Modeling and influence analysis of starter capacity and fuel schedule of a heavy duty gas turbine during start-up

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Long Abstract

Introduction

Heavy duty gas turbines operate in various transient conditions such as start-up, load change, shutdown. The start-up operation consists of cranking, purge, light-off and acceleration[1]. The start-up process of heavy duty gas turbines is a complex sequence involving several restrictions, which are turbine inlet temperature limit, compressor surge limit, flameout limit, maximum speed limit and so on. Also, instability due to compressor surge and stall might cause shutdown at low shaft speeds. Accordingly, the start-up operation of gas turbine is very important to guarantee safe operations.

This paper describes the modeling of a dynamic analysis program to simulate start-up transient behaviors of a large heavy duty gas turbine and presents results of the simulation.

Method and Result

Figure 1 shows the schematic layout of the gas turbine simulated in this study. Its predicted design power output and thermal effciency at generator end are 276 MW and 39.8%. The fuel is natural gas and ISO ambient condition is assumed. The simulation program was coded with Matlab[2] and has been developed to predict the transient behaviors of the start-up process of heavy duty gas turbines accurately. Each component of the system, including compressor, combustor, turbine, starter and ducts was modeled independently as a control volume to which mass and energy balances, generally described by the following equations, and off-design characteristic models were applied.

$$\sum \dot{m}_{\text{in}} - \sum \dot{m}_{\text{out}} = 0, \quad \sum (\dot{m}_{\text{in}} h_{\text{in}} - \dot{m}_{\text{out}} h_{\text{out}}) + \dot{Q} + \dot{W} = 0$$

where $\dot{m}$, h, $\dot{Q}$, $\dot{W}$ mean mass flow rate, specific enthalpy, heat transfer and power.

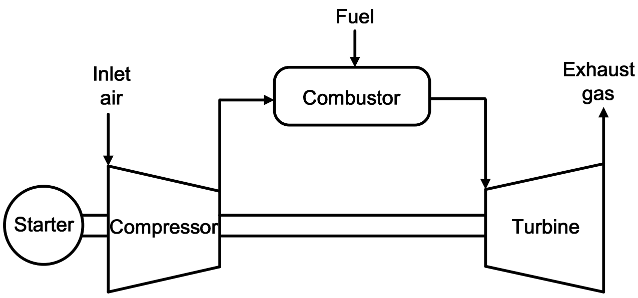

Figure 1. Gas turbine configuration

The mass and energy balance equations were solved numerically by the Multivariable Newton Raphson method. A quasi-steady model was used: the inertia of working fluid is assumed to be negligible compared with the mechanical inertia of the rotating shaft. The working (off-design) characteristics of the compressor and turbine were described by their performance maps. The combustor module is capable of dealing with a various types of gaseous fuels and complete combustion was assumed. All working fluids were assumed to be ideal gases. The rotational behavior of the rotor was described by the following equation.

$$I\frac{d\omega}{dt} = G_{Turbine} - G_{Compressor} + G_{Starter}$$

where I, ω, t, G mean polar moment of inertia, angular velocity, time and torque.

The transient behaviors were analyzed by applying a fuel schedule and starter engine torque characteristic[3]. The acceleration in the rotor speed and fuel mass flow rate during start-up were shown in Figure 2. The total start-up time of the gas turbine was selected using a reference [4]. The starter torque characteristic was scaled in order to satisfy the proposed start-up time. The fuel supply schedule (i.e. the change of the rate of fuel mass flow with time) was used as input in the simulation. The rotor shaft accelerates from zero to 3600rpm by the combination of the fuel schedule and the torque characteristic of the starter engine. The ignition speed is 720rpm, which is 20% of the full rotor speed. The rotational speed and the fuel mass flow rate showed a similar trend.

As shown in Figure 3, the starter engine played a role in accelerating the rotor speed toward idle speed(3600rpm). The starter engine cut-off speed was set at 50% of the full rotor speed. From the ignition speed(720rpm)to cut-off speed(1800rpm), the net torque required to accelerate the gas turbine shaft is provided by both the starter and fuel supply. The program is being used for the determination of the start-up control strategies of a heavy duty gas turbine under development will be further developed into a more sophisticated program which is capable of predicting starter sizing and designing the optimal control system of gas turbines.

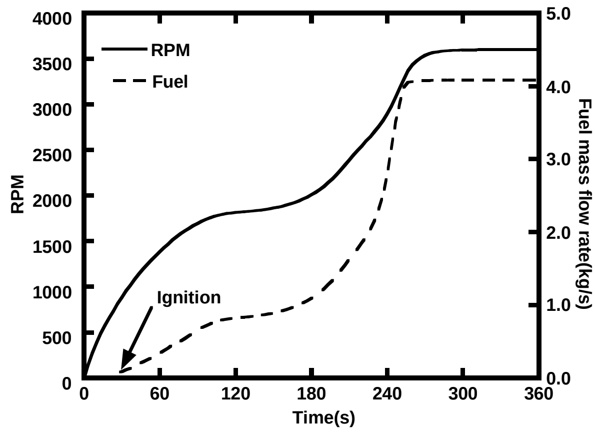

Figure 2. Fuel scheduling and gas turbine speed response during start-up

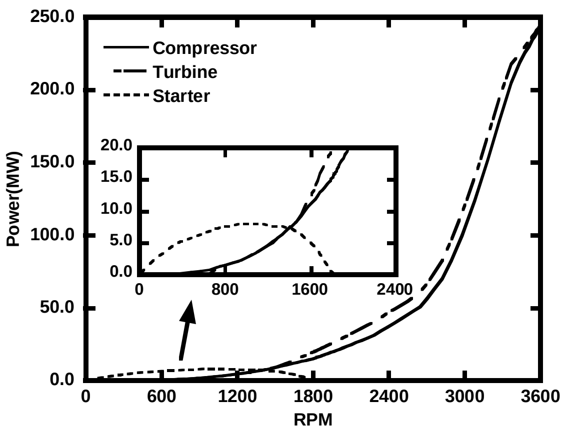

Figure 3. Components power during start-up

Acknowledgment

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