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Research on Modeling and Control of a 100 kW Micro Bio-Gas Turbine

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Abstract

In order to know about the influences of disturbance on the operating performance, the present work developed the overall dynamic simulation model of the micro gas turbine and investigated the control system under the disturbances of environmental temperature and unit load. The response processes of main parameters have been obtained. It found that the compressor pressure ratio and the fuel flow rate increase in the case of natural gas being replaced by pine gas. When the system reaches a new steady state, the main parameters change to different values. The output power decreases with the declining of the air mass flow when the ambient temperature rises, the biomass gas mass flow rate increases under the regulation of the control system to maintain the output power and rotating speed in which the thermal efficiency reduces by 1.40%. The thermal efficiency enhances with the increase of output load. The control system can quickly and effectively act to maintain the key parameters at desired value.

Keywords

Micro Gas Turbine, Biomass Gas, Overall Model, Turbine Control System

1. Introduction

Micro gas turbines with 25 kW to 300 kW output power have the advantages of good stability, strong fuel adaptability, and low pollution [1]. Biomass gas has been applied to mcro gas turbines. Aiguo Liu *et al.* [2] proposed adjustments and improvements for low-calorific value's biomass gas. Homam Nikpey Somehsaraei [3] and Qianqian Zhang *et al.* [4] studied the performance of biogas micro gas turbines and calculated the safe operating conditions of micro gas turbine when different biomass gas was applied.

When natural gas is used as micro gas turbine's fuel, Jiandong Duan *et al.* [5]

[6] proposed a load feed-forward control to shorten the adjustment time. Ebrahim Najimi *et al.* [7] studied a method applied to micro gas and the result showed that this control reduced the maximum amplitude of the speed deviation. Ying Shi *et al.* [8] showed that the controller has good stability and flexibility when the load disturbance changes suddenly. Jiandong Duan *et al.* [9] proposed two coordinated control methods for hybrid power generation systems and predicted the output power of a micro-gas turbine.

In this paper, the biomass gas micro turbine overall model is built and the control system under the disturbances of environmental temperature and unit load are studied. The responses processes of main parameters have been obtained. It will provide reference data for the response research of biogas-fired micro gas turbine under different disturbances.

2. Biogas-Fired Micro Gas Turbine Model and Performance Analysis

The biomass gas micro turbine mainly includes modules such as compressor, combustor, turbine and generator. The flowchart is shown in **Figure 1**.

The air is compressed to high-pressure by a compressor. In the combustor, the biomass gas combusts with air and produces high-temperature and high-pressure flue gas, then drives the turbine-generator to do work and to generate electricity.

The biomass gas is used as micro gas turbine's feed fuel, which is different from natural gas. The calorific value of biomass gas is much lower, at the same power generation capacity, the needed biomass gas mass flow will increase. And the combustion products are also different from the natural gas combustion, which result in the different specific heat capacity of the flue gas and thus the work done by the turbine changes accordingly.

2.1. Model Validation

Based on the basic parameters of T100 and the natural gas as feed-fuel, the main results from the simulation model are compared with the initial data and the comparison results of both types of fuel are shown in **Table 1**. When the fuel is

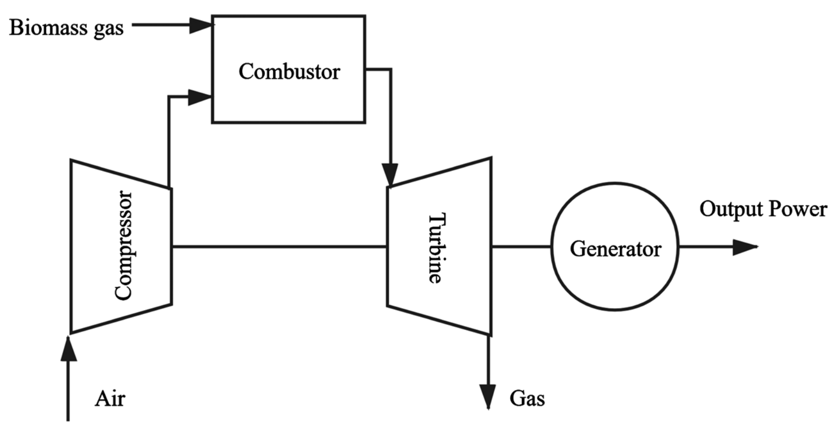

Figure 1. Flowchart of biomass gas micro gas turbine model.

changed to pine gas, it is necessary to make appropriate adjustments to the micro gas turbine to ensure that the flue gas flow rate is 0.79 kg·s^{-1} and the unit rated power is 100 kW. The error of the output power is less than 5%, and the other errors are also within the allowable range. The built model is reasonable. The fuel flow rate and the compressor pressure ratio increase to 0.118 kg·s^{-1} and 5.218 respectively, but both the compressor efficiency and the turbine efficiency decrease slightly.

2.2. Control System of Micro Gas Turbine

The gas turbine control system includes the speed control system, temperature control system and acceleration control system. These three types of control will generate the corresponding fuel reference value, and the minimum value output is selected by the minimum value selector. The overall schematic diagram of the micro gas turbine control system is shown in Figure 2.

Table 1. Comparisons of basic parameters of T100 and simulation results.

System parameters	Basic parameters of T100 (natural gas)	Simulation results (natural gas)	Simulation results(pine gas)
Compressor pressure ratio	4.5	4.5	5.218
Compressor efficiency (%)	81.30	81.30	78.27
Fuel flow (kg·s^{-1})	0.013	0.013	0.118
Outlet temperature of combustor (K)	1223	1188	1220
Turbine exhaust temperature (K)	923	858.6	888.5
Turbine efficiency (%)	82	81.92	79.83
Flue gas flow (kg·s^{-1})	0.79	0.79	0.79
Unit rated power (kW)	100	102	101.2

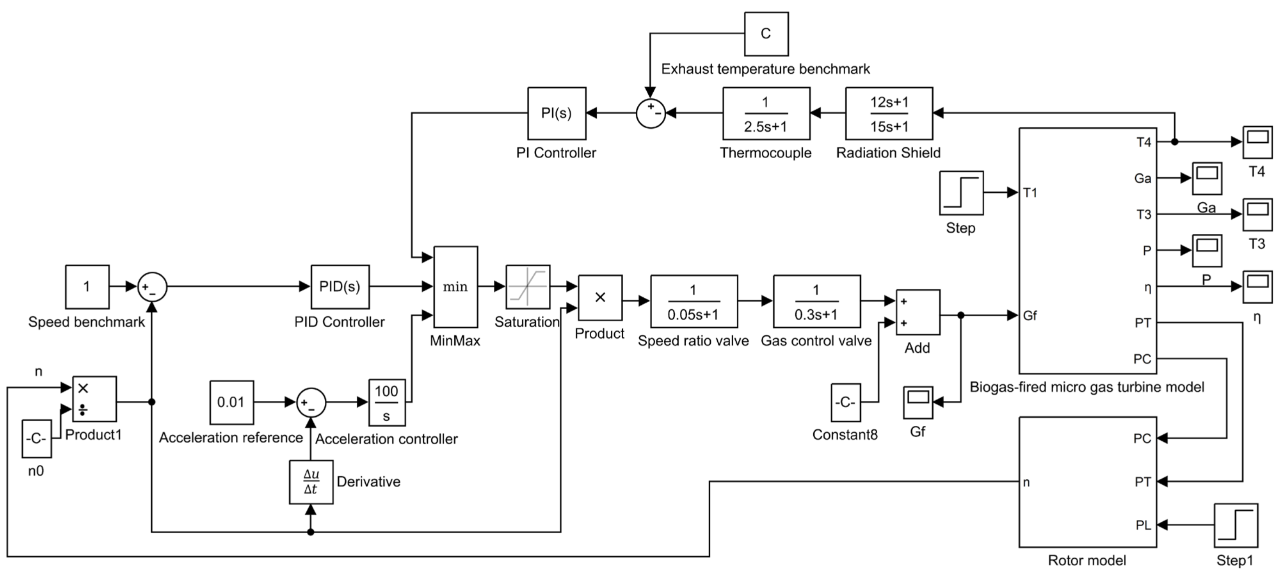

Figure 2. Schematic diagram of micro gas turbine control system.

3. Simulation Results

3.1. Ambient Temperature Disturbance

In the condition of ambient temperature disturbance, the simulation results are shown in Figure 3.

When the ambient temperature steps from 15˚C to 25˚C, the speed of the unit decreases to 999.7 rad·s^{-1}. Under the adjustment of the control system, the fuel input is increased, and then the speed increases quickly, and goes up to its initial

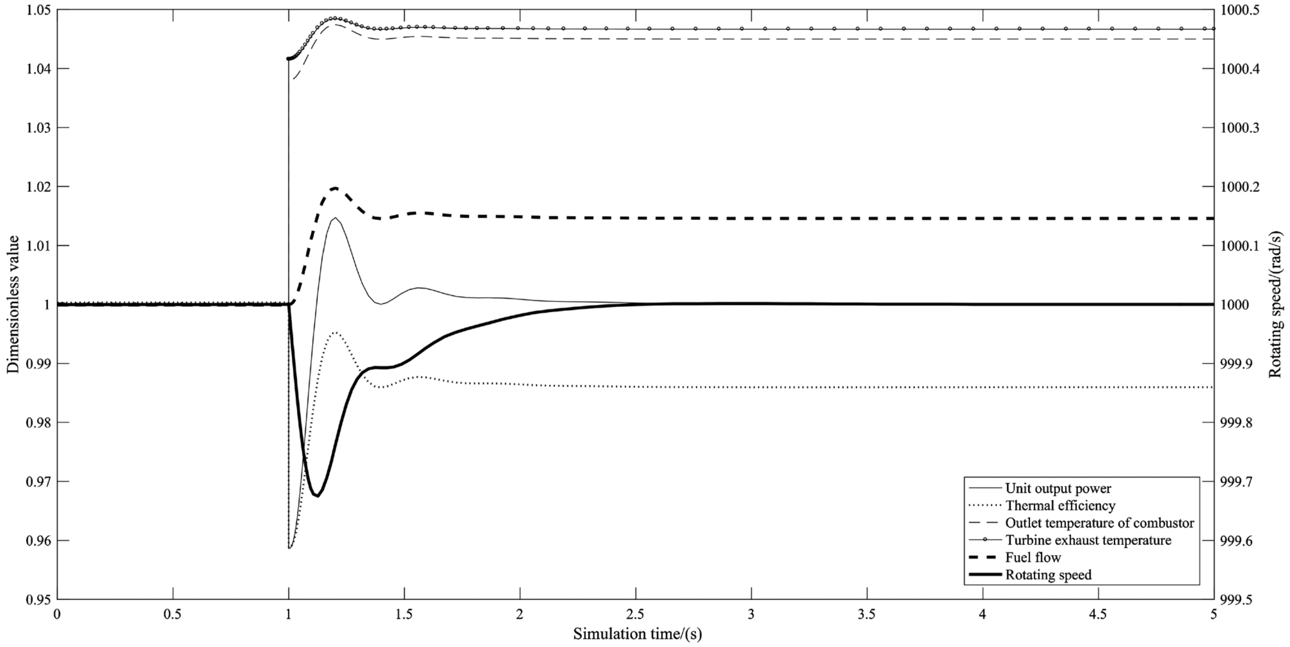

Figure 3. Dynamic responses of micro gas turbine under ambient temperature disturbance.

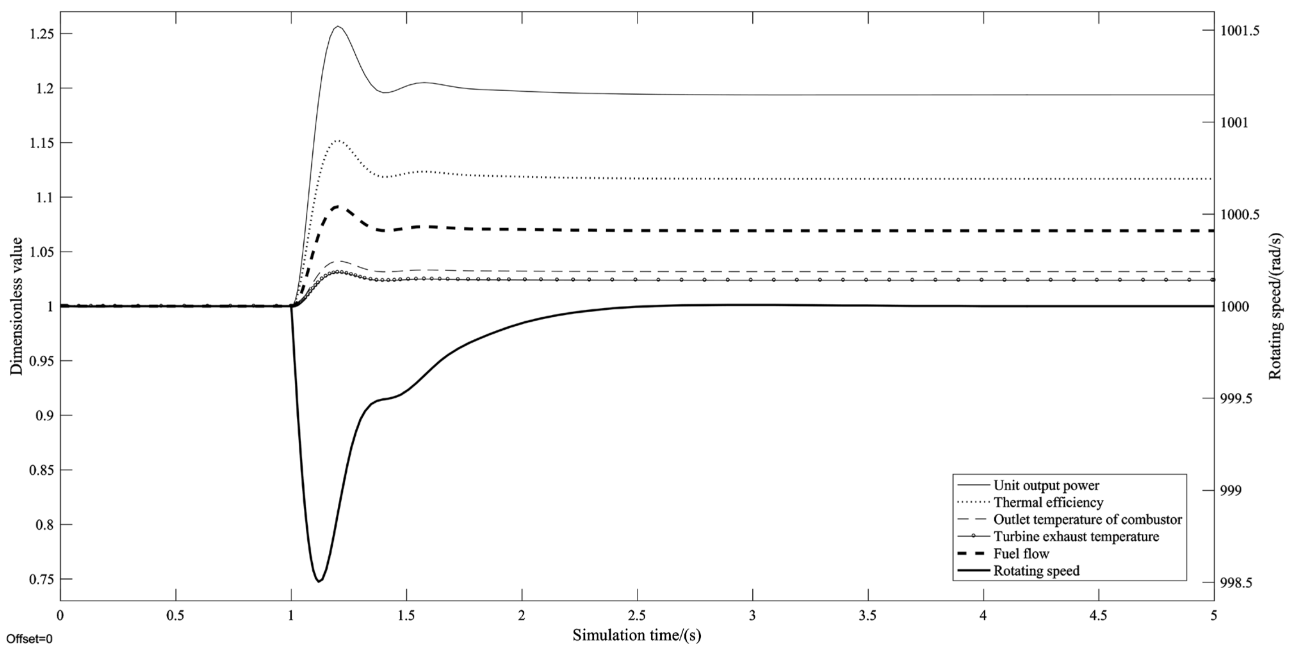

Figure 4. Dynamic responses of the micro gas turbine.

value, then it is gradually adjusted to a new steady state. The unit output power has an inverse process with speed. The biomass gas mass flow rises to the maximum value of 1.02, then declines and stays constant. The outlet temperature of the combustor and exhaust gas temperature of the turbine have the same processes. But the thermal efficiency reduces to 0.9588, about 1.4% relatively. It showed that the control system can quickly and effectively act to maintain the key parameters such as output load, rotating speed at rated value.

3.2. Load Disturbance

When the input load steps 20%, the simulation results are shown in **Figure 4**.

It showed that the output load can rapidly follow the demand and become stable under the regulation of the control system. The fuel flow rate and the thermal efficiency increase obviously with a slight rotating speed offset.

4. Conclusions

1) The fuel flow rate and the compressor pressure ratio increase to keep the output power constant when the fuel is changed from natural gas to pine gas, but the compressor efficiency and turbine efficiency decrease slightly.

2) The output power and the thermal efficiency decrease on condition that the ambient temperature rises. The biomass gas mass flow should be increased though action of the control system. Micro gas turbines are sensitive to change of the ambient temperature.

3) When the micro gas turbine has load disturbance, the control system mainly adjusts the fuel flow to make the micro gas turbine reach a new equilibrium state to meet the operating requirements. And the performance of micro gas turbine has been enhanced.

4) The control system works effectively and speedily to overcome various disturbances to maintain the key operating indexes at desired value.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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