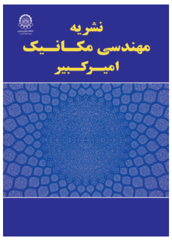

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Modeling and Simulation of MGT70 Gas Turbine Start-up Procedure

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ABSTRACT: In this paper, transient behavior of heavy duty gas turbines in starting regime is analyzed and its characteristics are evaluated. Starting a gas turbine is quasi-transient process. So, the integral form of unsteady conservation equations and the ideal gas state equation are used in order to model the system. A new method is proposed to analyze the compressor performance of gas turbine during start-up condition. Compressor stages are grouped into three categories (front, middle, rear), which each of them has a different performance curve in low-speed. Also, the effects of the inter-stage bleed valves modulation are investigated. Finally, the dynamic behavior of a 160 MW MAPNA gas turbine is simulated during start-up condition. The simulation results are compared with the field data and a good agreement is observed between them. This research has shown the important rule of an exact estimation of start-up procedure (fuel, blow off valves, power of starter motor) for stable operation of compressor and, eventually, of the gas turbine.

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1- Introduction

Gas turbines suffer transient operation during start-up, load change and shutdown. In recent years, many efforts have been done to analyze the gas turbines transient behavior. A 150 MW gas turbine transient behavior during load change was studied by Kim et al. [1]. Agrawal and Yunis developed a generalized mathematical model to estimate gas turbine starting characteristic. They calculated the start-up time at any ambient temperature or altitude [2]. Asgari et al. developed physical and black box model using artificial neural network to evaluate the transient performance of gas turbine [3].

In this paper, a model is developed which can estimate the transient behavior of gas turbine during start-up procedure. Unsteady one-dimensional conservation of mass, momentum and energy equations, Newton's second law and the ideal gas state equation are applied to each component in order to develop the model. A new method is proposed to analyze the compressor performance. Compressor stages are grouped into three categories (front, middle, rear), which each of them has a different performance curve in low-speed. Also, the effects of the inter-stage bleed valve modulation are investigated. Then, the dynamic behavior of a 160 MW MAPNA gas turbine is simulated.

2- Gas Turbine Model Development

The integral form of unsteady one-dimensional conservation of mass, momentum and energy equations is applied to each component in order to develop the model [4]. By integrating these equations over the control volume, the ordinary differential equations can be obtained. It is supposed that the variables in the storage terms are presented by the control volume exit values. The equations can be solved using the initial and boundary conditions.

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3- Compressor

In this paper, a new and simple method is used. In this method, from the input of compressor to the first stage (5^{th} stage) which has the first bleed valve is modeled as the first control volume. The second control volume is considered from the stage 5 until the 10^{th} stage which has the second bleed valve. Finally, the last control volume is from the stage 10 to the output of compressor. By using this method comparing with the stage by stage method, the number of variables is reduced to 12 which three of them are the boundary conditions. So, nine variables are remained which can be obtained by solving the three equations of conservation for each control volume. The variables are the temperature, pressure and axial velocity at each control volume input and output. Three of them are boundary conditions which are output temperature and input and output pressure.

By substituting the following expressions and the ideal gas state equation into the three equations of conservation, the equations can be expressed as a function of pressure, temperature and velocity variables.

$$\dot{m} = \rho A V_x = \frac{P}{RT} A V_x \tag{1}$$

$$\dot{m} V_x = \rho A V_x^2 = \frac{P}{RT} A V_x^2 \tag{2}$$

$$\dot{m}H = \rho A V_x H = \frac{P}{RT} A V_x \left[C_p T + \frac{1}{2} \left(\frac{V_x}{\cos \alpha} \right)^2 \right] \quad (3)$$

4- Combustion Chamber

Combustor chamber is also considered a control volume. The governing equations are the conservation of mass, momentum and energy.

5- Turbine

The model of turbine is similar to the compressor model. The only difference lies in the method for evaluating steady-state characteristics. Here, with given inlet conditions, the expansion ratio of pressure is obtained by the following equation:

$$\frac{\dot{m}_{in}\sqrt{T_{t,in}}}{P_{in}} = K\sqrt{1-\left(\frac{P_{out}}{P_{in}}\right)^2} \quad (4)$$

where K is calculated from design point characteristics. The mass flow rate of coolant air extracted from the compressor is also considered. Therefore, the effect of coolant air must be considered in evaluating the stage characteristic.

6- Rotating Shaft

The rotational motion of shaft can be presented by using the energy equation for a rotating shaft:

$$J\frac{d\omega}{dt} = \frac{\dot{m}C_p\Delta T_{turb} - \dot{m}C_p\Delta T_{comp}}{\omega} + G_{starter} + G_L \quad (5)$$

where G_L is the load torque. It is equals to zero because there is no load during start-up procedure.

7- Simulation Results and Discussions

The proposed gas turbine model is simulated by MATLAB/SIMULINK. A comparison between the responses of the model and real plant data is presented to validate the proposed model. Variation of rotational speed is shown in Figure 1. The rotational speed is well approximated. The time required to reach the rated speed is accurate enough. These results confirm that the fuel, starter motor torque and blow off valves schedules were reasonably estimated.

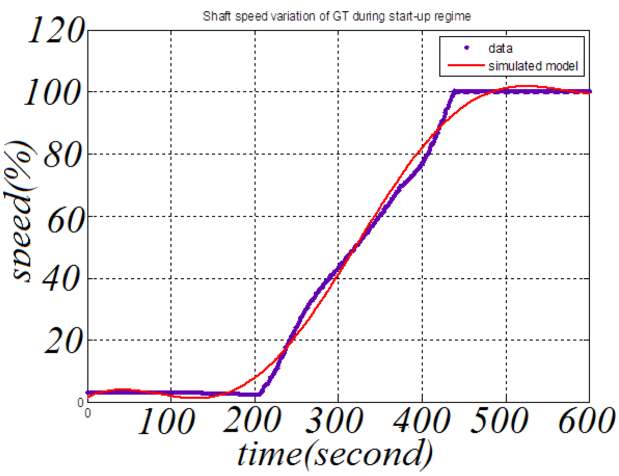

Figure 1. Speed variation versus time during start-up procedure

In order to investigate the effect of bleed valves modulation, the start-up characteristics which are previously predicted are compared with those of the case without bleed valves modulation. The operating and surge lines are depicted in Figure 2 for both cases. The surge margin in gas turbines for power generation is about 15-20% at the every equilibrium running point [5]. The modulation of bleed valves increases the surge margin as shown in Figure 2.

In Table 1, the error functions are listed as; upper bound error Max(|e|), lower bound error Min(|e|), mean absolute error MAE, root mean square error RMSE.

Table 1. Speed and TET error functions (% of rated speed)

	Max(|e|)	Min(|e|)	MAE	RMSE
Speed (%)	7.9262	0.004	2.1356	2.7145
TET (°C)	39.9370	8.5471×10^{-4}	3.4665	8.7329

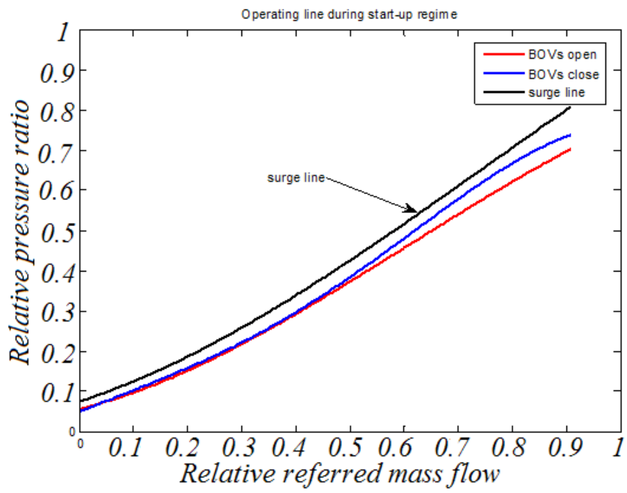

Figure 2. Operating and surge line during start-up procedure

8- Conclusions

The transient behavior of MGT-70 MAPNA gas turbine during start-up procedure has been simulated. This research has demonstrated the important rule of a precise estimation of start-up procedure for stable operation of compressor and, eventually, of the gas turbine. The presented gas turbine model can be used for control system design synthesis such as sliding mode control in order to have safe operation of a compressor particularly during start-up.

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