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EXPERIMENTAL STUDIES ON INLET AIR THROTTLING OPERATING STRATEGY IN CCHP SYSTEM

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ABSTRACT

An experimental rig of a micro gas turbine is built and investgeted. This rig is composed of the Capstone C65 micro gas turbine and throttle device, which can be operated under variable speed and inlet air throttling (IAT) operating strategies. The speed remains constant in each object throgh the combined variable speed operating strategy and throttle device. When the gas turbine is operated under IAT operating strategy, the air is throttled and the output power decreases. Moreover, the slight variation is presented on the electric efficiency of the gas turbine between IAT and variable speed operating strategies. This study provides a feasible operating strategy of the gas turbine to improve the off-design performance of the energy system.

Keywords: CCHP system, IAT operating strategy, off-design performance

NONMENCLATURE

Abbreviations	
CCHP	combined cooling, heating and power
FESR	fuel energy saving ratio
IAT	inlet air throttling
TIT	turbine inlet temperature
Greek letters	
η	efficiency
Subscripts	
f	fuel
g	flue gas
e	electricity

1. INTRODUCTION

The CCHP systems are based on the cascade utilization of fuel energy. The flue gas flows through turbine, absorption chiller and hot water exchanger in sequence to produce electric power, cooling energy and hot water, respectively [1]. However, the CCHP systems deviate from the design performance due to the fluctuant energy demands of users. Regardless of system configurations, the appropriate operating strategy is an essential requirement to improve the off-design performance, for its feature to strengthen the match between energy demand and supply [2]. Different from the traditional turbine inlet temperature (TIT) operating strategy, the mass flow rate of the compressor inlet air is decreased with system operating strategies, and therefore the output power is reduced under part-load conditions. Meanwhile, the more output of the high quality flue gas enhance the off-design performance of the energy systems [3]. The mass flow rate of inlet air is reduced by varying the the inlet guide vane position to matain the temperature of the flue gas, thereby increasing the effeciency of the combined cycle [4, 5]. Adjusting the rotational speed operting strategy is widely used in micro gas turbine especially for the recuperated gas turbine [6]. Kim el al. [7] analyzed the off-design performance characteristics of recuperated gas turbine under different operating strategies. The variable speed operating strategy provides the more efficient part load operation than TIT operating strategy. However, this operating strategy is not adequate for small/large gas turbine without available digital power controller. Han el al. [8] proposed the inlet air throttling (IAT) operating strategy for the CCHP system. The ambient air is throttled by the

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throttle device before enter into the compressor. The lower air density is obtained at the the compressor inlet to decrease the output power. The CCHP system presents a higher fuel energy saving ratio compared with TIT operating strategy.

The user's energy demands of surplus heat and electric power may change frequently according to the variation of the enviromental conditions. For example, the heating or cooling demands are higher than the electric power demends in hot summer and cold winter, while the opposite results are presented in the transition seasons. The operating strategy is a feasible way to improve the off-design performance of the CCHP system. However, little literature are focused on the the experimental study with different operting strategy. for the gas turbine. This paper aims to (1) construct an experimental prototype of a micro gas turbine; (2) conduct experimental investigations of the off-design performance under variable speed and IAT operating strategies.

2. SYSTEM DESCRIPTION

2.1 Experimental rig

The experimental rig of the micro gas turbine are shown in Figs. 1 and 2. The micro gas turbine has a designed output power of 65 kW when operated under the standard condition (15 ^{o}C, 101.325 kPa). The rig comprises seven parts: Capstone C65 micro gas turbine, throttle device, natural gas boosting system, hot-water exchanger, cooling water circular system, data collection and mangement system and protection and safety systems.

2.2 System operating strategy

The experimental rig can be operated in two

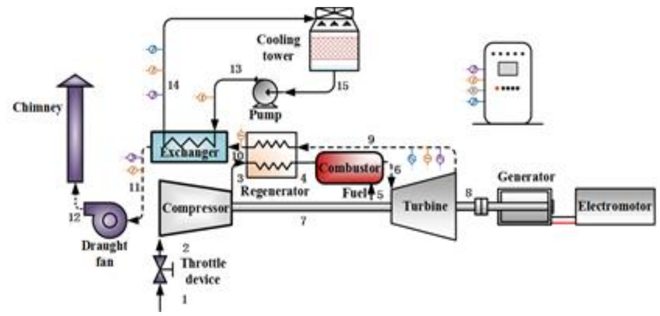

Fig 1. Schematic configuration of the experimental rig.

operating strategies including variable speed operating strategy and IAT operating strategy. However, the IAT operating strategy based on constant speed is not easy to be implemented on the micro gas turbine. When the output power increases from 36 to 65 kW, taking 5-7.5 kW in the load level as an object, the speed will be able to remain constant as long as rising output power cooperate with changing flow area of the compressor inlet. The basic steps are as follows.

Before the output power is adjusted, first start the micro gas turbine with the low load level. (ex: 36 kW, 81262 r/min) (1) The speed rises, whereas the output power remains constant when the flow area of the compressor inlet is decreased by increasing the numbers of the rubber stopper. (ex: 36 kW, 83870 r/min) (2) Increasing the output power and the speed rises due to the variable speed operating strategy. Meanwhile, increasing the flow area of the compressor inlet to maintain the speed constant by decreasing the numbers of the rubber stopper. (ex: 38.5 kW, 83759 r/min) (3) Repeating steps (1) and (2) until the output power increases to 65 kW.

3. DATA REDUCTION

For the micro gas turbine operation model, the

Fig 2. Photo of the experimental rig.

input heat of the fuel (Q_f) is caculated by:

$$Q_f = W + Q_g \tag{3.1}$$

where W is the output power of the gas turbine, Q_g is the recovered heat of the gas turbine.

$$Q_g = m_{11}(h_{10} - h_{11}) \tag{3.2}$$

where m_{11} is the mass flow rate of the flue gas, h_{10} and h_{11} are the enthalpy of the flue gas corresponding to different temperatures.

In this study, the electric efficiency (η_E) is chosen to evaluated the off-design performance of the micro gas turbine . The electric efficiency is defined as

$$\eta_e = \frac{W}{m_f \cdot LHV} \tag{3.3}$$

where m_f is the mass flow rate of the fuel, LHV is the lower heating value of the natural gas.

4. RESULTS AND DISCUSSION

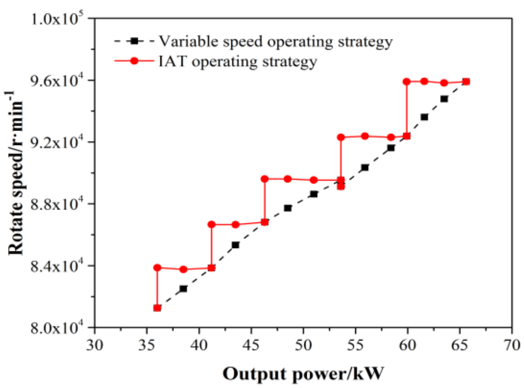

Fig 3. Rotate speed of the gas turbine with different operating strategies

The rotate speed variations versus decreasing the output power of the micro gas turbine with different operating strategies are presented in Fig. 3. The rotate speed decreases from 95903 to 81262 r/min in the gas turbine output power range (65-36 kW) under the variable speed operating strategy. In cases of IAT operating strategy, the speed remains constant in each object based on combined changing flow area of the compressor and output power. The results not only provide experimental conditions of the IAT operating strategy, but also the feasibility of experimental device is verified.

The exhaust temperature variations under different operating strategies are shown in Fig.4. The exhaust temperature continuously decreases when the output power decreases from 65 to 35 kW. In contrast, the exhaust temperature remains constant in each object with the IAT operating strating. Moreover, the turbine outlet temperature maintains the same value of 634 °C. It should be indicated that the variable speed operating startegy leads to a more difference between turbine outlet temperature and exhaust temperature. The greater heat recovery effect at the recuperator is implemented, which enhances the efficiency of the gas turbine. Therefore, the mass flow rate with the variable speed operating strategy decreases faster than that with the IAT operating strategy with the decreases of the load level, as shown in Fig.5.

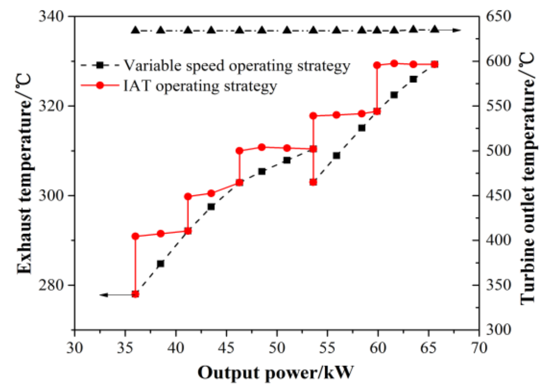

Fig 4. Turbine outlet temperature/exhaust gas temperature with different operating strategies

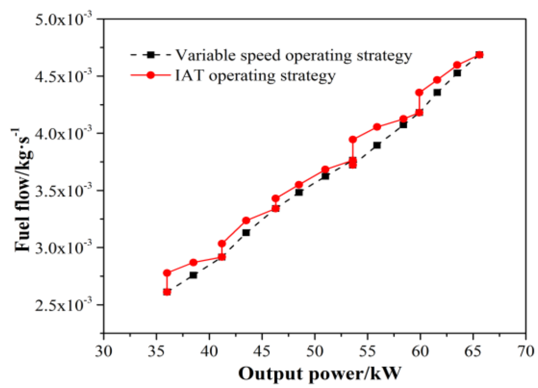

Fig 5. Mass flow of the natural gas with different operating strategies

The electric efficiency of the gas turbine under part-load conditions shown in Fig. 6 confirms the superiority of the variable speed operating staretegy. When the output power decreases, the electric efficiency with the IAT operating strategy under part-load conditions declines quickly due to deteriorated efficiency of the compressor and heat racovery effect. Moreover, the difference of the part-load efficiency between variable speed and IAT operating strategies is slightly within 2%, which means that the off-design performance can be obtained via different operating strategy with almost same consumption of natural gas.

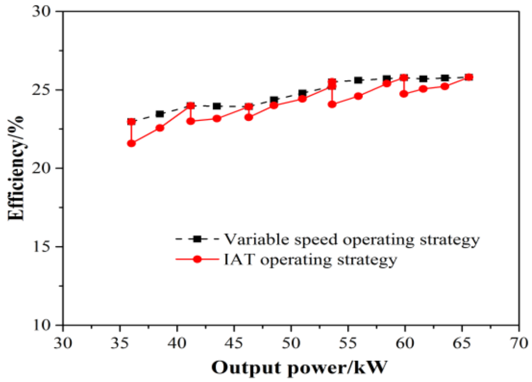

Fig 6. Efficiency of the gas turbine with different operating strategies

Conclusion the effect of IAT opearting strating on the mass flow rate of flue gas is similar to variable speed operating strategy, as shown in Fig. 7. The mass flow of the air decreases with the decrease of the air density through the throttle device, which verifies the feasibility of the IAT operating strategy.

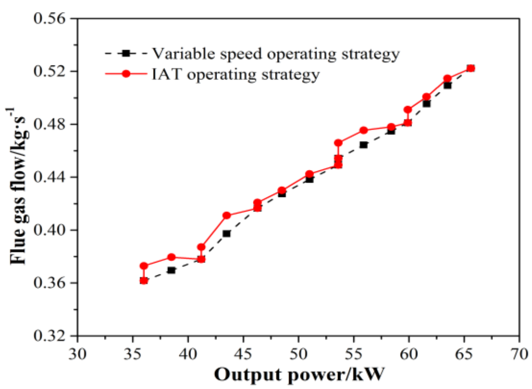

Fig 7. Exhaust gas flow with different operating strategies

5. CONCLUSIONS

This study investigated the off-design performance of the gas turbine under different operating strategies. An expermental rig with the Capstone C65 micro gas turbine is built and tested. The system can be operated under variable speed and inlet air throttling (IAT) operating strategy.

In the each object, the constant speed is achieved which integrates the air throttle device with variable speed operating strategy. In the IAT operating strategy, the mass flow rate of the air is decreased throgh throttle device, thus decreasing the output power of the gas turbine. The experimental results showed, by the improvement of the temperature of the flue gas, the more high-quality exhaust heat is used for cooling and heating production. However, the electric efficiency is decreased. Therefore, the study indicates that both variable speed and IAT operating strategies showed a simliar thermodynamic performance. Furthermore, the study also demostrates the IAT operating strategy can achieve better off-design performances campared with the traditional turbine inlet temperature (TIT) operating strategy.

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REFERENCE

[1] M. Liu, Y. Shi, F. Fang, Combined cooling, heating and power systems: A survey, Renewable and Sustainable Energy Reviews, 35 (2014) 1-22.

[2] Z. Wang, W. Han, N. Zhang, B. Su, M. Liu, H. Jin, Analysis of inlet air throttling operation method for gas turbine in performance of CCHP system under different operation strategies, Energy Conversion and Management, 171 (2018) 298-306.

[3] Q. Chen, W. Han, J.-j. Zheng, J. Sui, H.-g. Jin, The exergy and energy level analysis of a combined cooling, heating and power system driven by a small scale gas turbine at off design condition, Applied Thermal Engineering, 66 (1) (2014) 590-602.

[4] F. Haglind, Variable geometry gas turbines for improving the part-load performance of marine combined cycles – Combined cycle performance, Applied Thermal Engineering, 31 (4) (2011) 467-476.

[5] T.S. Kim, Comparative analysis on the part load performance of combined cycle plants considering design performance and power control strategy, Energy, 29 (1) (2004) 71-85.

[6] F. Bozza, M.C. Cameretti, R. Tuccillo, Adapting the Micro-Gas Turbine Operation to Variable Thermal and Electrical Requirements, Journal of Engineering for Gas Turbines & Power, 127 (3) (2005) 514-524.

[7] T.S. Kim, S.H. Hwang, Part load performance analysis of recuperated gas turbines considering engine configuration and operation strategy, Energy, 31 (2–3) (2006) 260-277.

[8] W. Han, Q. Chen, R.-m. Lin, H.-g. Jin, Assessment of off-design performance of a small-scale combined cooling and power system using an alternative operating strategy for gas turbine, Applied Energy, 138 (2015) 160-168.