CHAPTER 6

CONTROL OF HEAVY DUTY GAS TURBINE PLANTS
FOR PARALLEL OPERATION

Gas turbines are mostly used in isolated operations and small networks. These plants have to be connected to grid to meet the future increase in power demand. Under parallel operation, such systems tend to become unstable after a severe disturbance and may cause an inevitable plant shut down. Therefore, there is a need for effective design and control to maintain synchronism during parallel operation.

The PID controller, ANN controller and FLC developed and presented in chapter 3, 4 and 5 respectively for heavy duty gas turbine plant are applicable for isolated operation. The transfer function model of heavy duty gas turbine plant discussed in chapter 2 consists of valve positioner, fuel system, turbine and the rotor. In the model presented in section 2.5, the system speed is compared with the set value and the error signal is given as an input to the governor. For isolated operation, the set point will be fixed. Whereas, the set point is the normal means for controlling gas turbine output when operating in parallel. The set point can be operated either manually or by automatic / remote control mechanism. Depending upon the variation in the set value during synchronization and parallel operation, the controller has to operate effectively and make the steady state error zero.
The performance of controller is studied with the set point varied from 1.0 to 1.2 and later from 1.2 to 0.8. First, the performance of the system is studied for the set point variation without any controller. There will be steady state error during all the set change because of the drooping character of the governor. Since, ZN tuned PID controller is the benchmark to compare the performance of different controllers, the PID controller developed in section 3.2 using ZN method is included in the system. The response of the system with ZN tuned PID controller is analyzed for set point variation. Later, the GA tuned PID controller developed in section 3.4 has been incorporated in the gas turbine plant and the performance is analyzed.

Further, Artificial Neural Network (ANN) and Fuzzy Logic Controllers developed in chapter 4 and 5 respectively replace the conventional PID controller. The performance of gas turbine plant incorporated with soft computing controllers under parallel operation is studied. The time domain performance of the system has been compared for these controllers in order to select an efficient controller for the parallel operation of gas turbine plants.

6.1 PARALLEL OPERATION OF HEAVY DUTY GAS TURBINE PLANTS

The digital set point is the normal means for controlling the turbine output, when operating in parallel and using a droop governor. The block diagram of the digital set point with speed governor is shown in Figure 6.1. The digital set point is equivalent to a logic controlled counter and digital to analog converter that generates the ramp function at a
selectable, predetermined rate. There are two modes of synchronizing, one which uses the conventional synchronizing relay, operating on the set point, and the other a microprocessor based synchronizer. The synchronizing relay has the time period of 6 min and microprocessor based synchronizer has 4.5 min. set point time periods subsequent to synchronizing (can be either manual or automatic) which is under the control of operator using raise/lower switch or automatic/remote.

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Figure 6.1 Block diagram of digital set point incorporated in gas turbine plant
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6.2 PARALLEL OPERATION WITHOUT CONTROLLERS

The mathematical model of heavy duty gas turbine plant with variable set point has been developed using MATLAB in Simulink environment. The Parameters used in developing the transfer function model is provided in Appendix 1. During parallel operation the set point of the gas turbine plant keeps varying to maintain synchronism. To test the controller action of gas turbine, the set value is varied from 1.0 to 1.2 and then 1.2 to 0.8 at 10 and 20 sec respectively. After incorporating the set point variation in the Simulink model, the system is simulated and the response shown in Figure 6.2.
From Figure 6.2, it is evident that the system response has steady state error while the set point is at 1.0, 1.2 and 0.8. This error is due to the drooping characteristics of the speed governor.

### 6.3 PID CONTROLLER FOR PARALLEL OPERATION

PID controller is therefore required to make the offset to zero. For getting optimal performance, the values of PID controller tuned using ZN method as explained in chapter 3 are used. ZN tuned PID controller is developed in Simulink environment and included in the heavy duty gas turbine model. The response is then simulated for the set point variations. Figure 6.3 shows the response of heavy duty gas turbine plant with ZN tuned PID controller.

The response clearly shows that ZN tuned PID controller improves the system response by removing the offset for all the set variations. But there is more peak overshoot. To overcome the problem of more overshoot, PID controller tuned using genetic algorithm can be utilized.
Figure 6.3 Response of gas turbine plant with ZN tuned PID controller and without PID controller.

The GA tuned PID is found to be the better controller than ZN tuned PID controller for isolated operation. As explained in chapter 3, the coding for Genetic Algorithm is written in MATLAB in M-file environment using GA toolbox. For fitness function calculation, the transfer function model of heavy duty gas turbine plant developed in Simulink is interlinked with the M-file. By using the GA toolbox and transfer function model, the PID values are tuned. The response of system with GA tuned PID controller for set point variations is simulated and furnished in Figure 6.4. Since GA tuned PID controller is responding faster, the set point variation from 1.0 to 1.2 is provided at 5 sec and the variation from 1.2 to 0.8 at 10 sec.

The response clearly shows that the offset is removed by using ZN tuned PID controller in very less time. The transient response is also much improved in terms of less rise time and peak overshoot. The
comparison of the performance of GA tuned PID controllers using different fitness functions like ISE, ITAE and ITSE. ITAE penalizes long duration transients and it is much more sensitive than ISE and ITSE. Therefore, PID controller tuned using GA with ITAE as fitness function is found to be the better option.

![Graph showing comparison of the performance of GA tuned PID controllers using different fitness functions like ISE, ITAE and ITSE. ITAE penalizes long duration transients and it is much more sensitive than ISE and ITSE. Therefore, PID controller tuned using GA with ITAE as fitness function is found to be the better option.](image_url)

**Figure 6.4** Comparison of gas turbine plant response with GA tuned PID controller tuned using ISE, ITAE and ITSE.

### 6.4 ANN CONTROLLER FOR PARALLEL OPERATION

Soft computing controllers like ANN controller and FLC have been considered in this study. ANN controller developed in chapter 4 is now incorporated with the heavy duty gas turbine plant to study its performance under parallel operation i.e. during set point variations. Backpropogation algorithm is used for training. The algorithm is written using MATLAB in M-file environment using ANN toolbox. The detailed architecture of trained ANN is furnished in section 4.4.
After training, the ANN is transferred from M file environment to Simulink environment and included in the heavy duty gas turbine replacing the PID controller. The response of the heavy duty gas turbine plant with ANN controller is then simulated for set point variations and furnished in Figure 6.5.

![Graph showing comparison of gas turbine plant response with ZN tuned PID controller and ANN controller](image)

**Figure 6.5 Comparison of gas turbine plant response with ZN tuned PID controller and ANN controller**

Figure 6.5 shows that the ANN controller removes the offset, but the transient response is poor when compared to GA tuned PID controller. Though ANN controller provides better transient and steady state response compared to ZN tuned PID controller, it is not the optimal controller for heavy duty gas turbine plant in spite of its soft computing advantage.
6.5 FLC FOR PARALLEL OPERATION

Finally, FLC developed using Fuzzy logic toolbox as discussed in chapter 5 has been considered for the study. Since both Sugeno and Mamdani models provide same control action, Sugeno model has been chosen for this parallel operation study. The Sugeno model FLC is then embedded into the heavy duty gas turbine plant Simulink model replacing the PID controller. The set point variations from 1.0 to 1.2 and then from 1.2 to 0.8 are given at 5 and 10 sec respectively because of the fast acting nature of the controller. The response of the heavy duty gas turbine plant with FLC for set point variations is shown in Figure 6.6.

![Figure 6.6 Comparison of gas turbine plant response with Genetic tuned PID controller and Fuzzy controller](image)

The response clearly shows that FLC not only removes the offset at much less time but also improves the transient response without overshoot compared to ANN and PID controllers.
6.6 OPTIMAL CONTROLLER FOR PARALLEL OPERATION

PID controller for gas turbine plant has been tuned using ZN method and Genetic algorithm. PID values are tuned effectively by Genetic algorithm compared to ZN tuned values. Though PID controller still has its importance in industrial use today, there are many recent advancement in the field of control engineering, Later, the PID controller has been replaced by soft computing controllers like ANN and Fuzzy logic. The ANN controller improves both steady state and transient response of gas turbine plant when compared to ZN tuned PID controller. The developed FLC yields the optimum response of the system in terms of no overshoot and less settling time with zero steady state error compared to an ANN controller and a PID controller tuned using either ZN method or Genetic algorithm.