analysis has been performed on two different NGCC CHP plants, both connected to the same DH network, in the city of Turin (Italy). The study considers both energy performance and pollutant emissions, focusing on CO, NO_X and NH_3, which are the most critical emissions associated with this technology (NH_3 emissions being caused by the SCR flue gases cleaning systems). The variation of system performance over the years with respect to the different operation conditions is considered in detail. This paper shows some preliminary results, which will be the basis for further analyses and comparisons with other CHP systems of different sizes and technologies.

2. Case study

Three different CHP units are used as case studies in the present work; two of these, named in the following “2GT” and “3GT”, are installed in the “Moncalieri” plant, located in Moncalieri, a small town close to Turin, Italy. The third unit, named in the following “TON”, is installed in the “Torino Nord” plant located in the northern zone of Turin. Both these plants are owned and operated by the same company and they both feed the existing DH network of the city of Turin. The Moncalieri plant has been renovated several times and it has been operative in its current configuration from 2008; the Torino Nord plant, on the other hand, has been built in 2011 to be coupled with the extension of the DH network in the northern zone of Turin.

Table 1 summarizes the main technical data of the three considered units.

Fig. 1 and Table 1 report the current configuration for the three CHP units in terms of main component of thermal-electrical groups. It can be seen that 2GT and 3GT units have identical configuration

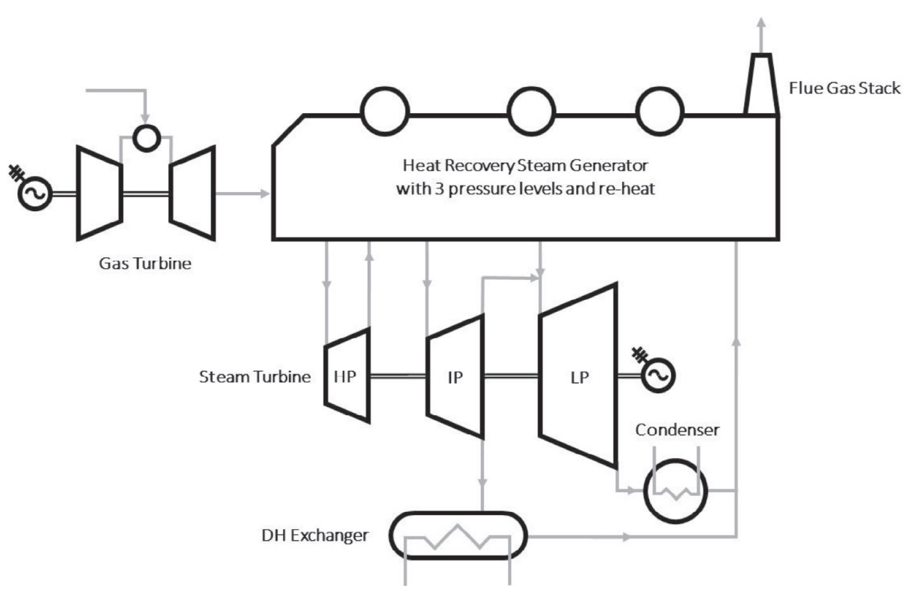

Fig. 1. General configuration scheme for the three considered units (elaboration from References 14–16).