CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

The future technology for electricity production mainly depends on distributed energy. The distributed energy includes solar panel, micro hydropower, wind turbines, gas turbines and reciprocating engines. These distributed resources avoid transmission losses. The most accepted commercial fuels for gas turbines and reciprocating engines are gasoline, natural gas, propane, diesel and kerosene and renewable gases like, bio diesel and bio gas.

Biomass plants are commonly connected to small networks or even in isolated operation such as, oil fields in desert area, offshore installations and bio-gas plants. Biomass is attractive as a potential energy resource, and an important fuel in several developing countries. Biomass is potentially renewable. The energy produced by biomass plants is of competitive cost and enables the small energy consumers to generate their own electricity, with low emission of CO₂.

1.2 THE GENESIS OF THE THESIS

Biomass gasification is a technology that transforms biomass into syngas, which is the mixture of hydrogen and carbon monoxide. The biomass gasification can be done either by atmospheric-pressure air-blown
fluidized-bed gasification with wet scrubbing as explained by Waldheim (1998) et al. or by pressurized air-blown fluidized-bed gasification with hot-gas clean up as described by Salo (1998) et al., Paisley (1997) et al. technology of atmospheric- pressure indirectly heated gasification with wet scrubbing can also be used. Small scale gasification for combined heat and power in distributed generation has expanded rapidly.

As far as biomass plants are concerned, either reciprocating engines or gas turbines will be used to obtain mechanical energy from the bio fuel. The gas turbines are advantageous than reciprocating engines by virtue of their smaller size at the same power rating, unidirectional with far less vibrations, less moving parts, high speed operation and lower operating pressure. The concept of combining a pressurized gasifier with gas turbine is first described by Gumz (1950). Gas turbines used for higher ratings in order of MW are called heavy duty turbines and lower order ratings (KW) as micro turbines.

The current scenario of the power system is that the biomass plants are used for isolated operations. They are not connected in parallel to any other plants. These plants face severe stability problem when connected to grid. But in future, power generation from the biomass plants will not be a stand alone plant. It has to be connected to grid or with other plants for effective and reliable power system operation. Generally biomass plants are operated using reciprocating engines and micro turbines and are very weak because of low capacity. Reciprocating engines and micro turbines are therefore highly unstable. Hence, in this thesis, heavy duty gas turbine plant has been taken up for investigation. The gas turbine systems that enable the use of biomass are important for future technologies for electricity generation.
Biomass based gas turbine plants are basically dynamic devices, and have the tendency to become unstable after a severe disturbance. Therefore, there is a need for effective design and control to maintain stability, otherwise, may cause an inevitable plant shut down. Further, an effective control system is required for parallel operation.

1.3 LITERATURE SURVEY

Extensive literature survey has been carried out in the field of heavy duty gas turbine plants on two areas. One is on the mathematical modeling and another in the area of control of heavy duty gas turbine plants. After identifying the problem, the literature survey is carried out for developing the optimal controller for heavy duty gas turbine plant.

1.3.1 Mathematical modeling of heavy duty gas turbine plants

Cohen et. al. (1987) described about the operation, the thermodynamic cycle and its analysis of gas turbines in detail.

Gumz (1950) is the earliest reference found describing the concept of combining a pressurized gasifier with a gas turbine engine, although Gumz himself indicates an earlier work proposing this concept. He also states that the combination could certainly benefit for the future development of pressurized hot gas cleaning to avoid excessive turbine blade wear.

Waldheim et al. (1998) reported that the biomass gasification technology adopted here was atmospheric-pressure air-blown fluidized-bed gasification with wet scrubbing, having HHV of 1500 kcal/kg.
Salo et al. (1998) proposed another method for biomass gasification, in which pressurized air blown fluidized-bed gasification with hot-gas clean-up was used for large scale biomass gasification. The HHV is 1300 kcal/kg.

Paisley et al. (1997) presented a new method of biomass gasification, which yielded fuel with HHV of 4300 kcal/kg. In this method atmospheric-pressure indirectly-heated gasification with wet scrubbing had been done for the large scale gasification of biomass.

Rowen (1983) has proposed the mathematical representation of heavy duty gas turbines limited to simple cycle, single shaft, generator driven gas turbines. Rowen has also developed the model by conducting experiments on the functional representation of the gas turbine and its control. This model has been adopted by General Electric Company for developing their speedtronic control series for gas turbines.

Hannett and Afzal Khan (1993) dealt about the combustion turbine model validation. They discussed about the governor model which is an important variable affecting the dynamic performance of the system. Detailed dynamic models had been proposed for two types of governor control i.e., GE speedtronic governor control and Woodward governor control.

Louis N. Hannet et. al. (1994) reported the experiments on a twin shaft gas turbine for the governor response to disturbance. A computer simulation model was also presented. This paper dealt in detail the engine speed control and exhaust gas temperature control. The procedures, for testing and model derivation were also presented.
F. P. de Mello et al. (1994) described the various aspects of combined cycles made up of gas turbine, waste heat recovery from boiler and steam turbine and developed models designed to simulate the response of the combined cycle plant for use in system dynamic performance studies.

S.M. Camporeale et al. (1997) proposed the non linear mathematical model for the simulation of the dynamic behavior of a regenerative single shaft power plant. The model was suitable for other gas turbine plants, such as steam injected gas turbines, combined cycle power plant. With time domain plots, the accuracy of the model was validated.

Zhu et al. (2002) developed a model for analyzing the load performance of microturbines and fuel cells. They presented the simplified slow dynamic model of gas turbines. They have integrated the microturbine with the fuel cell and the control strategy and load following service in the distribution system was simulated.

Centeno et al. (2005) reviewed the dynamic models of gas turbine for power system stability studies. It explained the main control loops and the purpose of each one as well as different ways to implement them. Simulations were also carried out to show the performance of each control loop.

Guda et al. (2006) presented the modeling and simulation of a microturbine generating system suitable for isolated as well as grid connected operation under different load conditions.
1.3.2 Control of heavy duty gas turbine plants

Francisco Jurado et. al. (2002) has reported about the biomass based plant controlled using soft computing controller. The PID controller tuned using Ziegler Nichols’ method was also presented. Fuzzy controller performance on biomass plant was studied.

Francisco Jurado et. al. (2004) discussed the performance of the microturbine system in grid connected mode. It was found that micro turbines were having a stability problem when connected to grid.

Rekha T. Jagaduri et. al. (2006) dealt about the modeling and control of distributed generating systems including fuel cell and gas turbine. Fuzzy logic controller was also proposed for improving the dynamics of the combined distributed plant.

For getting more details about thermodynamic principles, operation, performance characteristics and control of gas turbine plants, the articles and user manuals published by General Electric Company and Cummins India Limited were studied.

1.3.3 Developing optimal controller for heavy duty gas turbine plants


Gopal (2002) presented the control systems principles and design. This book explains the basics of control systems, PID controllers, tuning of PID controllers and an introduction to soft computing controllers.
Ziegler and Nichols (1942) proposed one of the most important publications in the history of automation, instrumentation and control systems. The Tuning rules for PID controllers have been presented.


Bansal (2006) gave the overview and literature survey of Artificial Neural Networks (ANN) application to power system. This paper gives complete survey in the area of ANN applied to power system analysis and control.

Chun Chien Lee (1990) presented the concept of fuzzy logic in control system. A survey of the Fuzzy Logic Controller (FLC) was presented. A general methodology for constructing a FLC and accessing its performance was described. Further problems that need further research were also pointed out. This paper explored the complete Fuzzy Logic Controller mechanism.

Bansal (2003) reviewed the comprehensive set of references on fuzzy set theory application in various areas of power systems such as operation, planning and control. This Bibliography gave complete information about the fuzzy set theory applications in power system.

Mamdani (1974) published his pioneering research on fuzzy control along with his colleagues because of the motivation by Zadeh’s seminal papers on the linguistic approach. Mamdani was the person who implemented the fuzzy set theory in the controls area. Mamdani model for control was a milestone in the area of FLC.
Sugeno M (1985) gave the new dimension for the Fuzzy Logic Control. Modifications were made in the mechanism of the FLC. The output membership functions in this model were made as constants. This made the Sugeno model to get deviated from the Mamdani model.

The simplification is made by some researchers, but there is no proof for simplification. Simplification of mathematical model with simulation proof is required. Further, No appropriate governor is recommended by the researcher for gas turbines. Choice of governor for better performance of the gas turbine is required. Further, the governor parameter also has to be optimized.

The literature survey on control of gas turbine shows that the tuning of PID controller for gas turbine plant using Genetic Algorithm is not yet attempted by any researcher. It also shows that soft computing controllers can easily be embedded in the recent microcontroller based gas turbine controllers. The control of heavy duty gas turbine plants using Neural Networks is also not attempted by the researchers. Subsequently the coherency between the papers is explained in the next section 1.4.

1.4 FORMULATION OF RESEARCH PROBLEM

With the literature survey in the field of heavy duty gas turbine plant, the current scenario of the plant control is studied thoroughly. In this thesis, an attempt has been made to improve the heavy duty gas turbine plant performance using soft computing techniques.
1.4.1 Controllers for gas turbine plants

The typical model of gas turbines consists of three control loops. They are

- Load-frequency control
- Temperature control
- Acceleration control

The simple representation of such a model is shown in Figure 1.1. 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 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. The control loop will be further described in section 2.2.3.

The acceleration loop takes control in the case when the acceleration of the generator exceeds the acceleration limit. The control reduces the fuel signal and the output power of the gas turbine, thus limiting the acceleration. This control loop will be further described in section 2.2.2.

Figure 1.1 Representation of gas turbine plant
The output of the three control loops is the input to a minimum value gate so that the loop which takes control is the one in which output is the lowest of the three. The output of the minimum value gate commands the fuel system and therefore the mechanical power is delivered by the gas turbine.

### 1.4.2 Load frequency control

Basically two types of controls are identified on the heavy duty gas turbines for load frequency control. They are

- GE Speedtronic Governor Control
- Woodward Governor Control

The Model structure for the GE speedtronic control is based on the concept proposed by W.I. Rowen (1983). The Speedtronic Governor Control is derived from the complete Transfer Function Model of Heavy Duty Gas Turbine Plant furnished in Appendix 1. The governor in speedtronic control can be either operated in droop mode or in isochronous mode. The governor operates on the error speed signal. The schematic diagram is shown in Figure 1.2.

![Figure 1.2 Schematic diagram of Speedtronic control](image-url)
The Woodward governor control consists of a PID controller for the speed error input signal. Electrical power is measured by a watt transducer, scaled and added to the error signal to provide droop. The block diagram for Woodward control shown in Figure 1.3 is derived from the Governor Turbine System for a combustion Turbine with Woodward Governing Controls presented in Appendix 2. These control loops are described in detail and the performance are analyzed by P. Centeno, I. Egido, C. Domingo, F. Fernandez, L. Rouco and M. Gonzalez (2005)

![Block diagram of Woodward control](image)

**Figure 1.3 Block diagram of Woodward control**

The fuel system and turbine dynamics for the both the controls are same. Depending upon the type of control, the governor model block will be substituted. Based upon the work conducted by L.N. Hannett and Afzal Khan on combustion turbine dynamics model validation from tests (1993), it is found that the model structure provided by W.I. Rowen for the speedtronic governors to be adequate.
1.4.2.1 Speedtronic Control

In late 1940 the gas turbine was introduced in the industrial applications in gas pipeline pumping and utility peaking. The early control systems were based on hydro-mechanical steam turbine governing practice explained by IEEE Committee report (1973) and by Ramey and Skooglund (1970). The independent devices were provided for further protection like over speed and over temperature.

The Speedtronic gas turbine control system introduced by D. Johnson, R. W. Miller and T. Ashley from General Electrics is the latest derivative in the Speedtronic series. This controls the liquid, gas or both fuels in accordance with the requirements of the speed, load control under part load conditions. Though this control is highly efficient, it is not providing an accurate control. Since this speedtronic system is using microcontroller, the soft computing techniques can be easily embedded. However, no attempt has been made so far in the Speedtronic series to develop an accurate controller using these techniques. The development of optimal controller for Heavy Duty Gas Turbine Plant Using Soft Computing Techniques is therefore taken up for research work.

Soft computing is an innovative approach to constructing computationally intelligent systems, has just come to limelight. It is now realized that complex real world problems require intelligent systems that combine knowledge, techniques and methodologies from various sources. These intelligent systems are supposed to possess humanlike expertise within a specific domain, adapt themselves and learn to do better in changing environments.
In this thesis, genetic algorithm, neural networks and fuzzy logic have been used. Genetic Algorithm is a population based algorithm with crossover, inversion, and mutation. This search technique is highly effective in solving optimization problem. So this algorithm is used for tuning the PID controller parameters. Neural networks recognize the patterns and adapt themselves to cope with changing environment. It is used as a controller for gas turbine plant in this work. Fuzzy inference systems incorporate human knowledge and perform inferencing and decision making. This knowledge based inference technique is used as a controller for gas turbine plant. These soft computing controllers will increase the accuracy of control.

1.5 AIM OF THE THESIS

The concept of gas turbine control system, which is applied in this work, is based on the Speedtronic description as presented by Rowen (1983). In the existing system, soft computing techniques can be incorporated for better control. For developing and analyzing the soft computing controller action on heavy duty gas turbine plants, a simple and effective mathematical modeling of the gas turbine is required. Moreover, appropriate soft computing controller has to be developed for that gas turbine plant which has to improve the performance.

1.5.1 Mathematical modeling of gas turbine plants

The detail theory of gas turbine is provided by Cohen (1987). The modeling of gas turbine plant exists in literature. Depending upon the application, the model complexity varies. Fwke (1972) and Shobeiri (1987) modeled the gas turbine plant based on fundamental mass,
momentum and energy balance. Their model describes the gas flow dynamics by dividing the gas turbine into number of sections. The thermodynamic state is assumed to be varying with respect to time and constant with respect to location.

Simple models of gas turbine plant have been obtained by decomposing the plant into three sections, i.e. compressor, combustor and turbine and mathematically reducing the set of partial differential equations into set of ordinary differential equation. This facilitates easier application within computer simulated program. Using steady state engine performance data, another model for gas turbine is developed by Hung (1991).

Very simple models result by assuming that the gas turbine is operated close to rated speed. Such a mathematical representation of heavy duty gas turbine plant is developed by Rowen (1983). His mathematical model has been used by F.P. de Mello and Ahne (1994) in his Dynamic Models for Combined Cycle Plants in Power System Studies. In Governor / Turbine Model for a Twin Shaft Combustion Turbine developed by Hannett (1995), also Rowen model is used. In the micro turbine also, the same model has been used for simulation. For the comprehensive study of the gas turbine plants, the mathematical model should be simple.

The first phase of the thesis work is to simplify the model and to optimize the parameters. Therefore, a simulation study has been carried out with all the three controllers viz., temperature controller, speed controller and acceleration controller. It is found that the gas turbine is predominantly controlled by means of speed controller, whereas the need for the interactive limit imposed by temperature control is significantly
diminished. Therefore, the temperature controller can be eliminated. The acceleration controller will be active only during starting and heavy load change. Hence, if the frequency variation is not greater, the acceleration controller can be neglected. This work enables to simplify the complete transfer function model to a simple speed controller.

No specific governor for speed control has been recommended yet. The Choice of suitable governor has also not been investigated so far. While evaluating the performance of speed governor with droop and isochronous type, it is found that droop governor is essential for the better performance of the gas turbine plant. Although the governor has been identified, there is a necessity to optimize the droop setting value. To optimize the droop setting value, SYSTAT software has been used for writing the equation. Later using optimization techniques, the equation is optimized to obtain the optimal value of droop setting. Simplification of Rowen’s Model, Choice of Governor and optimization of the parameters, thus, formed the first phase of research work.

1.5.2 PID controller for gas turbine plants

Although the model is simplified, appropriate governor has been identified and the droop setting optimized in the first phase of thesis, the gas turbine performance is not acceptable. There is a need to include PID controller to improve both transient and steady state response. The second phase of the thesis is therefore to tune the PID controller. The PID controller has been tuned using Ziegler Nichols’ method, Performance Index method and Genetic Algorithm. A complete study of gas turbine with PID controller, tuned using different methods has been made. It is
found that Genetic Algorithm tuned PID controller yields better performance.

1.5.3 Soft computing techniques for development of optimal controllers

The third phase of the work is to replace the PID controller by means of soft computing controllers. The soft computing control technique is not yet implemented by General Electrics in their SPEEDTRONIC control. In their last SPEEDTRONIC Mark V, microprocessor has been used for control. This enables to go for soft computing controllers. Incorporating this controller in the already existing system is also simple. Different soft computing techniques like Artificial Neural Network and Fuzzy Logic have been employed. In Fuzzy Logic, both Sugeno and Mamdani models have been used and the performance of heavy duty gas turbine plant with these soft computing controllers has been studied.

Finally the work is extended further to investigate the performance of these controllers, when the plant is in parallel. The set value will be changing under parallel operation. So, by changing the set value, the performance of the heavy duty gas turbine with the developed controllers has been studied. The comparison shows that for effective functioning of heavy duty gas turbine plant during load variation and also during the change in the set value in parallel operation, the controller developed using fuzzy logic yields optimal response. The proposed approach flow diagram is shown in Figure 1.4
1.6 ORGANIZATION OF THE THESIS

Chapter 2 presents the modeling of heavy duty gas turbine plant. Its simplification is made with the validated simulation results. The appropriate governor for the gas turbine plant is found. The droop setting value of governor and rotor time constant value of the plant have been optimized.

Basic concepts of Proportional-Integral-Derivative (PID) controller are presented in chapter 3 and the values of PID controller for gas turbine plant have been optimized using Ziegler Nichols’ method, Performance
Index method and Genetic Algorithm. The performance of these tuned PID controllers has been compared and the optimal PID controller identified.

Chapter 4 discusses about Artificial Neural Networks (ANN). The ANN controller for the gas turbine has been developed by proper data collection and training. The trained ANN controller replaces the conventional PID controller and its performance is analyzed in comparison with PID controller.

Chapter 5 depicts the concept of Fuzzy Logic Controller (FLC). The FLC has been developed for the gas turbine plant in both Sugeno and Mamdani models. The rules for both the models have been developed. The developed FLC replaces the conventional PID controller and its performance is compared with the other controllers.

The set point in the gas turbine plants is the normal means for controlling gas turbine output when operating in parallel. Depending upon the variation in the set value during synchronization and parallel operation, the controller has to operate effectively. Chapter 6 discusses and illustrates the soft computing controller for gas turbine plants for effective functioning during variation in the set value. An efficient controller for the gas turbine plants has been identified.

Finally conclusions and scope for future work related to this area are discussed briefly in chapter 7.