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Data-driven Predictive Control of Micro Gas Turbine Combined Cooling Heating and Power system

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Abstract: Micro gas turbine-based combined cooling, heating and power (MGT-CCHP) system is in an important direction toward the development of smart buildings and district energy systems, which provides a clean, highly efficient and reliable means of producing energy for multiple use. However, the control of MGT-CCHP system is a challenge, due to its behavior such as large thermal inertia, and strong coupling among multi-variables. For this reasons, this paper develops a data-driven predictive controller for the MGT-CCHP system to improve its operating performance. The technique of subspace identification is utilized to construct the predictor directly from the input-output data, which can be used to estimate the future behavior of the system. The predictive controller is then designed to regulate the multi-variable MGT-CCHP system under the input-constraints. The effectiveness of the proposed control approach is demonstrated through simulation results on an 80kw MGT-CCHP simulator.

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Keywords: Micro gas turbine-based cooling, heating and power system, predictive control, data-driven predictive control, subspace identification.

1. INTRODUCTION

Micro gas turbine-based cooling, heating and power (MGT-CCHP) system is a promising energy generating unit, which has the ability to provide hot water, absorbing cooling and electricity simultaneously. Because the thermal energy stored in the exhaust gas of gas turbine can be continually used as heat source of water heater or chiller, the energy efficiency of the integrated MGT-CCHP system is up to 80% (Colombo, Armanasco, & Perego, 2007), and moreover, although the investment and maintenance cost of MGT-CCHP unit is higher compared with conventional internal combustion engine, the MGT-CCHP system is much small in size and thus can flexibly be installed in a small residential or commercial district. Therefore, for the purpose of energy saving, consumption reduction and environmental protection, employing the MGT-CCHP devices has been promoted as the primary direction of leading energy developments (Xu et al., 2010, Wu, & Wang, 2006).

Current studies of the MGT-CCHP unit mainly focus on the static system configuration and operation optimization, in which, the capital cost, operation profit, energy consumption and environmental protection indices are taken into account (Savola, & Fogelholm, 2007, Shin et al., 2009). Although the dynamic characteristics and modeling of MGT-CCHP system have been studied in the past few years (Anvari et al., 2015, Rey et al., 2015), the control approaches for the MGT-CCHP system are still staying in the stage of conventional PID control.

In Yang (2009), PID control loops are designed for an MGT-CCHP unit, in which the "trial and error" approach is used to tune the controller parameters at the given operating point. However, when the set-point changes, strong oscillation occurs in the output-variables, which may reduce the efficiency of the plant and threat the safety of many devices. As a direct approach to improve the conventional PI/PID controller, a frequency-domain design method based decoupling PI algorithm is proposed in Zhang (2015), which can achieve smaller overshoots and faster responses.

However, since the dynamics of the MGT-CCHP system has complex properties such as large thermal inertia, strong coupling among multi-variables and unknown disturbances, the PID approaches which are devised on the basis of separate single-input, single-output (SISO) loops are no longer sufficient in meeting performance specifications. Advanced control techniques are called for to improve the operation of MGT-CCHP system.

Predictive control has been extensively used in the area of power generating unit control recently, and has shown to be effective in overcoming the problems of multi-variable, large inertia and constrained system (Wu et al., 2015). Under the traditional design framework, modeling is the first and foremost step in predictive controller design. Because the input-output data of a system can be easily acquired during the operation, data-driven models are employed for most of the predictive controllers. However, the modeling procedure is still complex and the modeling mismatch that will greatly

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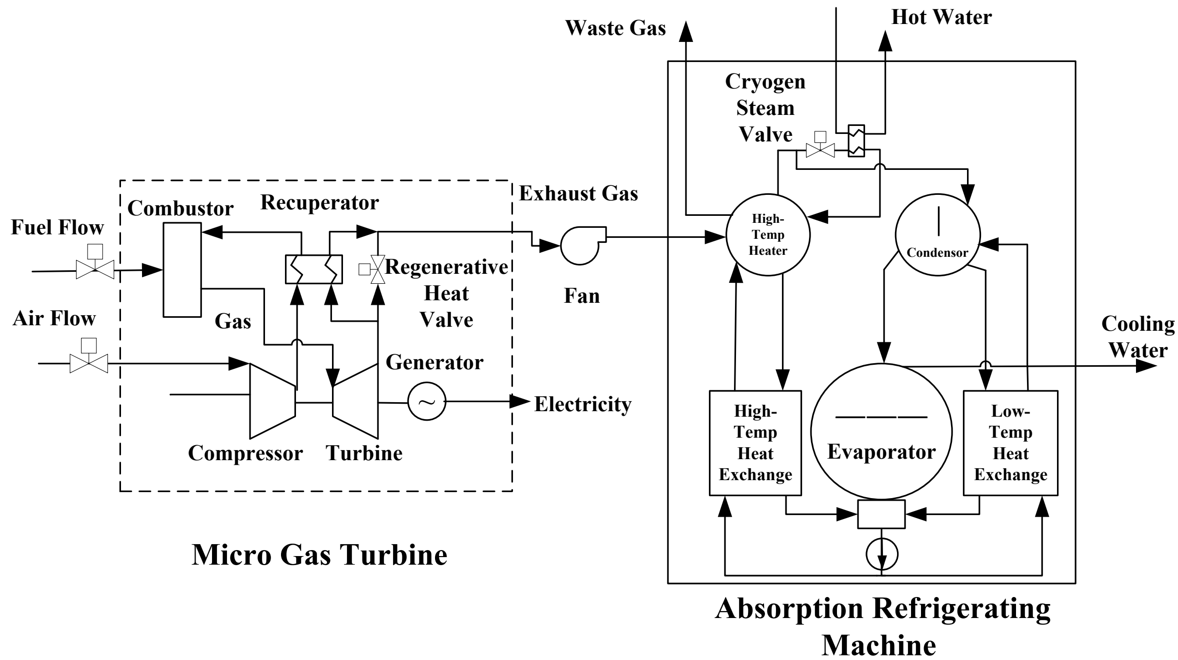

Fig. 1. Schematic diagram of the MGT-CCHP process.

degrade the control performance is unavoidable. On the other hand, since the models are developed from the data, data itself contains more information than the model developed, which implies that data can be directly used to build the controller.

For these reasons, this paper proposes to develop a predictive controller for the MGT-CCHP system directly from the input-output data. The subspace identification (SID) approach is utilized to construct the predictor from the data without developing the plant model (Kadali, Huang, & Rossiter, 2003, Wu et al., 2013, 2014). Therefore, the modeling effort for the conventional model predictive control (MPC) and resulting model mismatches can be avoided.

The proposed data-driven predictive controller (DDPC) is implemented in an 80kw MGT-CCHP simulator. The remainder of this paper is organized as follows: Section II introduces the MGT-CCHP system and its dynamics. The DDPC is presented in Section III. Simulation results are given in Section IV and conclusions are drawn in Section V.

2. SYSTEM DESCRIPTION

The MGT-CCHP system under consideration is composed of an 80kw regenerative micro gas turbine and a 425 kw double-effect lithium bromide absorption refrigerating machine. The compressed air is preheated in the recuperator with the exhaust gas from gas turbine and then piped into the combustor, where the mixed fuel gas and air is burned, producing flue gas in high pressure and temperature. The flue gas is expanded to drive a micro gas turbine to produce electrical energy and then sent into the absorption refrigerating machine as the heat source of cryogen after heating the compressed air. The cryogen heats the water in the high temperature heater for hot water supply and then is chilled in the condenser. After leaving the condenser, the condensed cryogen absorbs the heat from the water in the evaporator for refrigeration and is fed into the high temperature heater for another cycle. Following this way, besides generating the electricity, the MGT-CCHP system is also capable of producing 60℃-80℃ hot water and 7℃-12℃ cooling water from the exhaust gas of micro gas turbine.

The model of this MGT-CCHP unit is developed from the lumped parameters modular modeling approach based on the first principles. It is then simplified and used as a simulator validated in the MATLAB environment. The output variables of the system are: power output y_1 (kw), cold water temperature y_2 (℃), and hot water temperature y_3 (℃), control inputs into the system are valve actuator positions that control the flow rate of fuel, represented as u_1; regenerative heat load, represented as u_2; and flow rate of cryogen steam, represented as u_3.

The behavior of the MGT-CCHP system is complex due to the strong couplings among the multi-variables and the relatively large thermal inertia property of the absorption refrigerating machine, which is demonstrated in Fig. 2 for a step response test when the three inputs are applied sequentially. Therefore, advanced control techniques are needed in place of the conventional PI/PID controllers.

3. DATA-DRIVEN PREDICTIVE CONTROL OF THE MGT-CCHP SYSTEM

Consider the objective function:

$$J = (\hat{y}_f - r_f)^T Q_f (\hat{y}_f - r_f) + \Delta u_f^T R_f \Delta u_f \tag{1}$$

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