

**[GAS TURBINE FUEL AND AIR
CONTROL SYSTEM]**

By

[MARZUKI BIN NODIN]

FINAL DESIGN PROJECT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:



[Mr Rosdiazli Ibrahim]

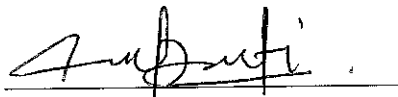
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June 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

A handwritten signature in black ink, appearing to read 'Marzuki Bin Nodin', is written over a horizontal line.

[Marzuki Bin Nodin]

ABSTRACT

Advancement in power generation has tended to enhance the ability in producing a more efficient power especially in mass power generation. In producing an efficient power generation, fuel consumption is one of the major criteria that need to be enhanced. Recent advance in fuel flow control have the potential for a significant impact on the design and performance of modern gas turbine engine. Fuel flow control has the potential to enhance mixing of fluids, modify wake behavior and reduce drag. The need of designing a efficient gas turbine fuel and air flow control has drive the author to make a first step in designing and improving the gas turbine fuel and air control system. As been mentioned before this requirement in heavy power generation are much important in a greater living for main kind. From this study and design author will go in-depth in real application of control system design. The definition of fuel and air control system that author adopt here is the used of the small modification (especially in steps response) to change the decision making or fuel and air consumption for the existing gas turbine available. The design will be base on DIDATEC TGT 1,5KW gas turbine (UTP). The design will be done by real time data and linear time invariant system, also theoretical formulation that will be studied by author for the improvement project. The improvement design that been done by the author will be the implementation of Fuzzy Logic system , where this implementation have shown a tremendous improvement and benefit especially in real time application with ambiguous decision making system. Author also will analyze and design others conventional control system such as PID controller and also Lead-lag compensator design. The design of system will be done with the help of MATLAB and SIMULINK software for comparison and system implementation.

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CHAPTER 1 INRODUCTION

Modern gas-turbine engines are complex systems that convert chemical potential energy into useful flow energy safely, reliably, and efficiently, with minimum life cycle cost and weight. As such, they move large quantities of air, and their ability to deliver depends on our ability to control the flow^[1]

The existing system in controlling the air flow and fuel are done by conventional controller such as PID controller and compensator design. In developing and coping modern industries nowadays, modern controller which is more faster and “smart” are used in order to give a more promising operation. One of the methods used is by fuzzy logic implementation.

1.1 Background

Gas turbine works base on continuous thermodynamic process, there is a continuous flow of compressed air from the compressor section, continuous combustion within the combustion chamber, and continuous power output from the turbine section.

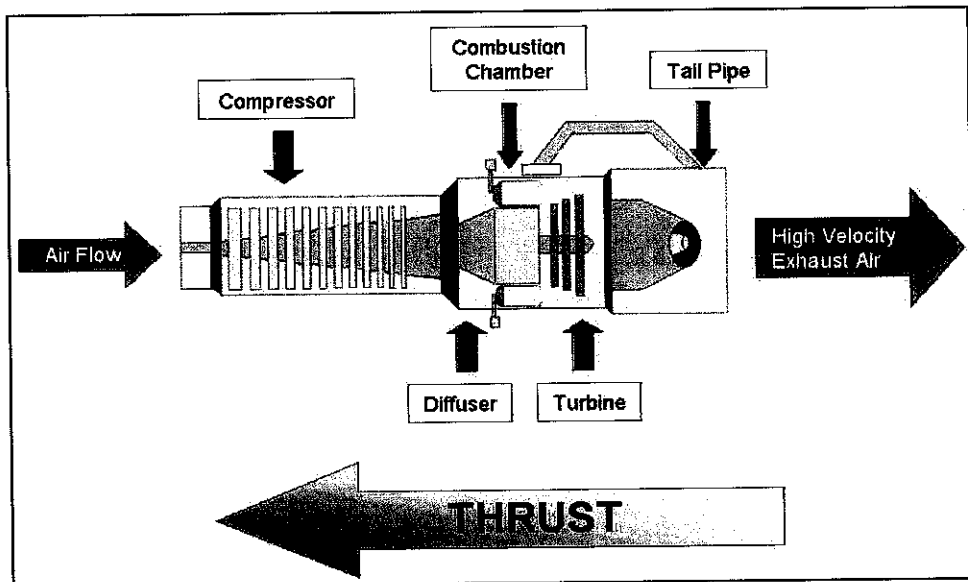


Figure 1 Gas Turbine Layout

The gas turbine event of cycle comprise of the following four processes:

- **Compression** : Atmospheric air is compressed.
- **Combustion** : Fuel is added to the compressed air and ignited
- **Expansions**: Air and combustion gases expand through nozzles
- **Exhaust**: Air and combustion gases are discharge gas are discharged into the atmosphere.

In order to complete this system the support system are introduce to enhance the efficiency of the turbine operation and power generation the basic support system for normal gas turbine consists of five support system which is:

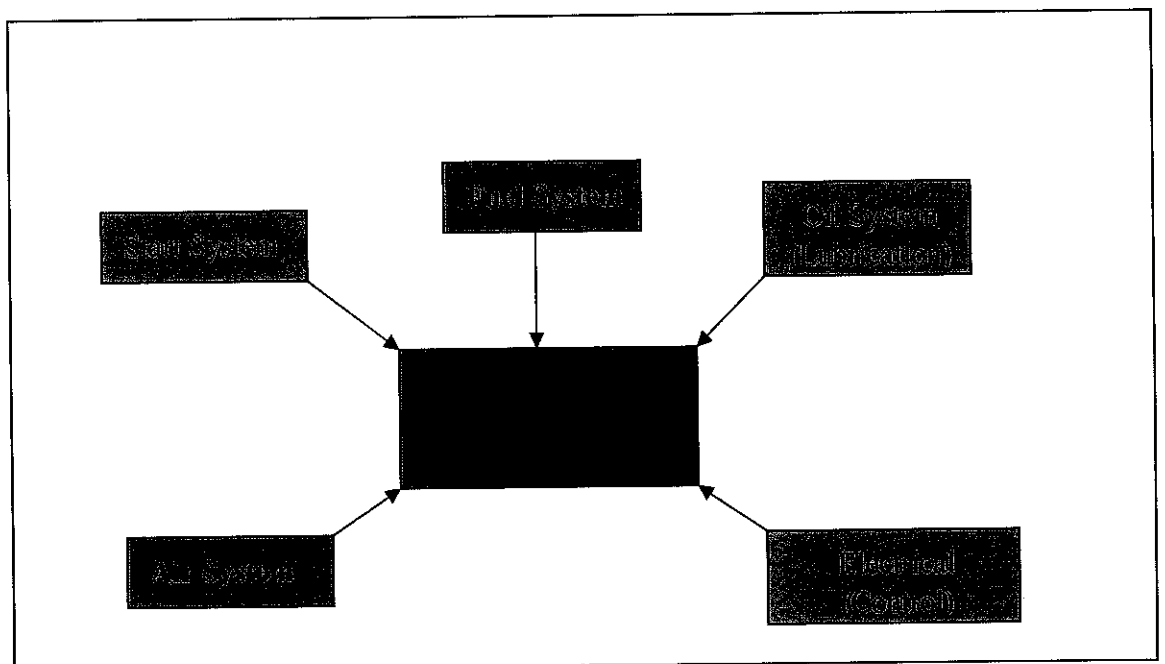


Figure 2 Gas Turbine system

The main adjustment and indicator for effectiveness and efficiency of the gas turbine is on the fuel system and air system. The collaboration of these two systems in term of the ratios and the flow rate can give the effective burning in producing the efficient power. From the development of gas turbine around the world the manipulated control system that been done is on this fuel and air system.

1.2 Problem Statement

Gas turbine is one of the major equipment available in heavy industries such as oil and gas industries. Gas turbine is one of the most critical and effective way in power generation where the gas available is plenty. In gas turbine field the performance indicator is on the power generation and the efficiency of turbine. The major part that have been developed recently is on fuel control system as well as the air intake system. A lot of improvement and redesign project have been done in this part. This has shown that the needs of more effective and efficiency in gas power generation are taken seriously.

In order to make a more improved design, one of the best way is by using the fuzzy logic control system which prove to be faster, reliable and easy to design and implemented, added that the fuzzy system can learn by itself and improve performance. Recently in mass power generation especially in gas turbine industries the implementation of fuzzy logic system to the gas turbine system especially in fuel and air ratio has not been done or develop. This is one of the great opportunity to the author to really explore and prove that the implementation of fuzzy logic for better performance can be done.

1.3 Objective and Scope Of Study

- To study on the existing gas turbine system.
- To establish the system transfer function by empirical modeling and system identification
- To design the fuel and air controller by adapting Fuzzy Logic Control, conventional PID controller and Lead-Lag Compensator

Although the study of the gas turbine control is very wide, which involved a lot of part, either mechanical or electrical part. The concentration will be only on the system of controlling the fuel and air intake. The analysis and design will be divided into two different parts of analysis. The first part is by assuming system in first order system, where the process reaction curve method will be used. In second part where the system is assumed in second order system, system identification method will be used. The implementation of the fuzzy logic system for both air and fuel system also been done in this controller design since fuzzy logic implementation is one of the latest technology that have prove to give a better performance especially in variable system. The comparison of the steps response of the gas turbine with the various method will be done with the reference to the steps response of the system. In This project also the research and understanding on the available fuel system will be done. The concentration of the system will be on turbojet gas turbine type due to its similarity to the existing UTP gas turbine. This type of gas turbine system is also the best fundamental system to study with its major disadvantage on fuel consumption as been explained in the problem statement.

CHAPTER 2 LITERATURE REVIEW AND THEORY

2.1 The Gas Turbine

The gas turbines are confirmed as the power generators. Nowadays; it is not rare to used gas turbine for the production of electricity energy for propelling or air apparatus.

Some advantages of using the gas turbine are:

- It is mechanically simple and consecutively the reduced dimensions and weight in comparison with the others equipment of equal power.
- The possibility to feed with several fuel like liquid gas or kerosene where it is more less expensive.

The gas turbines are one of the internal combustion machines of non-alternative type. When comparing with others alternative engines such as internal combustion engines or diesel engines where gas transformation occur in an organ (cylinder) only, but the transformation of the gas turbine occur in different organs where the gas circulates successively.

2.1.1 The Brayton Cycle (The Constant-Pressure Engine)

In gas turbine the event on each stage are continuous, so it can be said that the gas turbine engine works on what is commonly called an open cycle. In relation to this the cycle of gas turbine can be represented by graph below:

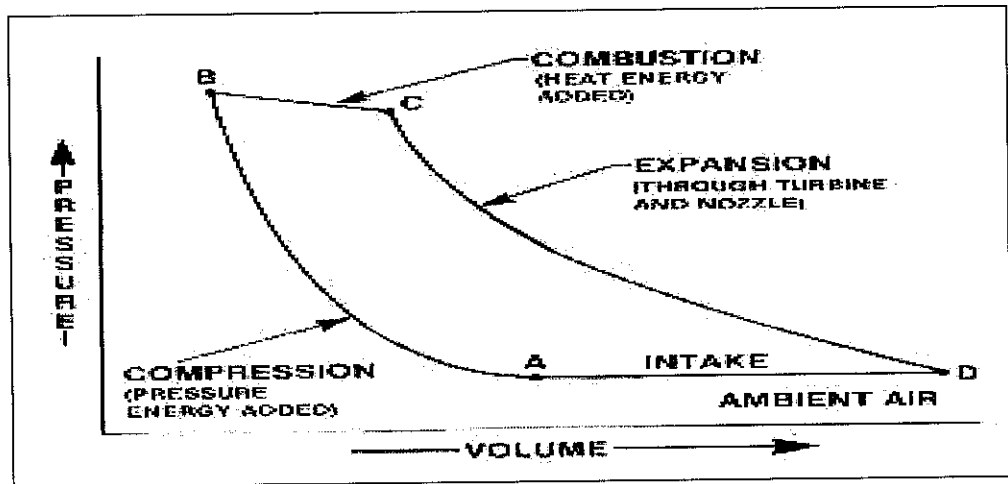


Figure 3 The Bryton Cycle Graph

From the graph the actions or reactions are given in five stages where as we can see from point A to B the compression stage occur where in this stage the pressure will rise highly as displayed. In this section the air has been compressed in order to produce an effective burning. This compressed air and gas will experience the second stage of the cycle (point B to C), In this cycle/stage the burning of compressed gas and air will happen. This will tend to rise the temperature of the gas turbine. The next cycles is the expansion cycle where the burning mechanism will expanse to produced power from this cycle, the power will be used to turn the turbine on. In this condition the temperature will decrease slowly and also the pressure will decrease due to the used of the power. The last cycle in gas turbine is on the exhaust cycle where the depressurize of the system happen. This will tend to return the cycle to the starting cycle where the compression process will occurred back. This process will tend to repeat in producing the cycle of power supply in rotation. This behavior or cycle are refer to Bryton Cycle.

2.1.2 Efficiency of The System

2.1.2.1 Specific Fuel Consumption (SFC)

Engine thermal efficiency can be defined as the engine's energy output divided by the fuel's energy input. One of the principal measures of jet engine efficiency are *Specific Fuel Consumption, SFC* or thrust-specific fuel consumption TSFC. Specific fuel consumption is the ratio between the fuel flow (in pounds per hours) and the thrust of the engine

$$SFC = \frac{W_f}{F_n}$$

2.1.2.2 Equivalence Specific Fuel Consumption (ESFC)

ESFC is used to compare the fuel consumption between turboprop engines

$$ESFC = \frac{W_f}{ESHP}$$

where ESHP is the equivalent shaft horsepower. That can be obtained by

$$ESHP = SHP + \frac{F_n}{2.5}$$

Many factors that can effect the overall efficiency of the gas turbine from the reading and research. The main factors is :

1. Component efficiency
2. Type of fuel used
3. Engine operating factors. This include the fuel and air system where the ratio of the fuel can contribute to effective burning.

2.2 Turbojet Gas Turbine System.

The "heart" of a gas turbine-type engine is the gas generator. A schematic diagram of a gas generator is shown in Figure 4. The compressor, combustor, and turbine are the major components of the gas generator which is common to the turbojet, turbofan, turboprop, and turbo shaft engines. The purpose of a gas generator is to supply high temperature and pressure gas.

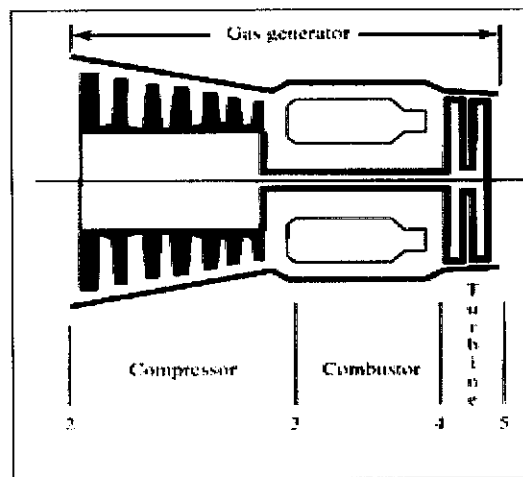


Figure 4 Gas Generator

By adding an inlet and a nozzle to the gas generator, a turbojet engine can be constructed. A schematic diagram of a simple turbojet is shown in Figure 4 and a turbojet with afterburner in Figure 5. In the analysis of a turbojet engine, the major components are treated as sections. Also shown in Figure 5 the station numbers for each section.

The turbojet was first used as a means of aircraft propulsion by von Ohain (first flight August 27, 1939) and Whittle (first flight May 15, 1941). As development proceeded, the turbojet engine became more efficient and replaced some of the piston engines.

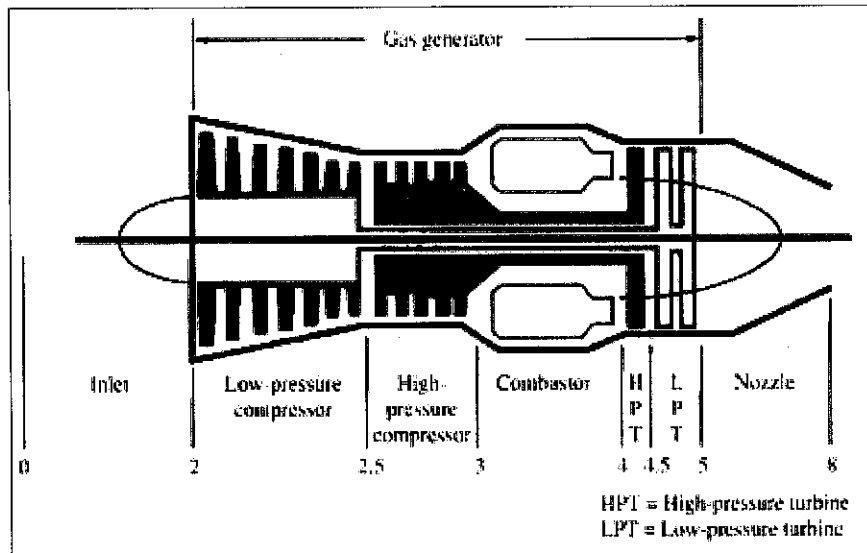


Figure 5 Turbojet Engine Layout

The thrust of a turbojet is developed by compressing air in the inlet and compressor, mixing the air with fuel and burning in the combustor, and expanding the gas stream through the turbine and nozzle. The expansion of gas through the turbine supplies the power to turn the compressor. The net thrust delivered by the engine is the result of converting internal energy to kinetic energy.

The turbojet engine is a reaction engine. In a reaction engine, expanding gases push hard against the front of the engine. The turbojet sucks in air and compresses or squeezes it. The gases flow through the turbine and make it spin. These gases bounce back and shoot out of the rear of the exhaust, pushing the plane forward.

2.3 Fuzzy Logic Basic Understanding

The basic idea of multi-valued logic has been explored to some extent by a number of mathematicians in this century, but the real breakthrough was made by Prof. Lotfi Zadeh from the University of California in Berkeley. The fuzzy theory was adopted wholeheartedly by the Japanese, and their advances in the field of fuzzy control have won the attention of engineers throughout the world. Fuzzy theory gives a whole new approach to the mathematics of thinking; it is a change of paradigm for western world scientists and mathematicians, and like all changes of paradigm has been initially strenuously resisted, except in the Far East, where two-valued Aristotelian logic has not been too deeply ingrained.^[2]

2.3.1 What is Fuzzy Logic

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth – truth values between “completely true” and “completely false”^[2]

FL is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL’s approach to control problems mimics how a person would make decisions, only much faster.

2.3.2 How Fuzzy Logic Works

FL requires some numerical parameters in order to operate such as what is considered significant error and significant rate-of-change-of-error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them. For example, a simple temperature control system could use a single temperature feedback sensor whose data is subtracted from the command signal to compute “error” and then time-differentiated to yield the error slope or rate-of-change-of-error (“error-dot”). Error might have units of degs F and a small error considered to be 2F while a large error is 5F. The “error-dot” might then have units of degs/min with a small error-dot being 5F/min and a large one being 15F/min. These values don’t have to be symmetrical and can be “tweaked” once the system is operating in order to optimize performance. Generally, FL is so forgiving that the system will probably work the first time without any tweaking.

FL incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FL model is empirically-based, relying on an operator’s experience rather than their technical understanding of the system. For example, rather than dealing with temperature control in terms such as “SP =500F”, “T <1000F”, or “210C <TEMP <220C”, terms like “IF (process is too cool) AND (process is getting colder) THEN (add heat to the process)” or “IF (process is too hot) AND (process is heating rapidly) THEN (cool the process quickly)” are used. These terms are imprecise and yet very descriptive of what must actually happen. FL is capable of mimicking this type of behavior but at very high rate^[4]

2.3.3 Why Used Fuzzy Logic?

The usage of fuzzy logic has many advantage when comparing to normal conventional controlled technique. Some of the reasons and advantageous of using the fuzzy logic system are:

- **Fuzzy logic is conceptually easy to understand:** Fuzzy reasoning are very simple due to simplification of the mathematics formulations.
- **Fuzzy logic is flexible:** It is easy to be massage it or layer the system without starting the design from scratch for any given system.
- **Fuzzy logic is tolerant of imprecise data:** In fuzzy logic the reasoning are build under the understanding of the system is not truly accurate. Where the design will look at the decision base on the process not to the end of the conclusion.
- **Fuzzy logic can model nonlinear functions of a arbitrary complexity:** Fuzzy logics can be used to create any set of input-output data.
- **Fuzzy logic can be built on top of the experience of experts:** In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic rely on the experience of people who already understand the system.
- **Fuzzy logic can be blended with conventional control techniques.**
- **Fuzzy logic is based on natural language.**

In fuzzy logic system there are basically two type of Fuzzy that can be implemented which is Mamdani and Sugeno type. With respect to this type of fuzzy logic there are some similarity, differences and advantages to the system. Some of the properties of this fuzzy logic type are as tabulated below:

Table 1 Comparison Of Fuzzy Logic

	Mamdani	Sugeno
Similarity	The consequent parts of the rules are the same	
Difference	The consequent parts are fuzzy sets	The consequent parts are singletons (single points) or mathematical functions of them
Advantages	<ul style="list-style-type: none"> • easily understood by a human being. Simple as four elementary • Program constrained as an analysis tool. 	<ul style="list-style-type: none"> • More effective computationally. More not concerned with mathematical analysis and in system analysis, functions are continuous in the output of a rule.

2.3.4 Limitation of Conventional Controllers

In conventional controllers some of the limitation of the controllers can be summarized as below:

1. *Plant nonlinearity.* The efficient linear models of the process or the object under control are too restrictive. Nonlinear models are computationally intensive and have complex stability problems.
2. *Plant uncertainty.* A plant does not have accurate models due to uncertainty and lack of perfect knowledge.
3. *Multivariables, multiloops and environment constraints.* Multivariate and multiloop systems have complex constraints and dependencies
4. *Uncertainties in measurements.* Uncertain measurements do not necessarily have stochastic noise models.

5. *Temporal behavior.* Plants, controllers, environments and their constraints vary with time. Moreover, time delays are difficult to model.

2.4 Fuzzy Logic Implementation on Four Stroke Engine

Implementation of the fuzzy logic system have been done and developed by Professor S.H Lee of engineering Research center from university of Brighton. The research of Fuzzy Air Fuel Ratio Control of a small gasoline engine was develop to achieve and monitoring of the regulation of the fuel ignition system. The control system of this experiment was done by determination of the amount of fuel required from the fuzzy a algorithm that used the engine speed and manifold air pressure as input valves

The set up of the system have been done by adjusting the Electronics Control of the air and fuel ratio (AFR) that have been used widely in four stroke engine. The adoption of the fuzzy system in mapping the demand of the fuel in the engine have been done in this experiment. As the behavior of the fuzzy logic system that it can interpret the system as close as human decision, the efficiency of the fuel demand can be done more accurately.

In this experiment the setup of the system has been done by using the same feed forward system as been used in AFR. The block diagram of the system with fuzzy implementation can be represented as:

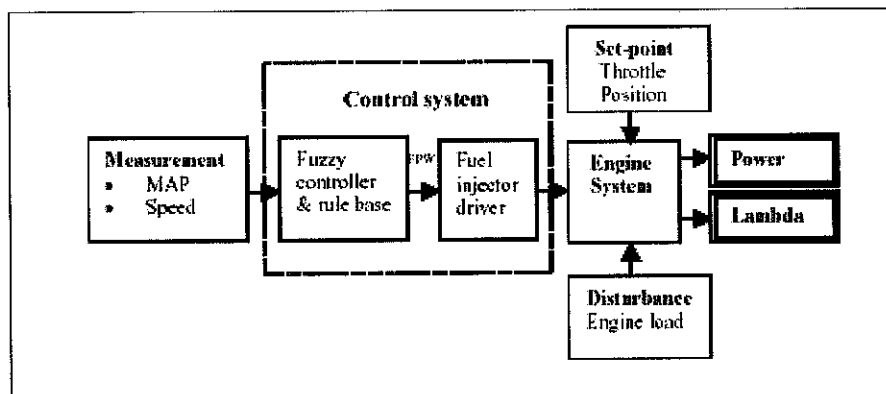


Figure 6 Block Diagram for Feed Forward and Fuzzy Logic Scheme

The set up of the experiment have been done by using the Bosh Suffolk single-cylinder engine having the capacity of 98cc. by the used of PC-based data acquisition system utilizing the data and analysis was done by programmable controller (Intel 82C54) by the sensor attach on the system the engine load estimation have been made in order to get the pattern of the system behavior. The measurement of the air pressure, Engine speed and throttle position have been done and can be represented as:

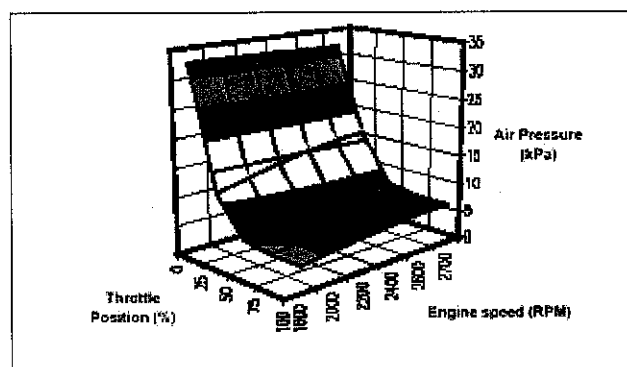


Figure 7 Fuzzy Plotted

2.4.1 Fuzzy Logic Implementation of the system

The fuzzy system have been embedded using the Fuzzy Development Environment (FDE) that was latter converted to C++ code the execution module on microcontroller. The fuzzy control loop can be summarize as:

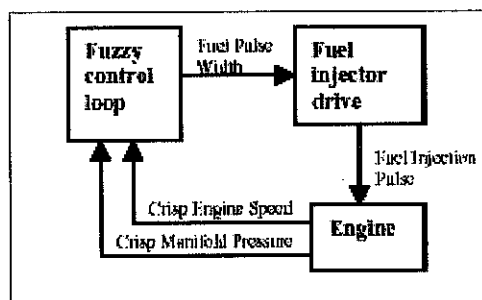


Figure 8 Fuzzy Control Loop

The implementation design of the system are as similar to the fuzzy implementation in MATLAB where the fuzzy set input and rule base are set up for engine speed, pressure and the output of defuzzification is the fuel consumption required.

From the experiment done the experimental result that have been achieve shows that the system gave s a more high performance to the system with high efficiency of the fuel consumption for the engine power and torque . The results are as attached in APPENDIX A

This experiment and system has shows that the implementation of the fuzzy logic system can be done in combustion engine, since the gas turbine engine are as similar to the four stroke internal combustion engine the implementation of the fuzzy system to the air- fuel ration control using fuzzy implementation can be done with almost the same method done in this proceeding paper.

2.5 Conventional Control System Design

2.5.1 PID Empirical modeling

A linearized quantitative version of this model can be obtained with an open-loop experiment, by using the following procedure.

1. With the plant in open loop, take the plant manually to a normal operating point. Say that the plant output settles at $y(t) = y_o$ for a constant plant input $u(t) = u_o$.
2. At an initial time t_o , apply a step change to the plant input, from u_o to u_{∞} (this should be in the range of 10 to 20% of full scale).
3. Record the plant output until it settles to the new operating point. Assume that you obtain the curve shown in Figure 9. This curve is known as the *process reaction curve*.
4. Compute the parameter model as follows:

$$K_o = \frac{y_{\infty} - y_o}{u_{\infty} - u_o}; \quad \tau_o = t_1 - t_o; \quad \nu_o = t_2 - t_1 \quad (6.5.1)$$

The model obtained can be used to derive various tuning methods for PID controllers. One of these methods was also proposed by Ziegler and Nichols. In their proposal, the design objective is to achieve a particular damping in the loop response to a step reference. More specifically, the aim is to obtain a ratio of 4:1 for the first and second peaks in that response. The suggested parameters are shown in Table 2.

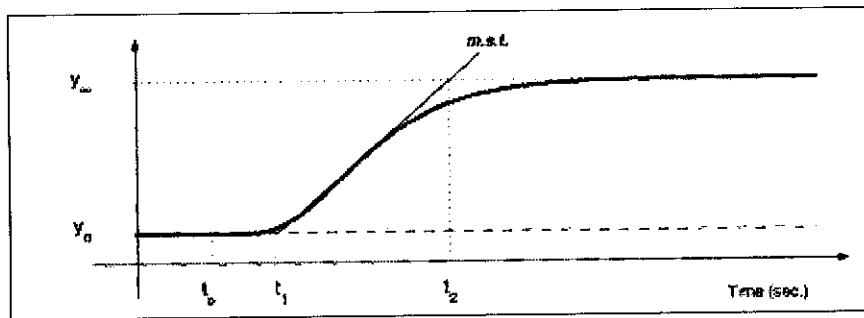


Figure 9 Plant Step Response

The parameter-setting rules proposed in where we have again normalized time in delay units.

Table 2 Ziegler-Nichols Tuning By using The Reaction Curve

	K_p	T_r	T_d
P	$\frac{\nu_0}{K_o \tau_0}$		
PI	$\frac{0.9\nu_0}{K_o \tau_0}$	$3\tau_0$	
PID	$\frac{1.2\nu_0}{K_o \tau_0}$	$2\tau_0$	$0.5\tau_0$

In this designing one of the method used in determining the system transfer function and the system behaviors that will be used in the analysis and design is the process reaction curve method. Although it is simple, it have been proved to provides adequate models for many applications. There are two different graphical techniques that can be used in this modeling which is called method I and method II. In this design the author has use method II as method I has larger errors in the parameter estimates. In figure 10 the process reaction cure of open loop calculation base on process can be calculated and determine by the formula given.

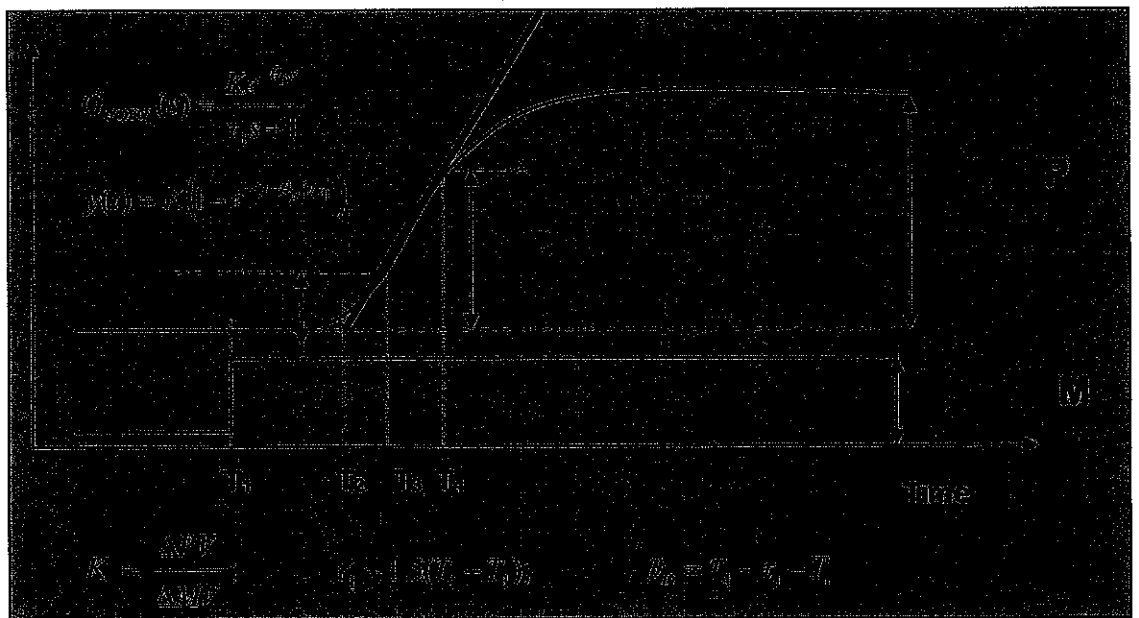


Figure 10 Process Reaction Curve

2.5.2 Controller Tuning Method (PID Tuning).

In this design project one of the way in order to design an efficient control system of the fuel and air controller is by using the PID controller since in this design project the system will be single input single output (SISO) system this approach is the best approach can be done. There is other type of approach can be used in designing a stable and fast response system such as root locus analysis. The discussion of the PID control implementation can be summarized as below:

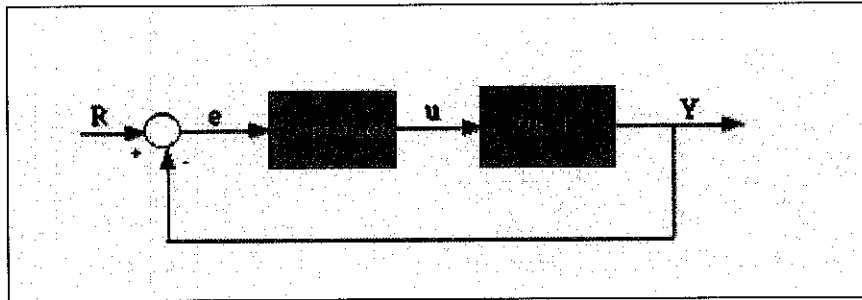


Figure 11 Feedback System

The transfer function of the PID controller can be represented as:

$$K_p + \frac{K_i}{s} + K_d s = \frac{K_p s^2 + K_p s + K_i}{s}$$

- K_p = Proportional gain
- K_i = Integral gain
- K_d = Derivative gain

PID controller works in a closed-loop system using the schematic shown above. The variable (e) represents the tracking error, the difference between the desired input value (R) and the actual output (Y). This error signal (e) will be sent to the PID controller, and the controller computes both the derivative and the integral of this error signal. The signal (u) just past the controller is now equal to the proportional

gain (K_p) times the magnitude of the error plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error.

$$u = K_p e + K_i \int e dt + K_d \frac{de}{dt}$$

This signal (u) will be sent to the plant, and the new output (Y) will be obtained. This new output (Y) will be sent back to the sensor again to find the new error signal (e). The controller takes this new error signal and computes its derivative and its integral again. This process goes on and on.

2.5.3 The characteristics of P, I, and D controllers

A proportional controller (K_p) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (K_d) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers K_p , K_d , and K_i on a closed-loop system are summarized in the table shown below.

Table 3 PID Responses

Note that these correlations may not be exactly accurate, because K_p , K_i , and K_d are dependent of each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for K_i , K_p and K_d .

2.5.4 Zeigler-Nichols Open Loop Method

This open loop tuning method was originally proposed by Ziegler and Nichols (1942). In this tuning method the process reaction curve established from the system on the analysis of the plot have been used to fine the Proportional, integral and differential parameters that can be used in the PID design. In the gas turbine system author has decided to used proportional and integral only controller in for the design. The summary of the coefficient that has been used are as follows:



2.6 Lead-Lag Compensator

Closely related to PID control is the idea of lead-lag compensation. These ideas are frequently used in practice, especially when compensators are built with electronic hardware components. The transfer function of these compensators is of the form

$$C(s) = \frac{\tau_1 s + 1}{\tau_2 s + 1} \quad (6.6.1)$$

When $\tau_1 > \tau_2$, this is a *lead network*, when $\tau_1 < \tau_2$, this is a *lag network*. The straight-line approximation to the Bode diagrams for these networks are given in Figure 12 and Figure 12 (where τ_1 and τ_2 differ by a factor of 10 : 1).

The lead compensator acts like an approximate derivation. In particular, we see from Figure 12 that this circuit produces approximately 45° of phase advance at $\omega = 1/\tau_1$ without a significant change in gain. Thus, if we have a simple feedback loop which passes through the -1 point at, say, frequency ω_1 , then inserting a lead compensator

such that $\omega_1 \tau_1 = 1$ will give a 45° phase margin. Of course, the disadvantage is an increase in the high-frequency gain, which can amplify high frequency noise.

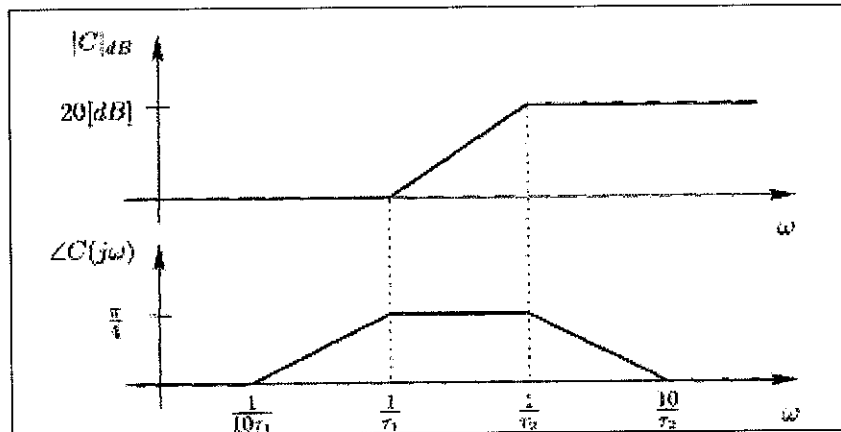


Figure 12 Approximate Bode Diagrams for Lead Networks.

An alternative interpretation of a lead network is obtained by considering its pole-zero structure. From (6.6.1) and the fact that $\tau_1 > \tau_2$, we see that it introduces a pole-zero pair, where the zero (at $s = -1/\tau_1$) is significantly closer to the imaginary axis than the pole (located at $s = -1/\tau_2$).

On the other hand, a lag compensator acts like an approximate integrator. In particular, we see from Figure 13 that the low-frequency gain is $20 [dB]$ higher than the gain at $\omega = 1/\tau_1$. Thus, this circuit, when used in a feedback loop, gives better low-frequency tracking and disturbance rejection. A disadvantage of this circuit is the additional phase lag experienced between $1/10\tau_2$ and $10/\tau_1$.

Hence, $1/\tau_2$ is typically chosen to be smaller than other significant dynamics in the plant.

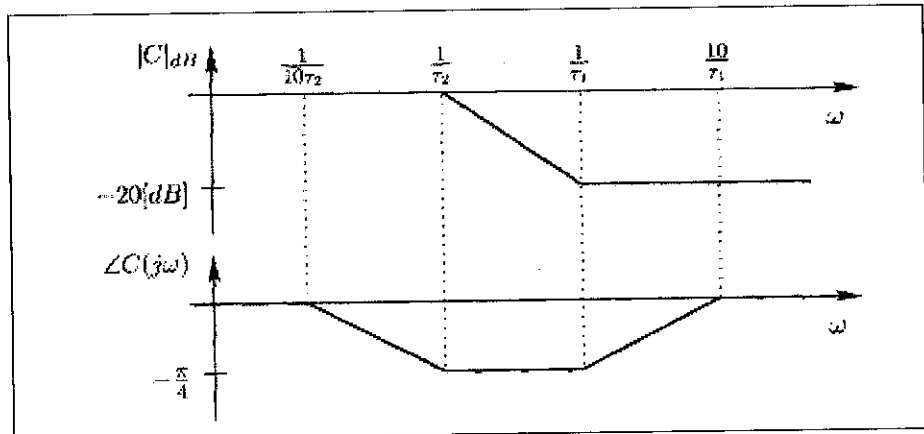


Figure 13 Approximate Bode Diagrams for Lag Networks

From the point of view of its pole-zero configuration, the lag network introduces a pole (located at $s = -1/\tau_2$) that is significantly closer to the imaginary axis than the zero (located at $s = -1/\tau_1$).

In summary, the lead network feature used in design is its phase-advance characteristic. The lag network instead is useful due to its gain characteristics at low frequency.

2.6.1 Bode Diagram Design (Compensator Design)

One technique for compensator design is to work with Bode diagrams of the open-loop response (loop shaping). Using Bode diagrams, the design of gain and phase margin specifications, adjust the bandwidth, and add notch filters for disturbance rejection can be done.

A Bode plots measures in the frequency domain much like an oscilloscope measures in the time domain. A Bode plot has two parts: the gain curve and the phase curve. The gain curve displays the ratio of the output to the input in *decibels* or *dB*. Decibels are defined by the equation:

$$\text{Gain} = 20 * \log_{10}(\text{Output}/\text{Input})$$

Bode plots for motion systems typically have a gain of 0 dB (input = output) at low frequencies and decline at higher frequencies. This is expected: at low frequencies the output will precisely follow the input. At high frequencies, the motion system cannot keep up. This is why gain plots for servo systems usually look like a mountain ridge. They start at 0 dB on the left, stay flat as they move right, and at some frequency start falling off. Like a scope plot, responsiveness and stability can be read from a Bode plot. Most of this information is in the gain plot. Responsiveness is usually measured by *bandwidth*. Bandwidth is the frequency where the gain falls to -3 dB (i.e., where Output = 0.7 * Input) as shown in Figure 14. Higher bandwidth corresponds to faster settling times. Stability is measured in *peaking*, the characteristic where the gain plot first climbs a few dB before starting to fall. Peaking in the Bode plot corresponds to overshoot in the scope plot. More than 1 or 2 dB is usually considered excessive; the system in Figure 14 has less than 1 dB of peaking. Bode plots are useful at several levels. First, they provide understanding about control theory.

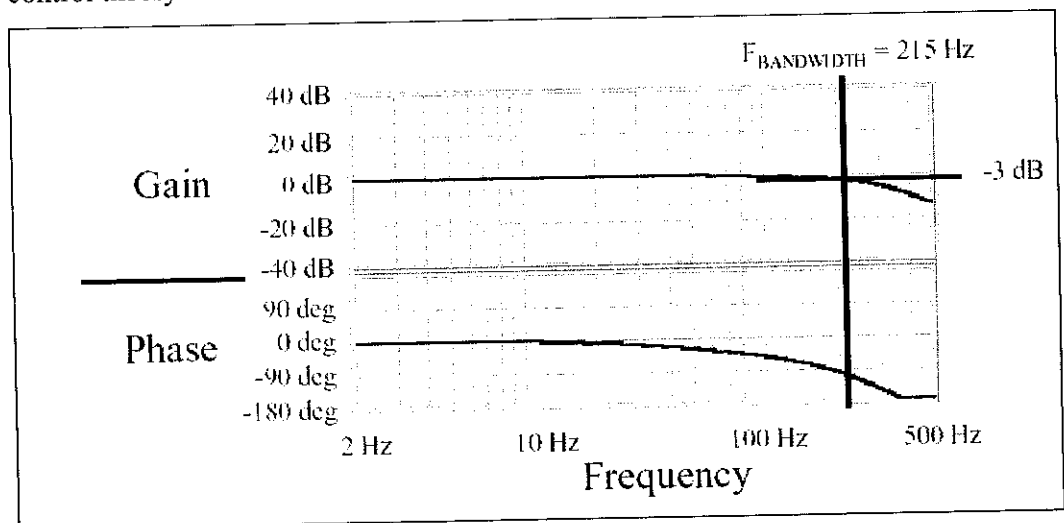


Figure 14 Bode Plot Design

2.6.2 Root Locus Design Method (Compensator Design)

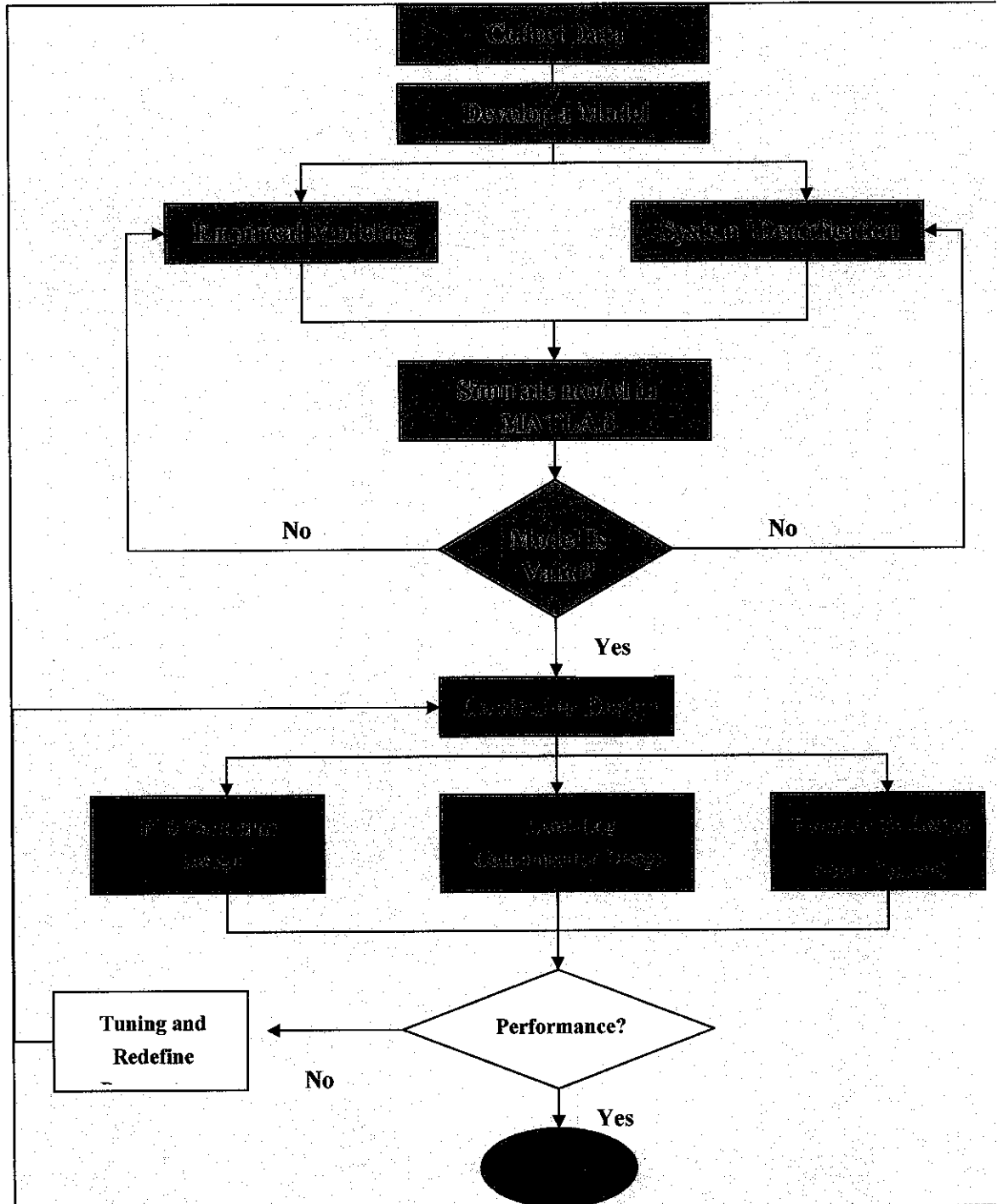
A common technique for meeting design criteria is root locus design. This approach involves iterating on a design by manipulating the compensator gain, poles, and zeros in the root locus diagram. The root locus diagram shows the trajectories of the closed-loop poles of a feedback system as a single system parameter varies over a continuous range of values. Typically, the root locus method is used to tune the loop gain of a SISO control system by specifying a feedback gain the closed-loop pole locations. Root-locus plots are used to plot the system roots over the range of a variable to determine if the system will become unstable, or oscillate.

The potential for unstable operation is inherent in all feedback control systems. Consequently, it is desirable to analyze their stability characteristics and their damping characteristics so that both the absolute stability and the relative stability (peak overshoot, settling time, etc.) of the system can be determined. Classical control theory uses a method commonly known as root locus analysis,

CHAPTER 3 METHODOLOGY/PROJECT WORK

3.1 Overall Methodology and Project Work

The overall project work and methodology can be summarized as below:



3.2 Collecting Data From Gas Turbine

In obtaining the data from the gas turbine system the procedure in execution of the gas turbine have to be done first. In using the DIDATECT gas turbine the steps taken for starting and stopping the gas turbine are as follows:

Starting process

- Confirm feed presence
 - Electrical supply = 400V+ neutral
 - LPG (open valve of the bottle)
 - Water system network (10l/min approximately)
 - Compressed air (about 6 bars)
- Put the main switch on
 - Reset LPG electro valve through the push-button placed on the small box
 - Adjust the synoptic pressure reducing valve on 1 bar
 - Flow meter valves is open
 - Control the indicator verify that the red pilot lamp “default” is off
- Start the hydraulic unit
- Start the Cycle
 - Observed
 - Pre-aeration time
 - The ignition
 - The air self-feed announced by green blinking pilot lamps

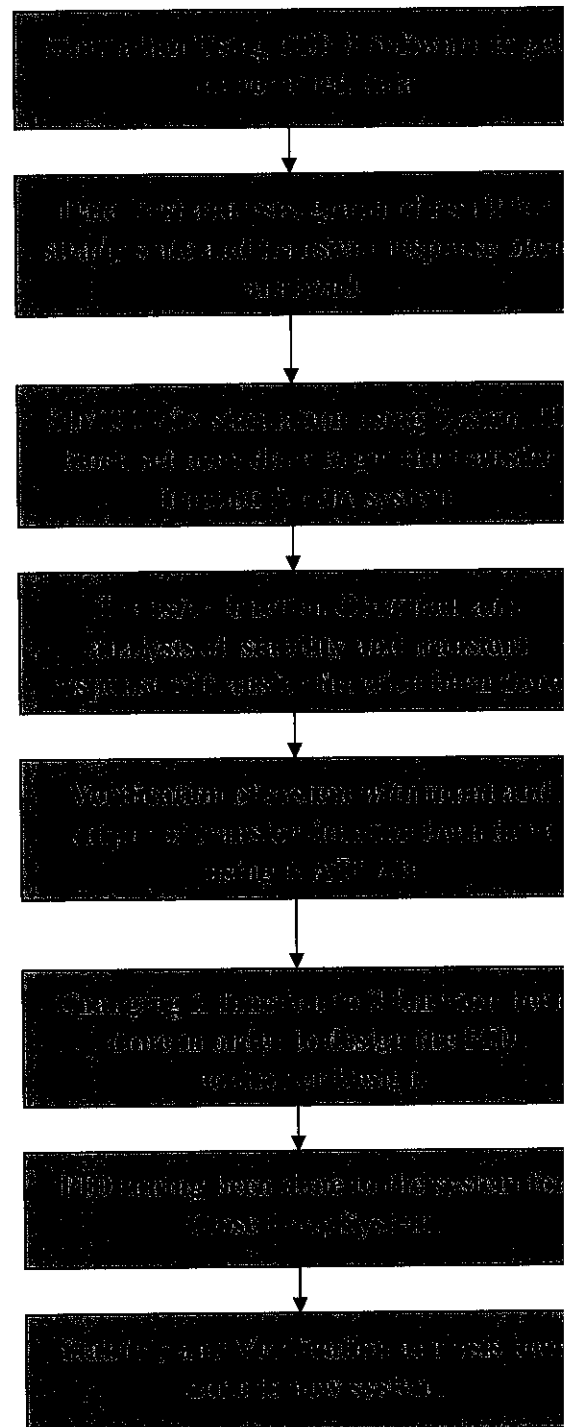
Some of the pictures of the gas turbine execution are as attached in APPENDIX F

3.3 Turbojet System Simulation Analysis (Software Data)

Analysis and design simulation have been done in experimenting the system and making the proper simulation of the system. In this design project author have decided to used the turbojet engine for simulation and design purposes since the unavailability of UTP DIDATEC gas turbine due to some technical problem by the mechanical department. In this design project and simulation there are mainly two software been used throughout the designing process which is Gas Turbine Simulator (GSP 9.1) and MATLAB and SIMULINK.

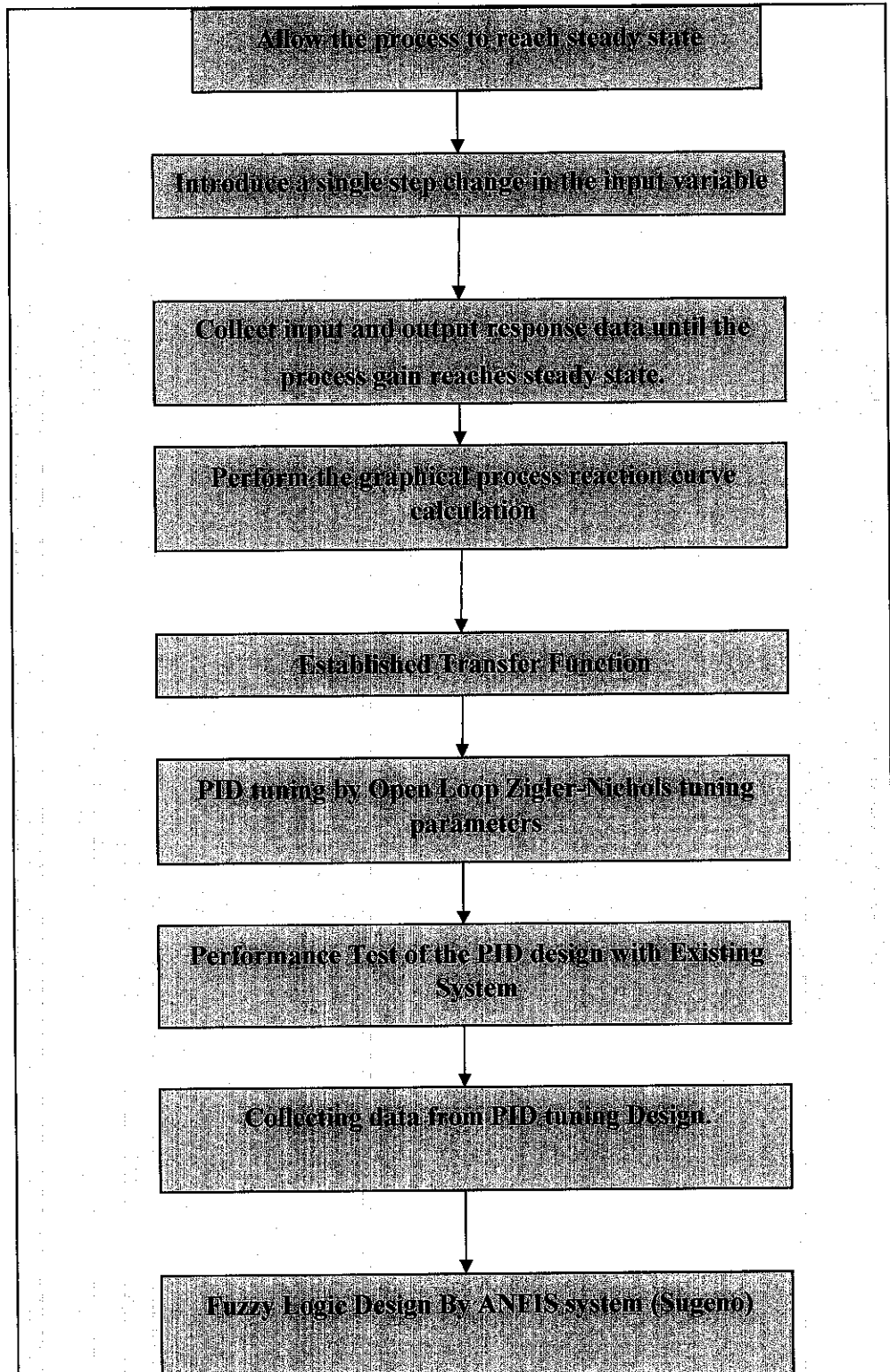
The reason of choosing the turbojet system as the design system is due to the similarity of the system with the DIDATEC system and it is the fundamental arrangement of the gas turbine system that relates directly to the theory applied. With this system the basic understanding of gas turbine stages and operation can be easily understood despite it will be similar to the real design process done

The methodology or steps taken in this design for turboprop system can be summarize as:



3.4 Empirical Modeling Design Method.

As been mention is introduction the system determination and controller design have been done in two method. The first method used in determining the system and designing the controller are as shown below:

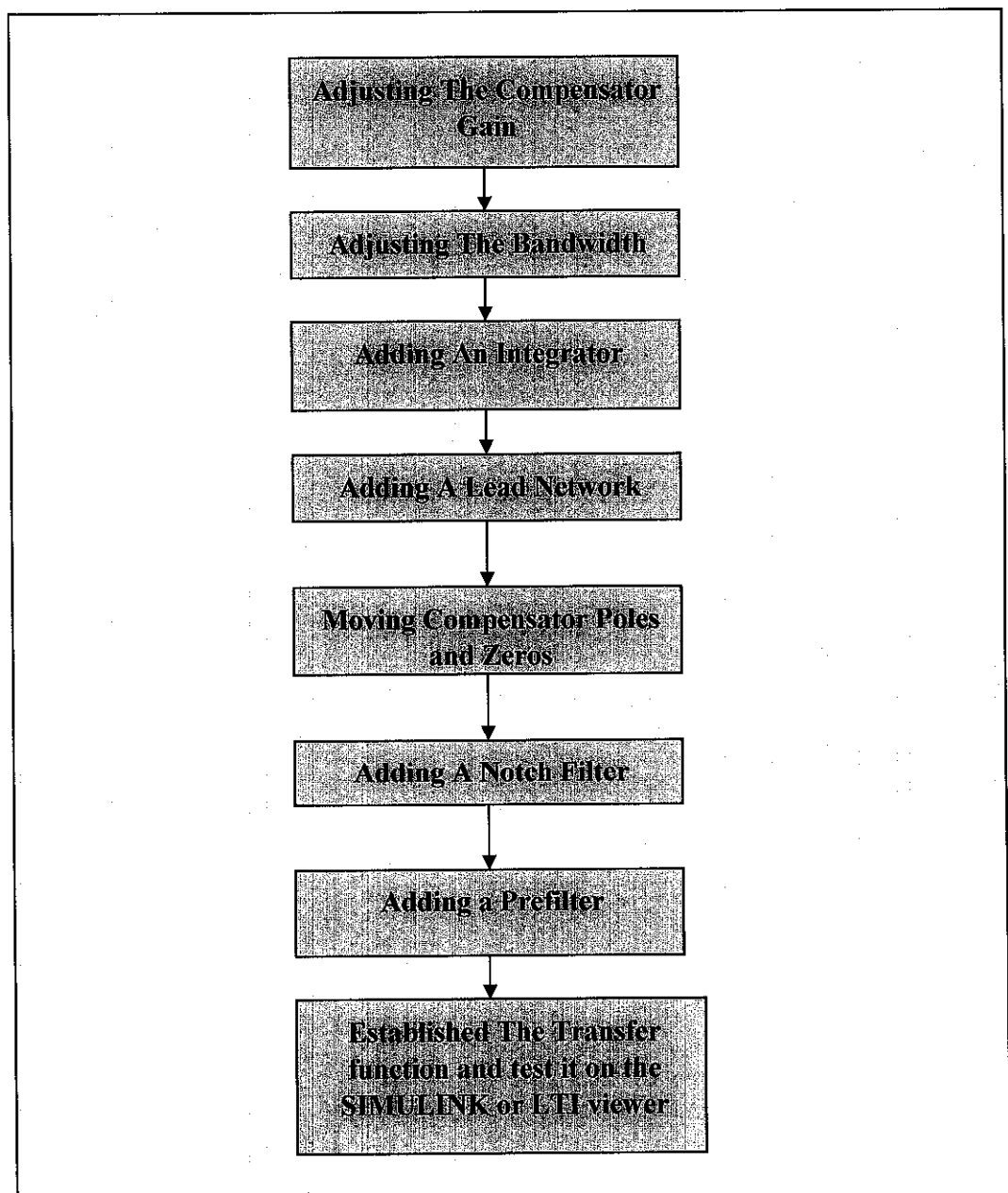


3.5 Conventional Control Design (SISO Model Design)

One of the controls strategy that was used before the modern control technique was introduce such as Fuzzy Logic and Neural Network is the Single Input Single Output (SISO) design. In this techniques the Compensator of the system have been adjusted.. The summary of the techniques used are as below for Bode Plot Modeling and Root Locus Design Method. This design method are mainly with respect to the performance of the system the necessary adjustment are only to be done if necessary.

3.5.1 Bode Diagram Modeling

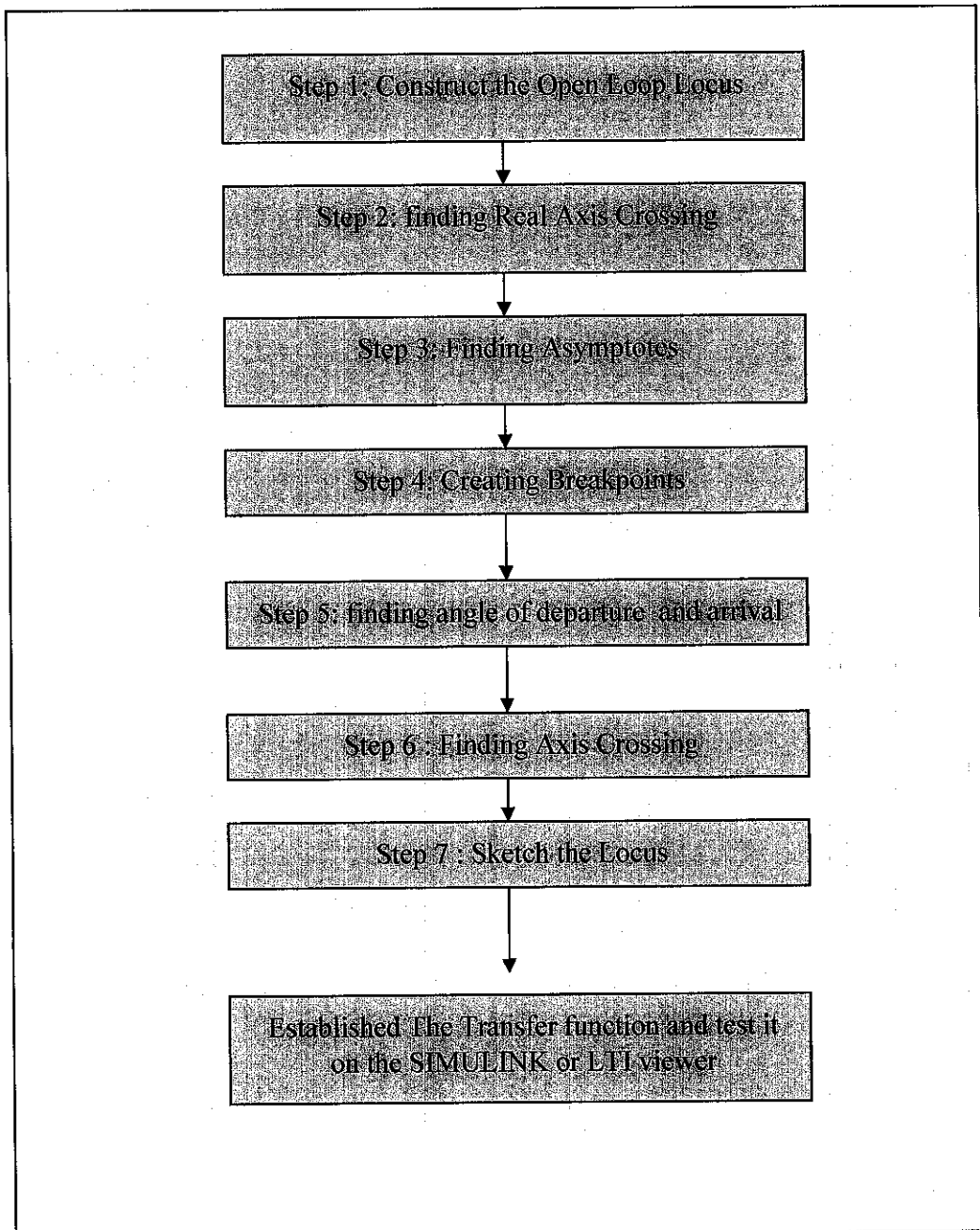
Table 4 Bode Diagram Modelling



3.5.2 Root Locus Design Modeling.

Step By Step Procedure in Constructing root locus and analyzing the root locus can be summarized as below. This root locus design are actually related to the bode diagram design since it is on the same toolbox in MATLAB.

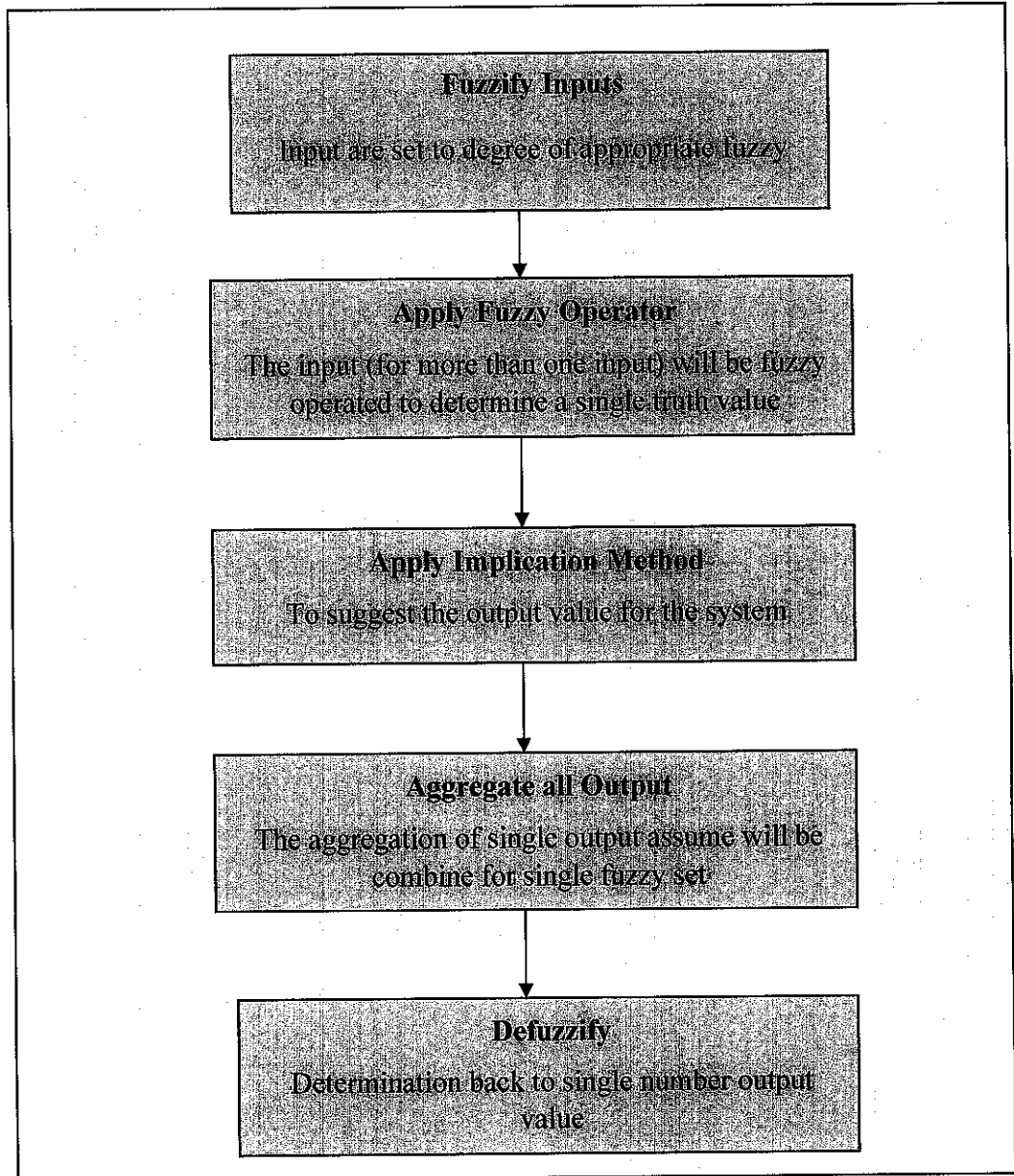
Table 5 Root Locus Modeling .



3.6 Fuzzy Logic Inference System

In fuzzy logic system the operation of the fuzzy logic system that been done in order to make the decision and conclusion are base on the fuzzify and defuzzify process of the system. The summary of the operation for the fuzzy logic system are as summarized below:

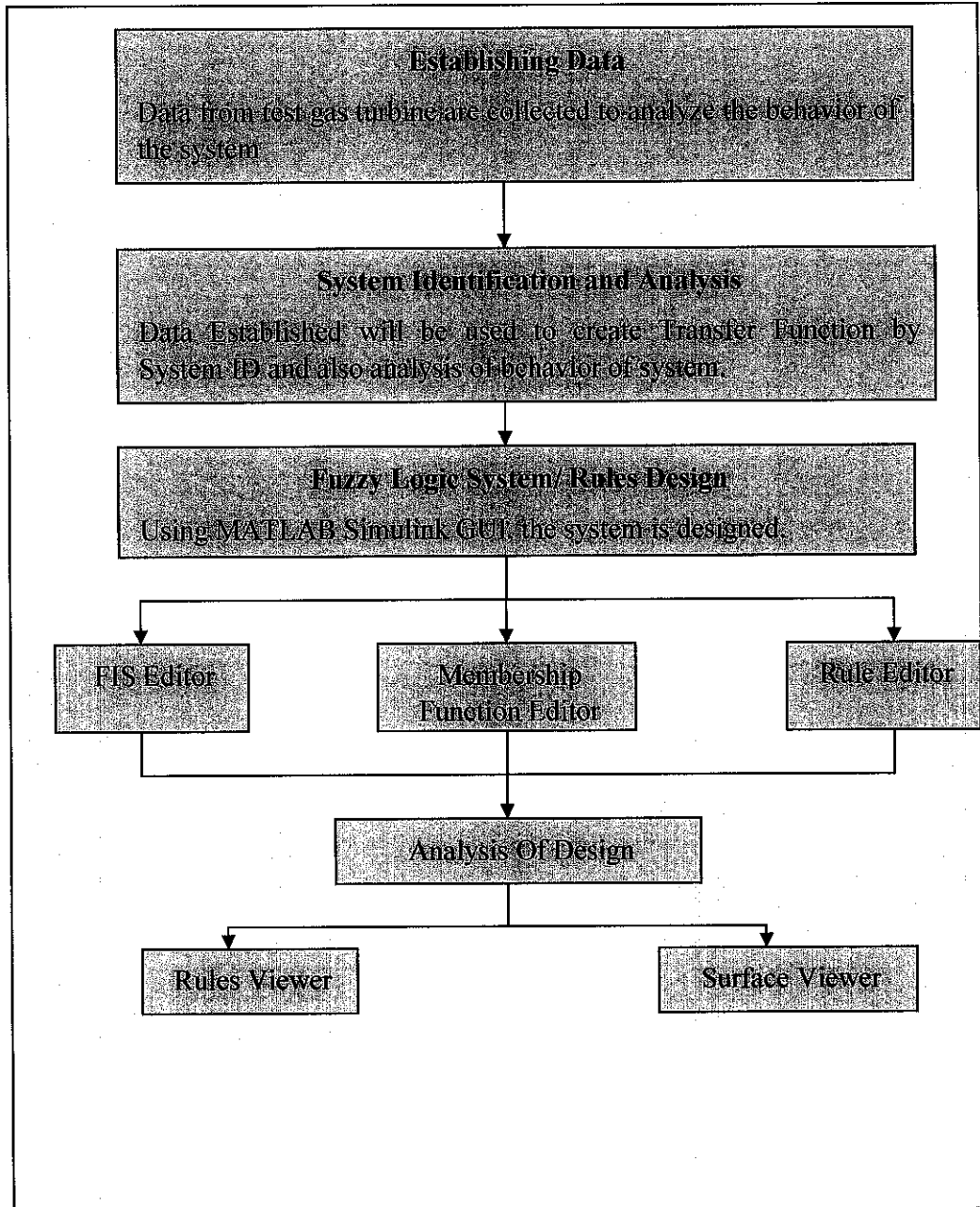
Table 6 Fuzzy Logic System



3.6.1 Fuzzy Logic Implementation on Gas Turbine System (By using Mamdani)

In fuzzy logic control design there are two method that can be used in designing the controller, one of the method is by using the mamdani approached. In this approached the system behaviors have to be well understood by the designer since the determination of the limit rules and function are base on the knowledge of the system.

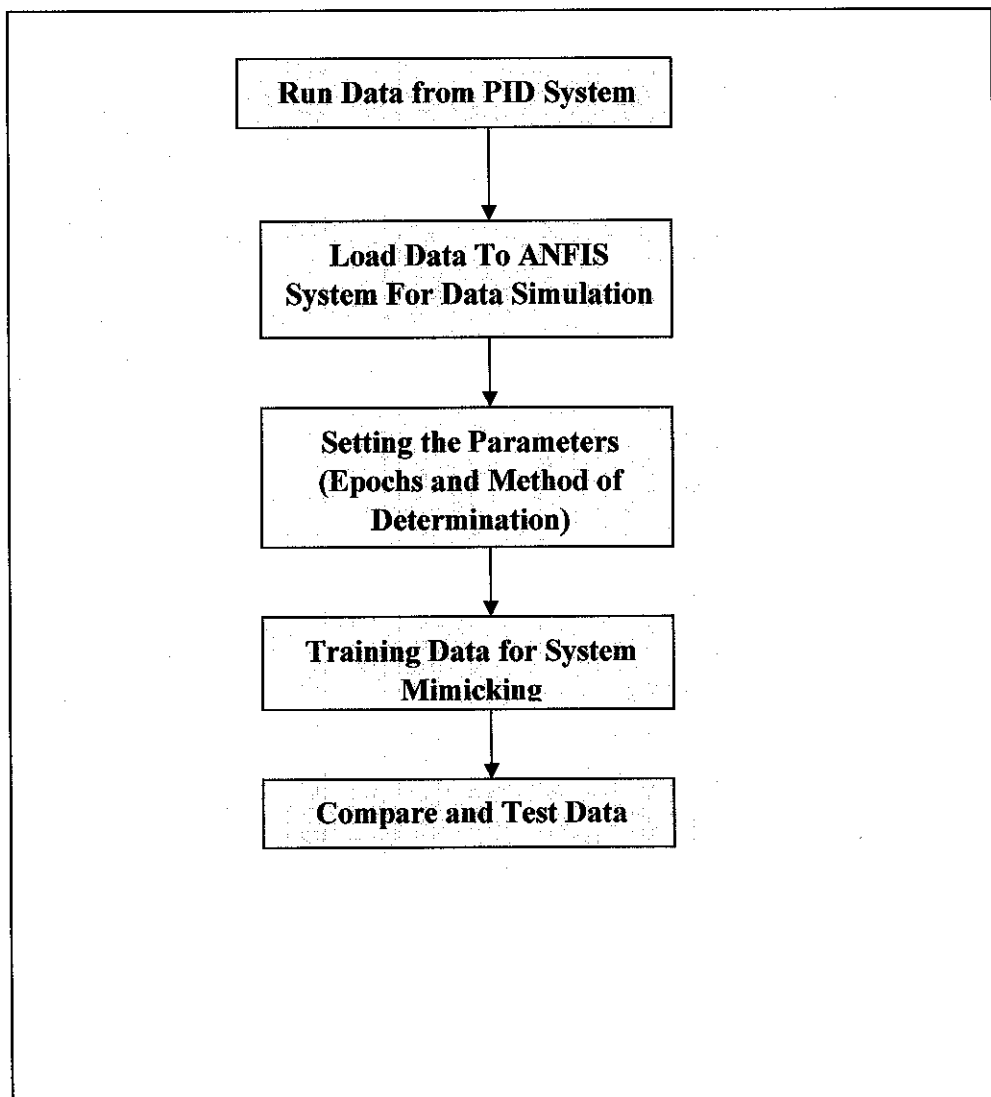
Table 7 Fuzzy Logic Implementation



3.6.2 Fuzzy Logic Implementation on Gas Turbine System (By using ANFIS Toolbox)

As mentioned in previous methodology another method that can be used in order to generate the fuzzy logic system is by using Adaptive NeuroFuzzy Inference System where the design will be based on collected data. In this method the fuzzy system has been trained by learning from the input and output relationship of the system.

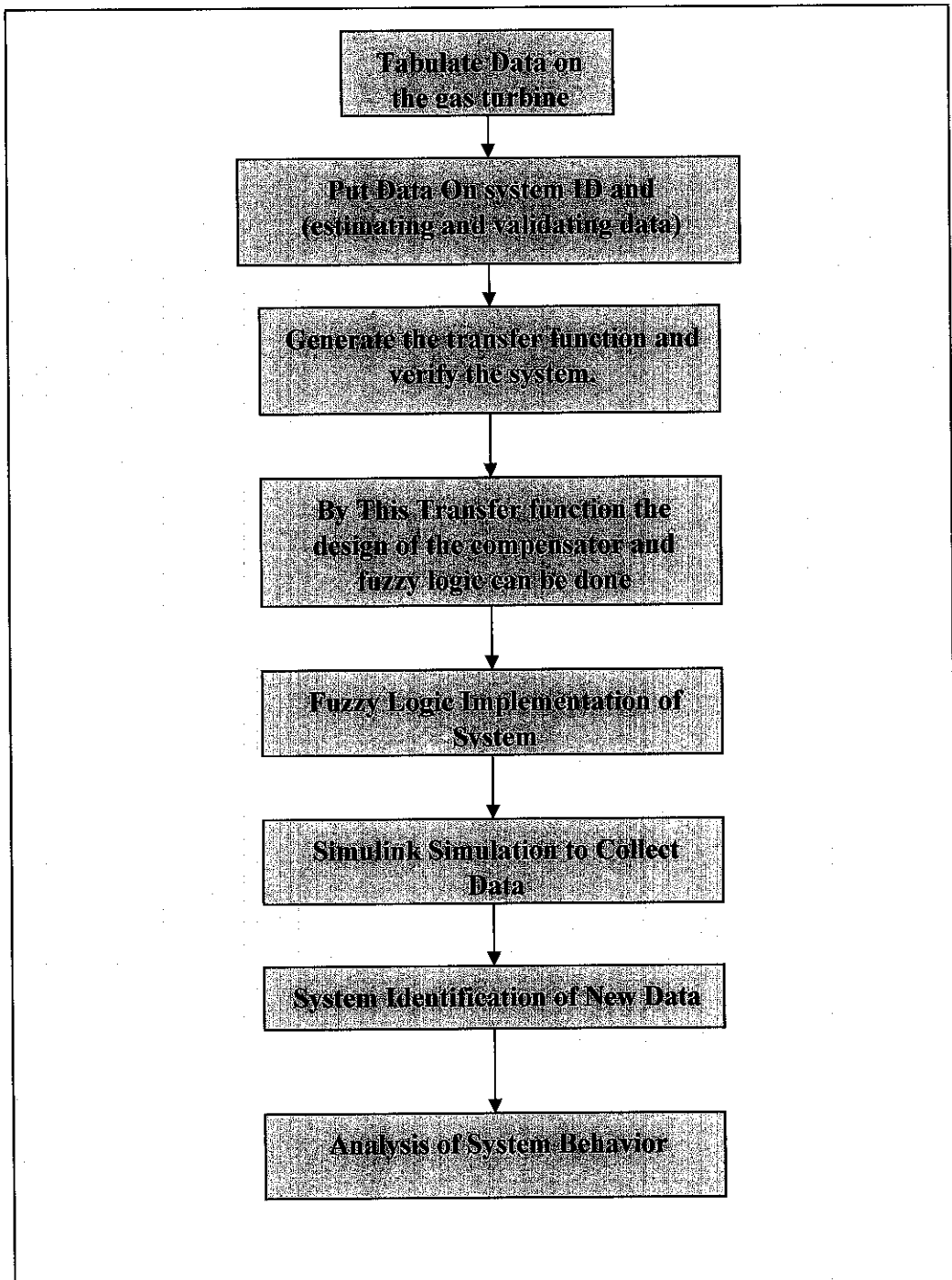
Table 8 Fuzzy Logic Implementation By ANFIS Toolbox



3.7 System Identification and LTI Analysis.

Another method that been used in determine the system transfer function is by using the System Identification and LTI Viewer toolbox , the summary of the steps in using this toolbox are as below:

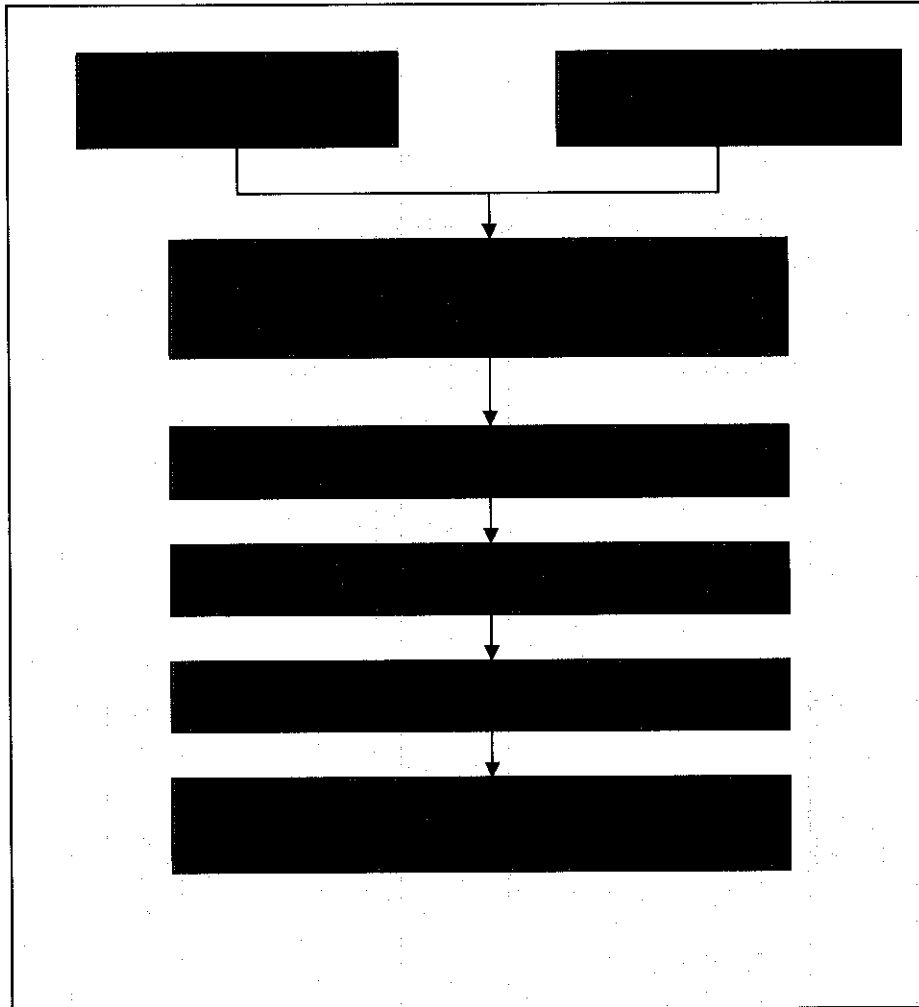
Table 9 System Identification Analysis



3.8 System Determination By System Identification Method

Another method that has been used others than using the empirical modeling is by System Identification method. This method by the help of MATLAB Toolbox can be used in order to generate the transfer function to represent the system. The summary of the steps taken in determining the transfer function are as summarize below:

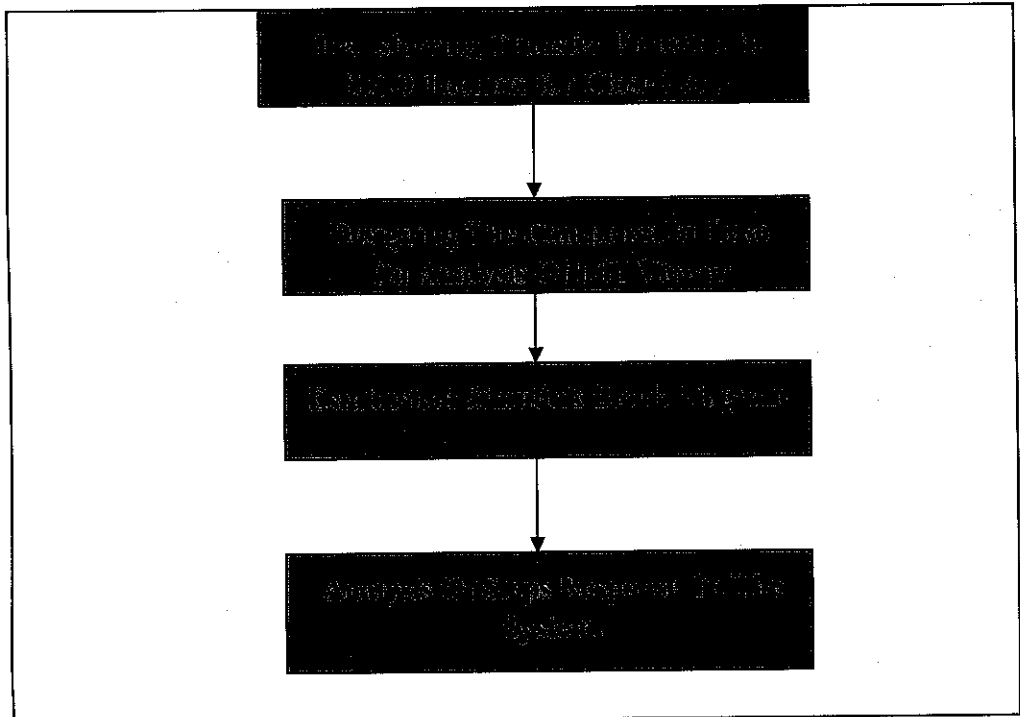
Table 10 System Determination



3.9 Lead-Lag Compensator Design Using SISO Toolbox

Another method that has been used in designing conventional controller of the system is by using the Lead-Lag Compensator design. In this design author tried to come out with another alternative method in designing the controller. In designing the compensator, the SISO Toolbox in MATLAB is used, the summary of the steps taken are as explained below:

Table 11 Lead-Lag Compensator Design



CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Establishing Data

The first steps as been mentioned in methodology are in collecting the data in order to see the behaviors and representing the system. In these design project two techniques of tabulating data for two separate systems has been done.

4.1.1 Data From GSP 9.1 Software (For Turbojet system)

Analysis and design simulation have been done by author in experimenting the system and making the proper simulation of the system. In this design project author has decided to used the turbojet engine for simulation and also UTP DIDATEC gas turbine. Mainly two software has been used throughout the designing process which is Gas Turbine Simulator (GSP 9.1) and MATLAB and SIMULINK.

The reason of choosing the turbojet system as the design system is due to the similarity of the system with the DIDATEC system and it is the fundamental arrangement of the gas turbine system that relates directly to the theory applied. With this system the basic understanding of gas turbine stages and operation can be easily understood despite it will be similar to the real design process. The process of analysis and design are as been attach to APPENDIX C

4.1.2 Data From DIDATEC Gas Turbine System.

4.1.2.1 Empirical Data

In this experiment the data of the system have been collected base on the steps response of the system. The data collected is on the load of the gas turbine. By adjusting the load value at the generating power the behavior of the system can be observed where increase of the fuel consumption and air intake can be observe on the system. In collecting the data for the empirical modeling as been mention in methodology the data were taken on steps of 50 of the load gain. This data are taken base on one second of the reaction. On each data tabulated with the total of 40 second of data. The data of the system and are as attached in APPENDIX D. This two steps response are taken since it will be used as the validation and estimation data in the analysis later on.

4.1.2.2 Overall Data

Author has the opportunity to observe the system operation in starting operating and shutdown of the gas turbine. The data that have been collected are as follows

- LPG flow rate
- Air volume
- Air admission at intake
- Compressed air
- Combustion chamber temperature and pressure
- Exhaust temperature and pressure
- Turbine speed
- Load attach to the system

The data that have been established are as attached in APPENDIX E

4.2 Air Control System Determination and Analysis by Empirical Modeling Method.

One of the methods in determining the transfer function and in designing the controller is by using the empirical modeling process reaction curve. Although this method is the simplest way in determining the transfer function of the system, but its has been prove that it can give the exact system behavior to the system.

4.2.1 Establishing Transfer Function From Process Reaction Curve

On the first steps taken in designing the empirical modeling of the system is by analyzing the process reaction curve. The process reaction curve shown below are the representation of the system plotted for one steps response of the gas turbine.

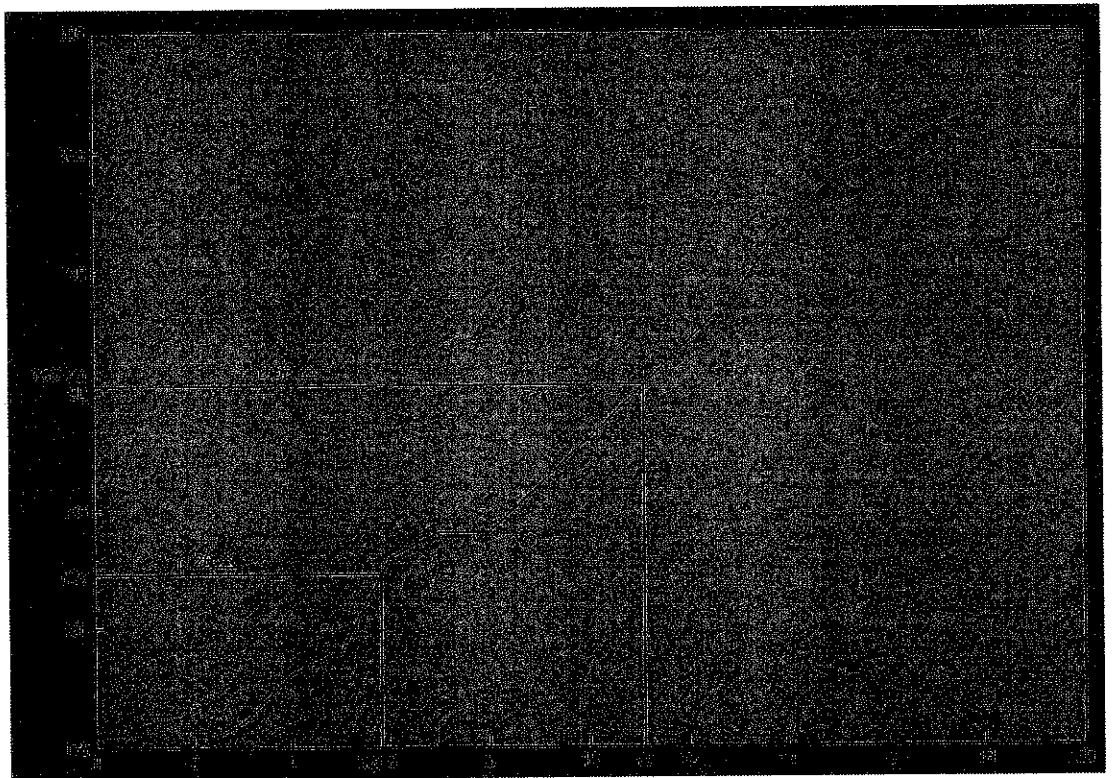


Figure 15 Process Reaction Curve of Air Intake System

From this process reaction curve the open loop transfer function can be obtained. This transfer function will then be used for analyzing and designing purpose in the next section. From this process reaction curve the data and time for 28% and 63% of the system have been tabulated and the calculation base on the formula has been done, the steps and calculations of the system are as below:

Calculation

$$\begin{aligned} 0.63\Delta &= ((205-175) \times 0.63) + 175 \\ &= 190.75 \end{aligned}$$

$$\begin{aligned} 0.28\Delta &= ((205-175) \times 0.28) + 175 \\ &= 182 \end{aligned}$$

By process reaction curve:

$$t_{63\%} = 11$$

$$t_{28\%} = 5.8$$

$$K_p = \Delta/\delta = 25/50 = 0.5$$

$$T = \frac{1.5(t_{63\%} - t_{28\%})}{7.8}$$

$$\theta = t_{63\%} - t_{28\%} = 11 - 5.8 = 5.2$$

From the calculation the transfer function of the system will be:

$$G(s) = \frac{0.5e^{-3.2}}{7.8s+1}$$

4.2.2 PID Design By Open Loop Zingler-Nichols tuning Parameters

The next step taken is on the designing of PID controller, in this designing author has decided to used the Zigler- Nichols tuning method since it can give the nearest tuning parameters that will be used in the tuning of the system steps response. From the formula tabulated above the design for the air system will be as follows:

By process reaction curve the tuning parameters of the system can be find by:

$$\begin{aligned}\alpha &= \theta/\tau \\ &= 3.2/7.8 = 0.41\end{aligned}$$

$$\begin{aligned}K_p &= 0.9/K\alpha \\ &= 0.9/0.41(0.5) \\ &= 4.39\end{aligned}$$

$$\begin{aligned}T_i &= 3.33(3.2) \\ &= 10.656\end{aligned}$$

By these tuning parameters the system reaction can be observer from the SIMULINK implementation:

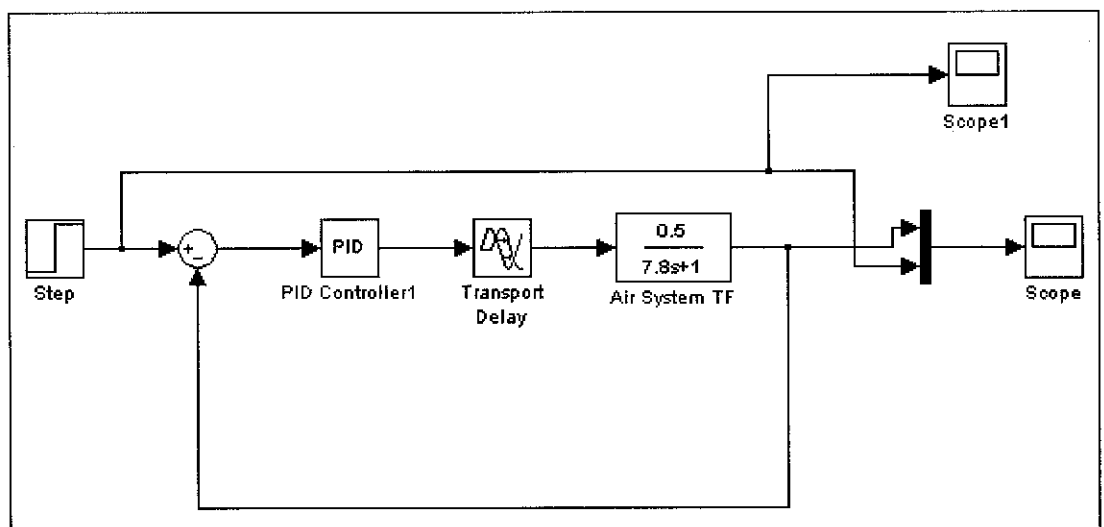


Figure 16 Simulink Representation of Air System

From the tuning parameters calculated author has found that the system is not functioning as desired steps response. So the trial and error method has been used in order to get the best performance for the system:

By PID tuning (trial an error) the best fit P and I parameters are

$$K_p=3$$

$$T_i=0.5$$

Analysis:

By this simulation, the analysis for close loop system can be done by observing the graph from the scope:

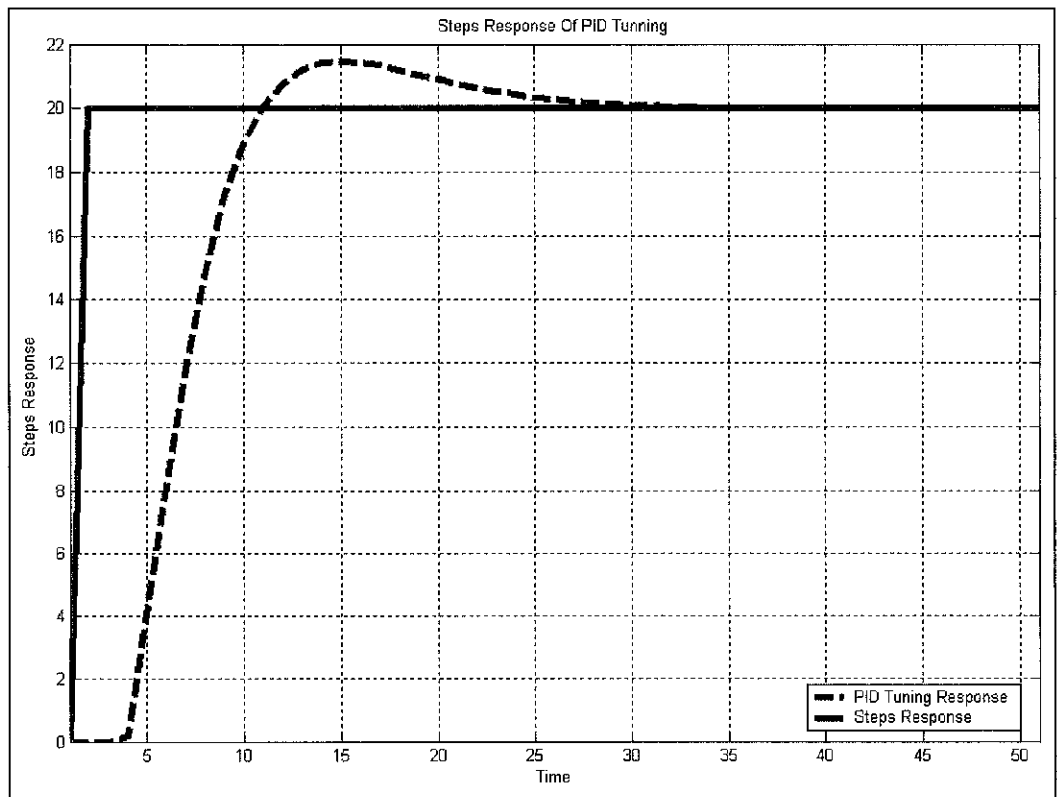


Figure 17 Steps Response of Air System

From the tuning that has been done the result that been plotted for the system are as shown above. As we can see that the system react to the step response with much more faster with a little overshoot to the system. As compare to the original step response the system are more faster in settling time where it takes about less than 25 second to be stable.

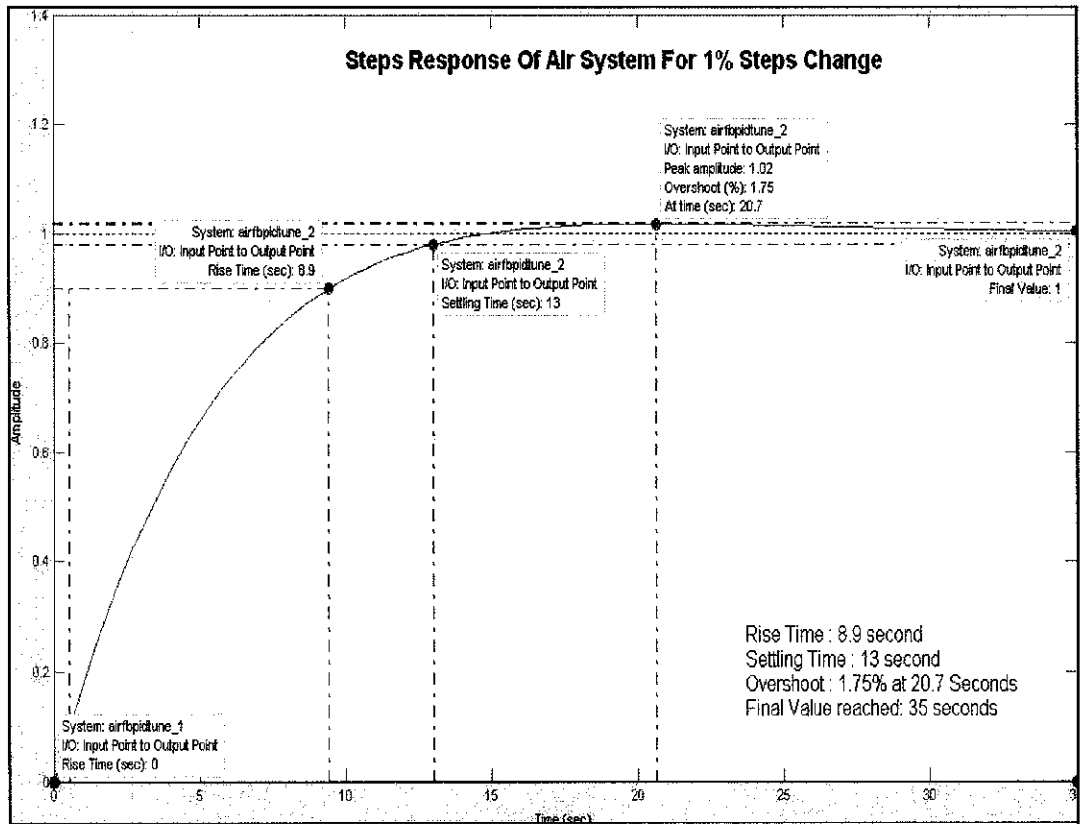


Figure 18 Steps Response of Air System (for 1% steps change)

The figure above shows the steps change of the PID controller, in this steps change the rise time taken is only 8.9 second and settling time required are 13 seconds. In this PID controller the overshoot of the system are only 1.75% only, by this simulation data the reaction of the system can be concluded as stable and improving.

4.2.3 Fuzzy Logic Controller Design.

In improving the system and designing a better control for the system, fuzzy logic design in another method in doing so.

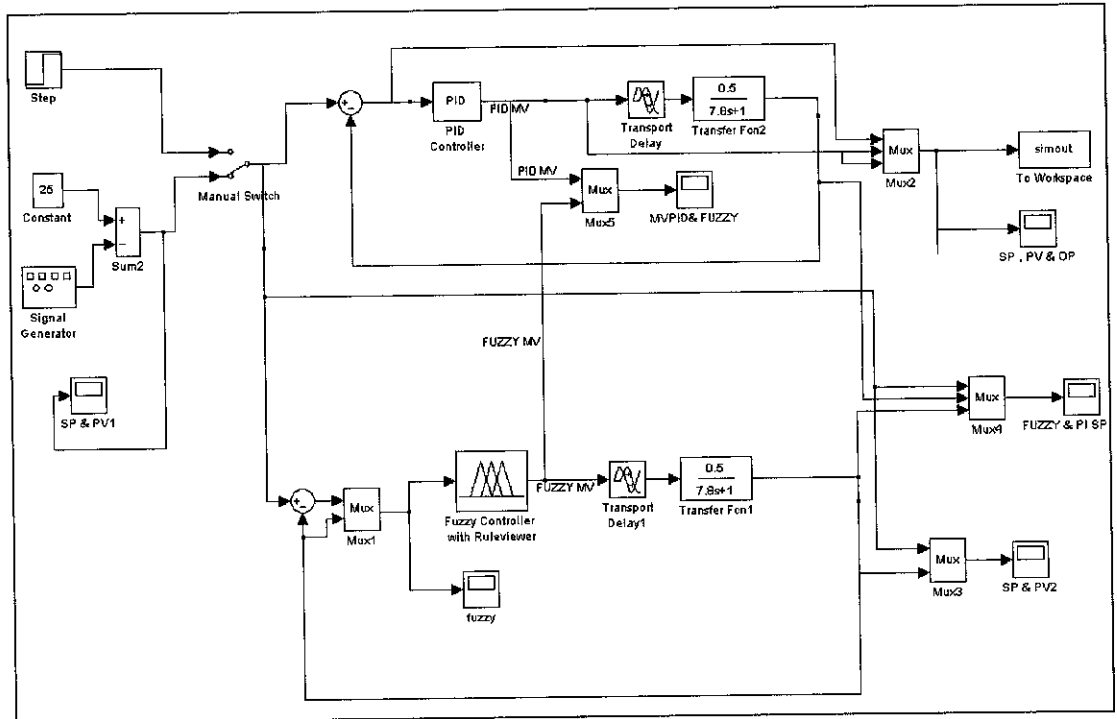


Figure 19 Fuzzy Logic System For Air System

Below are the layout of the fuzzy logic and PID system using the transfer function of the system. For the air transfer function the data that were used for fuzzy logic controller are taken with respect to the existing PID controller data establish from the close loop transfer function. In this design the fuzzy logic will be trained to give a better steps response on the step input that can be clearly see in the output plot of the step input, output from the PID controller design and the output after the fuzzy logic system implementation that will be explained later.

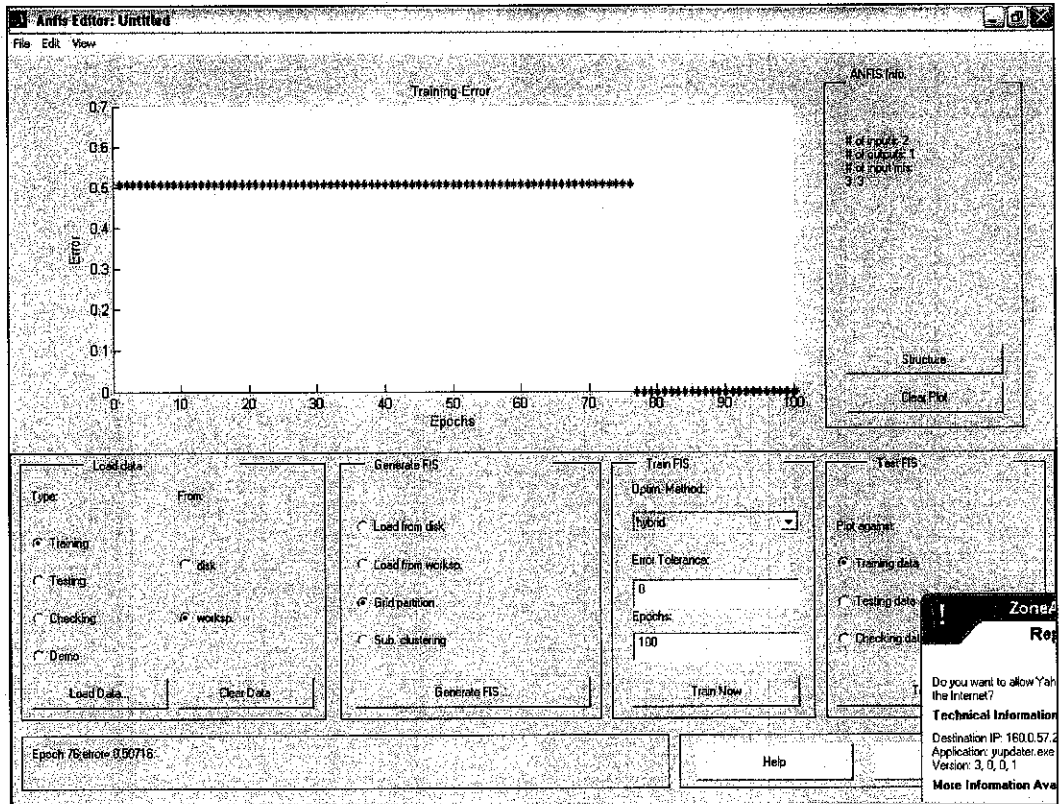


Figure 20 ANFIS GUI Training For Air System

On the first run of the system the data of the conventional PID controller are feed back on the workspace where it will be used in the fuzzy logic training. In this design method the ANFIS GUI toolbox has been used. Where the data will be used to train the fuzzy logic in order for the fuzzy logic to mimic the steps response and further improve the performance. From the above figure the data from the simulation of PID controller have been plot back in the ANFIS system where the data is train using 300 epochs. In this training the system have been set to used a 2 input and one output. Another characteristics of the design is that it using 3 membership function for each input in order for it to mimic and improve the system.

After training the data by using 300 epochs as been mention earlier the output data of the system and plotted data are as shown in figure below where we can see that the X plot represent the training data and the O plot is the real data established before. From this plot and training also the error of the mimicking of the system also can be determined where in this case the error establish is about 0.5067%

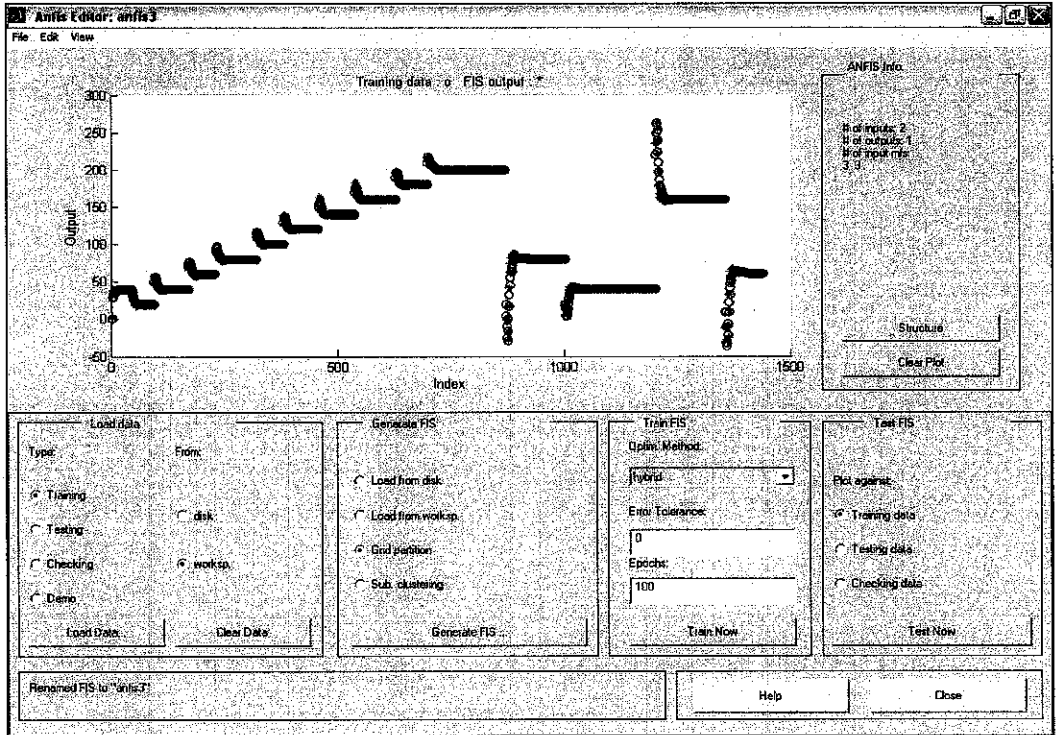


Figure 21 Training Data for Air System

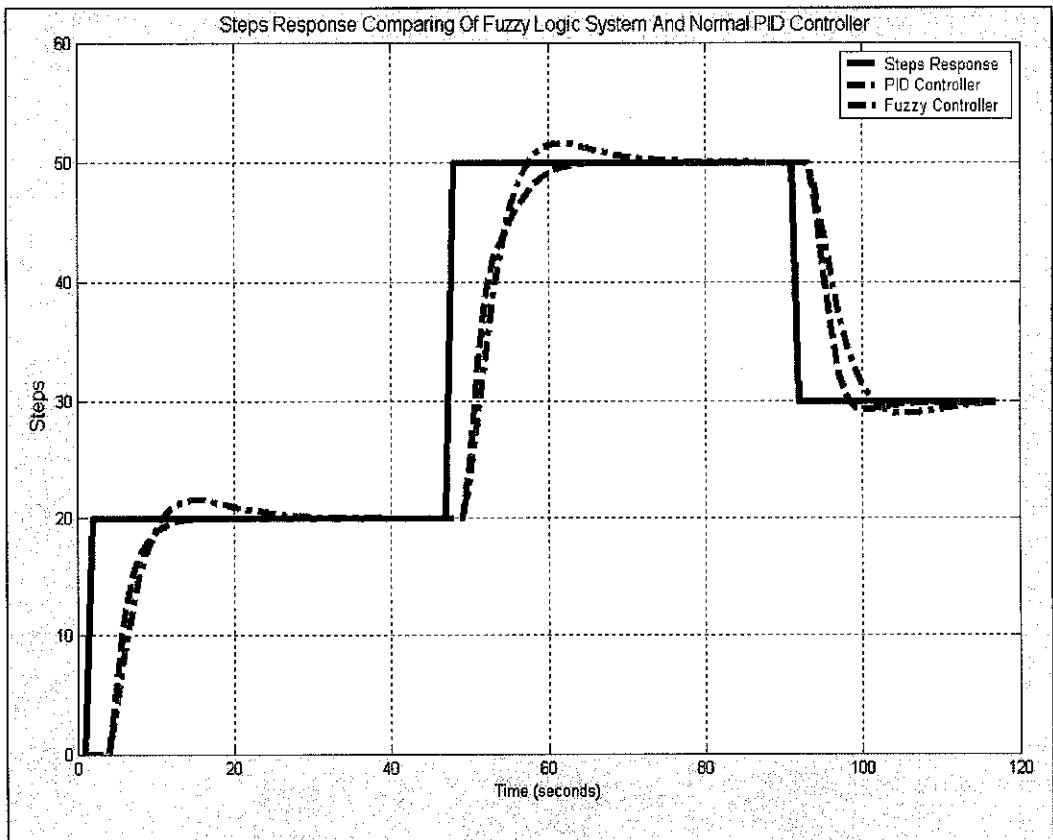


Figure 22 System Reaction For Air System

The output of the system are as shown in Figure 22. From this figure the step input, PID controller design output and Fuzzy logic controller output have been plotted and as can be see the output of fuzzy logic has shown that the system is more efficient and improve in the steps action comparing to the conventional PID design. From the graph the overshoot of fuzzy system is much less that the PID controller thus proving that the system is better. From the graph also there is no overshoot to the system as shown in the three steps response that have been applied (20%,50% and 30%) Another observation that can be observed in the system is that the action time taken to reached the steady state and set point is faster compared to the PID system.

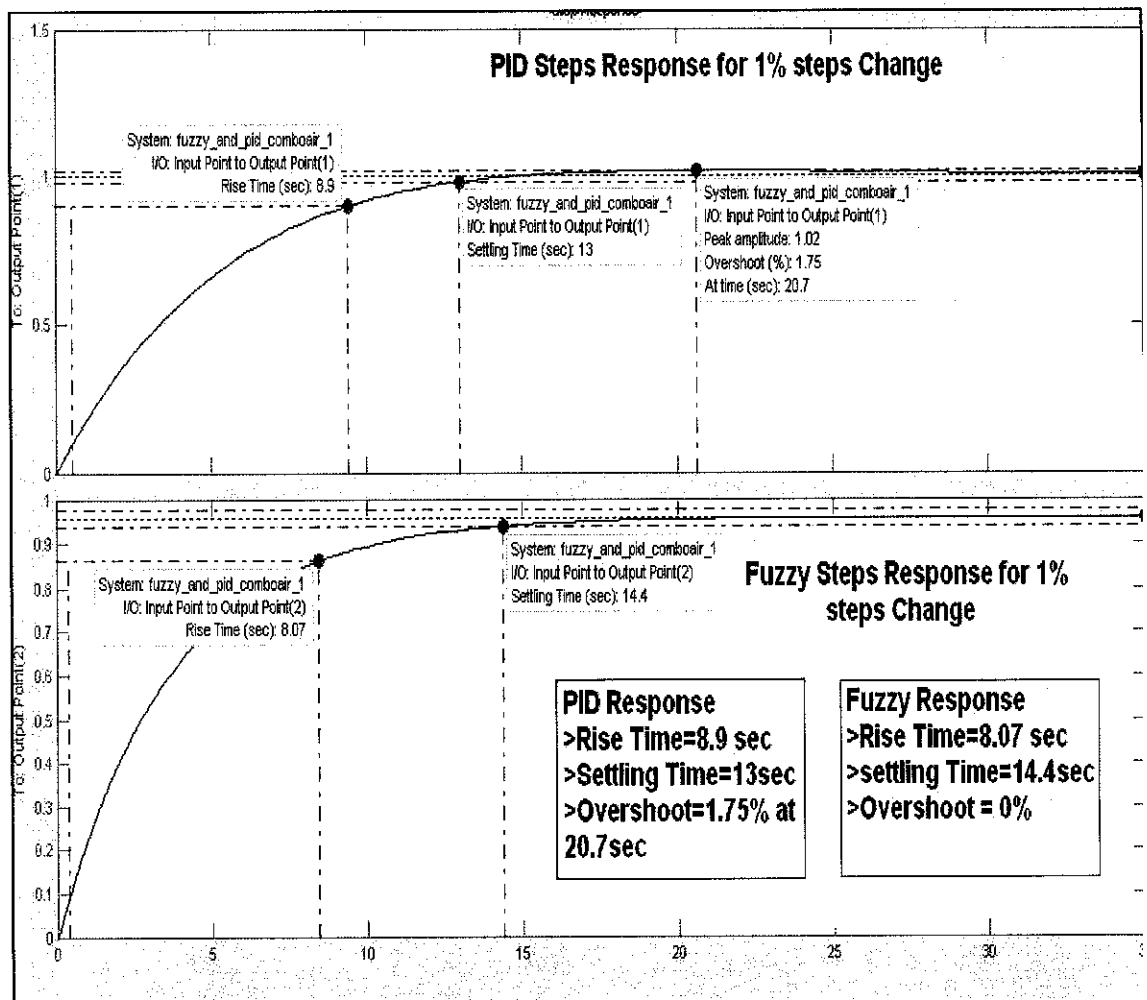
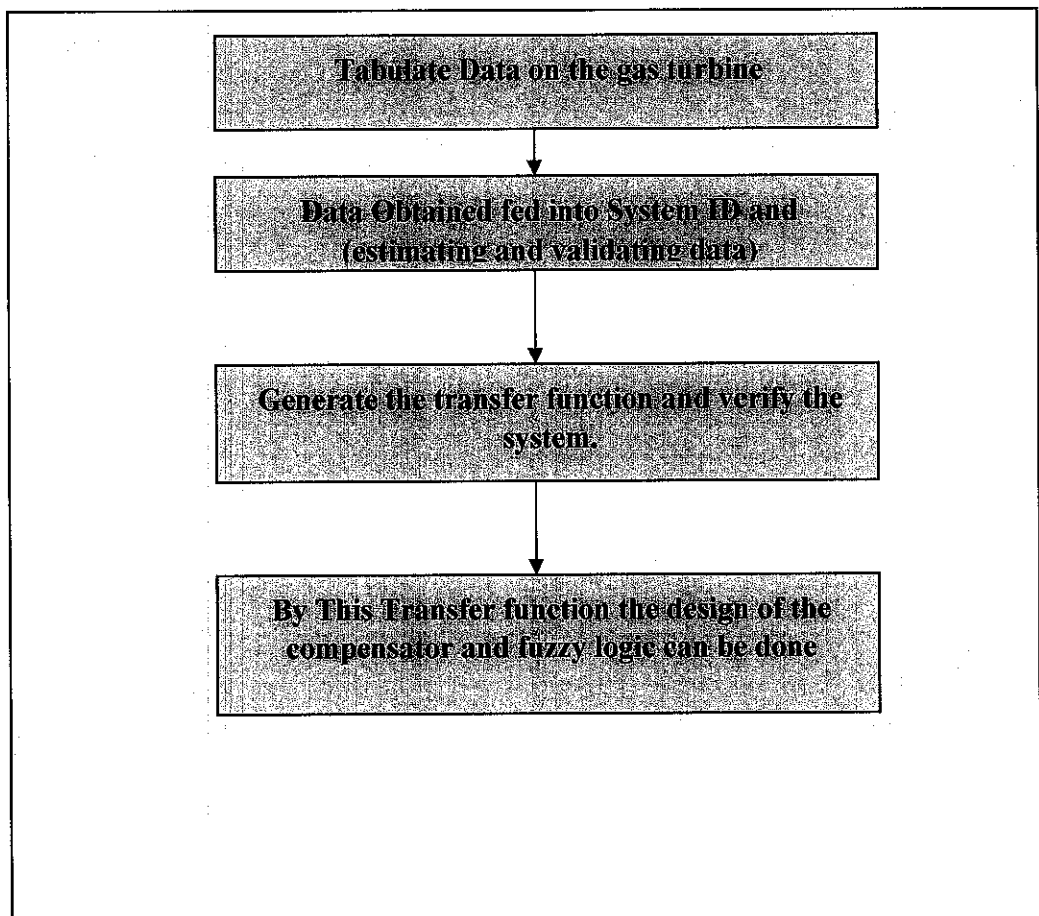


Figure 23 System Reaction For Air System

4.3 System Identification Method and LTI Viewer.

Another technique that has been used in analyzing the system behavior is by using the system identification method and analyzing the system using the LTI viewer toolbox. By using this method usually analyzers can see and analyze the system performance and comparison in many angle and analysis. In this design of gas turbine system this method will be used in designing the compensator and Fuzzy logic controller (Sugeno type). The analysis will first be feed in the LTI viewer and the system behaviors will be predicted by system identification. The basic steps taken for this analysis are:

Table 13 Analysis Of System ID and LTI Viewer



4.3.1 Establishing System Transfer Function Using System Identification for Gas Turbine System.

In obtaining the gas turbine system for further analysis the data establish form the DIDATECT gas turbine are used to obtained the required transfer function: since the data that have been established is a raw data with step response to some desired value (in this experiment the data are taken with respect to the load increase)

This data from the gas turbine are mainly the spontaneous effect of each steps of load increase. Since the reliable of the data have been done are not so valid (since a lot of factor can be arguing in such as environment condition, type of fuel)

In obtaining the transfer function using System Identification, the steps required are as follows:

Step 1: *Obtaining the data from DIDATEC gas turbine to the MATLAB workspace.*

The raw data from the DIDATEC can be put in the workspace just by creating the array in the workspace by

MATLAB coding : Air_pressure =[data string]
 Fuel_consumption = [data string]

Step2: *Using data for system identification model:*

- System Identification GUI can be called by typing *ident*
- Created data in the workspace can be imported in data views for verification.

String of data are created in workspace of the MATLAB

MATLAB Plotting:

Plot (time1,air1)

Plot (time1,air2)

4.3.1.1 Transfer Function Generating and Verification..

The steps taken can be summarize as below:

- Open System ID by typing *ident*
- Import Data from Workspace

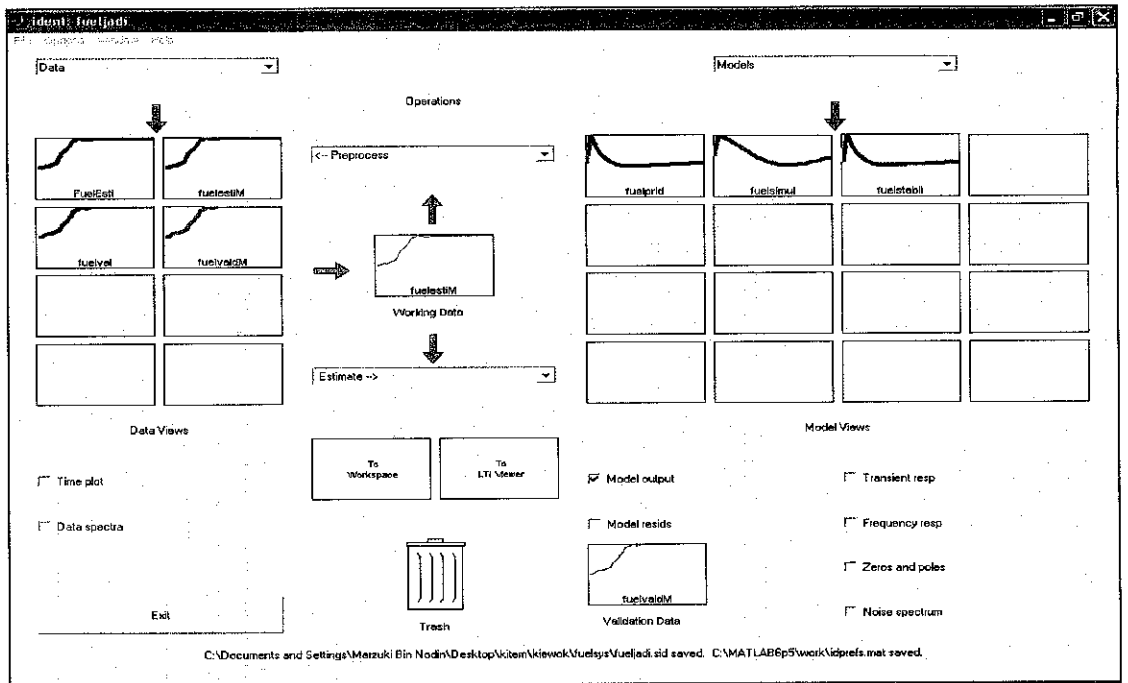


Figure 24 Air System ID Determination

The next step of the process is on removing the threads and means from the system. This can be obtained by doing some preprocess steps. The data that will be establish is as below:

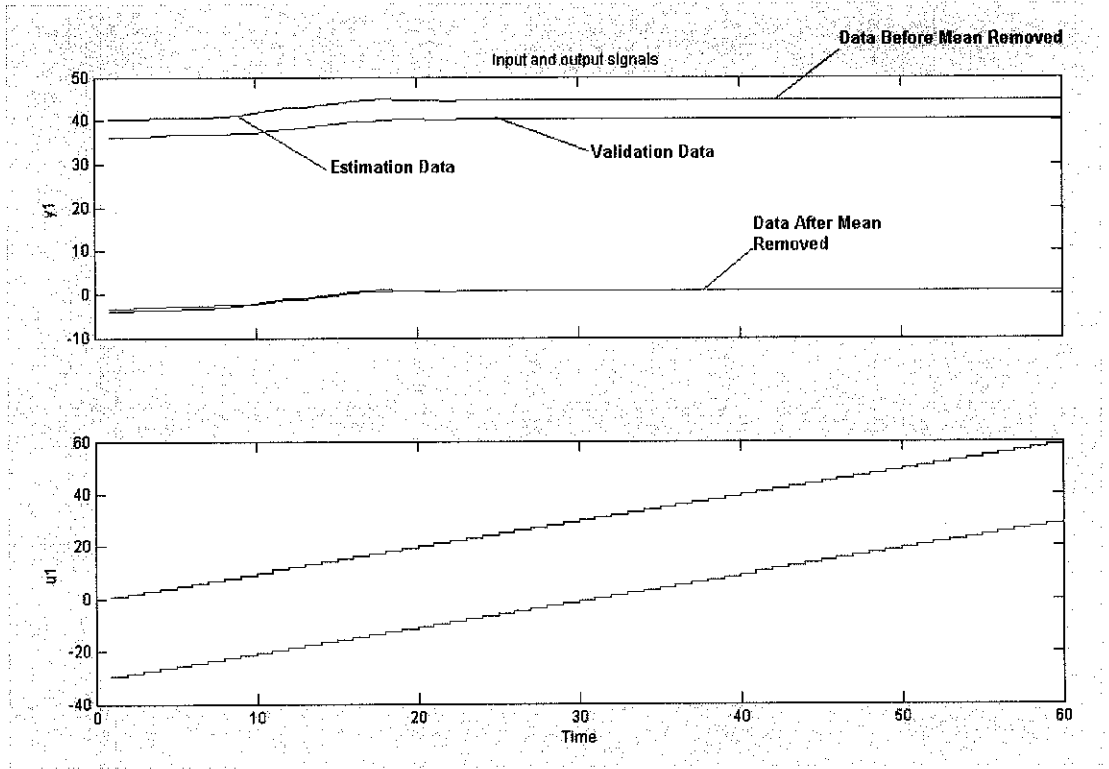


Figure 25 Air System After Removing Means

This diagram shows the data tabulated from the raw data establish from the gas turbine. Some of the preprocess activity have been done from the figure as label. The data have to be separated into two parts which is validate data and estimate data.

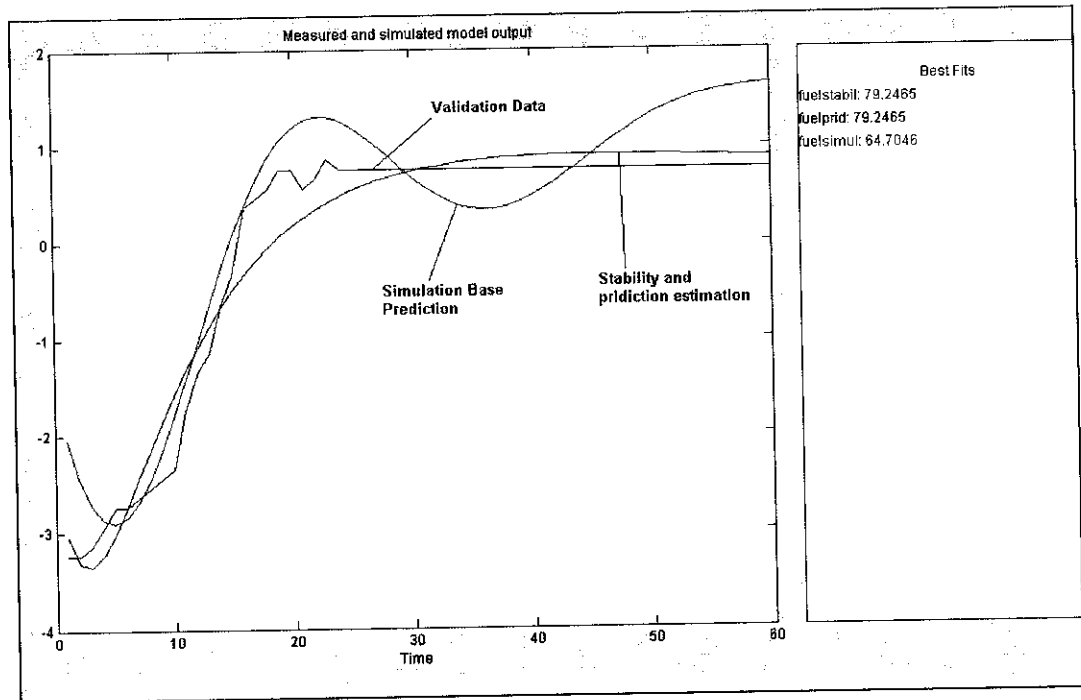


Figure 26 Error Estimation Of the system

From the system estimation the error estimation can be done where the plot of error for the estimation data with respect to the validation data can be observed and analysed. From this plot for the Air system we can see that the system shows that for the estimation using the simulation base on simulation 79.2465% of best fit achieve, this mean that the estimation data with respect to the validation data are 80% similar to the validation data.

4.3.1.2 Getting the Transfer Function

After the data have been established. The estimation data can be transferred to the workspace in order to establish the transfer function of the system:

By using MATLAB command

fuelstabil

Discrete-time IDPOLY model: $A(q)y(t) = B(q)u(t) + e(t)$

$$A(q) = 1 - 1.591 q^{-1} + 0.6234 q^{-2}$$

$$B(q) = 0.03136 q^{-1} - 0.03152 q^{-2}$$

Estimated using ARX from data set fuelestiM

Loss function 0.0115343 and FPE 0.013182

Sampling interval: 1

>> fuelstabiltf=tf(fuelstabil)

Transfer function from input "u1" to output "y1":

$$0.03136 z - 0.03152$$

$$z^2 - 1.591 z + 0.6234$$

Transfer function from input "v@y1" to output "y1":

$$0.1132 z^2 + 2.683e-017 z + 7.16e-018$$

$$z^2 - 1.591 z + 0.6234$$

I/O groups:

<i>Group name</i>	<i>I/O</i>	<i>Channel(s)</i>
-------------------	------------	-------------------

<i>Measured</i>	<i>I</i>	<i>1</i>
-----------------	----------	----------

<i>Noise</i>	<i>I</i>	<i>2</i>
--------------	----------	----------

Sampling time: 1

```
>> fuelstabC=d2c(fuelstabiltf)
```

Transfer function from input "u1" to output "y1":

0.03972 s - 0.0032035

 $s^2 + 0.4726 s + 0.04091$

Transfer function from input "v@y1" to output "y1":

0.1132 s² + 0.2064 s + 0.1425

 $s^2 + 0.4726 s + 0.04091$

I/O groups:

<i>Group name</i>	<i>I/O</i>	<i>Channel(s)</i>
<i>Measured</i>	<i>I</i>	<i>1</i>
<i>Noise</i>	<i>I</i>	<i>2</i>

```
>> num=[0.03972 -0.0002035]
```

num =

0.0397 -0.0002

```
>> den=[1 0.4726 0.04091]
```

den =

1.0000 0.4726 0.0409

```
>> fueltf=tf(num,den)
```

Transfer function:

0.03972 s - 0.0032035

 $s^2 + 0.4726 s + 0.04091$

4.3.1.3 Verification of Data

After the transfer function has been established the transfer function has to be validate first in. From the simulation done, the output establish shows that the system relation between input and output are as the same as the real data used for the estimation and validation data. This prove that the system transfer functions are representing the system behaviors.

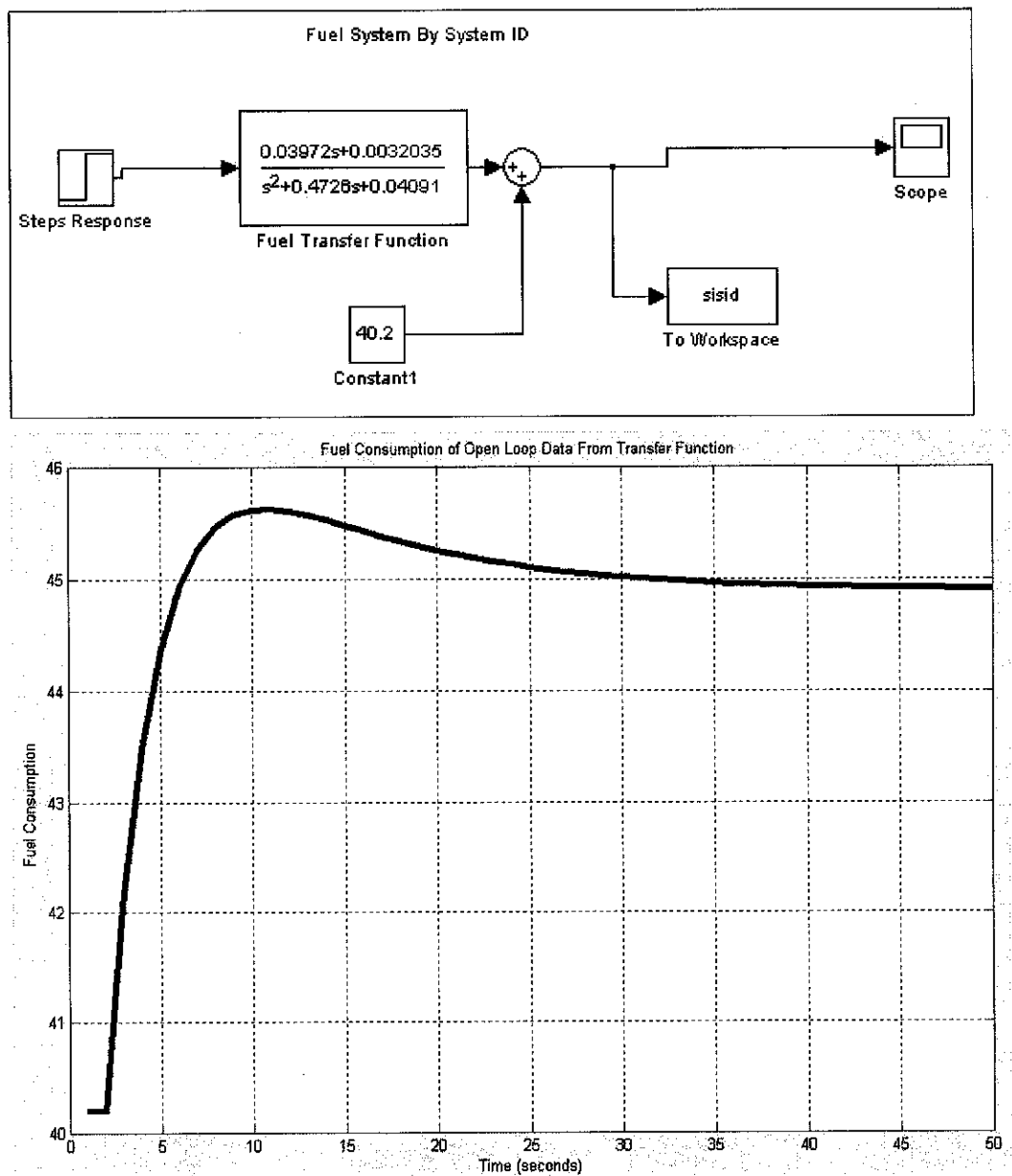
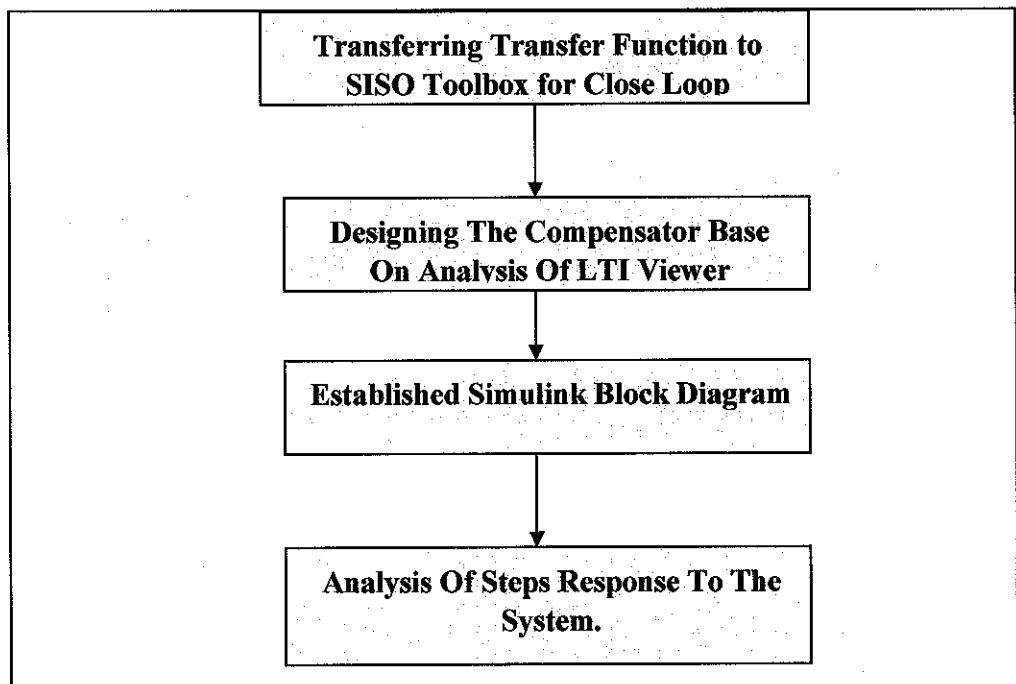


Figure 27 Validation Data for Air System

4.3.2 Close Loop System Lead Lag Compensator Design

When the transfer function of the system have been established the close loop system of the transfer function can be generated by designing the Lead Lag Compensator design. By the aid of SISO Control system Toolbox the design can be done by the following steps:

Table 14 SISO Toolbox Design



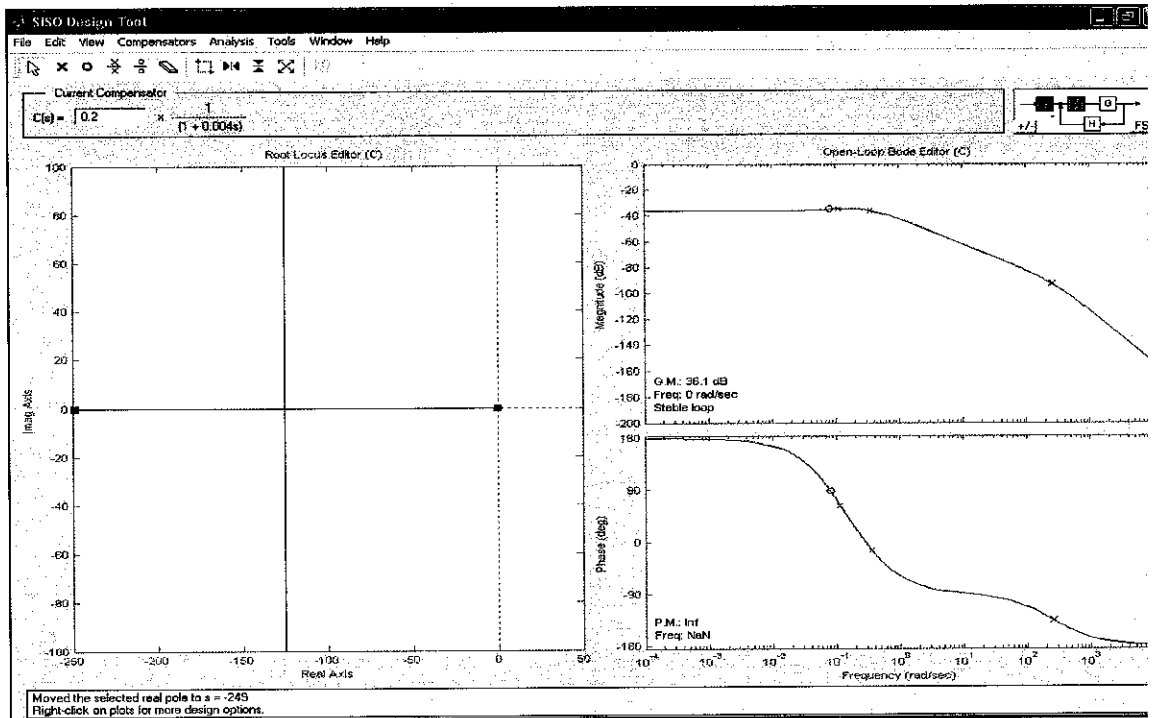


Figure 28 SISO Design Toolbox

By using SISO design tools the system compensator can be designed by analyzing the system behavior by referring to the system steps response that can be visualize by the LTI Viewer in the SISO toolbox. From the figure above the compensator has been designed by dragging (trail and error) the poles and zeros of the system by referring to the root Locus plot and open loop Bode Plots. In this design method the gain K and the poles and zeros of the system can be adjusted in order to get the best response to the system.

In Figure 29 the root locus and bode plot response of the system that have been adjusted (design) can be observed. This representation shows the response of the system (in term of bode plot and root locus). From the plot also the position and placement of poles and zeros of the system can be observed with respect to the system close loop response. In this design project the analysis of the response have been done by observing the steps response of the system by viewing the response using LTI viewer available.

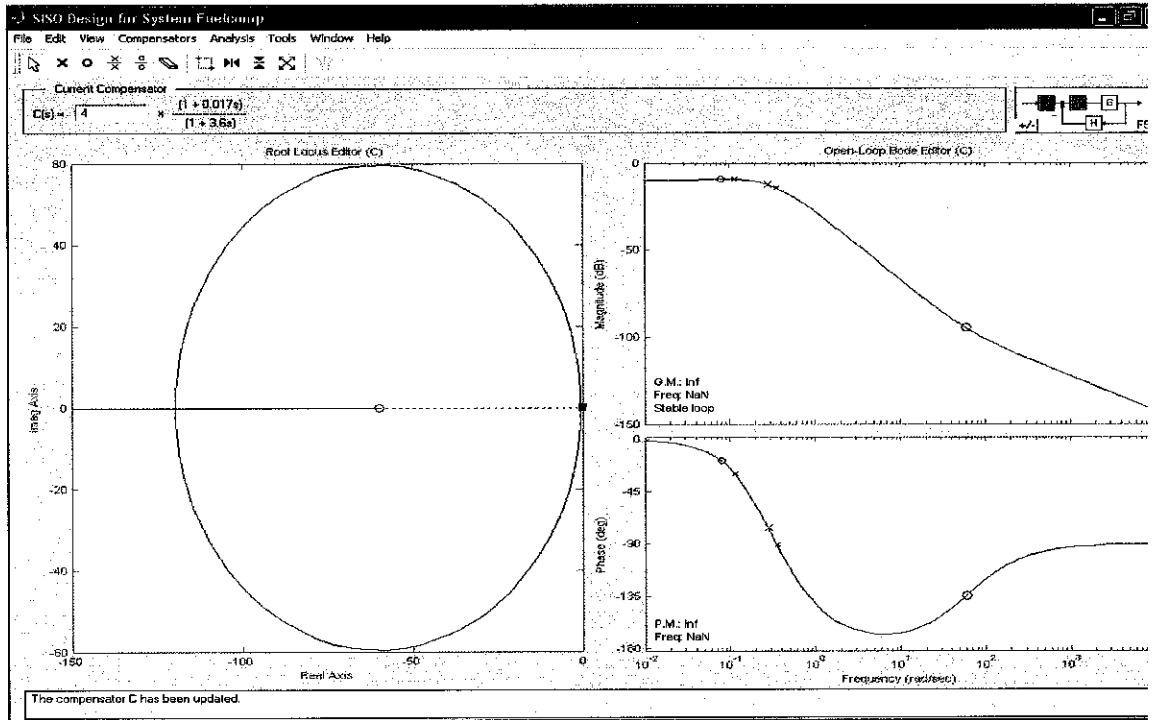


Figure 29 Root Locus And Bode Plot of Design Compensator

The system can be represented by SIMULINK representation to see the steps response and behaviors of the system with respect to the steps response given to the system. As can be observe from Figure 30 the system representation of the design compensator and the steps response of the system can be observe and simulated.

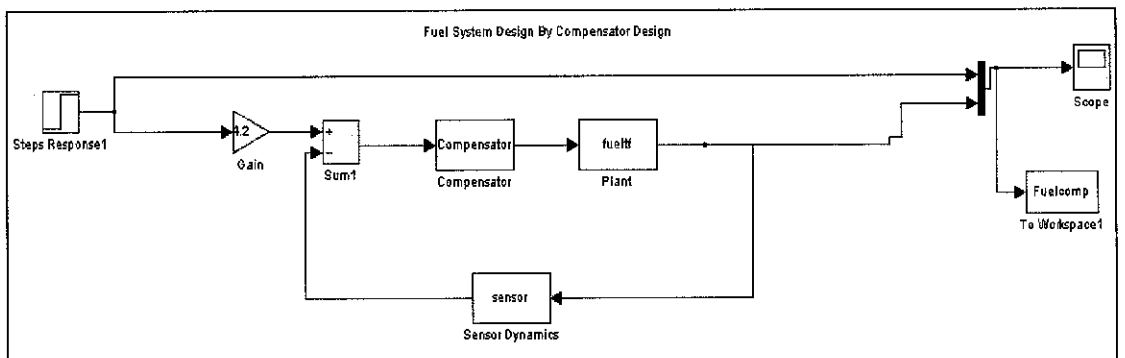


Figure 30 Lead Lag Compensator Design

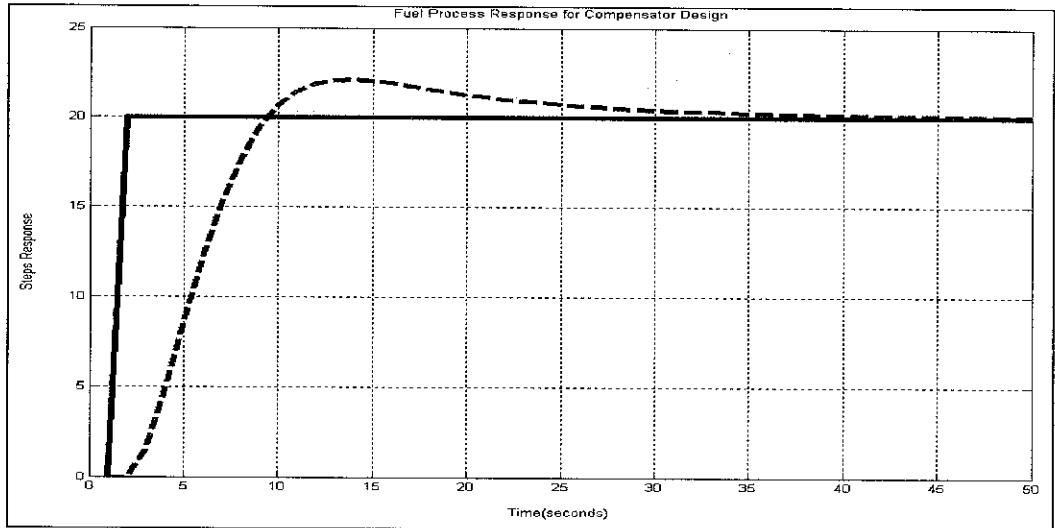


Figure 31 Close Loop Response for Air System.

The result of the system response with certain given steps response can be clearly by the plot in figure 31 and 32. In this plot the system representation of the steps given (20% of load) has shown the tremendous response with respect to that set point . as can be observe the response has shown that the overshoot of the system reach only 22% which is about 1% of overshoot. The settling time of the system also as can be see is good enough for gas turbine system which is about 35 second of the system response.

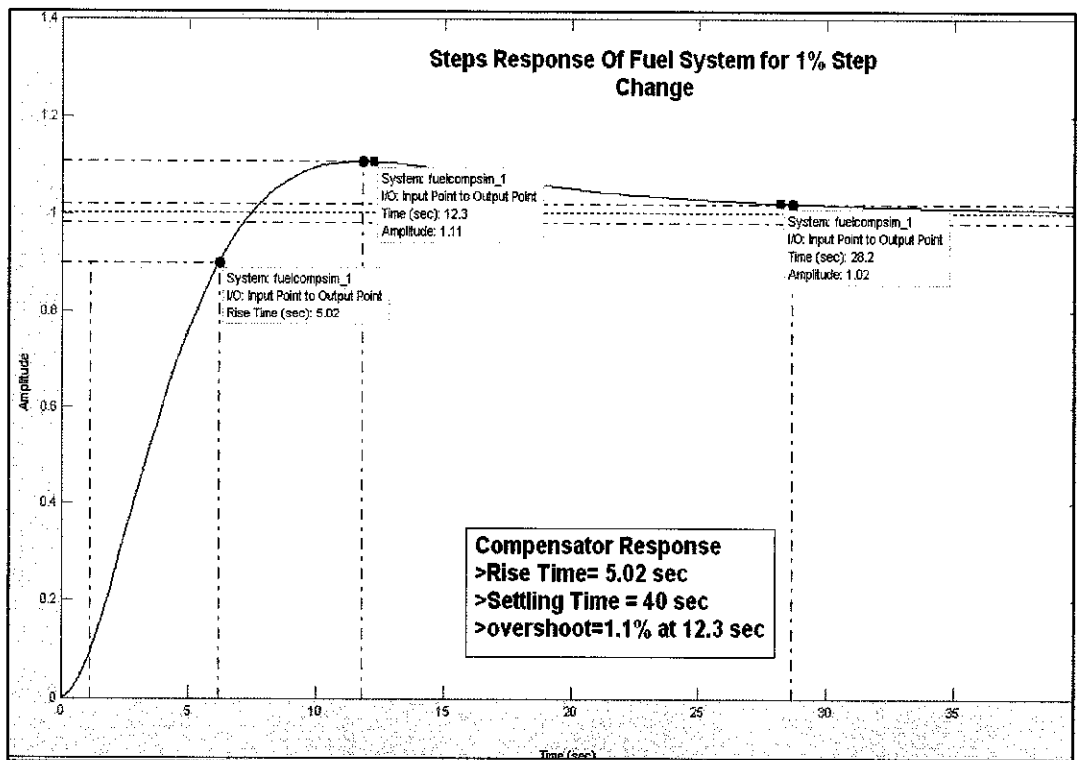


Figure 32 Close Loop Response for Air System.

4.3.3 Fuzzy Logic Controller Design

Fuzzy logic system implementation (using ANFIS)

In designing the more efficient system as been mention before the adaptation of fuzzy logic system have been done in this stage. The steps taken in this design are as follows:

Stage One: Creating System Data By referring to Compensator Design

The steps taken in designing the fuzzy logic system for fuel are a s similar to the empirical modeling design of fuzzy logic system. In using the ANFIS Toolbox the data from the compensator design can be used to determine the system controller:

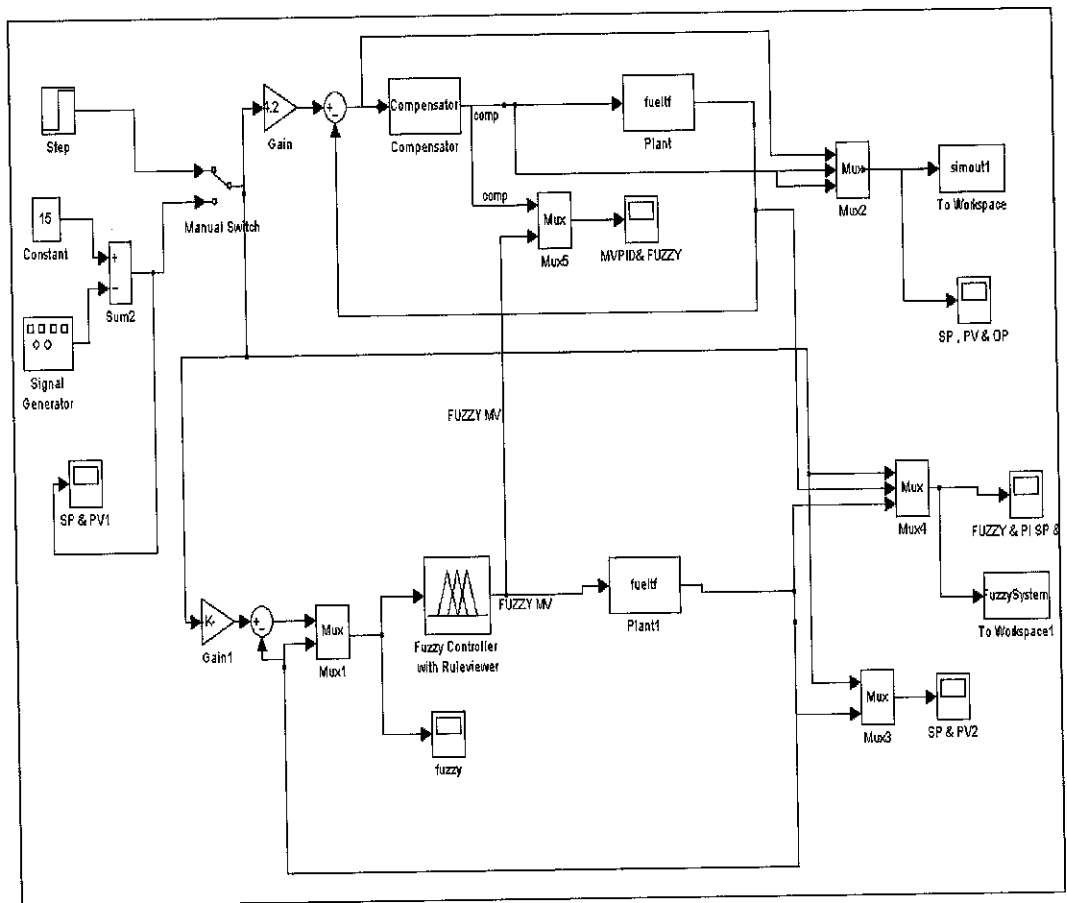


Figure 33 Compensator and Fuzzy Simulink Design

Stage Two: Creating fuzzy logic system using the ANFIS GUI toolbox

The system input will be train in order to produce the desired system output in this stage the system data have been train by using Sugeno type of fuzzy system. The data are taken with the fuel demand and the air supply desired.

This data are train in order to get the most accurate output desired for the system. In training the system the ANFIS GUI are used in order to achieve this result. The layout of the ANFIS modeling are as shown below:

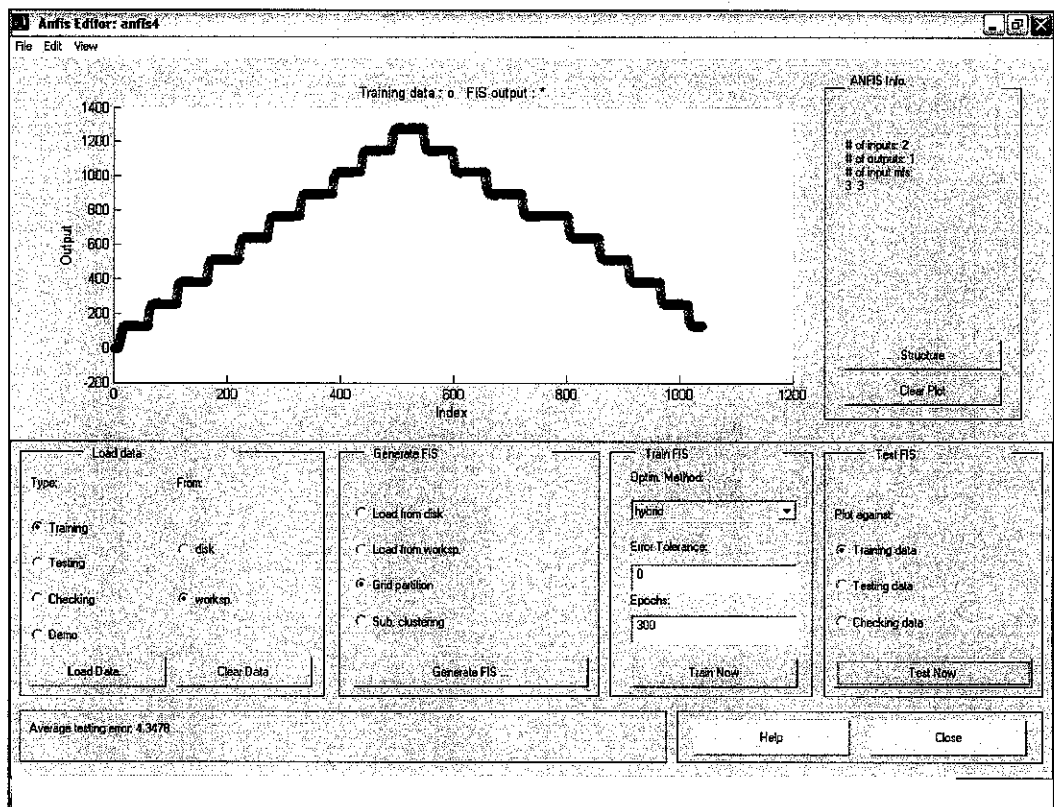


Figure 34 ANFIS GUI Design Tools

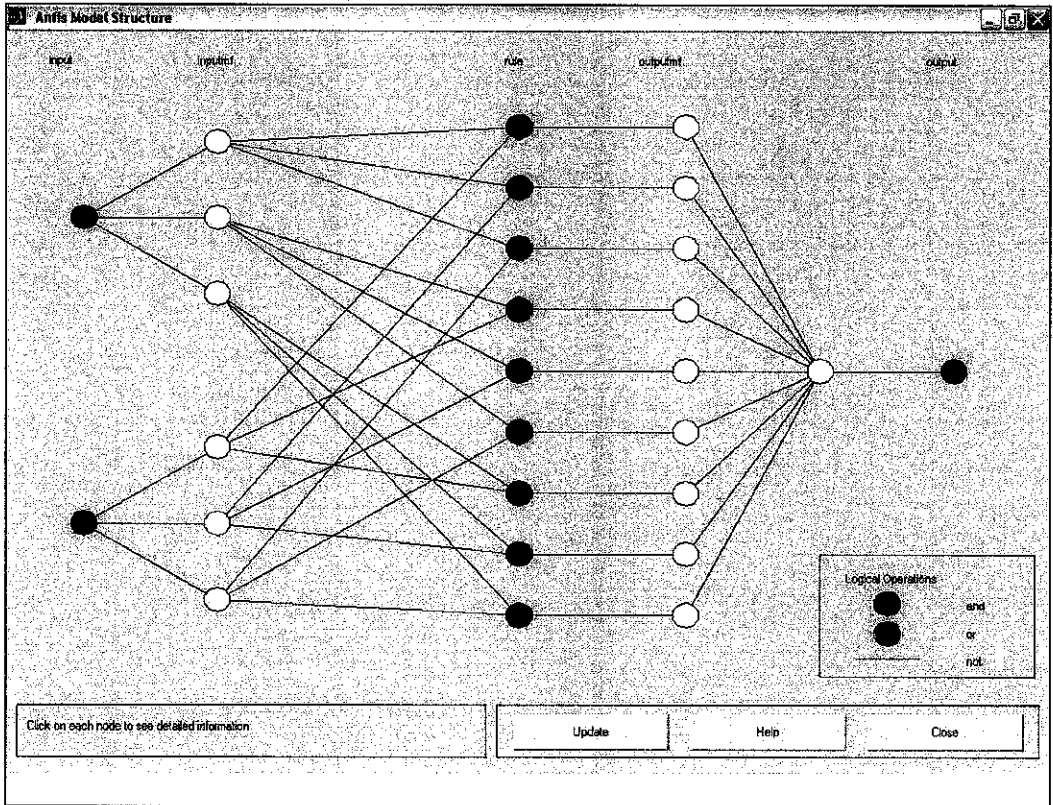


Figure 35 ANFIS Model Structure

The ANFIS Input Modelling dialog box is divided into two main sections: INPUT and OUTPUT.

INPUT Section:

- Number of MFs:** A text box containing the value "6".
- MF Type:** A list box containing the following options:
 - trimf
 - trapmf
 - zmf
 - psismf
 - genismf
 - and
 - sigmf
 - posimf
- Instruction:** "To assign a different number of MFs to each input, use spaces to separate these numbers."

OUTPUT Section:

- MF Type:** A list box containing the following options:
 - psismf
 - zmf

Buttons at the bottom include: Cancel, OK.

Figure 36 ANFIS Input Modelling

In this design the training for the data have been done for about 5 times

ANFIS info:

Number of nodes: 28

Number of linear parameters: 12

Number of nonlinear parameters: 12

Total number of parameters: 24

Number of training data pairs: 41

Number of checking data pairs: 0

Number of fuzzy rules: 6

Start training ANFIS ...

1 4.454874

2 4.454882

Designated epoch number reached --> ANFIS training completed at epoch 2.

Stage Three : Analysis Of the system of close loop steps response.

The analysis of the system are again have been done as the same method as the previous analysis:

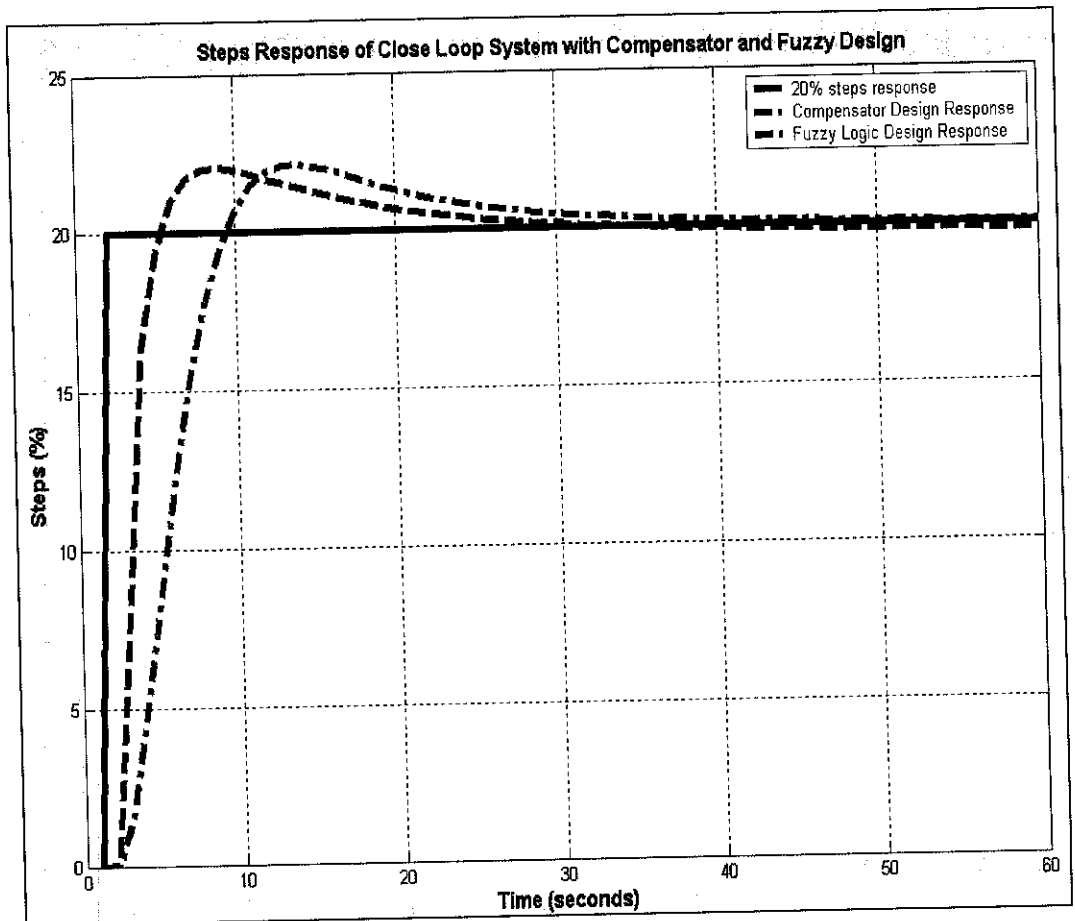


Figure 37 Steps Response of Fuzzy System

In this simulation that have been done for the 20% of steps input, the result that have been obtained in comparing with the compensator design and fuzzy logic design has shown that the fuzzy logic system has a better performance comparing to the compensator design. The response for fuzzy is much faster and also the settling time is much faster comparing to the compensator design.

From this analysis it shows that the system become more stable the reaction and settling time of the system become more faster when compare to the original system. This has proved that the system is more reliable and can give a more faster response to the system.

4.4 Fuzzy Logic Controller Using Mamdani Design.

The fuzzy logic implementation of the gas turbine using the Mamdani type of fuzzy have been explained in detailed in **APPENDIX B.** Briefly the design takes place by observing the behaviors of gas turbine with reference to the specification of the system. With this data the fuzzy logic for the system can be designed in such a way that it can operate as desired to the gas turbine behaviors. In designing with the MATLAB simulation toolbox the design of the fuzzy logic are been done steps by steps. Basically there are three main editors that was used in design the fuzzy logics which is FIS editor, Membership Function Editor and Rule editor. By adjusting and manipulating the value (as been explained in **APPENDIX B**) the system behavior can be cast on the fuzzy in order to “teach” the system on making decision for the given input to desired an precise output.

This construction of Fuzzy logic using Mamdani system is done *only* to get the better understanding of the fuzzy logic technique of the implementation.

4.4.1 Fuzzy Logic Implementation

4.1.1 Effect on the Gas Turbine System

In implementing the fuzzy logic system to the gas turbine air fuel control the effect that expected to occur is on the accuracy of the system in determining the desired output. As been explained in the literature review the effect in using the fuzzy logic are proven to generate a more accurate decision making especially in unpredicted system. In comparing with normal conventional system such as PID controller the fuzzy decision making is more reliable since the decision are made as similar to the process and can be easily understand by the user or designer. For an example in the design system of fuzzy logic on the gas turbine the input are cascaded to a very subjective ways in determine the value of the output desired. When comparing to others system the approach that were used is base on the discrete values where the decision will be in absolute value. Different from fuzzy logic system where the values are taken from the discrete value base on the rules determine by the designer.

Others effect that can be seen on the system is on the speed of the decisions, where the decision making of the system will be more faster compare to others conventional controllers. This will help in controlling the system where fast reaction can help in producing more efficiency system. In the case of gas turbines the more faster the decision on the amount of fuel needed can help in creating more effective burning and generating more power with respect to the fuels supply without any losses and thus can also help in reducing the emission due to the incomplete combustion.

4.5 Construction of Gas Turbine prototype

The construction of the prototype of gas turbine have been done in this stage, this construction done mainly to give a better picture of the system to the audience about the process and the system of the gas turbine. By constructing this prototype also author can give a more better picture about the system implemented in the gas turbine system.

The construction have been staged into a few part which is the design part, construction and implementation. Until now the construction stage will be done recently. In design stage the design of the model have been made so that the real prototype can be constructed, in design part there is several design have been made by the author which is the hardware construction, electrical wiring and PIC implementation .

In hardware construction the equipments used for the body of the prototype is the Perspex with two CPU fan to represent the blades of the turbine and compressor. The design of the hardware are as attached in **APPENDIX G**

This construction has been done as an extra part of the project so that something have been done in order to shows the author understanding on gas turbine system. Hopefully this prototype construction can be used in the EDX for this semester. The construction Diagram and picture are as attach in **APPENDIX G**

In electrical circuit construction for the gas turbine, some of the circuit that have been develop and done are:

- PIC Controller main Circuit = this circuit is used as the main microprocessor of the sequencing of the system.
- 2 Chasing Light (night rider) = for showing of the sequence
- Circular running light = for showing sequence purposes.
- Voltage Regulator = to step down the voltage supply from 12V to 9V to 5V
- Relay Circuit= to energize the system in sequence.

4.6 Problem Faced and Progress Done.

In this design project there are some problems and obstacles that have been faced by the author. Some of the problems that has occurred is on the a viability of the gas turbine system in UTP. Author has to wait for more that one semester in order to established the real data for the DIDATEC gas turbine system. The problem arised when the mechanical department have some problems in execution of that gas turbine, some of the problem that occur such as the space unavailability, the broken part of the system and also the unavailability of technician to handle the equipment. This problem arise due to the gas turbine condition that has not been used for a long period of time.

Another problem arise in this design project in the unavailability of equipments for the prototype design .The problem occur when the needed component such as IC and fan cannot be supply by UTP and the supplier.

In terms of the software design, the problem occur in getting the best result of the system. Some of the problem that occur in tuning the fuzzy logic system. And in making the system robust where in this author design certain configuration of steps response cannot be analyze by the fuzzy system.

The progress of the project throughout one year of the design project are as attached in APPENDIX H.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Control system design is one of the technological advancement in control. There are many method introduce to generate the better and more effective system in term of its operation and the responses due to the change and disturbances. In designing the control system many factors and criteria that need to be award and defined to create the most effective control system. In this design project author has the opportunity to go in dept on the control system design for conventional control system such as PID controller and also the advance control system practice which is the fuzzy logic system implementation. This is the very good start-up fro the author to understand the control system especially in industries purposes (Gas Turbine). The control system is one of the important field and criteria that need to be evaluated from time to time as the advancement in control strategies involved.

In this design project a uthor has managed to c create and a nalyzed t he Gas turbine system in two different methods which is empirical modeling method and System ID and LTI viewer method. From both method the system can be more improve in term of the steps response and the better reaction to the disturbances. In this design project student only concentrating on the steps response or linear time invariant system.

As far as the author effort put in the project this project can be further improved and continued by others researches especially in the realizing the system to the real gas turbine to see the behaviors of the system. This can be done by adapting microcontroller to the system where this cannot be done in author project since lack of time and some technical problem.

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APPENDIX A ENGINE TORQUE AND POWER FOR FUZZY SYSTEM

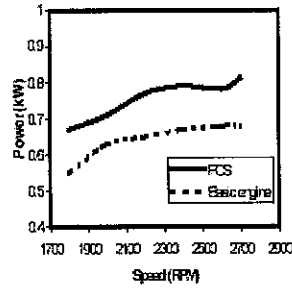


Figure 9: Engine power (TPS=25%)

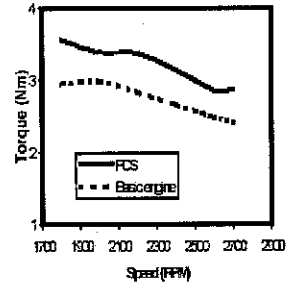


Figure 13: Engine torque (TPS=25%)

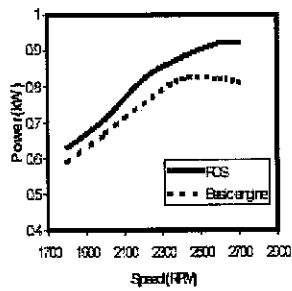


Figure 10: Engine power (TPS=50%)

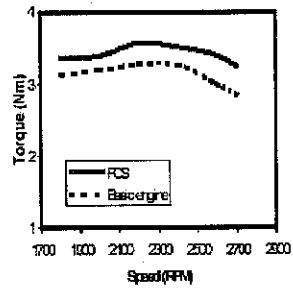


Figure 14: Engine torque (TPS=50%)

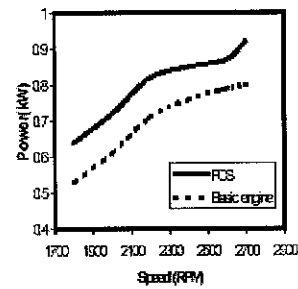


Figure 11: Engine power (TPS=75%)

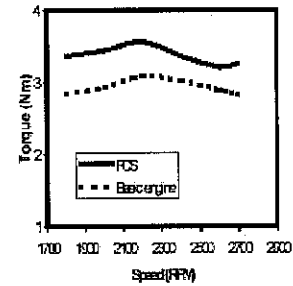


Figure 15: Engine torque (TPS=75%)

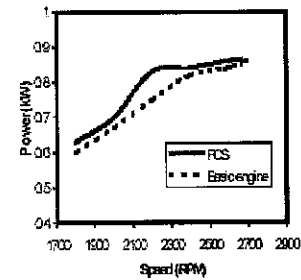


Figure 12: Engine power (TPS=100%)

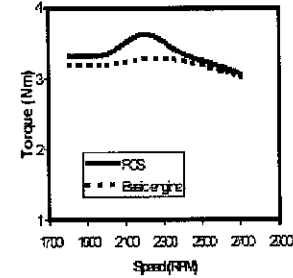


Figure 16: Engine torque (TPS=100%)

APPENDIX B FUZZY LOGIC IMPLEMENTATION BY MAMDANI TYPE FOR GAS TURBINE

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani [Mam75] as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes [Zad73]. Although the inference process we describe in the next few sections differs somewhat from the methods described in the original paper, the basic idea is much the same.

Mamdani-type inference, as we have defined it for the Fuzzy Logic Toolbox, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It's possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This is sometimes known as a *singleton* output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points. Sugeno-type systems support this type of model. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant.

In MATLAB fuzzy logic tools box there are mainly 3 main design interface in designing the system. The design takes place in 3 different editor that will be explained in part, their function and the design that have been made to the DIDATECT gas turbine system.

A.1 FIS Editor

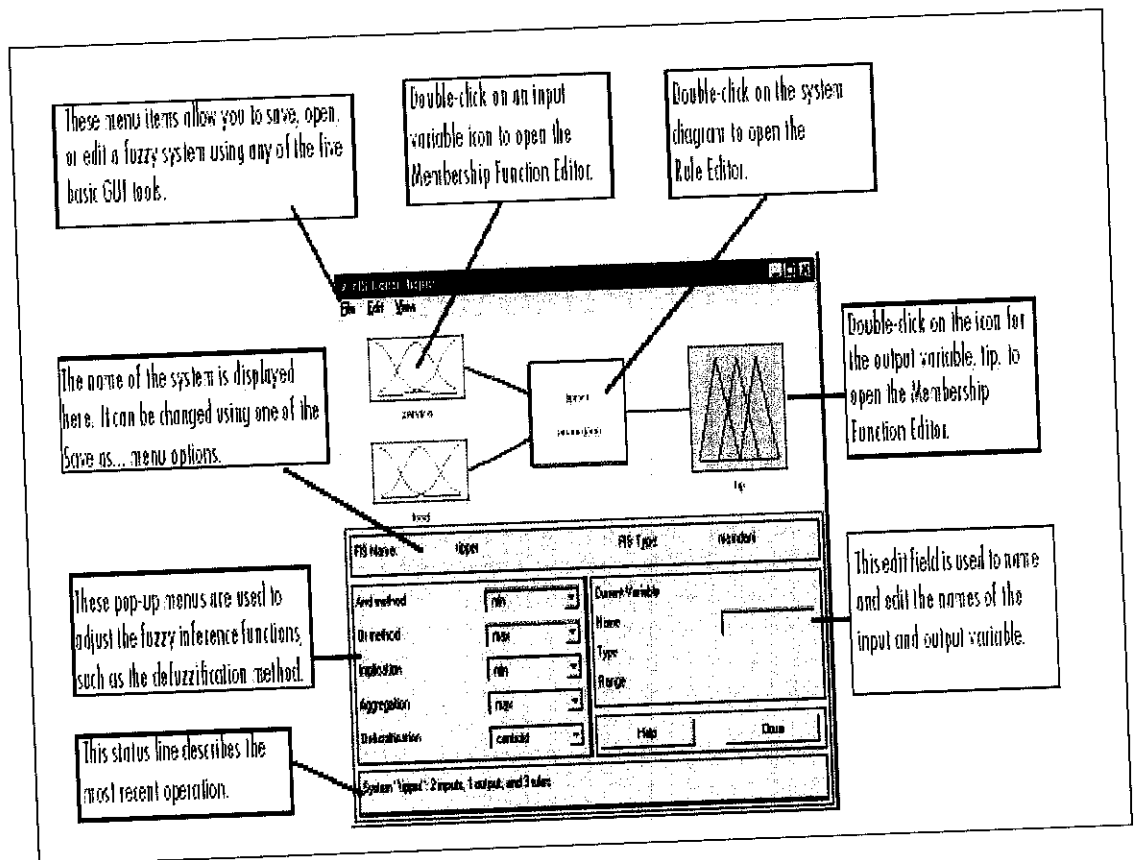


Figure A1 FIS Editor Example

The FIS Editor displays general information about a fuzzy inference system. There's a simple diagram at the top that shows the names of each input variable on the left, and those of each output variable on the right. The sample membership functions shown in the boxes are just icons and do not depict the actual shapes of the membership functions. This is the main windows of the design from this FIS editors overall picture of the system can be observed and see. The main displays that important in this windows is the input (colour in yellow) and output (colour in green). Others setting that can be done is on the method of analyses and the defuzzification of the system .

In designing for the gas turbine system the main adjustment done is on the input variable and also the type of fuzzy need to be used. From the figure given below the main fuzzy system used is the mamdani type. The input of the system are chosen to be three input which is the power consume by the turbine (which is the generated power), the compressed air which is air taken from the compressor (for this system the air are taken from the internal fan air supply) and the third input is the output temperature at the turbine. This input is mainly the safety input which is the monitoring of the temperature generated at the turbine will be monitor at the system. Where in this point the temperature is the highest. So the monitoring of the temperature changes in this stage is needed for safety of the environments as well as the equipment. The defuzzification of the system is taken to be a centroid type where the center reading of data (highest) result from the fuzzy operation will be taken as the output value after defuzzification.

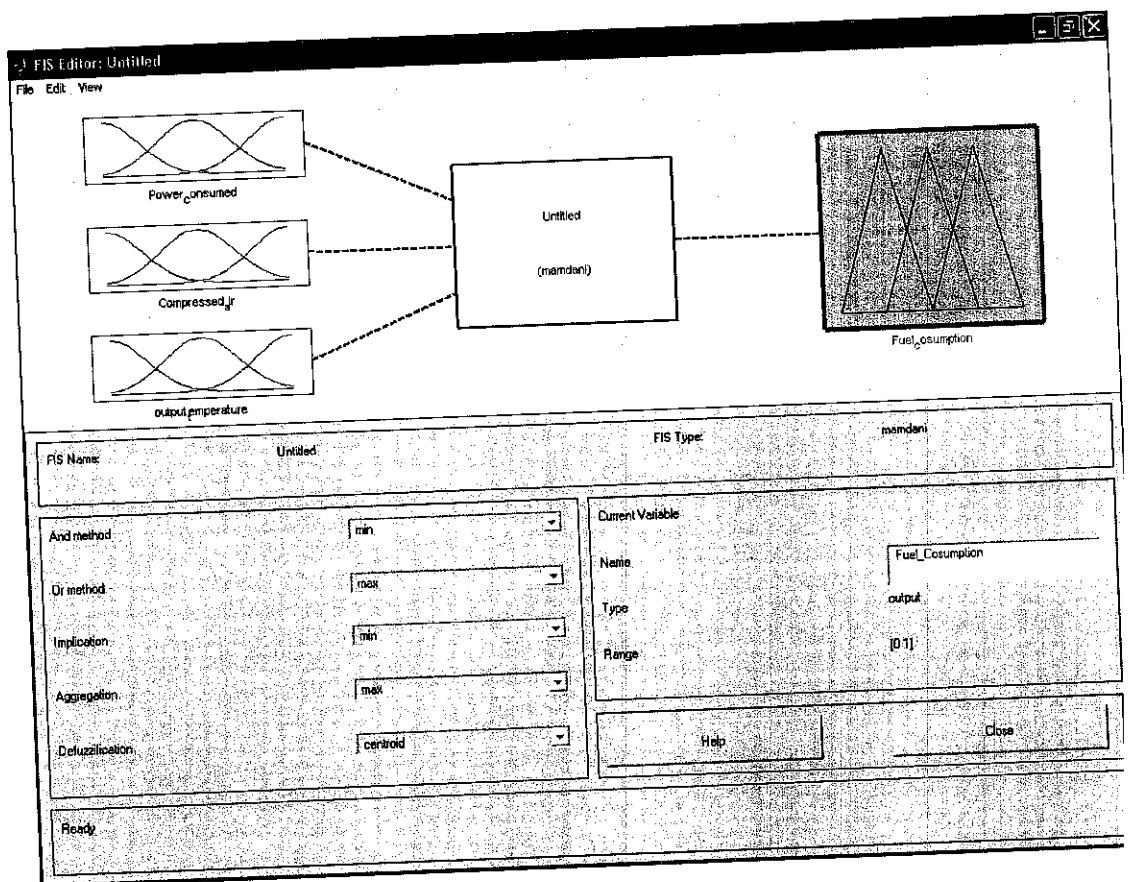


Figure A2 FIS Editor For Gas Turbine

A.2 The Membership Function Editor

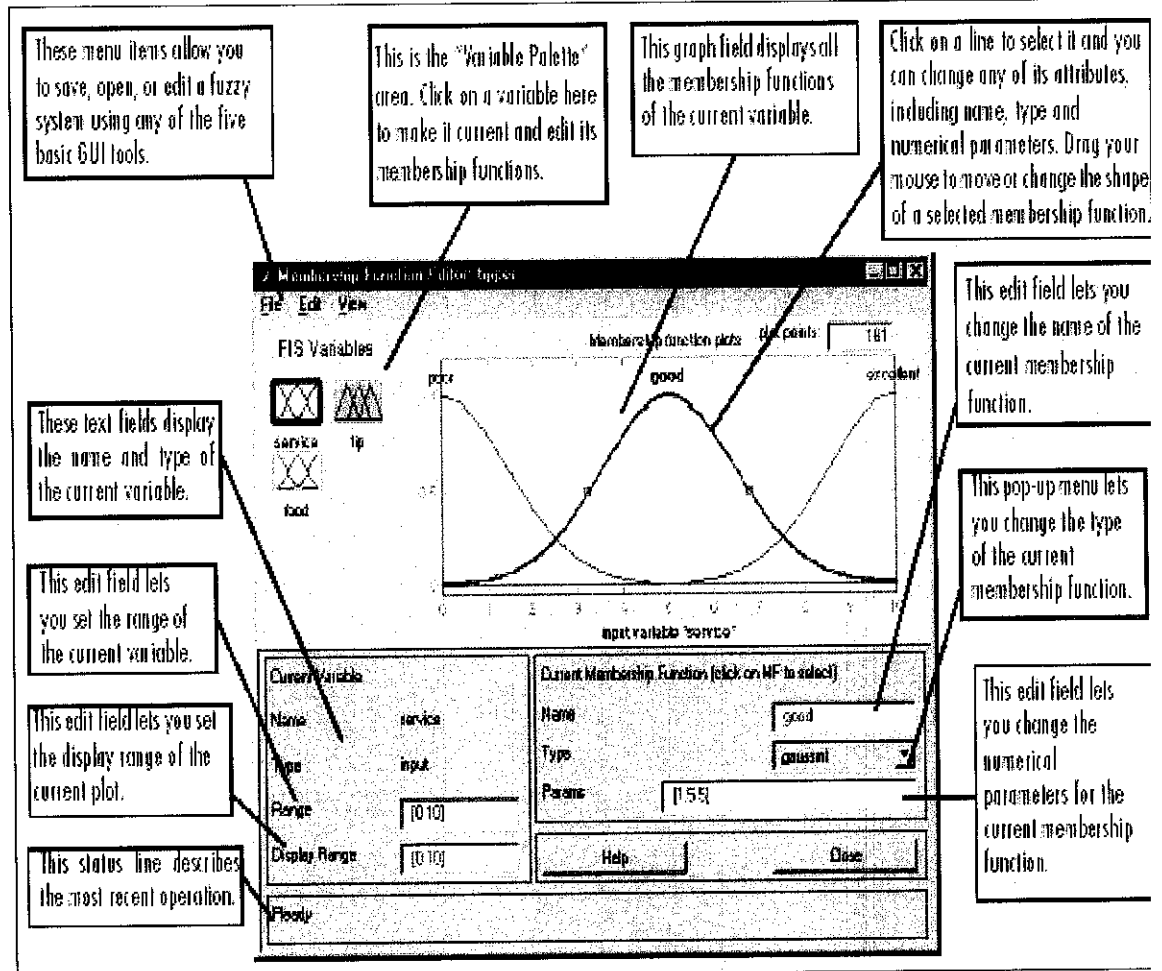


Figure A3 Membership Function Editor

The Membership Function Editor is the tool that display and edit all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system. This display or GUI will shows the input and the output of the design system that will be done. The set up of the value of the input and output also been done in this GUI. With this windows the set up of the desired input and output to matched the decision that will be done is set at designer design.

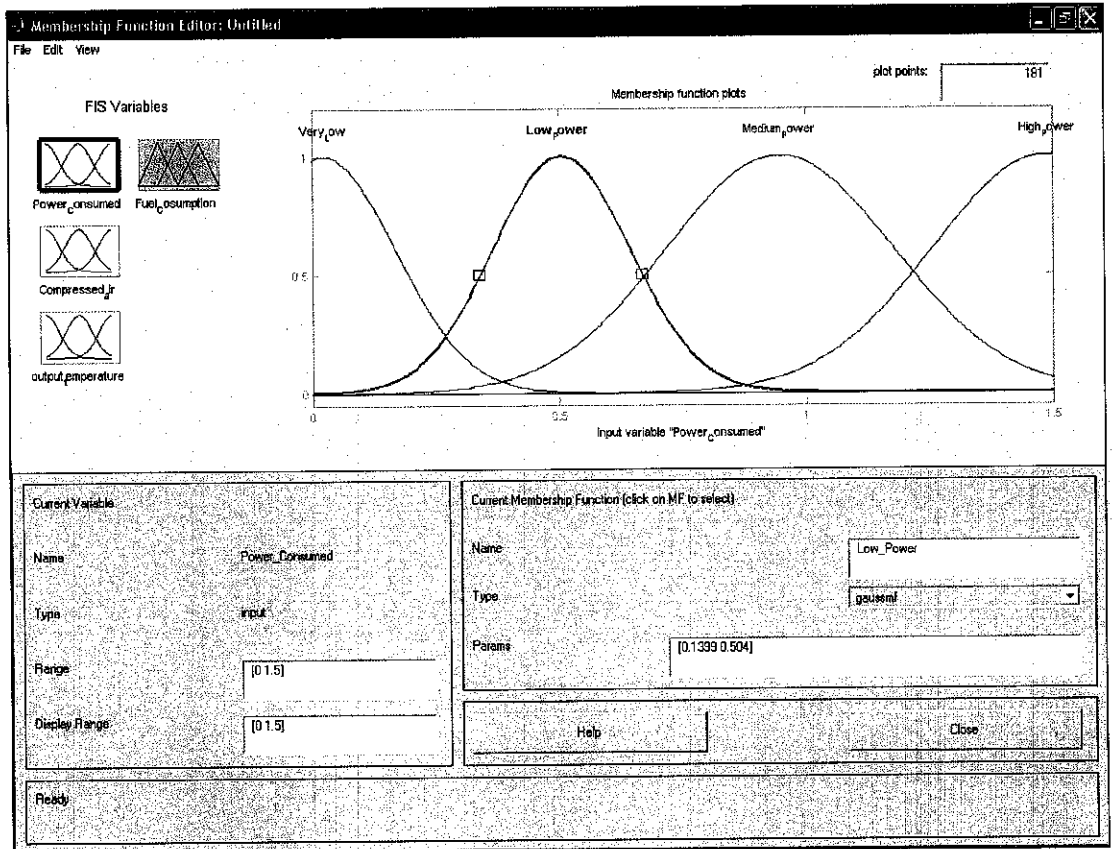


Figure A4: Membership Function Editor For Power Consumed

For the first input which is the Power Consumed by the gas turbine the set-up of the pattern for signed value are set as shown in figure. From the figure the value of the power are set to four different membership function which is very low power, low power, medium power and high power. The function is representing the value of power for the condition. For this system the Gaussian membership function are choose due to the asymmetric bell shape of the function which is suitable for this type of application. As reference form the gas turbine datasheet and behavior the rage of the power that can be generated by this gas turbine are taken until 1.5 K watt of power. The set-up of the rage for each membership function are done base on the behavior and pattern of operating of gas turbine.

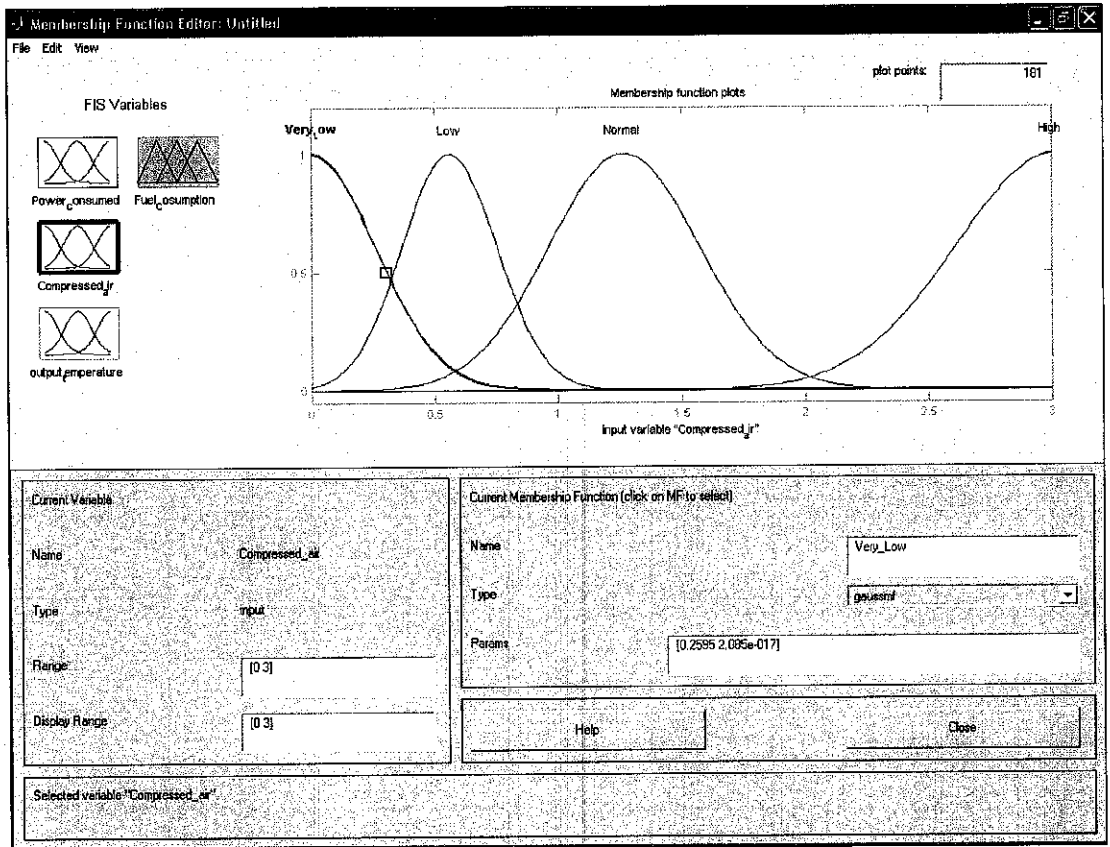


Figure A5: Membership Function Editor For Compressed Air

The second input that was used in this design is the amount of pressure at the intake or compressed air coming inside the combustion chamber. Since the study of this design in on fuel and air system the ratio of this fuel and air are studied and used for the design.

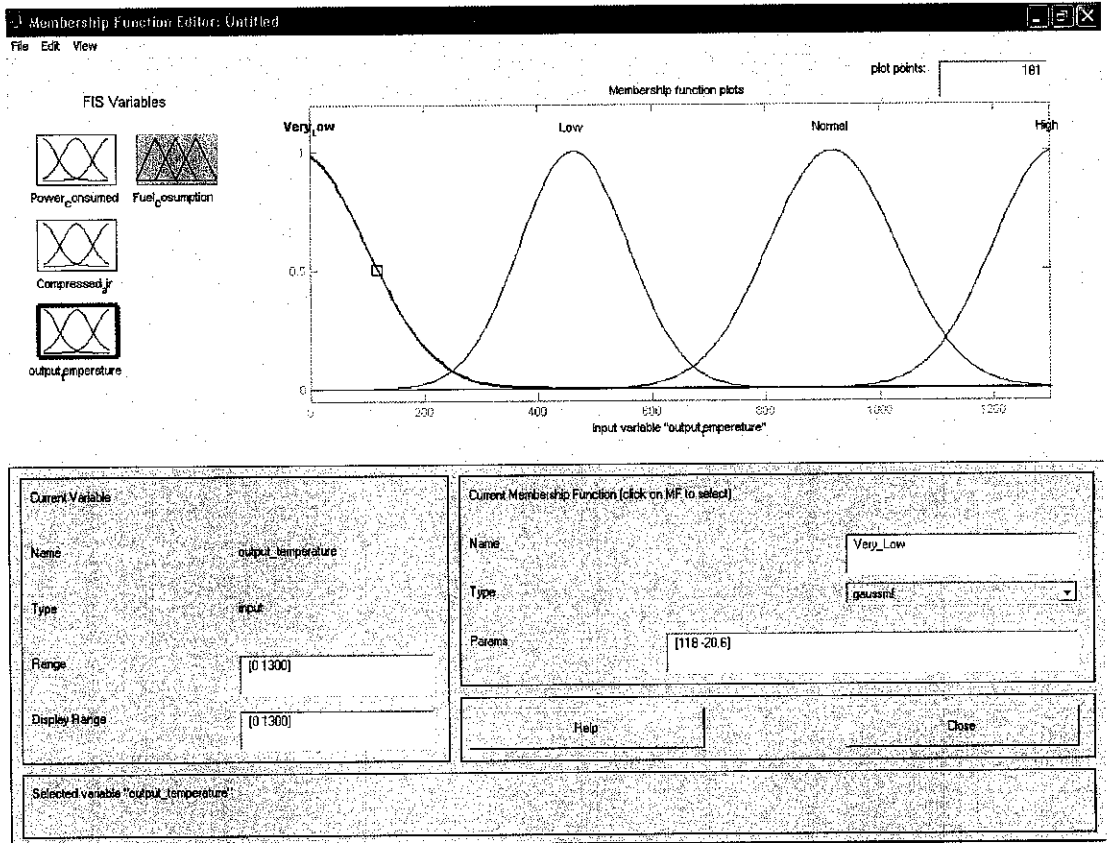


Figure A6: Membership Function Editor For Output Temperature

The last input of the system is the output temperature of the gas turbine this input is actually selected in as the safety precaution where the monitoring of the temperature at the turbine is important in protecting the environment and also the equipments. The temperature taken is the highest temperature allowed in the system by monitoring this values the highest temperature can be monitor. The other reason that this input are choose is due to behavior of gas turbine itself. In this temperature point the heat dissipated in this chamber will determine the power generated in term of the emission and also heat where the higher the heat dissipated the higher the power generated. In this membership function the function are divided into four part which is the very low temperature (where the power generated is normally very low) low temperature (mainly in starting event) medium (where power in idle or stable point) an a high temperature where this section indicate the hazard of the system and the action that need to be taken is by lowering the fuel intake from the output decision.

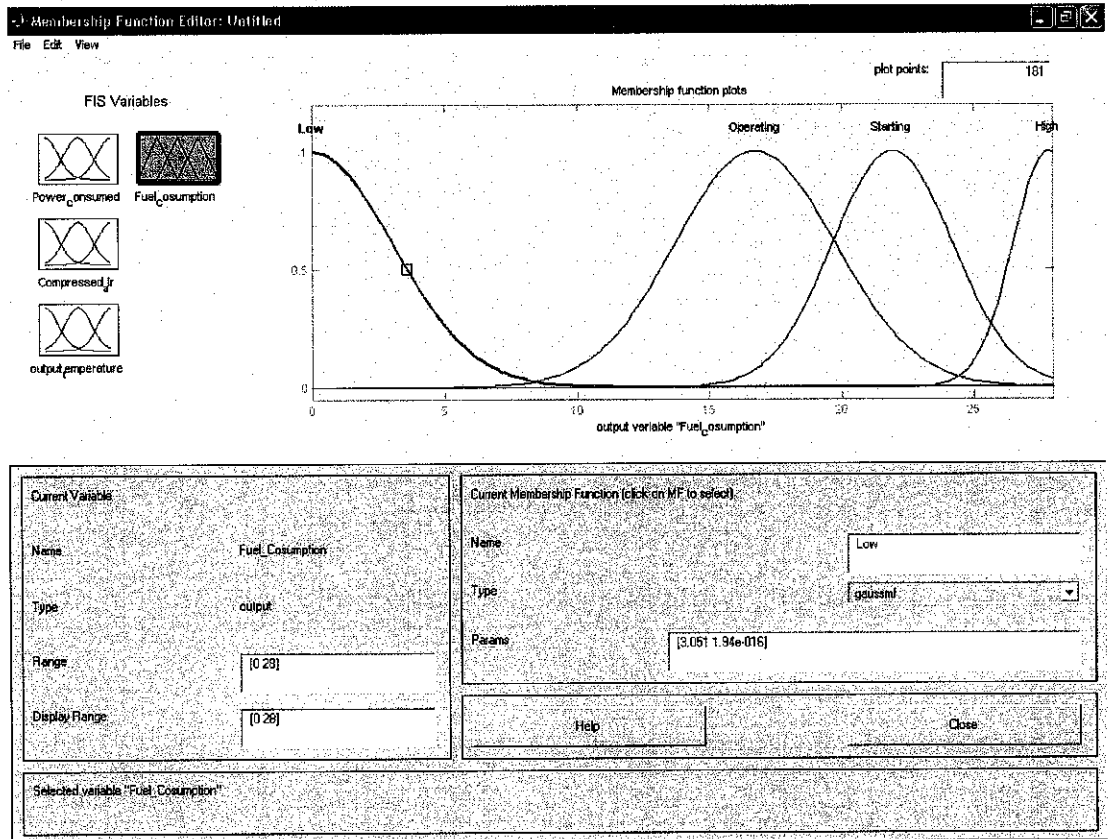


Figure A7: Membership Function Editor For Output Fuel Demand

For the output membership function the division of the range are made as shown where the output are divided into four part which is low fuel consumption (for the situation of high temperature at turbine) operating range (for normal operating) starting rage (which is the fuel required(range) in starting condition) and high fuel consumption rage where the fuel in this rage are more that the expected used of fuel (overused). The rage for the membership function are taken a s minimum value is zero and maximums is 28 gallon/ second.

A.3 The Rules Editor

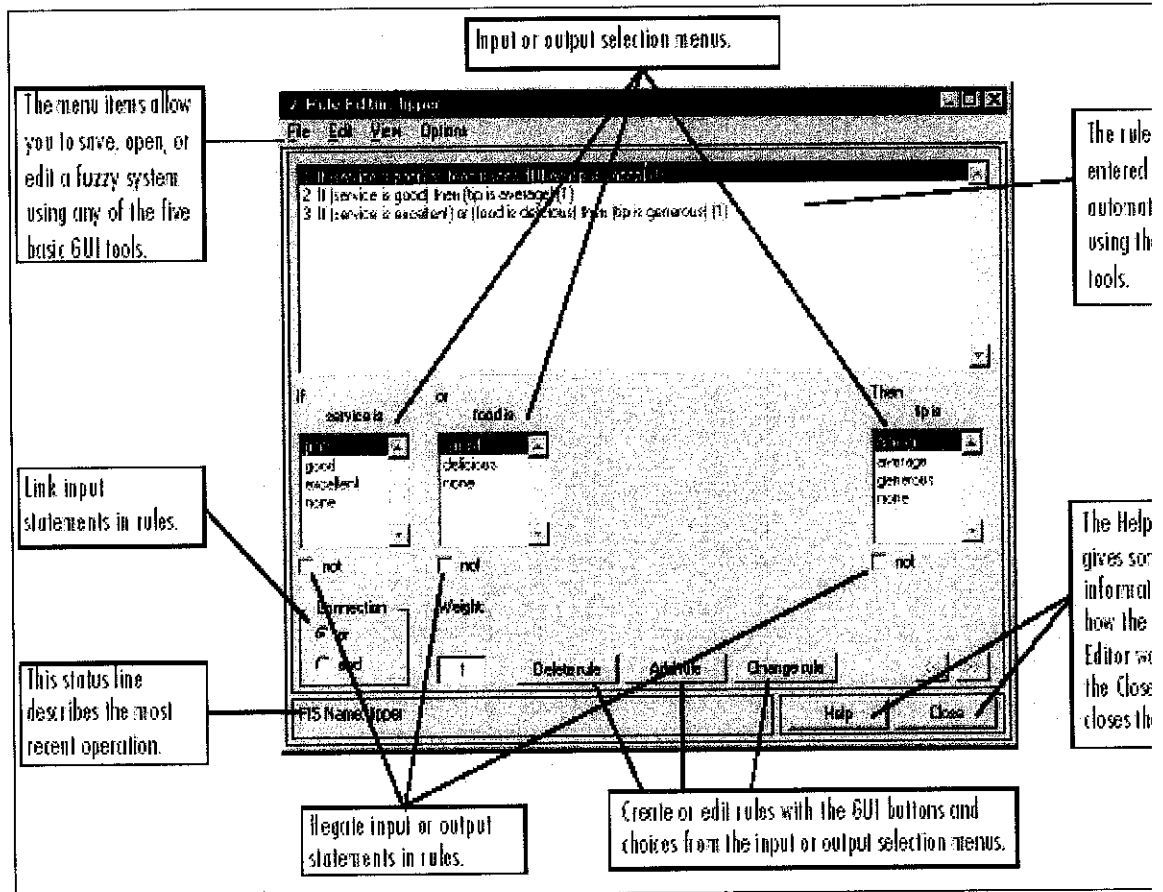


Figure A8 : Rules Editor

Based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor is used to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box, and one connection item. Choosing none as one of the variable qualities will exclude that variable from a given rule. Choosing not under any variable name will negate the associated quality. Rules may be changed, deleted, or added, by clicking on the appropriate button.

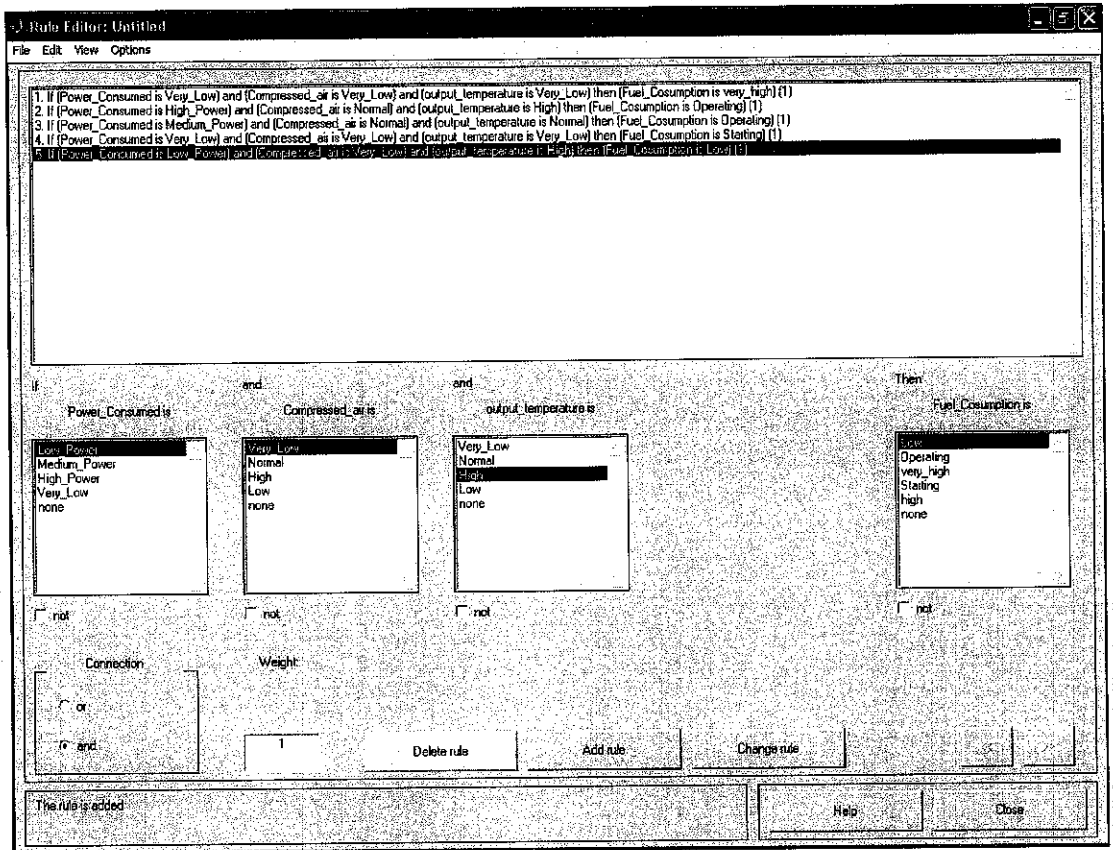


Figure A9: Rules Editor For Gas Turbine System

In author gas turbine fuzzy logic design some of the rules are as shown in the figure. This rules are generated base on the condition of the gas turbine for an example in the condition of the power consume is low, compressed air is medium or high and output temperature also low the expected value of the fuel consumption will be high in order to make the combustion ratio of air and fuel are in the most efficient values. The rules that been set in this example would be “ *if power consumed is low and compressed air is normal and output temperature is high then fuel consumption is high*”

A.4 The Rule Viewer

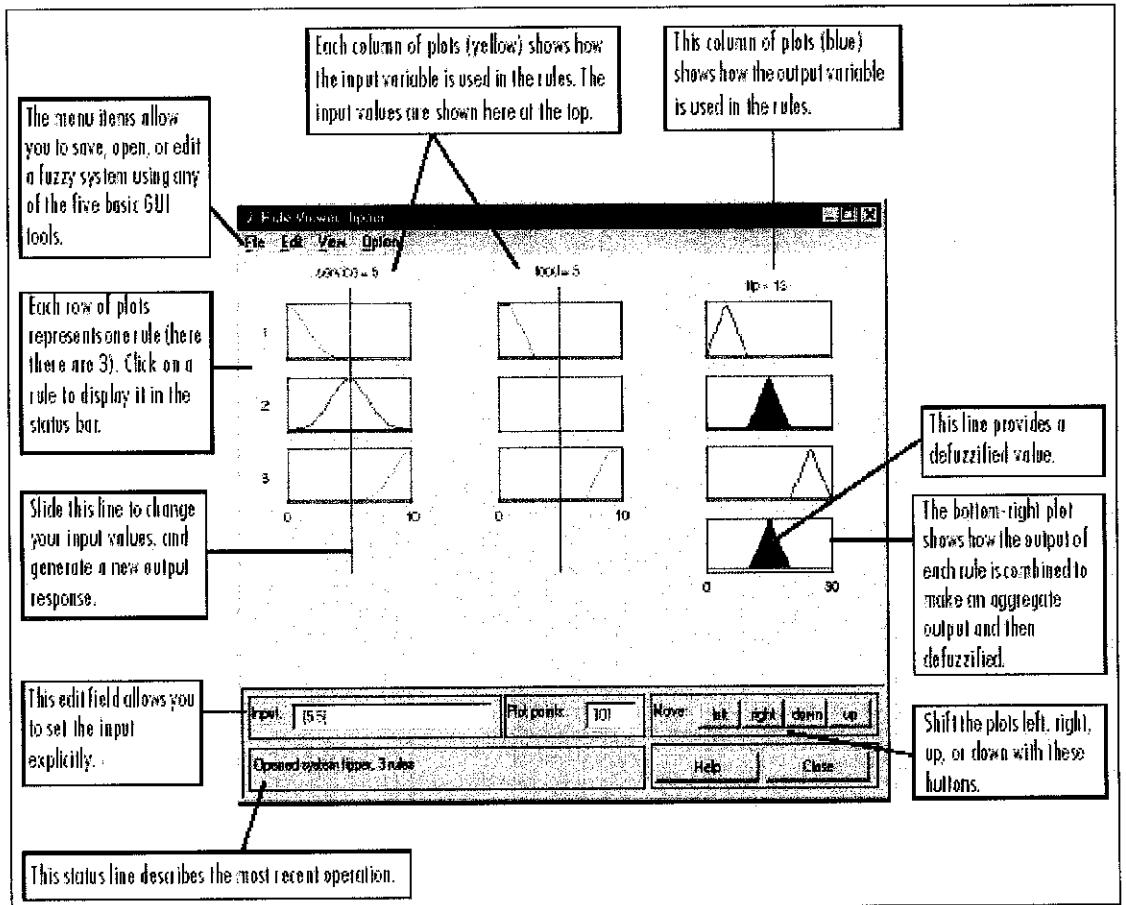


Figure A10: The Rules Viewer

The Rule Viewer displays a roadmap of the whole fuzzy inference process. It's based on the fuzzy inference diagram described in the previous section. You see a single figure window with 10 small plots nested in it. The three small plots across the top of the figure represent the antecedent and consequent of the first rule. Each rule is a row of plots, and each column is a variable. The first two columns of plots (the six yellow plots) show the membership functions referenced by the antecedent, or the if-part of each rule. The third column of plots (the three blue plots) shows the membership functions referenced by the consequent, or the then-part of each rule. If you click once on a rule number, the corresponding rule will be displayed at the bottom of the figure. The fourth plot in the third column of plots represents the aggregate weighted decision for the given inference system. This decision will depend on the input values for the system.

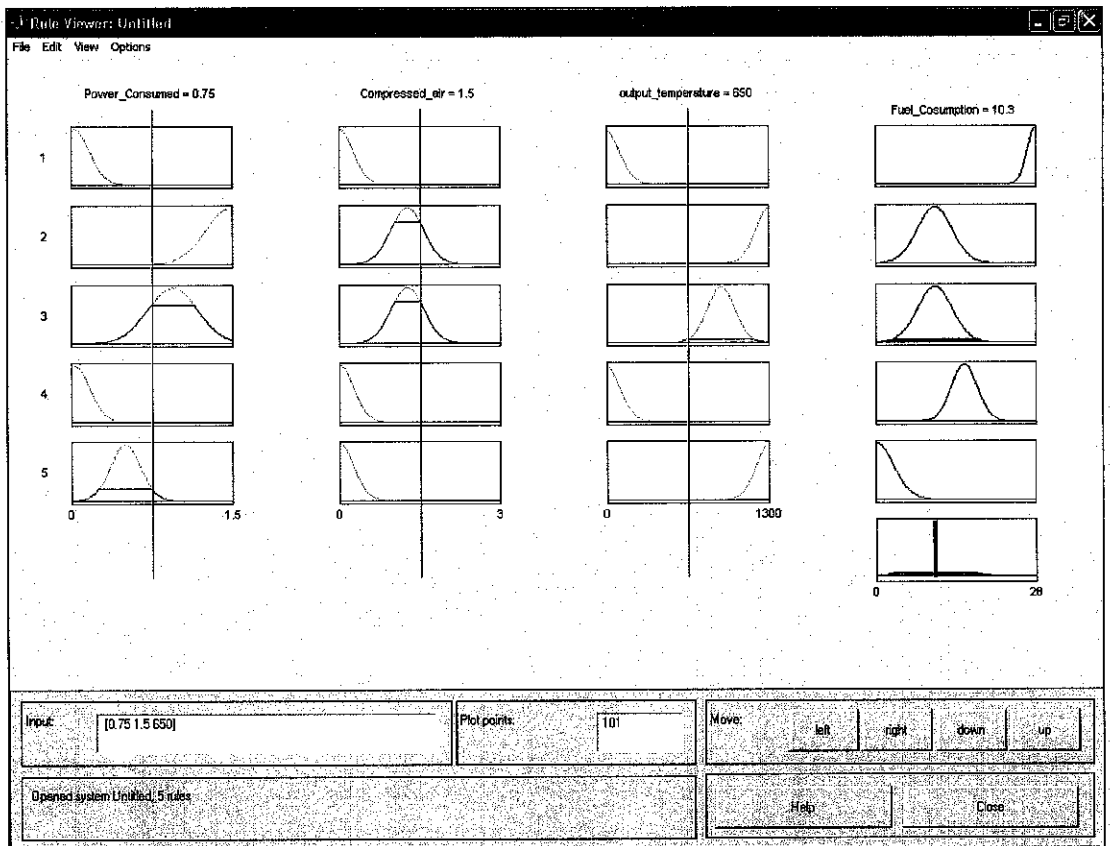


Figure A11: Rules Viewer For Gas Turbine System

In this gas turbine design the rule viewer of the system are as shown in the figure. The row of the graph represent the rules that have been set up in rule viewer and the column represent the input value that been set across the line. In this windows designer can see the effect of the input to the output by adjusting the value of input (the red line) and observe the output from the single box at the bottom of the boxes the thicker red line represent the value of output after defuzzyfication.

A.5 The Surface Viewer

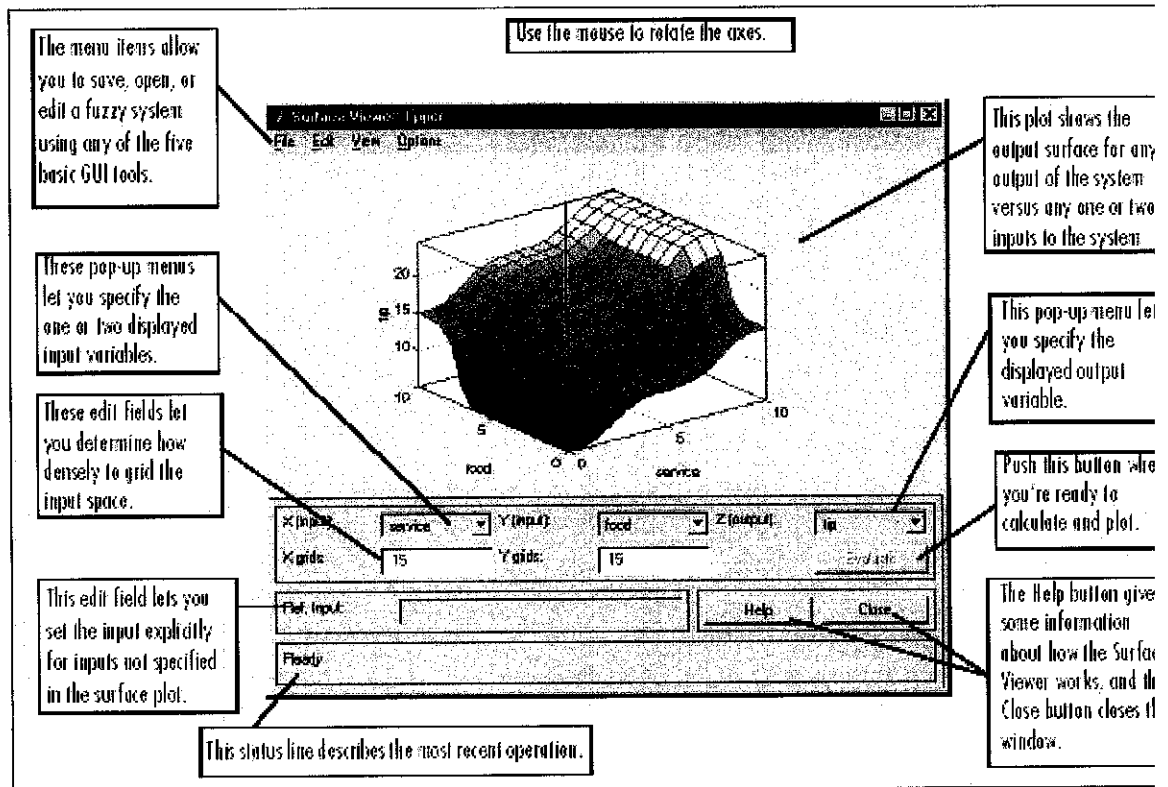
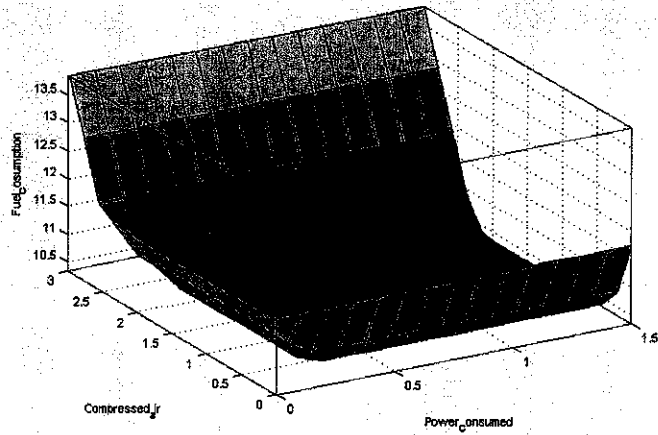


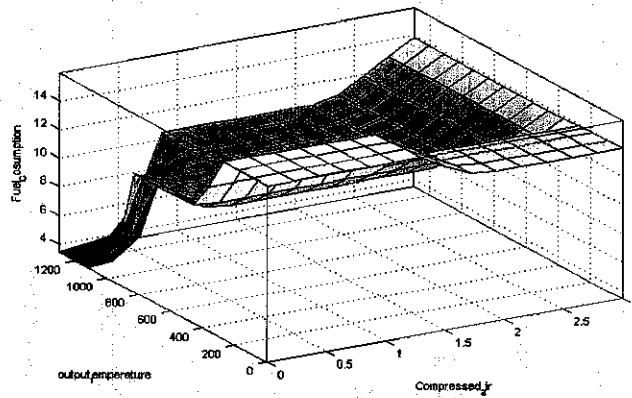
Figure A12 : The Surface Viewer

Same as the rule viewer, surface viewer is used to see the design fuzzy on the system. By this 3D plotted graph of input and output relationship designer can observe the expected behavior of the system.

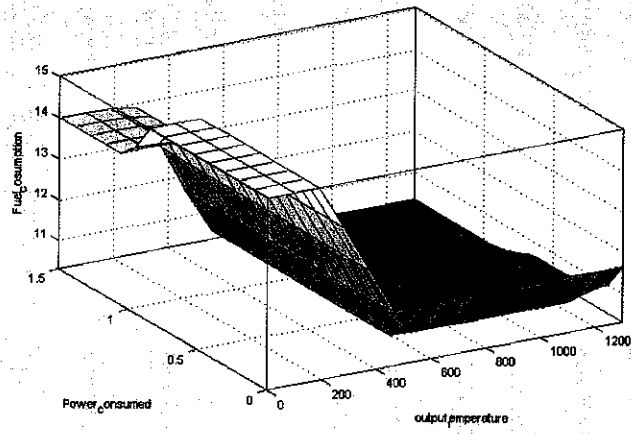
For the design gas turbine system the surface viewer of the design fuzzy are as shown in the figure. From the graph the design fuzzy can be observed from the plotted graph. As for example for the graph of Power Consumed (input) Vs Compressed air (input) vs Fuel Consumption (output). The relationship of this three variable can be observed where in certain point of power consumed and compressed air the expected output can be determine and observed.



X (input):	Power_Consumed	Y (input):	Compressed_air	Z (output):	Fuel_Consumption
X grid:	15	Y grid:	15	Evaluate	
Ref. input:	[NaN NaN 650]			Help	Close
Ready					



X (input):	Compressed_air	Y (input):	output_temperature	Z (output):	Fuel_Consumption
X grid:	15	Y grid:	15	Evaluate	
Ref. input:	[0.75 NaN NaN]			Help	Close
Ready					



X (input):	output temperature	Y (input):	Power_Consumed	Z (output):	Fuel_Consumption
X grid:	15	Y grid:	15	[button]	
Ref. Input:	[NaN 1.5 NaN]	[button] Help		[button] Close	
Ready					

APPENDIX C DATA COLLECTION FOR GSP 9.1 SOFTWARE

I) Simulation using GSP 9 software

I.I) Specification of Standard Turbojet System.

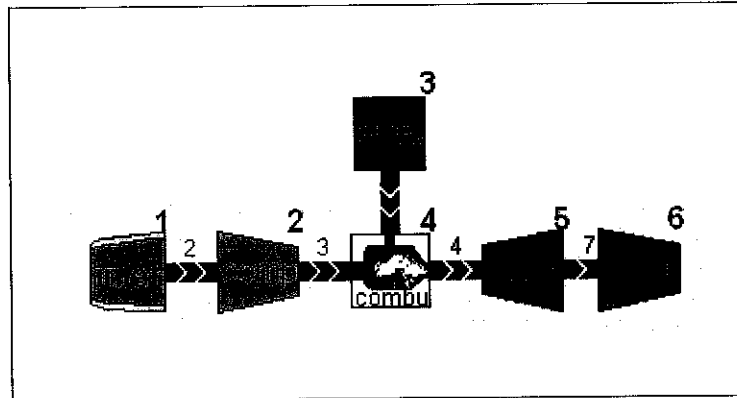


Diagram of Turbojet System inGSP

Inlet

Model Option : MIL-E-5008B (RR(pressure Ratio) according to this standard assumes RR=1 up to flight Mach 1. Above Mach 1, RR is reduced using a function of Mach.)

Design Mass Flow: 19.9Kg/s

Pressure Ratio : 1

Compressor

Model Option : Free State Rotor Speed

Rotational Speed : 16540rpm for 100%

Design Pressure Ratio : 6.92

Design Efficiency : 0.825

Combustor Unit

Combustor Efficiency : 0.995

Fuel Flow rate : 0.38 Kg/s

Total Pressure Lost at Design Point : 0.04%

Design Fuel : Jet-A/A1, Avtur

-Fuel Temperature : 288.15K

-H/C ratio : 1.9167j/Kg

-Cp of fuel : 2093J/Kg/K

-Temperature for fuel Hv Cp value specification : 298.15K

Manual Fuel Control:

Wf (Fuel Flow) : 0.38Kg/s

Transient Flow rate : 0.5kg/s

Turbine :

Model : Free State Rotor speed

Spool Inertia moment : 0.7578kgm²

Spool mech. Efficiency : 0.99

Rotational Speed : 16540 rpm = 100%

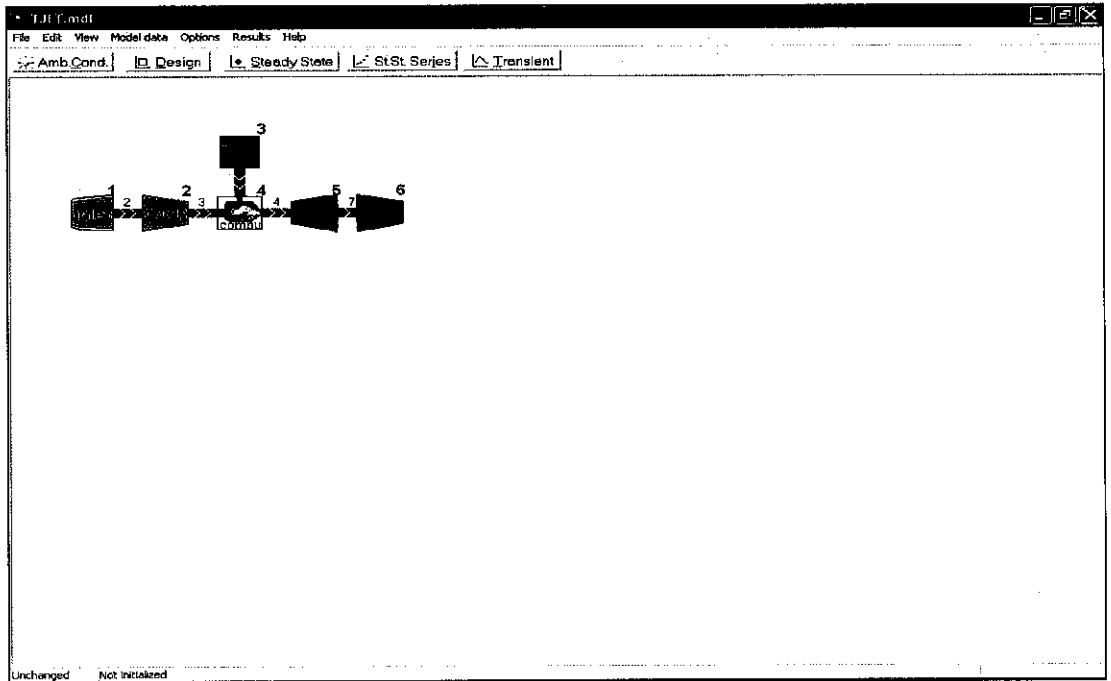
Design Efficiency : 0.88

Propelling Exhaust nozzle:

Model :Fixed area nozzle

Velocity Coefficient : 0.975

Simulation Procedure:



Main Layout of Turbojet system

After the design have been specified the system will be run through the simulator as shown below the setting or the coefficient of the system requirement have been key in the simulator system. After that the transient and steady state analysis will be done.

Combustor ID string Calc.Nr. 4

Output	Design	Fuel	Fuel pump	Water Inj.	Remarks
General	Design	Vol.dynamics	Pressure Loss	Emissions	Heat sink

design fuel flow [kg/s]

design inlet temperature [K]

design fuel-air ratio

design combustion efficiency [-]

rel. tot. pressure loss at design point [-]

Zero Wf in design Calc. (afterburner)

Specify:

Fuel flow

Exit temperature

Fuel-Air ratio

Output condition

Area

Mach No

Exit flow cross area [m2]

Exit mach number [-]

Turbine ID string Calc.Nr. 5

Variable Geometry	Deterioration	Output	Remarks
General	Design	Map	Vol.dynamics
		Cooling	Heat sink

shaft nr./suffix

spool inertial moment [kgm2]

spool mech. efficiency [-]

Model Options

Free state rotor speed

User specified rotor speed

Power balance at rotor speed

Free Power Turbine

External load / PTO

PTO [kW] Torque [Nm]

Compressor X

Compressor ID string Calc.Nr. 2

Variable Geometry	Deterioration	Output	Remarks
General Design	Map	Vol.dynamics	Heat sink
		Bleeds	

design rotational speed [rpm] = [%]

design pressure ratio [-]

design efficiency [-]

Exit flow cross area [m2]

OK Cancel Help

Simulation Result:

After the simulation have been done the result achieved from this simulation are tabulated in data from as shown in the figure and also in graph form:

Steady State Output TJFF.mdi

File Browse Breaks Graph Help

Point	Comment	W0	TT2	PT2 [bar]	W2	WC2	TT3	PT3 [bar]	PR_2	N1 [rpm]	Nc_2 [%]	DHW_2 [kW]	I.A.
	Design Point	19.900	288.15	1.0132	19.900	19.900	543.16	7.0117	6.9220	16540	100.00	5163.45	
0.000		19.907	288.15	1.0132	19.907	19.907	543.42	7.0151	6.9233	16599	100.12	5170.86	
0.100		19.907	288.15	1.0132	19.907	19.907	543.42	7.0151	6.9233	16599	100.12	5170.86	
0.200		19.910	288.15	1.0132	19.910	19.910	543.88	7.0271	6.9428	16570	100.19	5188.33	
0.300		19.912	288.15	1.0132	19.912	19.912	544.23	7.0438	6.9619	16569	100.23	5193.99	
0.400		19.919	288.15	1.0132	19.919	19.919	544.70	7.0527	6.9805	16606	100.39	5210.99	
0.500		19.926	288.15	1.0132	19.926	19.926	545.15	7.0615	6.9952	16622	100.48	5222.22	
0.600		19.932	288.15	1.0132	19.932	19.932	545.61	7.0705	6.9978	16636	100.59	5233.53	
0.700		19.939	288.15	1.0132	19.939	19.939	546.07	7.0795	6.9964	16653	100.68	5244.12	
0.800		19.945	288.15	1.0132	19.945	19.945	546.51	7.0876	6.9949	16668	100.77	5254.96	
0.900		19.951	288.15	1.0132	19.951	19.951	546.98	7.0952	7.0034	16682	100.88	5265.91	
1.000		19.956	288.15	1.0132	19.956	19.956	547.47	7.1049	7.0119	16697	100.95	5276.91	
1.100		19.962	288.15	1.0132	19.962	19.962	547.93	7.1134	7.0204	16712	101.04	5287.91	
1.200		19.968	288.15	1.0132	19.968	19.968	548.33	7.1217	7.0286	16724	101.11	5298.16	
1.300		19.973	288.15	1.0132	19.973	19.973	548.76	7.1297	7.0371	16739	101.20	5309.45	
1.400		19.979	288.15	1.0132	19.979	19.979	549.22	7.1380	7.0452	16751	101.28	5319.83	
1.500		19.984	288.15	1.0132	19.984	19.984	549.66	7.1469	7.0534	16764	101.35	5330.42	
1.600		19.989	288.15	1.0132	19.989	19.989	550.11	7.1552	7.0616	16776	101.43	5341.19	
1.700		19.994	288.15	1.0132	19.994	19.994	550.55	7.1635	7.0698	16789	101.50	5351.69	
1.800		19.999	288.15	1.0132	19.999	19.999	551.01	7.1718	7.0778	16801	101.58	5362.67	
1.900		20.004	288.15	1.0132	20.004	20.004	551.48	7.1801	7.0862	16813	101.65	5373.45	
2.000		20.009	288.15	1.0132	20.009	20.009	551.91	7.1883	7.0943	16825	101.72	5384.22	
2.100		20.014	288.15	1.0132	20.014	20.014	552.37	7.1962	7.1021	16835	101.79	5394.15	
2.200		20.018	288.15	1.0132	20.018	20.018	552.79	7.2045	7.1103	16847	101.86	5403.16	
2.300		20.023	288.15	1.0132	20.023	20.023	553.25	7.2124	7.1181	16857	101.92	5415.17	
2.400		20.027	288.15	1.0132	20.027	20.027	553.68	7.2204	7.1254	16868	101.98	5426.16	
2.500		20.032	288.15	1.0132	20.032	20.032	554.15	7.2286	7.1339	16878	102.04	5436.14	
2.600		20.036	288.15	1.0132	20.036	20.036	554.57	7.2369	7.1417	16887	102.10	5445.23	
2.700		20.040	288.15	1.0132	20.040	20.040	555.01	7.2441	7.1494	16897	102.16	5454.39	
2.800		20.044	288.15	1.0132	20.044	20.044	555.44	7.2522	7.1571	16905	102.21	5463.58	
2.900		20.048	288.15	1.0132	20.048	20.048	555.88	7.2598	7.1649	16915	102.27	5472.79	
3.000		20.052	288.15	1.0132	20.052	20.052	556.32	7.2673	7.1722	16923	102.31	5481.11	
3.100		20.055	288.15	1.0132	20.055	20.055	556.72						

103 records

Steady State Simulation Result

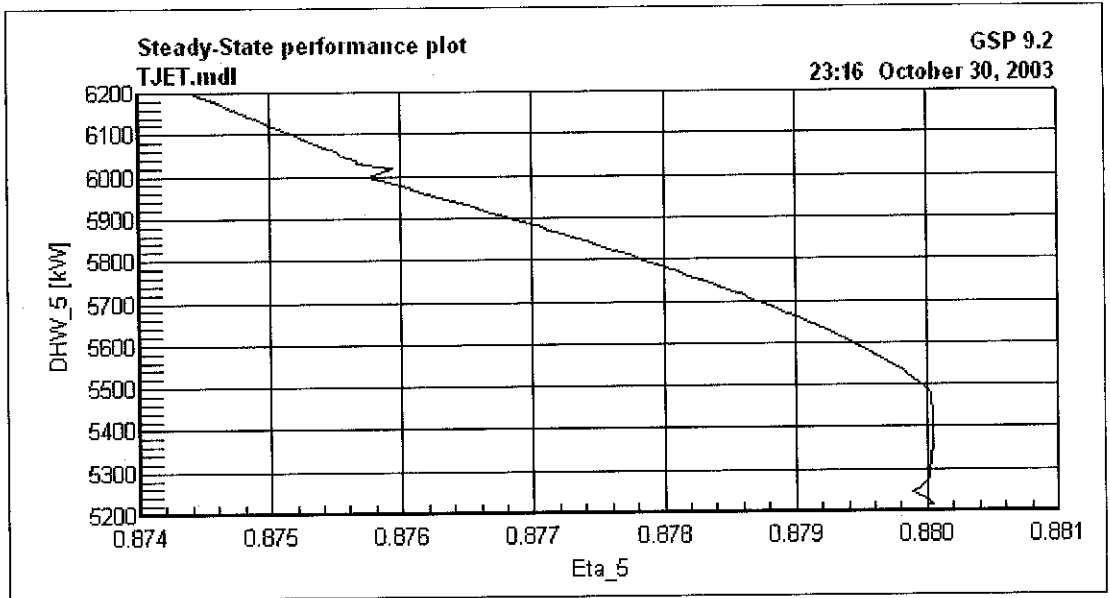
Transient Output TJFF.mdi

File Browse Breaks Graph Help

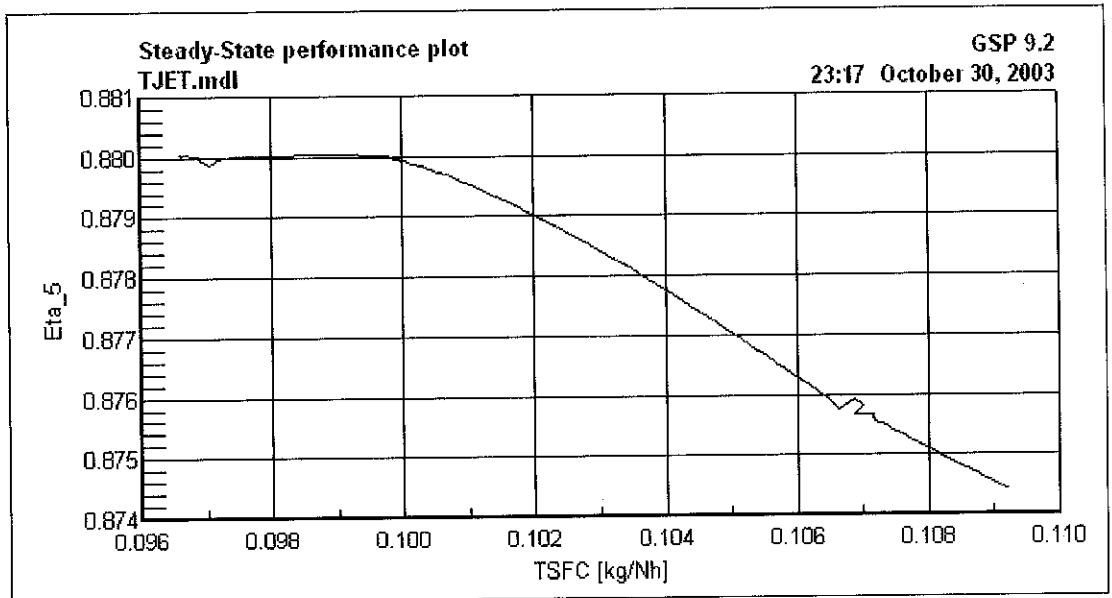
Time [s]	Comment	W0	TT2	PT2 [bar]	W2	WC2	TT3	PT3 [bar]	PR_2	N1 [rpm]	Nc_2 [%]	DHW_2 [kW]	I.A.
0.000		19.907	288.15	1.0132	19.907	19.907	543.42	7.0151	6.9233	16599	100.12	5170.86	
0.100		19.910	288.15	1.0132	19.910	19.910	543.88	7.0271	6.9417	16595	100.15	5185.09	
0.200		19.911	288.15	1.0132	19.911	19.911	544.15	7.0337	6.9417	16595	100.15	5185.09	
0.300		19.913	288.15	1.0132	19.913	19.913	544.42	7.0404	6.9493	16599	100.17	5192.03	
0.400		19.913	288.15	1.0132	19.913	19.913	544.42	7.0404	6.9493	16599	100.17	5192.03	
0.500		19.915	288.15	1.0132	19.915	19.915	544.71	7.0472	6.9595	16594	100.20	5198.35	
0.600		19.915	288.15	1.0132	19.915	19.915	545.05	7.0548	6.9626	16591	100.25	5206.13	
0.700		19.918	288.15	1.0132	19.918	19.918	545.40	7.0623	6.9699	16590	100.30	5214.07	
0.800		19.922	288.15	1.0132	19.922	19.922	545.76	7.0698	6.9774	16599	100.36	5222.40	
0.900		19.926	288.15	1.0132	19.926	19.926	546.13	7.0777	6.9851	16609	100.42	5231.08	
1.000		19.930	288.15	1.0132	19.930	19.930	546.51	7.0855	6.9925	16620	100.48	5240.09	
1.100		19.933	288.15	1.0132	19.933	19.933	546.91	7.0935	7.0007	16631	100.55	5249.40	
1.200		19.939	288.15	1.0132	19.939	19.939	547.31	7.1015	7.0087	16643	100.62	5258.96	
1.300		19.944	288.15	1.0132	19.944	19.944	547.72	7.1096	7.0167	16655	100.69	5268.76	
1.400		19.949	288.15	1.0132	19.949	19.949	548.15	7.1178	7.0247	16667	100.77	5278.77	
1.500		19.954	288.15	1.0132	19.954	19.954	548.57	7.1261	7.0328	16680	100.85	5288.96	
1.600		19.959	288.15	1.0132	19.959	19.959	549.01	7.1343	7.041	16693	100.92	5299.31	
1.700		19.964	288.15	1.0132	19.964	19.964	549.45	7.1426	7.0492	16705	101.00	5309.89	
1.800		19.969	288.15	1.0132	19.969	19.969	549.89	7.1509	7.0574	16718	101.08	5320.40	
1.900		19.975	288.15	1.0132	19.975	19.975	550.34	7.1593	7.0657	16731	101.15	5331.10	
2.000		19.980	288.15	1.0132	19.980	19.980	550.79	7.1676	7.0739	16744	101.23	5341.89	
2.100		19.985	288.15	1.0132	19.985	19.985	551.25	7.175	7.0821	16757	101.31	5352.73	
2.200		19.990	288.15	1.0132	19.990	19.990	551.70	7.1843	7.0903	16769	101.39	5363.63	
2.300		19.995	288.15	1.0132	19.995	19.995	552.16	7.1926	7.0985	16782	101.46	5374.57	
2.400		20.000	288.15	1.0132	20.000	20.000	552.62	7.2009	7.1067	16794	101.54	5385.53	
2.500		20.005	288.15	1.0132	20.005	20.005	553.08	7.2092	7.1148	16806	101.61	5396.50	
2.600		20.010	288.15	1.0132	20.010	20.010	553.55	7.2175	7.1231	16818	101.68	5407.48	
2.700		20.015	288.15	1.0132	20.015	20.015	554.01	7.2257	7.1312	16830	101.75	5418.45	
2.800		20.020	288.15	1.0132	20.020	20.020	554.47	7.2339	7.1393	16842	101.82	5429.41	
2.900		20.025	288.15	1.0132	20.025	20.025	554.94	7.2421	7.1474	16853	101.89	5440.36	
3.000		20.029	288.15	1.0132	20.029	20.029	555.40	7.2502	7.1554	16864	101.96	5451.27	
3.100		20.034	288.15	1.0132	20.034	20.034	555.89	7.2589	7.1634	16875	102.03	5462.16	
3.200		20.038	288.15	1.0132	20.038	20.038	556.32	7.2664	7.1714	16886	102.09	5473.01	

102 records

Transient Simulation Result



Steady State Graph For Power Vs Efficiency



Steady State Graph For Fuel Consumption Vs Efficiency

APPENDIX D EMPERICAL MODELLING DATA (STEPS RESPONSE DATA)

Step Data for AIR intake of gas turbine:

Steps Data For Fuel Intake of the Gas Turbine

steps	100-150	150-200			
			1	40.2	36.2
			2	40.2	36.2
1	175		3	40.4	36.3
2	175		4	40.5	36.5
3	176		5	40.5	36.7
4	178		6	40.6	36.7
5	179		7	40.7	36.8
6	183		8	40.9	36.9
7	184		9	41.1	37
8	184		10	41.7	37.1
9	186		11	42.4	37.7
10	188		12	42.9	38.1
11	190		13	43.1	38.3
12	192		14	43.6	38.8
13	194		15	44	39.1
14	197		16	44.5	39.8
15	199		17	44.7	39.9
16	200		18	45	40
17	201		19	44.8	40.2
18	202		20	44.8	40.2
19	200		21	44.7	40
20	200		22	44.7	40
			23	44.9	40.1
			24	44.9	40.1
			25	44.9	40.2
			26	44.8	40.2
			27	44.8	40.2
			28	44.8	40.2

29	44.8	40.2	45	44.8	40.2
30	44.8	40.2	46	44.8	40.2
31	44.8	40.2	47	44.8	40.2
32	44.8	40.2	48	44.8	40.2
33	44.8	40.2	49	44.8	40.2
34	44.8	40.2	50	44.8	40.2
35	44.8	40.2	51	44.8	40.2
36	44.8	40.2	52	44.8	40.2
37	44.8	40.2	53	44.8	40.2
38	44.8	40.2	54	44.8	40.2
39	44.8	40.2	55	44.8	40.2
40	44.8	40.2	56	44.8	40.2
41	44.8	40.2	57	44.8	40.2
42	44.8	40.2	58	44.8	40.2
43	44.8	40.2	59	44.8	40.2
44	44.8	40.2	60	44.8	40.2

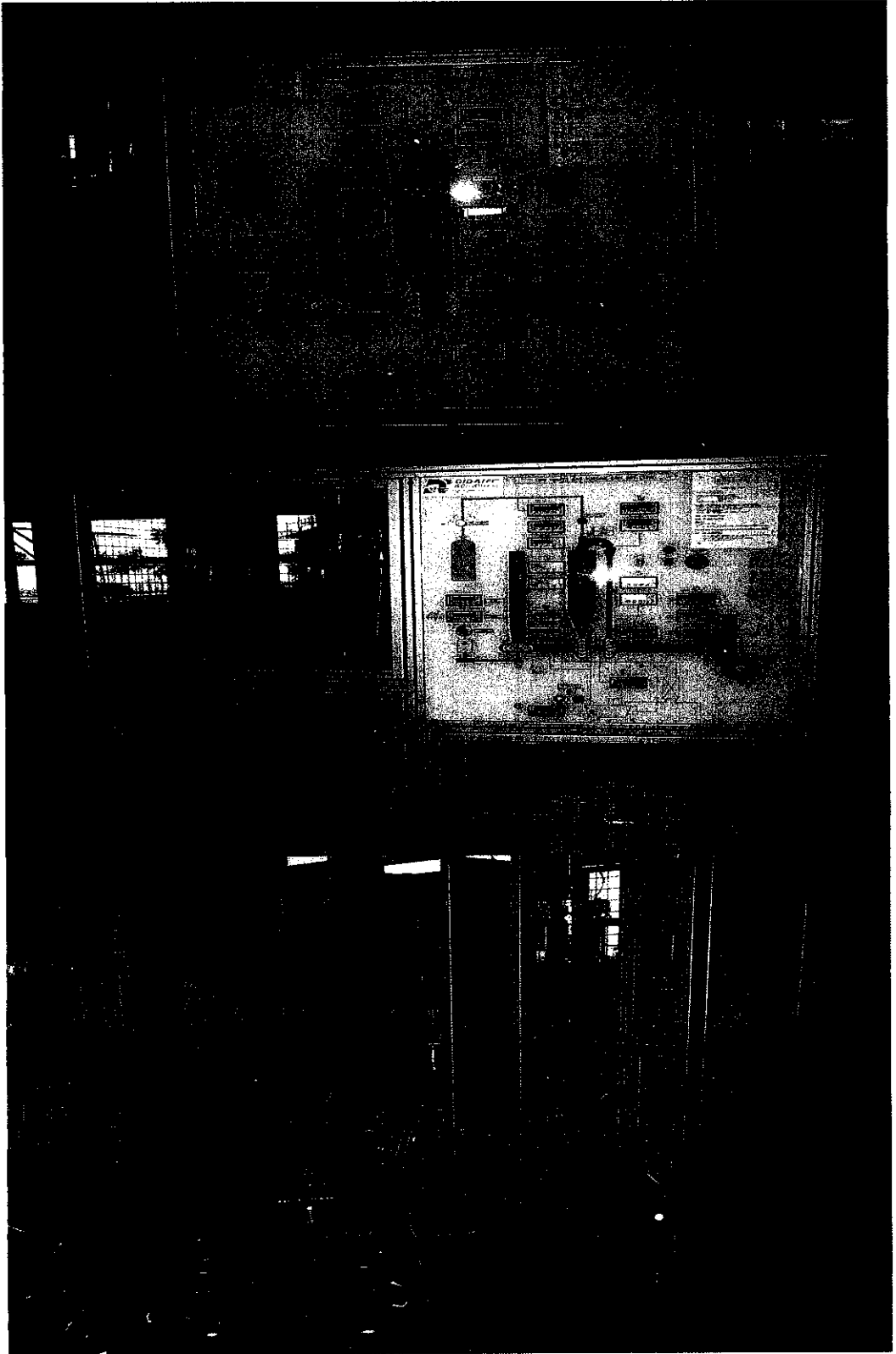
APPENDIX E OVERALL DATA OF DIDATEC GAS TURBINE

	Speed Direct Current Engine		Air Volume m ³ /h	LPG Flowrate L/m	Air admission		
	Rpm				T1	P1	
1			100	230	46.8	24.7	-81
2			150	175	40.2	25.2	-82
3			200	155	36.3	25.4	-82
4			250	158	34.2	25.5	-83
5			300	146	32.1	25.8	-84

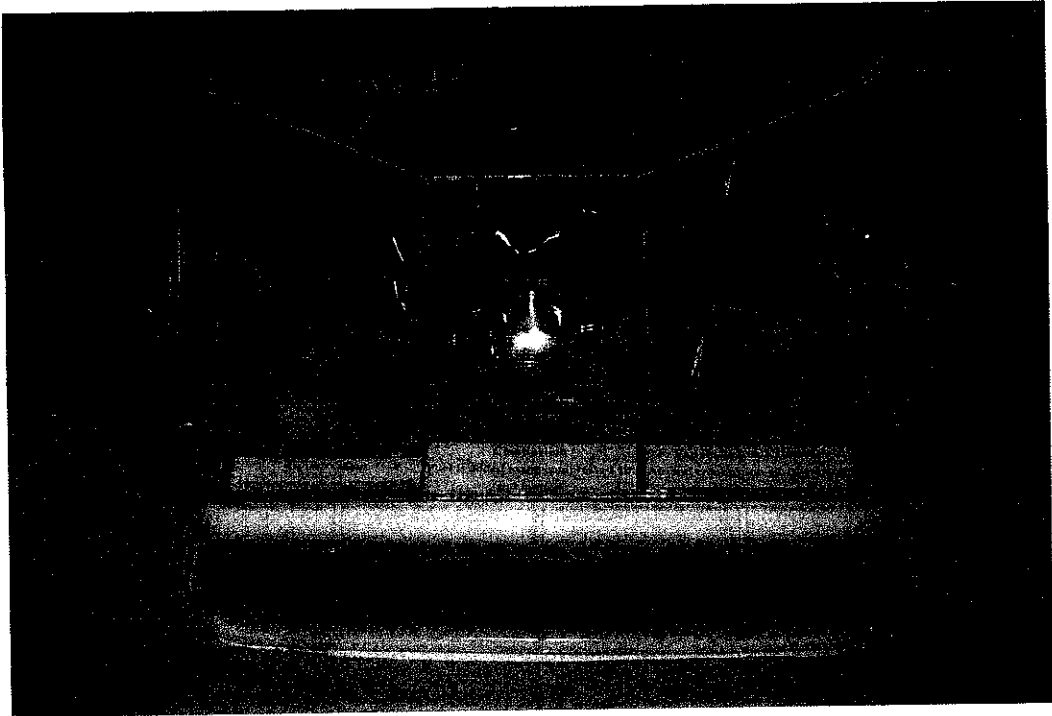
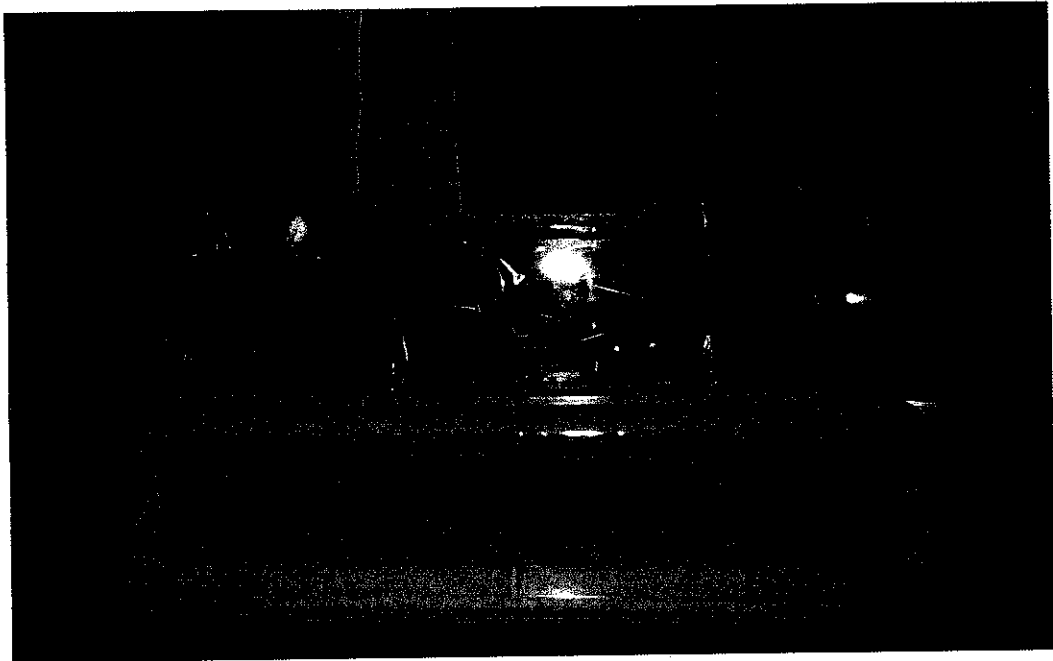
Compressed Air		Combustion Chamber		Nozzle		Exhaust		Oil
T2	P2	T3	P3	T4	P4	T5	P5	T6
87	0.57	568.7	0.56	654.7		95	563.8	-1
84.5	0.53	590.2	0.51	639.3		87	567.6	-1
81.4	0.48	583.9	0.47	625.1		80	558	-1
78.9	0.46	568.4	0.44	614.2		75	548.1	-1
76.3	0.42	549.2	0.41	600.9		70	536.9	-1

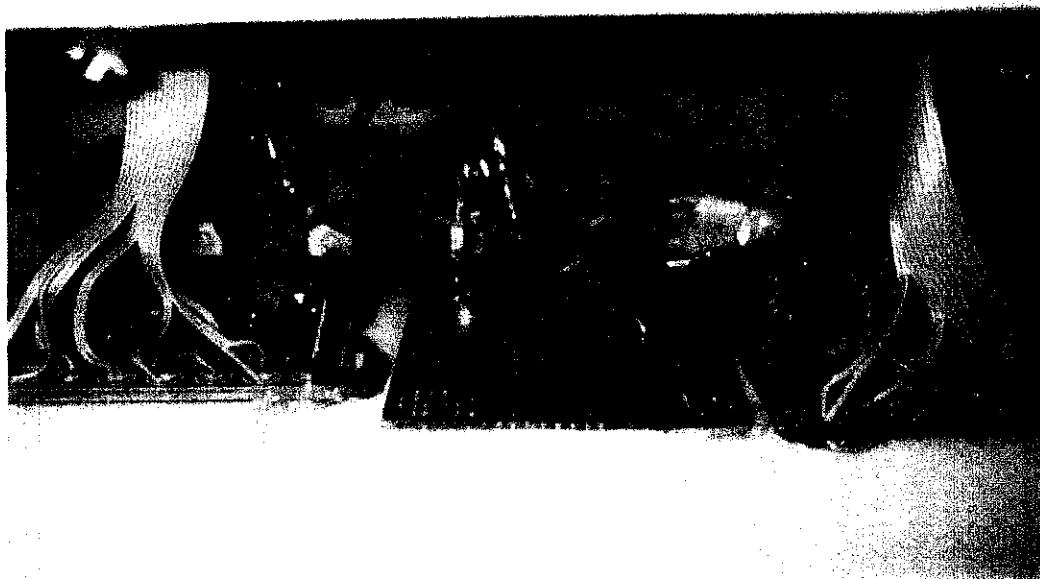
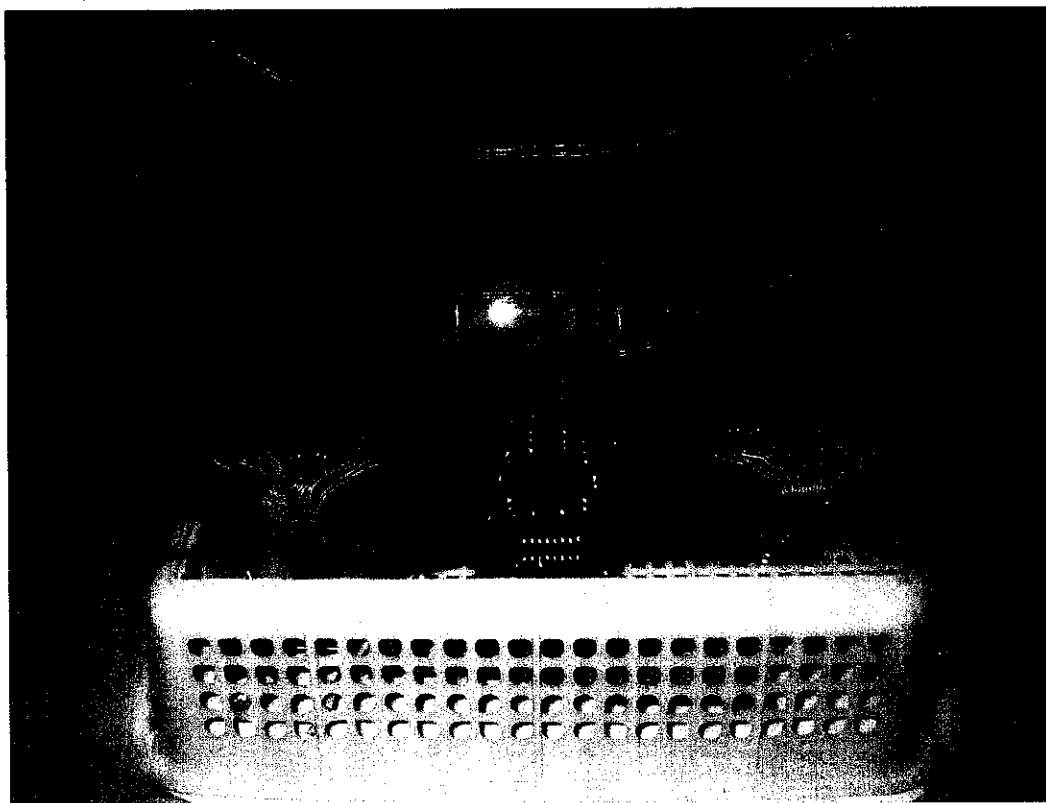
P6	LPG T7	P7	Turbine Speed RPM
2.72	23.7	1.51	91.05
2.06	23.9	1.3	87.23
1.73	24.4	1.18	84.79
1.56	25.1	1.09	82.11
1.41	25.6	1.01	79.74

**APPENDIX F
DIDATEC GAS TURBINE**



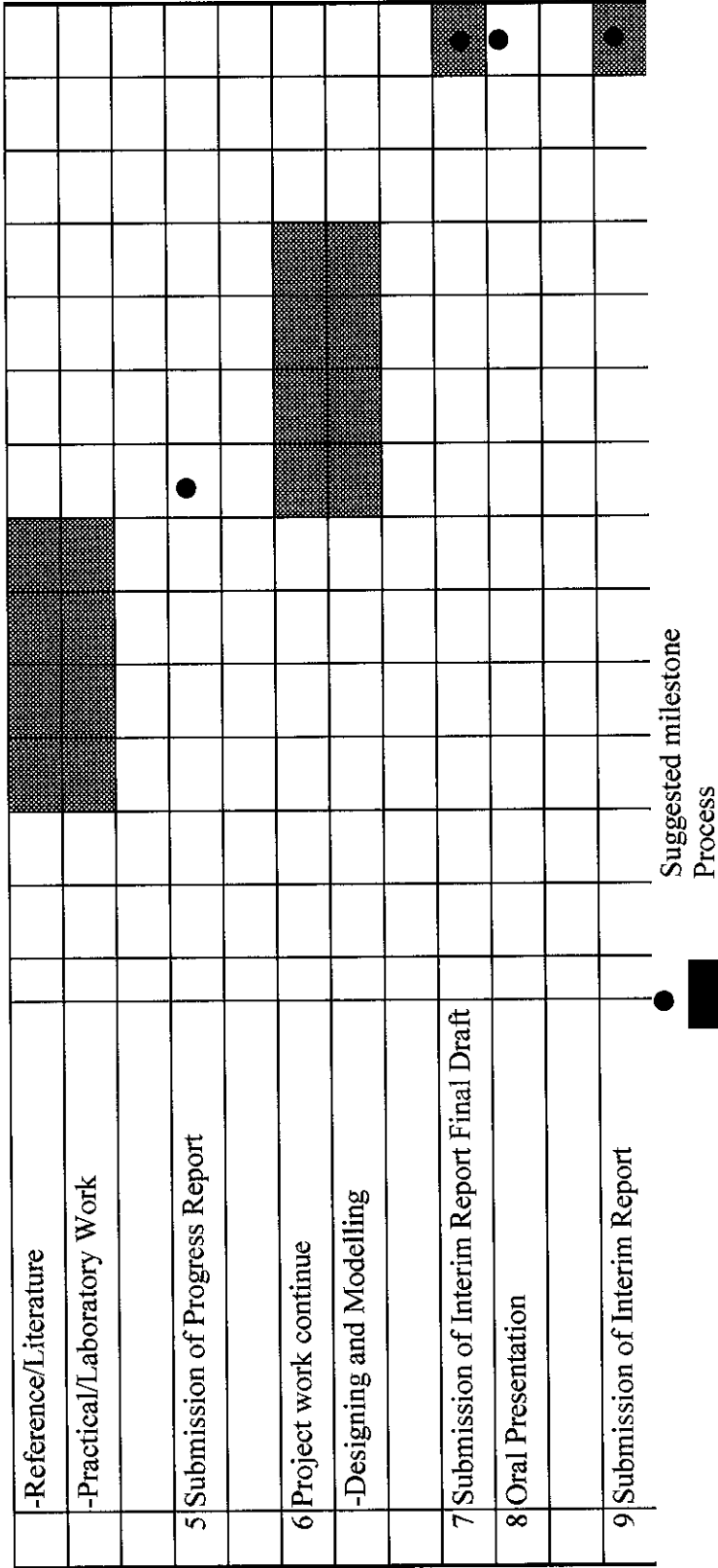
**APPENDIX G
HARDWARE PICTURE AND DESIGN**





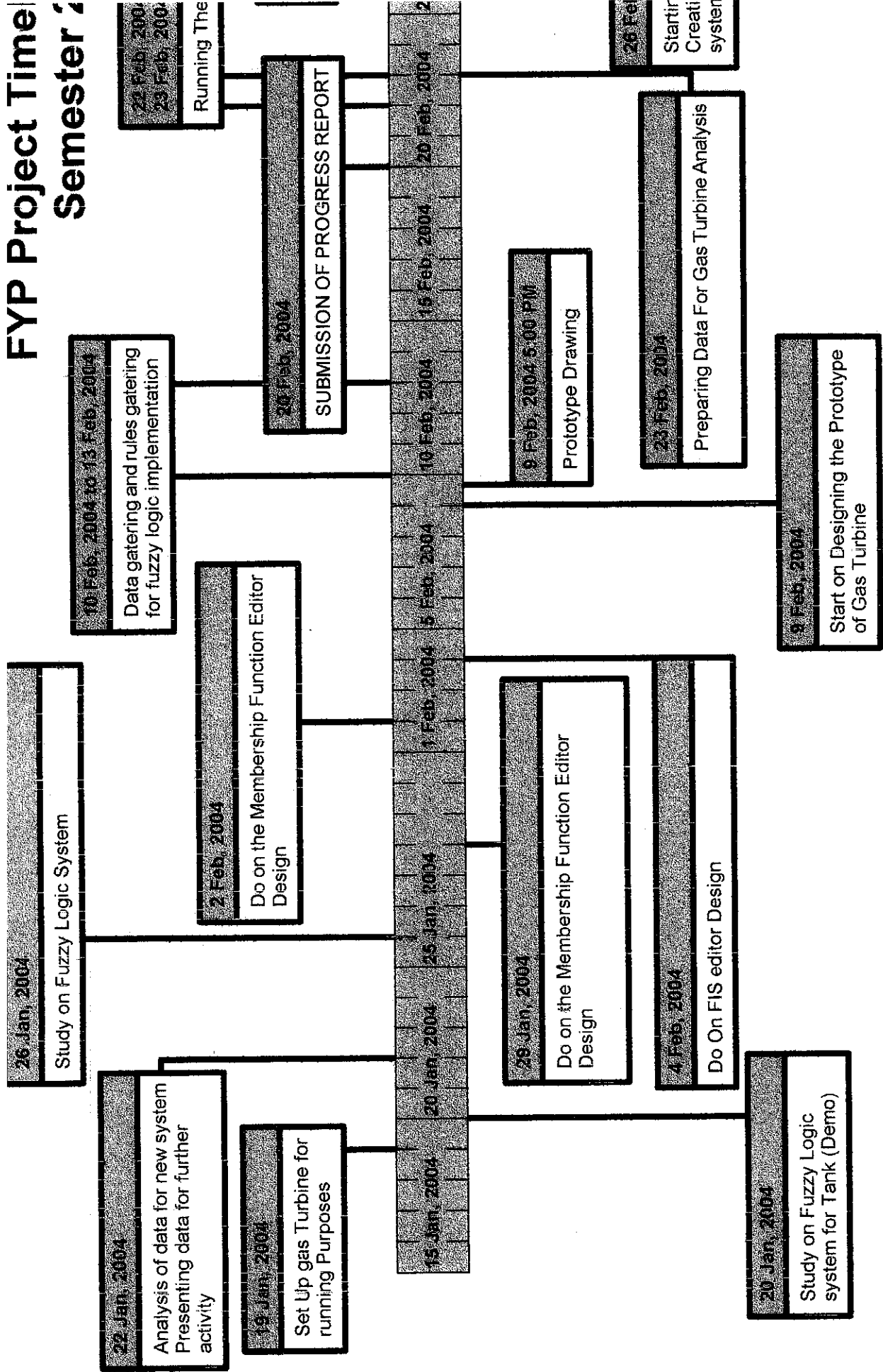
**APPENDIX H
OVERALL PROGRESS AND WORK**

No. Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Selection of Project Topic														
-Propose Topic														
-Topic assigned to students														
2 Preliminary Research Work														
-Introduction														
-Objective														
-List of references/literature														
-Project planning														
3 Submission of Preliminary Report			●											
4 Project Work														

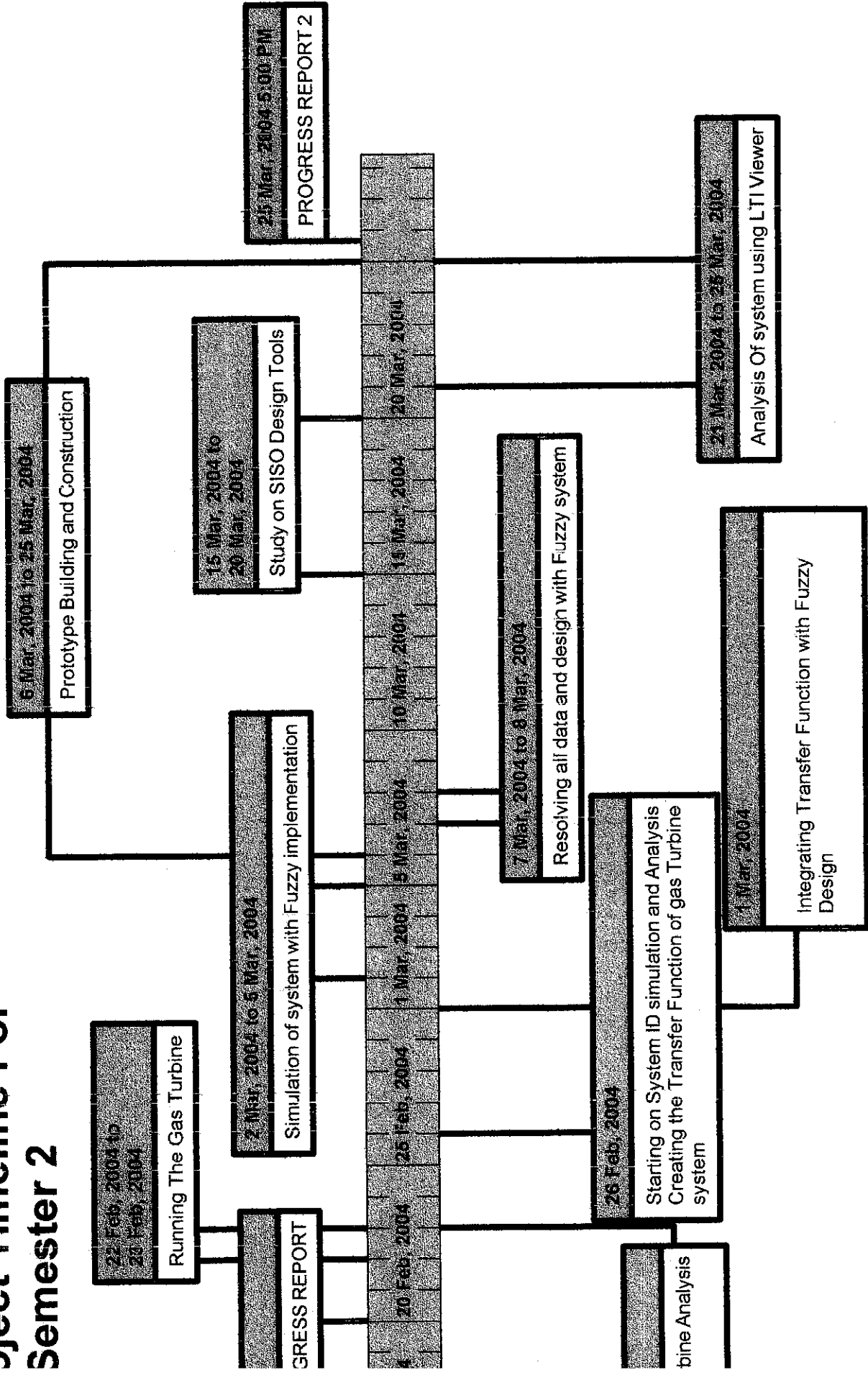


Gantt Chart Of Activity Done in Semester July 2003

FYP Project Time Semester 2



Project Timeline For Semester 2



FYP Project For 2nd Semster

Part 2

