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Design of Rowen's Model for Heavy Duty Gas Turbine (HDGT)

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ABSTRACT

In this paper, the parameters of Rowen's model for heavy duty gas turbines in dynamic studies are estimated by use of available operational and performance data. The transfer function model of heavy duty gas turbine is required for the analysis and development of optimal controllers. The speedtronic controller derived from Rowen's model has three controller namely, speed, acceleration and temperature. The model with all these controllers is developed with MATLAB/Simulink to study their response and arrive at the simplified model. The speed controller may have isochronous or drooping governor characteristics. The choice of governor characteristics for the simplified model is made from the response of the system simulated for an unit step load disturbance. The equations are to be validated with the response of the system simulated using MATLAB/Simulink.

Keywords : Dynamic Simulation, Thermodynamic Process, Rowen's Model.

I. INTRODUCTION

THE gas turbine is a main part of the current power plant, which produces a great amount of energy for its size and weight. The gas turbine has established growing service in the past 40 years in the power industry both among utilities and merchant plants as well as the petrochemical industry, and utilities throughout the world. The last 20 years has seen a noticeable growth in Gas Turbine Technology. The growth is developed by the enhancement of materials technology, new coatings and new cooling schemes. This, with the conjunction of increase in compressor pressure ratio, has increased the gas turbine thermal efficiency from about 15 to over 45 percent, which is suitable for power plants. In the past, large coal and nuclear power plants dominated the electric power generation. However, natural gas-fired turbines now dominate the field of Power generation because of their black start capabilities, higher efficiencies, lower capital costs, shorter installation times, better emission characteristics, and abundance of natural gas supplies. The construction cost of gas turbine power plants is roughly half that of comparable conventional fossil fuel steam power plants, which were the primary power plants until the early 1980s. More than half of all power plants to be installed in the foreseeable future are forecast to be gas turbine or combined gas-steam turbine types. Current low prices for crude oil make fuels such as diesel, kerosene, and clean gaseous fuels such as natural gas the most desirable for gas turbines. However, these fuels will become much more expensive and will eventually run out. So, provisions must therefore be made to burn alternative fuels. Now, gas turbines are used in a wide range of applications. Figure 1 shows a overview of gas turbine.

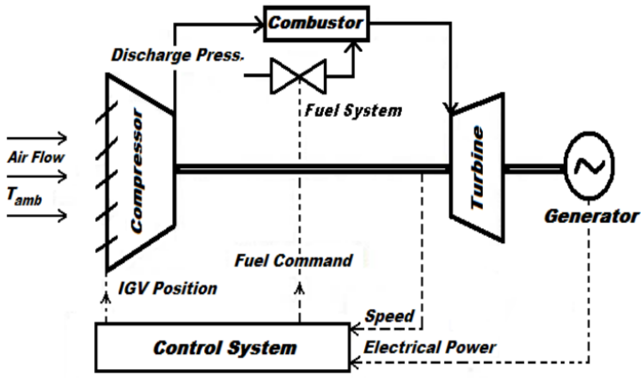


Figure (1): Gas Turbine System Overview

II. SYSTEM MODEL

The schematic diagram for a simple cycle, single shaft gas turbine plant operating on Brayton thermodynamic cycle is shown in Figure 2. At ambient condition air enters the axial flow compressor, compressed to some high pressure. No heat is added; however, air at the discharge of the compressor is at high temperature because of compression. Air enters combustion system after leaving the compressor, where fuel is injected and combustion occurs. The combustion mixture leaves the combustion system and enters the turbine. In the turbine section of the gas turbine, the energy of the hot gases is converted into work. Some of the work developed by turbine is used to drive the compressor and the remaining is available for useful work at the output flange of the gas turbine

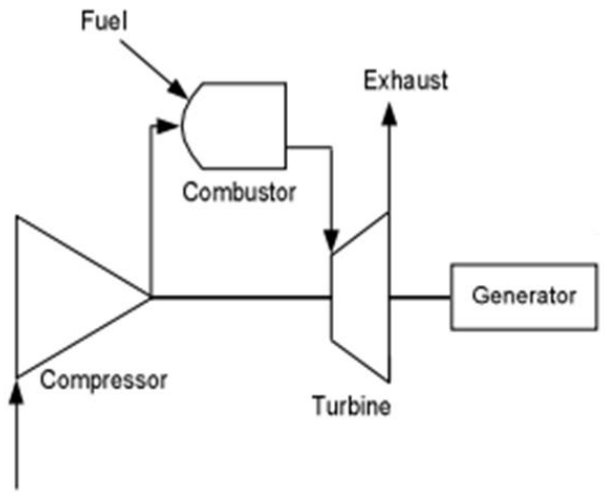


Figure 2 The schematic diagram for a simple cycle, single shaft gas turbine plant

The gas turbine model presented by Rowen is shown in Figure 3. The model includes controllers, fuel system, compressor and turbine. The controllers are speed controller, temperature controller and acceleration controller. The fuel system consists of valve positioner and fuel system actuator. The compressor - turbine system includes the combustor delay, exhaust system and torque function. The gas turbine is predominantly controlled by speed, acceleration and temperature controllers.

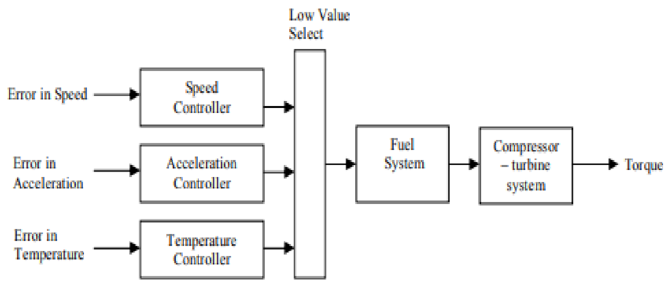


Figure 3. Block diagram representation of gas turbine plant

Speed controller

The block diagram representation of speed controller is shown in Figure 4. The speed governor does the control on speed. It works under part load condition. The speed governor is either droop or isochronous control and operates on speed error. The output is proportional to error in speed in case of droop governor. In case of isochronous governor the rate of change of output is proportional to the speed error. The speed governor output is given to the low value select

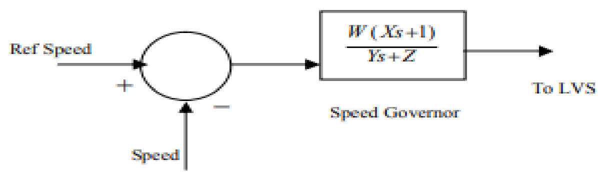


Figure 4 Transfer function block diagram of speed control loop

Acceleration controller

The acceleration control is used to limit the rate of rotor acceleration during start up. During normal operation it acts as secondary controller to reduce fuel flow and limit the tendency to over speed. The speed is differentiated to get acceleration and compared with the reference value of acceleration. The error in acceleration is given to the acceleration controller, whose output is given to the low value select. The Block diagram of acceleration control loop is shown in Figure 2.5.

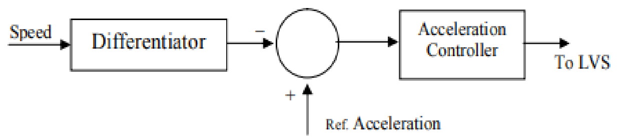


Figure 5 Transfer function block diagram of acceleration control loop

Temperature controller

Temperature control block diagram shown in Figure 6 is the normal means of limiting gas turbine output at a predetermined firing temperature, independent of variation in the ambient temperature or fuel characteristics. In the combustor, fuel is burnt which results in turbine torque. The exhaust temperature is measured using radiation shield cum thermocouple. The temperature is compared with the rated value and error is given to the temperature controller. The third input to the low value select will be the temperature controller output.

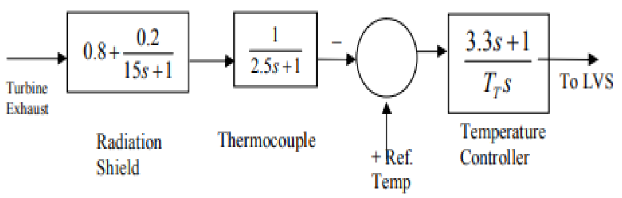


Figure 6 Transfer function block diagram of temperature control loop

Fuel System

One of the significant factors of gas turbine plant is that fraction of rated fuel is required to support self- sustaining, no-load conditions. This amounts to approximately 23 percent and is one of the economic driving forces to minimize operating time at full speed, no-load conditions. As a result, the active fuel control range of the governor is from 23-100 percent. The fuel from the fuel system through valve positioner produces mechanical energy in the turbine which acts as prime mover for the generator. The block diagram is shown in Figure 7

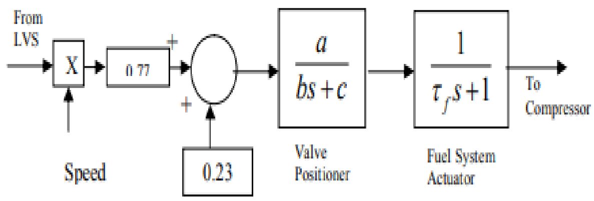


Figure 7 Transfer function block diagram of fuel system

Compressor - Turbine

The block diagram of the compressor – turbine is shown in Figure 8. The turbine is a non dynamic linear device. The compressor is a dynamic device having some time lag associated with the compressor discharge volume. For the change in input of the compressor the output will not respond instantaneously.

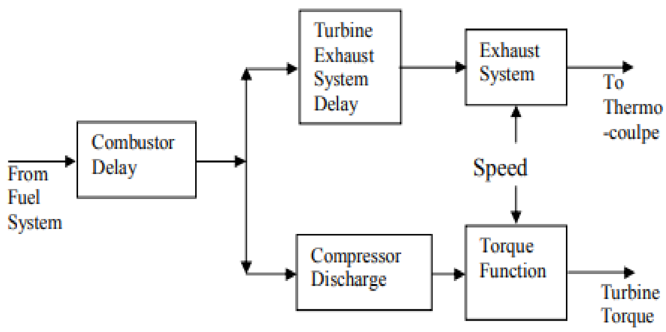
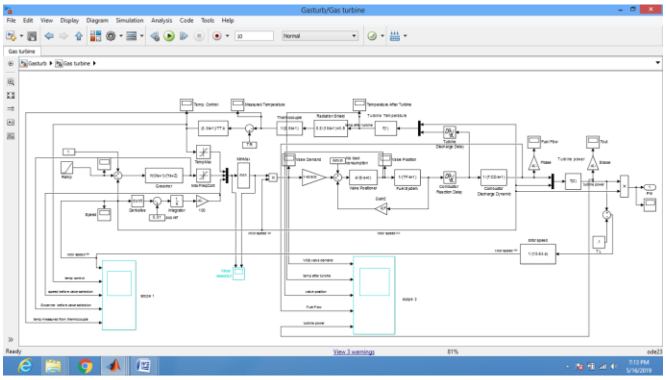
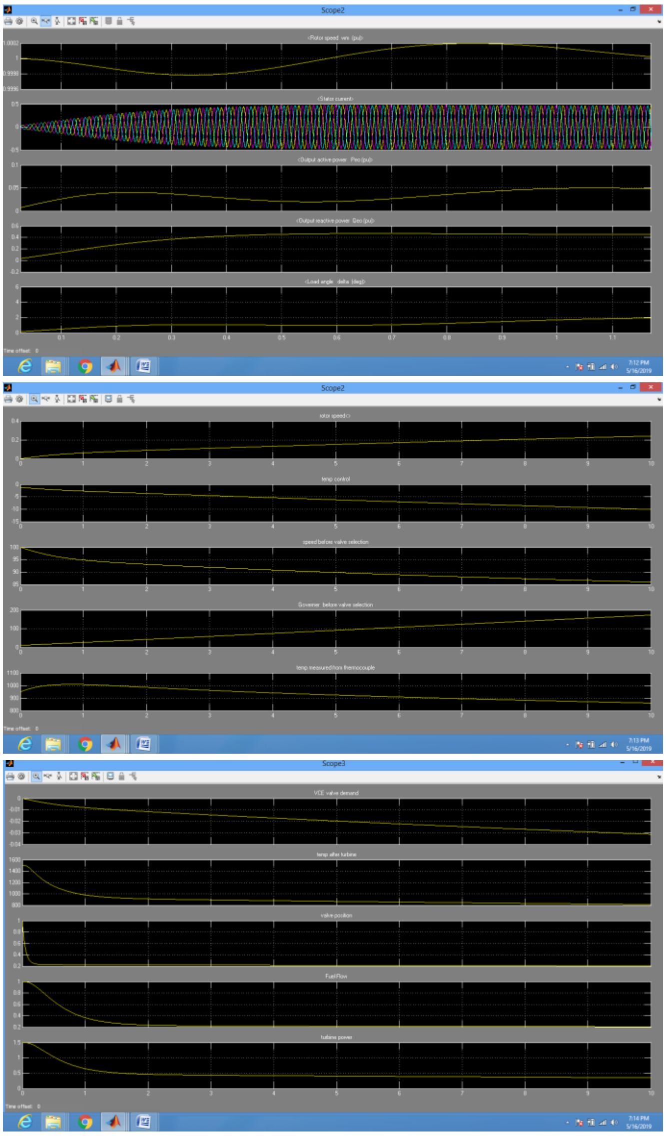


Figure 8 Block diagram of compressor – turbine system

Simulation turbine design:



Simulation results:



III. CONCLUSION

In this article, a simple procedure is used for estimating the parameters of Rowen's model for practical HDGTs. These parameters could be used in dynamic studies for many purposes. The way of obtaining the parameters are based on simple physical laws and explained to some extents to make it useful for who are involved in dynamic studies of HDGT. All the obtained results via simulations using Matlab/Simulink are highly matched with the involved scientific articles that published in different literatures. The same procedure could be applied for any scale (size) of gas turbines. However, it is noticeable that the obtained results are significantly depends on the selected operating conditions.

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