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Surveying the Control Loops of the Governor of the V94.2 Gas Turbine

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Abstract: Governor and turbine are relevant components of the generating units. In this paper, the control loops of the V94.2 gas turbine (GT) will be studied. The governor of the V94.2 gas turbine will be considered in this regard. As a matter of fact the V94.2 GTs play important role in the electricity grid of Iran. The main task of gas turbine governor is to prepare and establish proper command for Fuel Control Valve (F.C.V) and Inlet Guide Vane (IGV) in order to keep stable and suitable Air Fuel Ratio (A/F) and stability of flame in all condition of gas turbine operation. In this paper, these materials are explained further.

Key words: Governor · V94.2 Gas Turbine · Control loop

INTRODUCTION

Most of the Gaseous Power Plants in Iran include 6 V94.2 gas turbines which the nominal power capacity of every one is about 160 MW.

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine and a combustion chamber in-between. Energy is added to the gas stream in the combustor, where fuel is mixed with air and ignited. In the high pressure environment of the combustor, combustion of the fuel increases the temperature. The products of the combustion are forced into the turbine section. There, the high velocity and volume of the gas flow is directed through a nozzle over the turbine's blades, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature and pressure of the exhaust gas.

Gasses passing through an ideal gas turbine undergo three thermodynamic processes. These are isentropic compression, isobaric (constant pressure) combustion and isentropic expansion. Together these make up the Brayton cycle.

In a practical gas turbine, gasses are first accelerated in either a centrifugal or radial compressor. These gasses are then slowed using a diverging nozzle known as a diffuser; these processes increase the pressure and temperature of the flow. In an ideal system this is isentropic. However, in practice energy is lost to heat, due to friction and turbulence. Gasses then pass from the diffuser to a combustion chamber, or similar device, where heat is added. In an ideal system this occurs at constant pressure (isobaric heat addition). As there is no change in pressure the specific volume of the gasses increases. In practical situations this process is usually accompanied by a slight loss in pressure, due to friction. Finally, this larger volume of gasses is expanded and accelerated by nozzle guide vanes before energy is extracted by a turbine. In an ideal system these are gasses expanded isentropically and leave the turbine at their original pressure. In practice this process is not isentropic as energy is once again lost to friction and turbulence.

The main controller device of gas turbine is called Governor and the main task of gas turbine governor is to prepare and establish proper command for Fuel Control Valve (F.C.V) and Inlet Guide Vane (IGV) in order to keep stable and suitable Air Fuel Ratio (A/F) and stability of flame in all condition of gas turbine operation (Start up, Steady state, Load variation, Network disturbance...).

A governor to have the ability of controlling the closed loops of gas turbine should be very fast and accurate. Mainly, a GT governor is a fast PLC which its main task includes two important part. One part controls the run up situation of GT and the other part is related to the situation which GT is synchronized with the grid. The run up part includes starting, warming and acceleration steps. After the run up step of GT the governor controls the speed and the load simultaneously. One of the

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characteristics that distinguish the GT governor is that it can restrict the temperature of the turbine blades to a certain limit. Because of these complexities the governor of GTs are made as software [1, 2].

The main control variables of this system are fuel and air and the main target of governor is to keep air fuel ratio suitable to achieve arbitrary output power.

Researchers to study the operation of gas turbine have used various models including methods of modeling every parts of gas turbine individually or methods of modeling entire power plant as a black box using methods such as neural network. Among all of these methods, the IEEE model [3] and the Rowen model [1, 4] have been considered more. These two models are very similar dynamically but the main difference between them is the way that the turbine behavior is modeled in these two models. The IEEE model is mainly based on the thermodynamics equations and the Rowen model is mainly based on the test results. The researchers have used these two models and also have compared the mentioned models widely [5, 6].

Gas Turbine Governor Structure: Because it is not possible to store electric power in any significant quantity, the generated power must be matched to the demand from the grid. The gas turbine controller performs this function as part of primary control. The governor is responsible for:

- Low-stress startup and shutdown of the turbine
- Synchronization with the grid
- Loading of the turbine
- Frequency stabilization
- Ability to manage a load rejection and to cover plant load requirements
- Prevention of overloading of the gas turbine
- Prevention of overloading of the compressor
- Reaction to faults and special operating conditions

The typical model of gas turbines in stability studies consists of three main control loops:

- Load - frequency control.
- Temperature control.
- Acceleration control.

In addition in V94.2 there are two other control loops:

- Limit load control
- Compressor outlet pressure gradient control

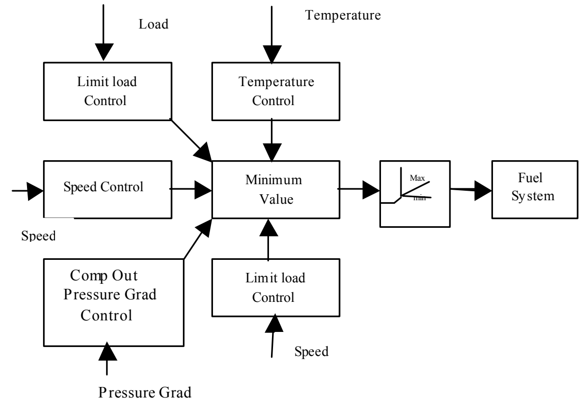

Figure 1 shows the simplified representation of such model.

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

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 limits. This control loop will be further described in the following.

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 task of the compressor pressure ratio limit controller is to prevent non-permissible operating conditions of the compressor. For this purpose, a limitation curve that is not to be exceeded is defined at a safe margin to the compressor instability limit, i.e. the so-called surge limit.

The limit load controller is to prevent that the gas turbine load exceeds this value. The load set point is preselected by the operator.

The output of the five 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 Load - Speed Control: The task of the load-speed controller is to regulate the load and/or speed as well as the frequency of the turbine-generator in each phase of operation. Depending on the requirements, the controller can be utilized as a load or speed controller.

The speed controller regulates the fuel mass flow during gas turbine startup after the speed set point has been reached. The speed controller regulates the no-load speed until synchronization. The speed Set point is adjusted with a synchronizer or by manual intervention until the turbine speed matches the system frequency (phase displacement = 0). The generator circuit breaker or circuit breaker (if the unit does not have a generator circuit breaker) is still open in this phase, load set point and actual load value are not effective yet and the combined load/speed controller acts as a straight speed controller. The generator circuit breaker or circuit breaker is closed after synchronization. The load controller assumes control of the fuel mass flow. Load operation with speed control is permissible only in exceptional cases which are described in the following two sections.

- Loading of the gas turbine in speed controller operation is permissible to establish a black system after a black start. Speed fluctuations caused by adding (auxiliary) loads can be compensated in this operating mode, even at low loads.
- After load rejection (to station service or island operation with loads less than approximately 40%), the gas turbine output is determined by the magnitude of the station service or the load required for the island. In this case, the combined load/speed controller is automatically switched to speed control. The over speed is compensated quickly by the quick adjustment of the fuel mass flow.

The load controller is to regulate the load specified by the set point control by adjusting the fuel mass flow.

After activating the generator circuit breaker, loading to target load set point takes place via the load gradients set in the set point control. The load controller allows load-controlled startup and shutdown of the turbine-generator.

In special operating and disturbance cases, the load controller must allow fast reduction of the load (e.g. response of humming).

If the system frequency changes at “load operation with load controller”, the combined load/speed controller allows for a respective increase or decrease of the fuel flow via the limit or primary frequency influence, provided frequency backup control is released for the current operating mode of the gas turbine.

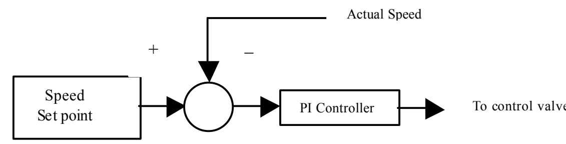

Fig. 2: Simplified representation of the Speed control

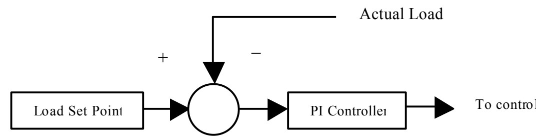

Fig. 3: Simplified representation of the Load operation with Load control

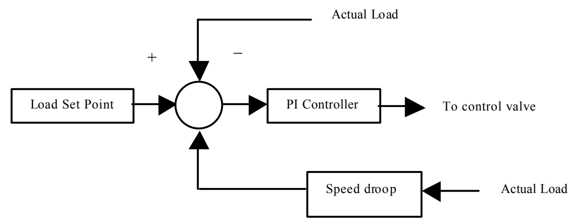

Fig. 4: Simplified representation of the Load operation with Speed control

Turbine Outlet Temperature Controller: The objective of the exhaust gas temperature controller (OTC controller) is to operate the gas turbine at optimum turbine inlet temperature by adjusting the fuel mass flow. In general, the turbine inlet temperature must be as low as necessary to rule out damage on components that carry hot gas and as high as possible to allow optimum gas turbine efficiency. The OTC controller.

- Keeps the turbine inlet temperature constant in peak (for optimum efficiency) or base load operation (for high efficiency at reduced material stress).
- Limits the turbine inlet temperature to its highest permissible value in partial load operation (in coordination with the IGV controller).
- Allows temperature controlled startup or operation in combined cycle plants based on block requirements.
- Quickly reduces the turbine outlet temperature at specific operating conditions or disturbances.

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.

As can be seen in Figure 5, 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.

It is of great importance to realize that the measuring of the turbine inlet temperature is a complex problem. For measuring temperature in the gas turbine, thermocouples are used generally. But the turbine inlet temperature is generally out of the range that thermocouples can work. As a result, usually the turbine outlet temperature is measured and with the thermodynamics relations the turbine inlet temperature is calculated.

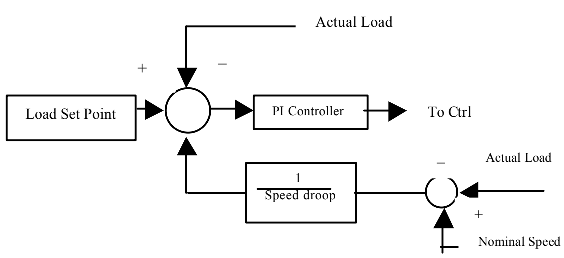

Fig. 5: Simplified representation of the Load operation with Load control/ frequency influence ON (Frequency Control or Droop Mode)

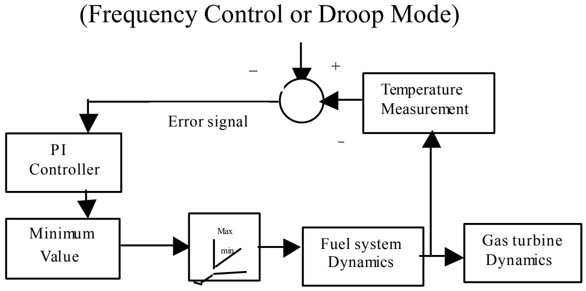

Fig. 6: Basic Outlet Temperature Control

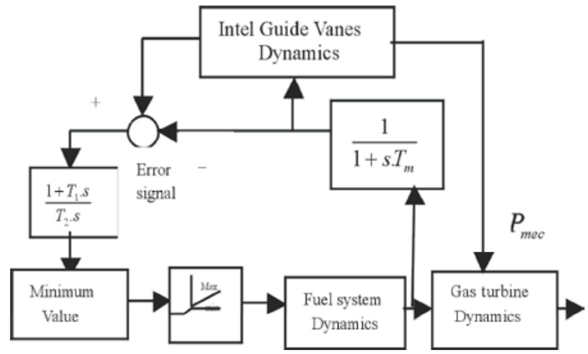

Fig. 7: Simplified representation of the Outlet Temperature Control as in [4]

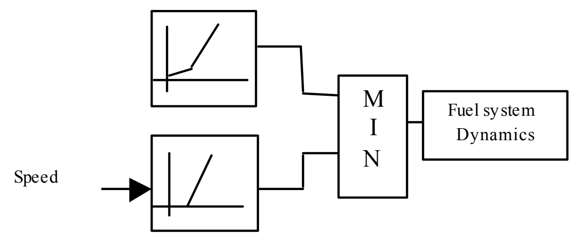

Fig. 8: Simplified representation of the Run up and Protection Control

In [4] the temperature control loop includes the action of the inlet guide vanes (IGV). 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. Figure 8 shows the corresponding block diagram.

The time constant T_m in the block diagram, represents the dynamics of the temperature measurement process.

Run up and Protection Function: Run up and protection function is designed to take control of the fuel system when the generator experiences an acceleration which exceeds a limit. This condition can occur during startup and load rejection processes.

It is not possible to accelerate the gas turbine from standstill or turning gear operation by simply supplying fuel. The reason being, proper combustion also requires a specific mass flow of combustion air. The combustion air is provided by the compressor of the gas turbine. Thus, the air mass flow is a function of the gas turbine speed. Depending on the gas turbine type, the combustion air mass flow is sufficient to release the supply of fuel to the burners of the gas turbine starting at approximately 10 to 20% rated speed.

The fuel supply must be slight at first and increased slowly because the air mass flow is still low. Supplying too much fuel at low air mass flow would lead to non-permissibly high turbine temperatures, or inhibit flame generation. If a small amount of fuel is supplied, the combustion energy is not sufficient to accelerate the turbine-generator.

However, to be able to start the gas turbine from standstill or turning gear operation, the generator - with the aid of the static frequency converter (SFC) - is used as a motor to drive the turbine generator.

The static frequency converter (SFC) is turned on when the gas turbine is started and remains on until approx 70% rated speed reached. When the static frequency converter is turned off, the combustion energy is sufficient to drive and accelerate the turbine-generator.

The corrected turbine outlet temperature drops as a result of the increased air mass flow associated with the increased speed and the fuel mass flow that is still the same at that time. To prevent this temperature drop, the fuel control valve is positioned based on a ramp function (gradient) to slowly increase the fuel mass flow, when the first speed limit value is exceeded.

When a second (higher) speed limit value is exceeded, the fuel control valve is positioned based on a steeper ramp function (gradient) to increase the fuel mass flow more rapidly, i.e. a higher combustion air mass flow is now available because of the higher speed. If required for startup, a transfer to an additional ramp function (gradient) may take place in VX4.2A/3A gas turbines with three speed limit values.

When rated speed is reached, the speed controller regulates the fuel mass flow. A limit function is provided to assure that the specified position of the control valve or the fuel flow does not exceed the permissible value for the respective speed. These functions are met by the ramp function generator. The initial value generated in the ramp function generator is processed further in the ratio adjuster and the position control circuit.

Turbine Limit Load Control: To assure that the mechanical stress on structural components does not become impermissibly high, a specified load must not be exceeded during gas turbine operation. This maximum permissible load is referred to as the limit load in the following specification. The limit load controller is to prevent that the gas turbine load exceeds this value. The load set point is preselected by the operator. If a very high load set point, such as the maximum, is selected, the temperature controller normally acts to impose a limit, so that the limit load is not reached. However, there are two cases in which the limit load is reached before the temperature controller intervenes. (Ambient temperature very low or steam water injection). The limit load controller is to prevent such a condition by appropriate positioning of the fuel valves.

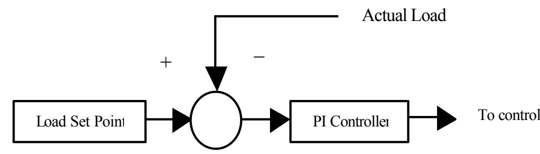

Fig. 9: Simplified representation of the Limit Load Control

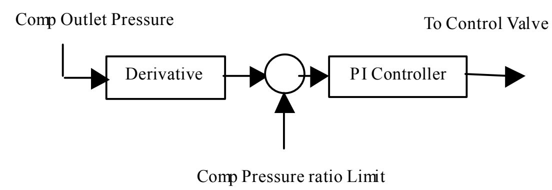

Fig. 10: Simplified representation of the Compressor Gradient Limit

Compressor Gradient Limit: The compressor of the gas turbine supplies air to the burners of the gas turbine and the components of the combustion chambers and the turbine to be cooled. The air is taken in through the air intake duct at ambient conditions (temperature, pressure and moisture) and supplied against the combustion chamber pressure applied by the turbine.

The task of the compressor pressure ratio limit controller is to prevent non-permissible operating conditions of the compressor. For this purpose, a limitation curve that is not to be exceeded is defined at a safe margin to the compressor instability limit, i.e. the so-called surge limit. In the event the limitation curve is reached, the following graded measures are taken:

The fuel flow is reduced via the gas turbine controller when the limitation curve is approached.

When the limitation curve is reached, the compressor guide blades are opened further, if it is expected that this measure will increase the margin between the operating line and the limitation curve.

During gas turbine operation, the operating point should always be below the limitation curve, so that this controller is not active. If the compressor pressure ratio would exceed the surge limit, the kinetic flow energy in the boundary layer is not sufficient to follow the pressure increase and the flow separates on the blades. If the flow has separated on one or several adjacent blades, the flow through the section is reduced. If the compressor pressure ratio continues to increase (as a function of the turbine), periodic separations occur on the blades. Consequently, the compressor surges. The surge frequency depends on the compressor as well as the series-connected components (combustion chambers, turbine).

The main goal of the control loops which have been mentioned so far is to produce a command for control valve. In the following, two other control loops will be noted which are to control the other aspects of gas turbine.

Ratio Adjuster of Fuel Valve: For the different operating modes of the gas turbine, the fuel control valves must be positioned based on the requirements of gas turbine operation. A standardized position set point between 0% and 100% must be provided for the control valve position control circuits. For this purpose, the various gas turbine control circuits generate a firing load set point for the respective task (e.g. exhaust gas temperature controller, limit load controller, etc.) which is made available at the controller output. The minimum value is selected from the firing load set points to limit the fuel flow to the permissible rate. In gas turbines intended for operation with two or several fuels (e.g. natural gas, fuel oil, heavy oil), the total firing load set point must be divided based on the selected fuel ratios, taking the heat value into consideration.

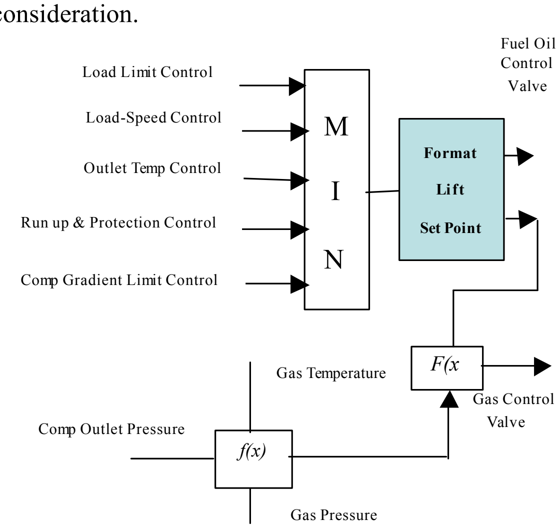

Fig. 11: Simplified representation of the Ratio Adjuster of Fuel valve

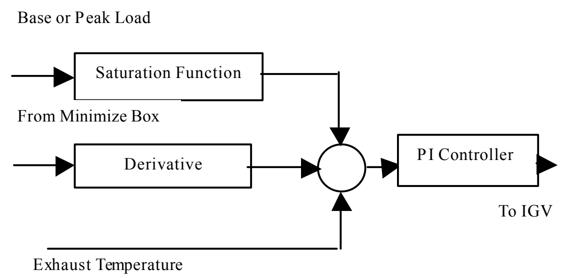

Fig. 12: Simplified representation of the Compressor Guide Blade Control

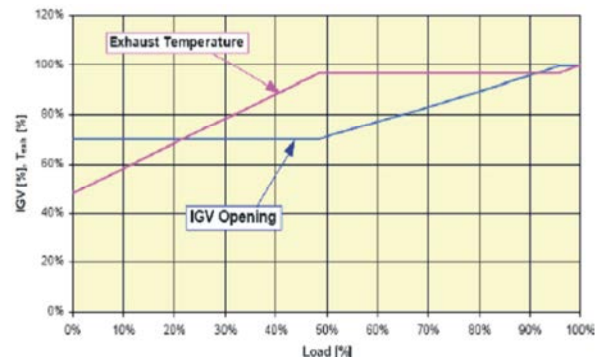

Fig. 13: The Curve of IGV Position and Outlet Temp based on the load ratio

Compressor Guide Blade Control: The compressor of the gas turbine is equipped with one or several rows of adjustable guide blades. Adjustment of the guide blade position within a limited, permissible range influences the air flow of the compressor and therefore also of the gas turbine. So the main duty of compressor guide blade controller is to prepare and establish proper command for IGV in order to keep stable and suitable air flow in air fuel ratio relationship. Opening of the compressor guide blades increases the air flow, while closing reduces the air flow.

At constant fuel flow, the turbine outlet temperature (exhaust gas temperature) decreases when the blades are opened and vice versa. By increasing or decreasing the fuel flow and the air flow at the same time, the turbine exhaust temperature can be held constant. Since the fuel/air ratio is held nearly constant in this process.

CONCLUSION

This paper has reviewed gas turbine models for power system stability studies. The main control loops of the typical models of gas turbines are described. The temperature and the acceleration control loops are described in detail and different ways to implement them are shown. Some aspects that should be taken into account when modeling the temperature control loop and Run up function are also described.

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