ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

Review On Exhaust Temperature Control Of Gas Turbine

Preeti Dhiman, Aakanksha Saxena, Akanksha, Deepali Tiwari, Durgesh Agrahari

Abstract*— Modeling and control of gas turbines (GTs) have always been a controversial issue because of the complex dynamics of these kinds of equipment. Considerable research activities have been carried out so far in this field in order to disclose the secrets behind the nonlinear behavior of these systems. Although the results of the research in this area have been satisfactory so far, it seems that there is no end to the efforts for performance optimization of gas turbines. A variety of analytical and experimental models as well as control systems has been built so far for gas turbines. However, the need for optimized models for different objectives and applications has been a strong motivation for researchers to continue to work in this field. This paper is aimed at presenting a general overview of essential basic criteria that need to be considered for making a satisfactory model and control system of a gas turbine.

Keywords—**Gas Turbine, modeling of gas turbine, designing of system using PI and PID PSO controllers.**

I. INTRODUCTION

The gas turbine engine is a complex assembly of different components such as compressors, turbines, combustion chambers, etc., designed on the basis of thermodynamic laws [1]. Gas turbines usually consist of an axial compressor, a combustion chamber and a turbine operating under Brayton cycle [2]. These three elements form the thermal block are complemented by the air intake system, the exhaust system, auxiliaries and controls (Figure 1).The air flow is drawn into the axial compressor and compressed through multiple stages of stator and rotor blades. The compressed air in the axial compressor is then mixed with fuel in the combustion chamber, where the combustion process takes place. The resulting hot gas is expanded through a multi stage turbine to drive the generator and the compressor. The fuel flow determines the power output of a gas turbine. The fuel and air flow together determine the firing temperature, which is the gas temperature at the exit of the combustion chamber. Gas turbine has become increasingly popular in different areas of industry due to their lower greenhouse emission and higher efficiency compared to other types of engine, such as diesel engines, especially when connected in a combined cycle setup. The control of gas turbine system, particularly its exhaust temperature control, is of primary concern. During transient, the system's transient response period should be as short as possible and the temporal peaks of the main parameters, such as turbine inlet temperature and rotational speed should not exceed certain reference values required for a safe and reliable operation. However, this is the main problem of the gas turbine; it suffers from undesirable transient response during start-up, load changes and shutdown as well as under abnormal conditions[3].The exhaust temperature control regulates fuel in order to provide a controlled temperature increase or decrease and an upper limit for normal operation. The average value of the thermocouples sorted highest to lowest is the exhaust temperature feedback. The inlet guide vane (IGV) control modulates the IGV angle on a schedule of corrected speed, which is a function of the compressor inlet temperature and the gas turbine speed when the gas turbine is started up. The IGV control also modulates the IGV angle to maintain high exhaust temperature during part load. The load brings the IGV angle to open due to increasing exhaust temperature. The IGV control program depends on the operation type selected of simple cycle operation and combined cycle operation. The acceleration control controls the acceleration rate of the gas turbine during the acceleration to operating speed. The acceleration control output is restricted by the minimum fuel limit to maintain flame. The speed control controls the speed of the gas turbine at operating speed when the turbine is not synchronized to the power system or is selected by the operator to perform frequency control in a multi-machine interconnected system. The exhaust temperature control regulates fuel in order to provide a controlled temperature increase or decrease and an upper limit for normal operation. The average value of the thermocouples sorted highest to lowest is the exhaust temperature feedback. [4]

II. STRUCTURE OF GAS TURBINE MODELS

The typical model of gas turbines in stability studies Consists of three control loops [6]:
- Load - frequency control.
- Temperature control.
- Acceleration control.

The load - frequency control is the main control loop during normal operating conditions. The temperature and acceleration control are active in the case of abnormal operating conditions.

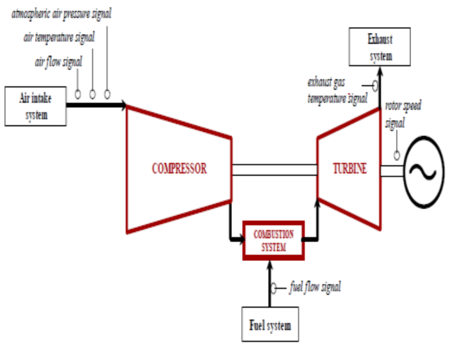

Fig .1 Single Shaft Gas Turbine Configurations

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

When the temperature of the exhaust gases exceeds the limit value, the temperature control takes action to reduce the output power of the gas turbine, so that the temperature comes within limit. The acceleration loop takes control in the case that the generator experiences high positive acceleration. When the acceleration of the generator exceeds the acceleration limit, the control reduces the fuel signal and the output power of the gas turbine is reduced, thus limiting the acceleration. The output of the three control loops are the input to a minimum value gate so that the loop which takes control is the one which output is the lowest of the three. The output of minimum value gate commands the fuel system and therefore the mechanical power delivered by the gas turbine. The output of the three control loops are the input to a minimum value gate so that the loop which takes control is the one which output is the lowest of the three. The output of minimum value gate commands the fuel system and therefore the mechanical power delivered by the gas turbine. To check the performance of the three control loops time domain simulations of several disturbances have been conducted. The power system simulated consists of a generator connected to an infinite bus through a power transformer. There is also a load connected at the generator terminals. This load represents an industrial consumption.[6]

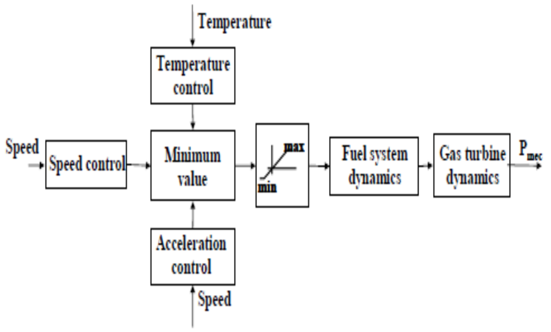

Fig 2 Simplified Representation of the Model Proposed in [5].

III. THE ROLE OF TEMPERATURE CONTROL LOOP

The temperature control loop takes control of the gas turbine when the exhaust temperature exceeds a fixed maximum value. If the load demanded to the turbine increases when the generator is running under normal operating conditions, the output power of the gas turbine will increase due to the action of the load - frequency control. This increase makes the exhaust temperature to rise. If this temperature is higher than the maximum rated exhaust temperature, the temperature control output will be lower than that of the load -frequency control, thus taking control of the response of the turbine. The temperature limit depends on the ambient temperature. In the case that ambient temperature increases, the exhaust temperature will tend to increase and the action of the temperature control loop will be to reduce the amount of fuel consumption of the gas turbine. On the other hand, when ambient temperatures decreases the exhaust temperature will tend to decrease also, thus not reducing the fuel consumption, and it might occur that the load - frequency control loop becomes the active control loop. The basic temperature control loop consists of the following components:

• Temperature measurement: this block represents the temperature measurement process.

• Comparison with a temperature reference: an error signal is obtained subtracting the output of the temperature measurement block to the temperature limit.

• PI controller: The integral part of the controller has non-windup limits. Usually the exhaust temperature is lower than the temperature limit, the error signal is positive and the trend of the integrator output would be to increase. The non-windup limits are necessary for the output of the integrator not to increase steadily. The limit imposed by the exhaust temperature is characterized by the parameter “Temperature reference” in the block diagram. This limit is expressed as the maximum power that the gas turbine can deliver and is affected by the ambient temperature.

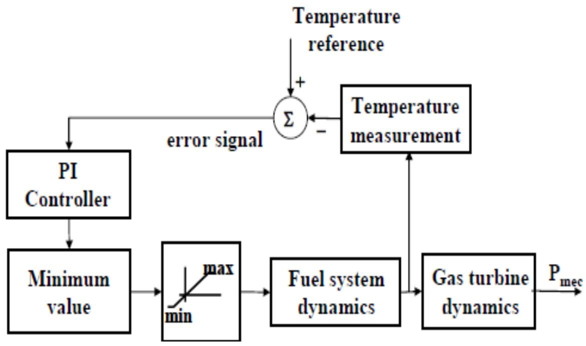

Fig 3 Basic Temperature Control Loop.

The model proposed in [7] includes the effect of reduction of fuel consumption when the speed of the machine decreases. This is due to the fact that exhaust temperature must be kept within limits at any time. When the turbine speed decreases the air flow through the compressor is reduced so that less fuel consumption is required by the gas turbine. If the fuel amount is kept in the same level, the exhaust temperature will increase, and the temperature control loop will tend to reduce the fuel consumption. This is shown in Figure 3.2 where the exponent Dm models that phenomenon. The time constant Tm in the block diagram represents the dynamics of the temperature measurement process. Once the temperature is measured it is compared with the temperature reference and an error signal is obtained. This error signal is the input to the PI controller. The output of the PI controller is one of the inputs to the minimum value gate where it will be compared to the outputs of the speed and acceleration control loops[7]. Although some models ([8], [9]) do not include a representation of a non-windup limit in the integral part of the PI controller, it is important to represent it to ensure that when the temperature control loop is not acting the integrator output reaches the limit. The limit would guarantee that the output of the integrator will not steadily increase and the temperature control loop acts as soon as it is necessary. If the operation of the temperature control loop is like to be inhibited a high value of

"Temperature reference" can be set. In [6] the temperature control loop includes the action of the inlet guide vanes (IGV).

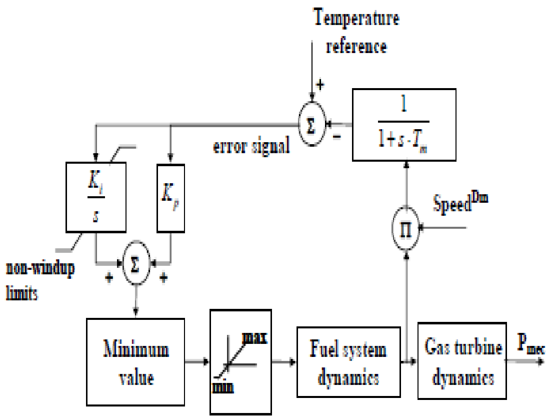

Fig 4 Temperature Control Loop of the Gas Turbine Model.

IGV are situated in the air-compressor stage of the gas turbine. The role of the latter is to regulate the mass flow of air drawn into the compressor. In the operation of open cycle gas turbines, IGV are controlled during the start-up of the gas turbine and its modeling can be neglected for simulations of the gas turbine response running under normal operating conditions [3]. Figure 3.3 shows the corresponding block diagram.

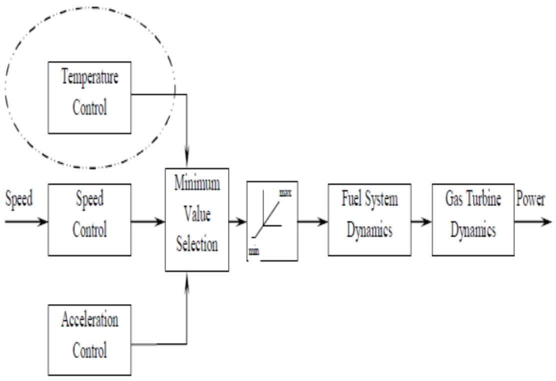

Fig 5 Simplified Representation of a Single Shaft Gas Turbine Model Proposed By Rowen (1992).

IV. SYSTEM DESIGN USING PSO PID CONTROLLER

There are several parameters that most process control systems aim to control. These include the rise time (the time required for the controlled parameters to go from 10 to 90% of the final desired values), settling time (the time required for the transient's damped oscillations to reach and stay within of the steady-state value) and the maximum overshoot (the maximum amount that the controlled parameters overshoot the desired values). PID controller is the most commonly used controller in the process control industry. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. PID control is often combined with logic, sequential functions, selectors and simple function blocks to build the complicated automation systems used for energy production, transportation and manufacturing. Its widespread use is attributed to its simple structure and robust performance over a wide range of operating conditions. The PID control signal is given by Equation 1:

U(t)= kp[e(t)+1/Ti (∫e(t)dt+Td{de(t)/dt})] (1)

Where u(t)is the control signal and e(t) is the control error, which is difference between the desired set point and the measured process variable. The control parameters consist of the proportional gain (kp), the integral time (Ti) and the derivative time (Td). Figure 4.1 shows the conventional PID controller, in which, each term has its own characteristic regarding to the control of the process. The effect of kp is to reduce the steady state error by increasing the value of gain, but it never eliminates the error. The other action of kp is to reduce the rise time. The action of integral gain, K_i =kp /Ti , is to eliminate the steady state error by reducing the value of Ti , but the tendency for oscillation also increases by this action. The derivative gain, K_d = kpT_d has the effect of increasing the stability of the system, reducing its overshoot as well as improving the settling time. Figure 1 shows the block diagram of the PID controller in controlling a process plant. Determination of the parameters that represent the specification and robustness of the closed loop and control loop performance over a wide range of operating condition is the main aim of PID controller tuning. However, it is often difficult to simultaneously obtain all the desirable qualities simultaneously. Therefore, a more systematic method is required to ensure an optimized performance of the control system every time the PID controller is used. The dynamical nature of the process control loop, which in this study is the exhaust temperature system of the gas turbine, leads to changes of operating conditions within the loop, and hence the loop performance. Changes in system performance may be attributed to the presence of process nonlinearities within the control channel, process aging, production strategy changes, modifications to the properties of raw materials and changes over equipment maintenance. Considering these dynamical conditions, tuning of the PID control parameters is necessary to ensure a continuously adequate performance of the control loop.

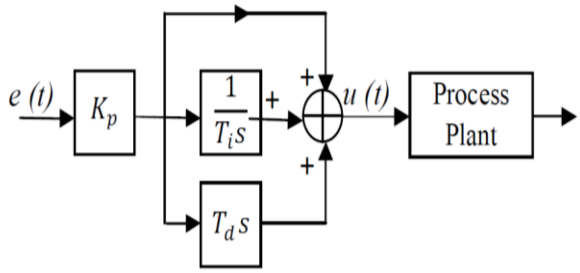

Fig 6 PID Controller Block Diagram

Control of exhaust temperature using PID is obtained using swarm particle optimization [9]. A gas turbine consists of a compressor, a combustion chamber and a turbine operating under the Brayton cycle. Four irreversible processes: isentropic compression, constant pressure heat

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

addition, isentropic expansion and constant pressure heat rejection, are the main constitutive elements of the ideal Brayton cycle. First, air is compressed in an adiabatic process with constant entropy (isentropic compression) within the compressor, which is usually an axial compressor. A pressure of 13 to 20 times higher than the atmospheric pressure is usually achieved after the compression stage. Fuel, either liquid or gas is then mixed with the compressed air and is burnt in the combustor (constant pressure heat addition). After this, the hot gas is allowed to expand through the turbine (isentropic expansion). This gas expansion drives the blades of the turbine and consequently the shaft of the generator connected to it. The maximum power output of a gas turbine depends on the shaft speed and the ambient temperature. The temperature control of a gas turbine limits the exhaust temperature by reducing the fuel flow as the air flow decreases with the shaft speed. Figure 4.2 shows the block diagram of the exhaust temperature block that includes the thermocouples used as the temperature sensors and radiation shields. In Figure 4.2, the exhaust temperature is measured using a thermocouple and is labelled. All the parameters in Figure 4.2, are taken as arbitrarily which can change according to the specifications of turbine.εCR is the combustion reaction time delay and εTD is the turbine and exhaust system transport delay which are very small and negligible[11].

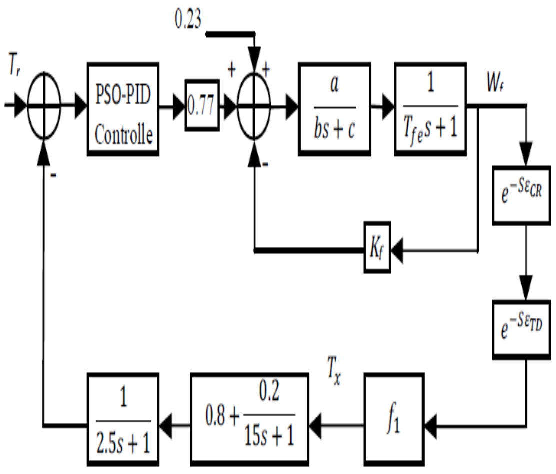

Fig 7 Exhaust Temperature Control Block Diagram

V. CONCLUSION

This paper has reviewed gas turbine models for power system stability studies. The main control loops of the typical models of gas turbines used in stability studies are described. The temperature control loops are described in detail and different ways to implement them are shown. The paper presents a new approach in optimizing the PID controller parameters to control the exhaust temperature of a single-shaft gas turbine system. Simulations show the performance of the temperature control loops when the gas turbine experiences increasing and decreasing steps in load.

REFERENCES

[1] H. Cohen, G.F.C. Rogers, H.I.H. Saravanamuttoo, Gas Turbine Theory, 4th Edition, Longman, London, 1996.

[2] R.T.C. Harman, Gas Turbine Engineering, First Edition, Macmillan Press Ltd., London, UK, 1981.

[3] International Journal of the Physical Sciences Vol. 7(5), pp. 720 - 729, 30 January, 2012.

[4] Gas Turbine Modeling For Load Frequency Control, U.P.B. Sci. Bull., Series C, Vol. 70, Iss. 4, 2008.

[5] W. I. Rowen, "Simplified mathematical representations of heavy duty gas turbines", Transactions of the ASME. Journal of Engineering for Power, vol. 105, pp. 865-70, 1983.

[6] PSS/E-30, PSS/E-30 Online Documentation, 2004.

[7] Review of Gas Turbine Models for Power System Stability Studies P. Centeno, I. Egido, C. Domingo, F. Fernández, L. Rouc, M. González Universidad Pontificia Comillas E.T.S. de Ingeniería (ICAI), and Institutor de Investigation Technological (IIT) Alberto Aguilera, 23, 28015 Madrid.

[8] W. I. Rowen, "Simplified mathematical representations of heavy duty gas turbines", Transactions of the ASME. Journal of Engineering for Power, vol. 105, pp. 865-70, 1983.

[9] L. M. Hajagos and G. R. Berube, "Utility experience with gas turbine testing and modeling", Proc. Winter Meeting of the IEEE Power Engineering Society, Columbus, OH, USA, 2001, pp. 671-7.

[10] Temperature Control Using a Microcontroller: An Interdisciplinary Undergraduate Engineering Design ProjectJames S. McDonald Department of Engineering Science Trinity University San Antonio, TX 78212.

[11] Optimized proportional integral derivative (PID) controller for the exhaust temperature control of a gas turbine system using particle swarm optimization, Ali Marzoughi, Hazlina Selamat*, Mohd Fua'ad Rahmat and Herlina Abdul Rahim, International Journal of the Physical Sciences Vol. 7(5), pp. 720 - 729, 30 January, 2012.

AUTHOR'S PROFILE

Preeti Dhiman received B.Tech Degree in 2003 with Honors and M.Tech. Degree in 2007 in Instrumentation & Control. She is currently working as Assistant Professor in Electronics & Instrumentation Department, Galgotias College of Engg. & Technology, Greater Noida. Her research interest includes Fuzzy Control, Intelligent Control and Evolution Algorithm.

Aakanksha Saxena pursuing B.tech in Electronics & Instrumentation from Galgotias College of Engineering & Technology, Greater Noida. Her interest includes Instrumentation & Digital Signal Processing.

Akanksha pursuing B.tech in Electronics & Instrumentation from Galgotias College of Engineering & Technology, Greater Noida. Her interest includes Instrumentation.

Deepali Tiwari pursuing B.tech in Electronics & Instrumentation from Galgotias College of Engineering & Technology, Greater Noida. Her interest includes Instrumentation, Control System and Digital Electronics.

Durgesh Agrahari pursuing B.tech in Electronics & Instrumentation from Galgotias College of Engineering & Technology, Greater Noida.His area of interest includes Instrumentation & control system.