

CHAPTER 1

INTRODUCTION

1.1 Background of Study

As early as 1970s, energy issues have become prominent and one of it is how to improve the efficiency of energy utilization. Primary way to utilize energy sources known are by using turbine. People have been using turbine all over the world to generate electrical power. Almost all electrical power on Earth is produced with a turbine of some type. A turbine is a rotary engine that extracts energy from a fluid flow. Very high efficiency turbines harness about 40% of the thermal energy, with the rest exhausted as waste heat. There are many different kind of turbine available. Some common ones are gas turbine, steam turbine, wind turbine, and locomotive turbine. It has been an issue on how to increase the efficiency of a turbine based on the factors that affect its performance.

There are currently two nos. of gas turbine installed in UTP Gas District Cooling Plant. Gas turbine engines are sometimes referred to as turbine engines. Such engines usually feature an inlet, fan, compressor, combustor and nozzle in addition to one or more turbines. Theoretically, each gas turbine in the plant is able to produce 4.2MW of power. However, due to some factors effecting the power production of the gas turbine, it is almost impossible to achieve the output power of 4.2MW.

Air-intake temperature of the compressor has been found to be one of the factors affecting the performance of a gas turbine. There had been many research work done on how to reduce the air-intake temperature of a gas turbine. One of the method uses to reduced the inlet air temperature is by using refrigerated cooling system. Since the UTP plant is also producing chilled water, this method will be use in this project. The readily available source will be utilized to reduce the intake temperature in this project.

1.2 Problem Statement

1.2.1 Problem Identification

One factor that influences the efficiency of gas turbine generator output is the air intake temperature. Low air intake temperature into the compressor will lead to increase in efficiency of the gas turbine in terms of electricity produce. With our local climate of wet and dry throughout the year, it is impossible to keep a constantly low air intake temperature naturally.

1.2.2 Significant of the Project

Hence, this project is intended to develop a way to control the air intake at relatively low temperature, enough for the turbine to perform efficiently. This project will use refrigerated cooling system by utilizing the chilled water source readily available in UTP plant. From research work done by others, it is proven to be at better advantage to solve the problem of gas turbine in UTP plant.

1.3 Objective of the Project

In order to complete this project within the time limit and the scope given, several objectives for this study have been identified and listed such as below:

1. Study on the effects of air intake temperature to the Gas Turbine Generator performance.
2. Predict the effect of changing the air inlet temperature on the output produced.
3. Develop a computer program to predict the effect of changing the parameter to the output power of the gas turbine.

1.4 The Relevancy of the Project

The research on how to reduce the temperature of air-intake for compressor has become increasingly important nowadays because of the increase in the world climate. The reduced intake temperature has been proved theoretically can increase the efficiency of a gas turbine. By installing the refrigerated cooling system, Since the existing methods have several disadvantageous and the cost of implementation is very high, utilizing the

chilled water source in the plant itself had been found as an effective method to increase the efficiency of the gas turbine.

1.5 Feasibility of the Project within Scope and Time Frame

This project started with study on how the air-intake temperature effect the performance of a gas turbine and what the suitable air-intake temperature are for it to fully performed. Find the relationship and how the inlet temperature affects the performance of a gas turbine performance. Next, with the information gathered, design a system that can be use to cool down the inlet temperature. Then, predict the effect of changing variables to get the temperature and the mass flowrate of the compressor. All the equipments and software used for this project are available in the Mechanical Engineering Lab. The information about the project can be obtained from the reference books or journals. With all the resources provided, this project can be considered a feasible project within the time frame given

CHAPTER 2

LITERATURE REVIEW

2.1 *Gas turbine Power Plants*

The gas turbine power plants may operate on either an open or closed basis. The open mode is a more common one. This is an engine which atmospheric air is continuously drawn into the compressor, where it is compressed to high pressure. The air then enters a combustion chamber, where it is mixed with fuel and combustion occurs, resulting in combustion products at an elevated temperature. The combustion products expand through the turbine and subsequently discharge to the surroundings. Part of the turbine work developed is used to drive the compressor; the remainder is available to generate electricity.

An idealization often used in the study of open gas turbine power plants is that of an air standard analysis. In air standard analysis, two assumptions are always made:

1. The working fluid is air, which behaves as an ideal gas.
2. The temperature rise that would be brought about by combustion is accomplished by a heat transfer from an external source.

With an air standard analysis, we avoid dealing with the complexities of the combustion process and the change of composition during combustion. An air standard analysis simplifies the study of gas turbine power plant considerably.

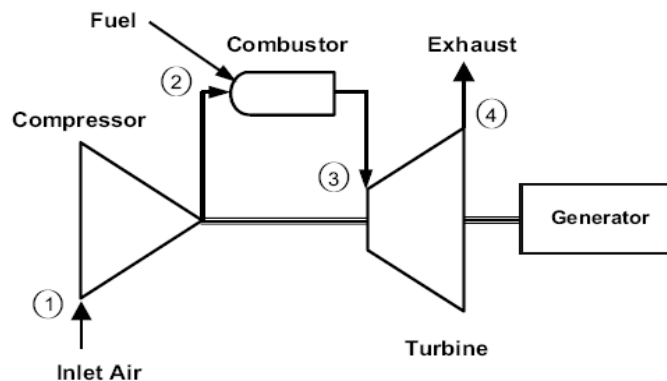


Figure 1: Simple-cycle, single-shaft gas turbine [5]

A schematic diagram of an air standard gas turbine is shown in Figure 1. The direction of the principle energy transfers are indicated on this figure by arrows. In accordance with the assumptions of an air standard analysis, the temperature rise that would be achieved in the combustion process is brought about by a heat transfer to the working fluid by the external source and the working fluid is considered to be air as an ideal gas. With the air standard idealization, air would be drawn into the compressor at state 1 from the surrounding and later return to the surrounding at state 4 with the temperature greater than the ambient temperature.

After interacting with the surroundings, each unit mass of discharged air would eventually return to the same state as the air entering the compressor. So we may think of the air passing through the components of the gas turbine as undergoing a thermodynamics cycle. A simplified representation of the states visited by the air in such a cycle can be devised by regarding the turbine exhaust air as restored to the compressor inlet state by passing through a heat exchanger of some sort where heat rejections to surroundings occurs. The cycle that results with this further idealization is called the air standard Brayton Cycle.

2.2 *Evaluating Principle Work and Heat Transfers*

The following expression for the work and the heat transfers of energy that occur at steady state are readily derived by reduction of the control volume mass and energy rate balances. These energy transfers are positive in the directions of the arrows in Figure 1. Assuming the turbines operates adiabatically and with negligible effects of kinetics and potential energy, the work developed per unit of mass is

$$\frac{W_t}{m} = h_3 - h_4$$

where m denotes the mass flow rate. With the same assumptions, the compressor work per mass unit of mass is

$$\frac{W_c}{m} = h_2 - h_1$$

The symbol W_c denotes work input and takes on positive value. The heat added to the cycle per unit mass is

$$\frac{Q_{in}}{m} = h_3 - h_2$$

The heat rejected per mass is

$$\frac{Q_{out}}{m} = h_4 - h_3$$

where Q_{out} is positive in value.

The thermal efficiency of the cycle in Figure 1 is

$$\eta = \frac{\frac{W_t}{m} - \frac{W_c}{m}}{\frac{Q_{in}}{m}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$

The net power developed can be calculated from the work done in the whole cycle.

$$W_{cycle} = m[(h_3 - h_4) - (h_2 - h_1)]$$

To evaluate the net power requires the mass flow rate m , which can be determined from the volumetric flow rate and specific volume at the compressor inlet as follows:

$$\dot{m} = \frac{(AV)_1}{v_1}$$

For the same pressure rise, a gas turbine compressor would require a much greater work input per unit of mass flow than the pump of a vapor power plant because the average specific volume of the gas flowing through the compressor would be many times greater than that of the liquid passing through the pump. Hence, a relatively large portion of the work developed by the gas turbine is needed to drive the compressor. Typical back work ratios of gas turbines range from 40% to 80%.

2.3 Ideal Air Standard Brayton Cycle

Ignoring irreversibilities as the air circulates through the various components of the Brayton cycle, there are no frictional pressure drops, and the air flows at constant pressure through the heat exchangers. If stray heat transfers to the surroundings are also ignored, the processes through the turbine and compressor are isentropic. The ideal cycle shown in figure 2 adhere to these idealizations.

Areas on T-s and p-v diagrams in figure 2 can be interpreted as heat and work, respectively, per unit of mass flowing. On the T-s diagram, area 1-4-a-b-1 is the heat rejected per unit of mass. The enclosed area in both diagrams can be interpreted as net work output.

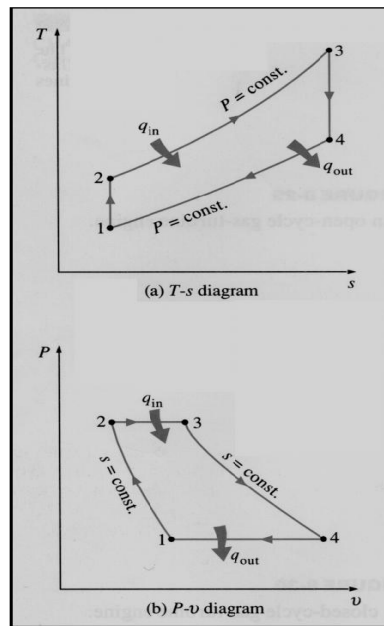


Figure 2: T-s and P-v diagram [Danise Lane]

2.4 Gas turbine irreversibilities and losses

Irreversibilities of Brayton cycle are caused by frictional effect in the compressor and turbine. As a result, there will be an increase in the specific entropy within the

components. Besides, there is pressure drop across the heat exchangers due to friction. Irreversibilities of Brayton cycle is used to describe the actual process involved in gas turbine. This cycle as represented in Figure 2-3, however ignored the pressure drop across the heat exchangers since the losses is too small.

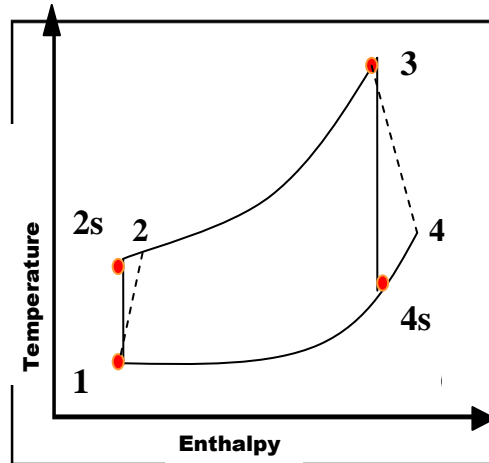


Figure 3: Effects of irreversibilities on the gas turbine

As cited by Michael and Howard (2004), the work developed by the turbine decrease and the work input into the compressor increases due to irreversibilities. In order produce appreciable net power output, the compressor and turbine should operate at its optimum efficiency.

The isentropic efficiency of turbine and compressor are:

$$\eta_t = \frac{(\dot{W}_t / \dot{m})}{(\dot{W}_t / \dot{m})_s} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

$$\eta_c = \frac{(\dot{W}_c / \dot{m})_s}{(\dot{W}_c / \dot{m})} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

2.5 Gas turbine degradation

The operation of each component in the gas turbine obeys the thermodynamic law. Since that changes in dependent variables (rotor speed, temperature, pressure and etc) defines the changes in independent variable (compressor pressure ratio, efficiency

and etc) (William 1996). Physical problems in gas turbine will result in changes of certain measurable parameter

Compressor fouling is indicated as drop in compressor efficiency and drop in compressor discharge pressure at a constant speed and load. This will result in load capacity reduction at a constant compressor inlet temperature. Due to compressor fouling, there will be drop of 2% compressor efficiency and 3% to 5% drop in load capacity at constant inlet ambient temperature (Tony 2002). Output of turbine can be reduced as much as 20% in cases of extreme compressor fouling (William 1996). However Tony (2002) cited that, 1psig decrease in compressor discharge pressure which will accompany the load reduction is not easily detectable with field instrument. While filter clog caused decrease in gas turbine power output, a decrease in compressor efficiency or an increase in the frequency of gas turbine compressor.

Performance recovery can be accomplished with compressor wash and filter cleaning or filter replacement. Output deteriorates along a decaying exponential curve. Removal of fouling deposits restores the gas turbine output to nearly the original value as in Figure 2-5:

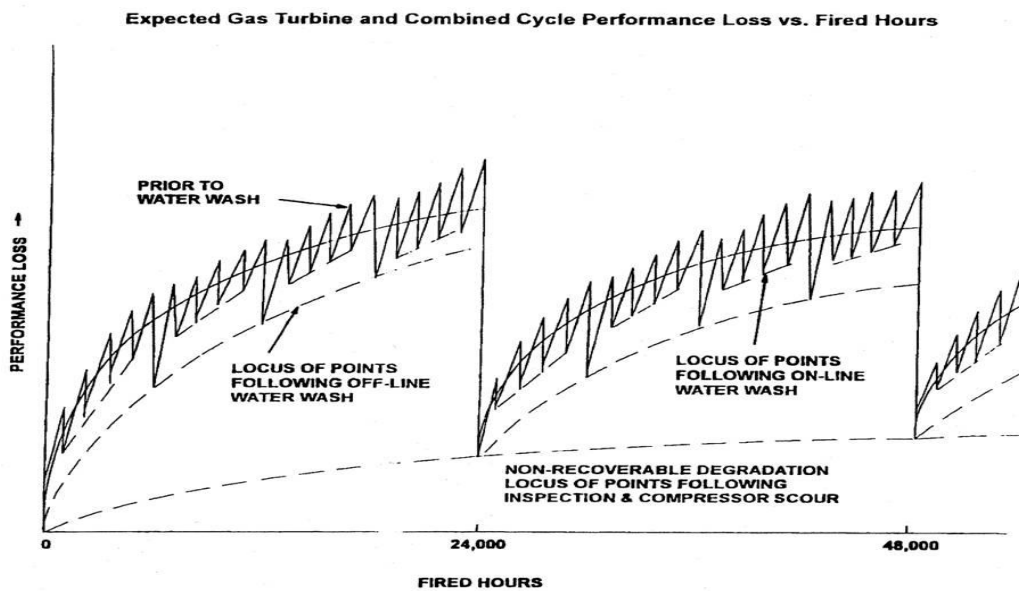


Figure 4: Performance loss to fired hours (Source: GE)

There are two types of compressor wash; online and offline water washing. On-line washing improves 1% gas turbine efficiency while off-line washing improves efficiency up to 2%-3% (Susan et al.)

During online water plain water is used while for offline water wash chemical detergent is added to water in proportion mentioned by supplier. The water temperature for both online and offline water washing should be higher than 60°C . However, the water used for the compressor wash should be properly treated to avoid accumulation of chloride on the compressor blade during the turbine operation due to the high temperature process. Most gas power plant uses demineralized water for this purpose.

2.6 Computer Program

There are many computer application that can be use to develop a computer program to predict the effect of changing the parameter of the input to the gas turbine on the output power. Some of the common ones are like the C language, Microsoft Access and Visual Basic. To write a program for a computer, u must use a computer language. In the earliest day of computers, the only programming languages available were machine languages. Each computer has its own machine language, which is made of streams of 0s and 1s. It becomes obvious that not many programs would be written if programmers continued to work in machine language. But today, instead of using machine language, scientist had managed to develop an easier way to command the computer to execute specific task, by using computer code.

Program development is a multi step process that requires you to understand the problem, develop a solution, write the program, and then test it. Your job is to determine how to take the inputs you are given and convert them into the outputs that have been specified. This is known as program design.

Visual Basic is a structured programming language which is one of the reasons that it is so popular. It is considered a high level language because it allows the programmer to concentrate on the problem at hand and not worry about the machine that the program will be using. Every Visual Basic program is made of a global declaration. The global declaration comes at the beginning of the program. The basic of global declaration is that they are visible to all parts of the program.

After the declaration of all data, come the functions where the computer program will ask the user to insert the input for the calculation of the program. This input will be use in the preceding functions mostly consists of equation to get the output of the program. With the complete code, the user can then run the program and test whether or not the desired output is achieved by inserting the needed input at the interface.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

This project will be based on the following project design. The details of every stage will be identified after this stage. Researches will be done from time to time so that the best methods and formula could be determined.

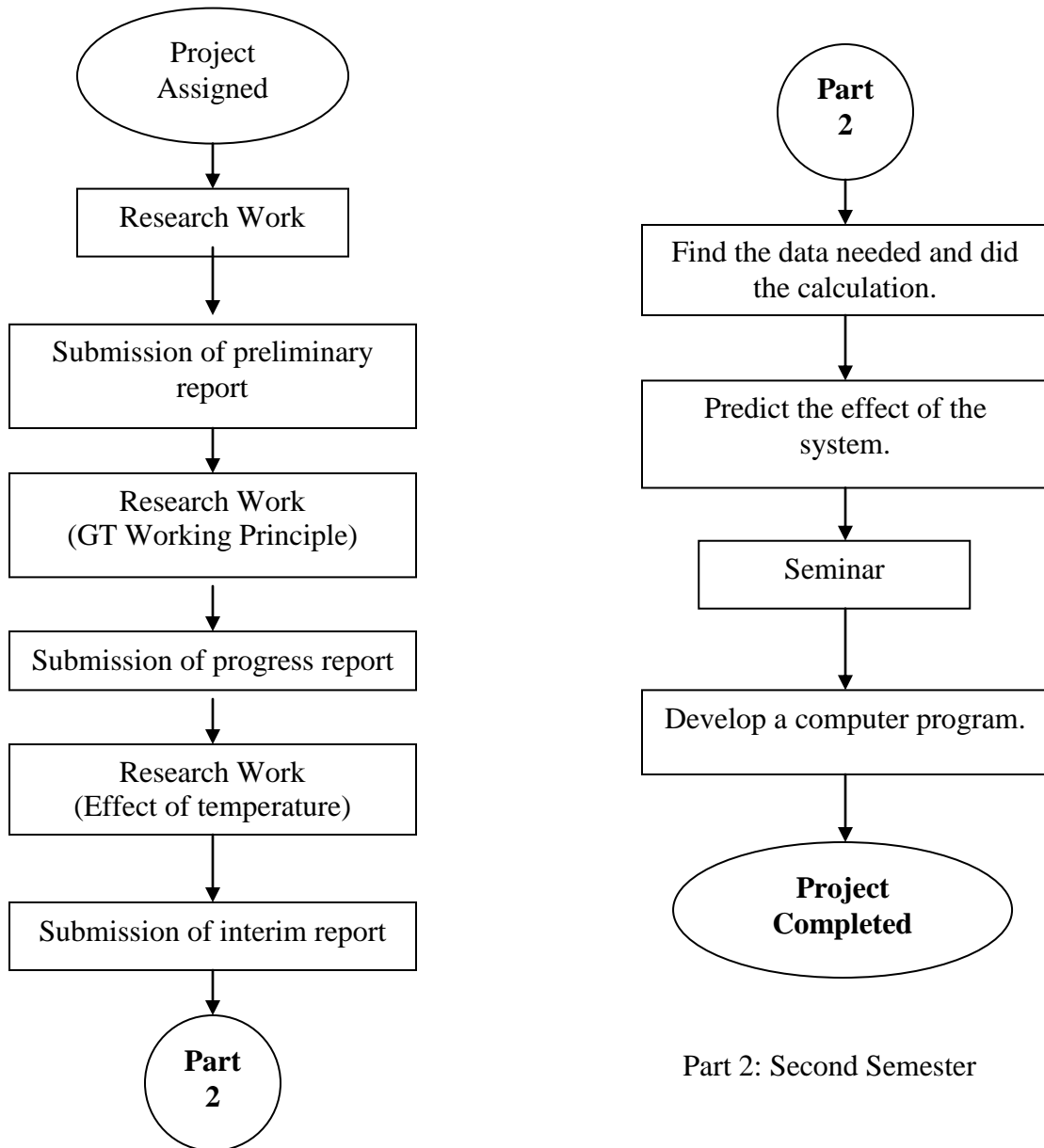


Figure 5: Project Design Flow Chart

CHAPTER 4

RESULT AND DISCUSSION

4.1 Effect of inlet temperature on Gas Turbine Performance

The mechanical energy produced by the expansion of the combustion gas through the turbine blade will be distributed to the generator and to rotate the compressor. As stated earlier, the compressor is used to compress the intake air before being channel into the combustion chamber. The amount of energy or work needed by the compressor depends on the mass flowrate of the inlet air. The higher the mass flowrate, the lower the work needed by the compressor and vice versa. So, to reduce the work needed by the compressor, the mass flowrate of the intake air will have to be increased. The mass flowrate can be increased by decreasing the temperature of the inlet air.

With lower temperature of inlet air, the mass flowrate of the air will be higher. Therefore, less work is needed by the compressor to compress the air. Since less work is needed by the compressor, much of the mechanical energy produced by the expansion process can be channel to the generator side to produce electricity and eventually increase the efficiency of the gas turbine.

The efficiency is also proven to be increased as the air inlet temperature to the combustion chamber decreases, the amount of heat that will be able to produce or Q_{in} will be much higher and therefore increasing the efficiency of the gas turbine.

$$\eta_{th, \text{Brayton}} = \frac{W_{net}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

4.2 Calculation of Work and Heat Transfer

To compare the theoretical power output by the Taurus 60 gas turbine, did the calculation by using the ambient temperature recorded by the GDC plant. Formula is developed by setting the performance datum based on engine design point for industrial unit which is the International Organization of Standardization (ISO) base load (Walsh 2004).

Compressor polytropic efficiency $\eta_{cp} = 88\%$

Combustion efficiency $\eta_b = 99.9\%$

Turbine polytropic efficiency $\eta_{tp} = 89\%$

Intake pressure loss = 2%

Combustor pressure loss = 3%

Mechanical efficiency = 99.5%

Generator efficiency $\eta_{generator} = 99.0\%$

LHV for natural gas = 43 034 kJ/kg

Source: Walsh 2004

Mass flow rate design for Solar Taurus 60 is

$\dot{m}_{design} = 21.4 \text{ kg/s}$ (Tony 2003, p269)

Density of air at ISO with $T_{amb} = 288.15\text{K}$ and $P_{amb} = 101.325\text{kPa}$ is

$\rho = P/RT = P/0.287T = 1.249 \text{ kg/m}^3$ (William 1996)

For accuracy the theoretical calculation takes into account the actual composition of fuel, working gas and the variation of specific heats and specific heat ratio with temperature.

Table 1: Mole composition of natural gas

Components	Chemical Formula	Mol (%)
Methane	CH_4	75.758
Ethane	C_2H_6	11.895
Propane	C_3H_8	5.957
Butane	C_4H_{10}	2.531
Pentane	C_5H_{12}	0.689
Hexane	C_6H_{14}	0.633
Carbon dioxide	CO_2	2.357
Nitrogen	N_2	0.150
Total		100

Table 2: Properties of Natural Gas

LHV (kJ/kg)	Chemical Formulae	Components Molar Mass (kg/kmol)	Gas Density (kg/m ³)	Mole Fraction (%)	Molecular Weight (kg/kmol)	New Density
43034	CH4	16.04	0.672776	75.758	12.15158	0.509681
	C2H6	30.07	1.265459	11.895	3.576827	0.150526
	C3H8	44.1	1.858142	5.957	2.627037	0.11069
	C4H10	58.12	2.450825	2.531	1.471017	0.06203
	C5H12	72.15	3.043508	0.689	0.497114	0.02097
	C6H14	86.18	3.636191	0.633	0.545519	0.023017
	CO2	44.01	1.858142	2.357	1.037316	0.043796
	N2	29.16	1.185366	0.15	0.04374	0.001778
					21.95015	0.922489

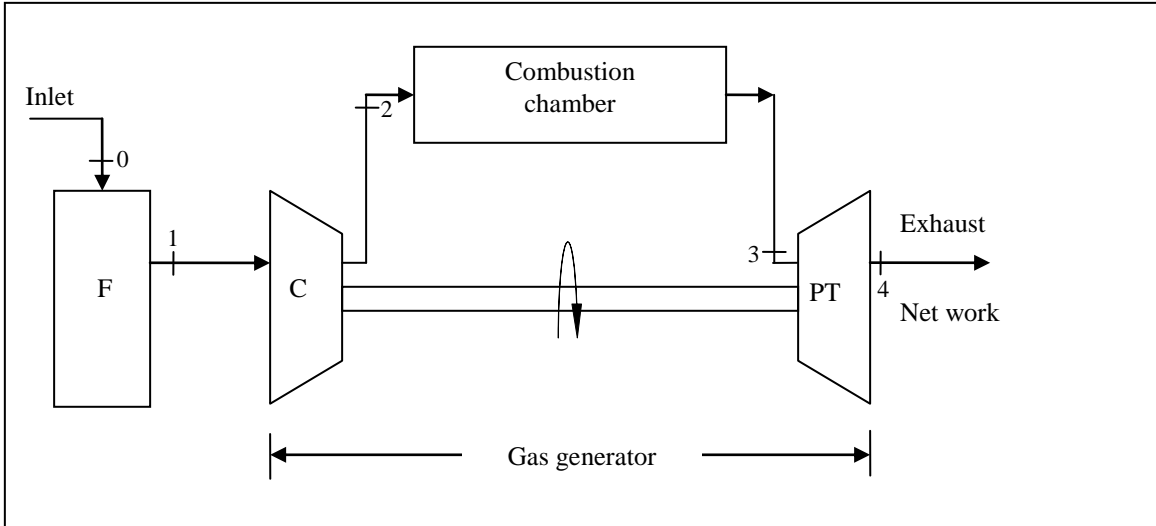


Figure 6: Schematic diagram of gas turbine for Taurus 60

Notations:

- F : Air inlet filter
- C : Compressor
- PT : Power Turbine

Compressor Section

$$P_0 = P_{amb}$$

$$T_0 = T_{amb}$$

By taking into account DP across the intake filter,

$$P_1 = P_{atm} + DP$$

Due to heat loss across the air intake filter,

$$T_1 \neq T_{amb}$$

PCD is the compressor discharge pressure that can be obtained from daily monitoring on site to get the compressor pressure ratio,

$$r_c = \frac{PCD}{P_1} = \frac{P_2}{P_1} \dots \dots \dots (1).$$

With compressor polytropic efficiency η_{cp} of 0.88, we can calculate the isentropic efficiency of the compressor

$$\eta_c = \frac{r_c^{(k-1)/\gamma} - 1}{r_c^{(k-1)/k \cdot 0.88} - 1} \dots \dots \dots (2)$$

The compressor discharge temperature, T_2 is

$$T_2 = \left[\frac{r_c^{(k-1)/k} - 1}{\eta_c} + 1 \right] T_1 \dots \dots \dots (3)$$

The specific compressor work is

$$W_{compressor} = Cp_{air} (T_2 - T_1) \dots \dots \dots (4)$$

In order to simulate the actual behavior of gas turbine through mathematical modeling, the specific heat is varies with temperature. To simplify calculation process specific heat is taken at average temperature between the compressor inlet and compressor outlet.

$$T_{avg} = \frac{(T_2 + T_1)}{2} \dots \dots \dots (5)$$

Therefore, the specific heat of air is calculated based on the formulae below:

$$Cp_{air} = \frac{Cp^o_{air}(T_{avg})}{MW_{air}} \dots \dots \dots (6)$$

where the molecular weight of air is taken as 28.97 Kg/KMole

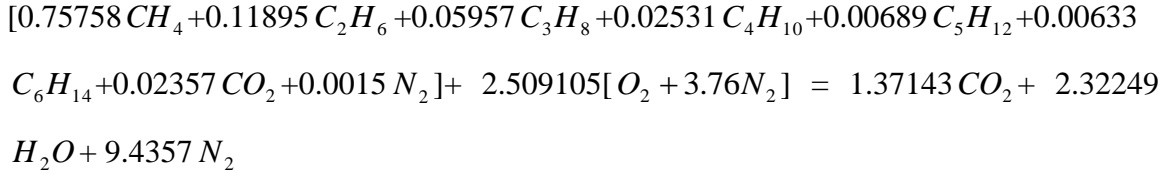
The specific heat ratio is

$$k = \frac{Cp_{air}(T_{avg})}{Cv_{air}(T_{avg})} = \frac{Cp_{air}(T_{avg})}{Cp_{air}(T_{avg}) - R} = \frac{Cp_{air}(T_{avg})}{Cp_{air}(T_{avg}) - \frac{\bar{R}}{MW_{air}}} \dots \dots \dots (7)$$

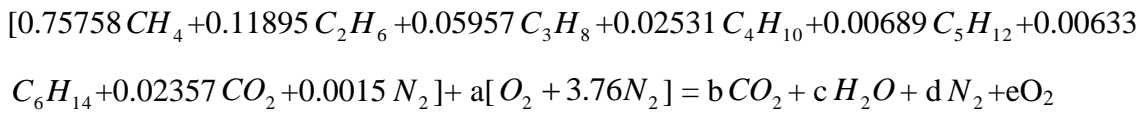
where $\bar{R} = 8.314$ KJ/Kmole

Combustor Section

Assuming the stoichiometric equation of the combustion process is described as:



With excess air combustion process, the equation is



Gas turbine operates with theoretical air of 300% to 400% (Boyce, 2006). During this model development, excess air into the combustor is assumed to be 300% in order to obtain the moles of air in the combustion process.

$$\% \text{ Excess Air} = \left(\frac{N_a}{2.509105} - 1 \right) 100 \dots \dots \dots (9)$$

Then, the air to fuel ratio of the combustion process is:

$$\frac{A}{F} = \left(\frac{\% \text{ Excess Air}}{100} + 1 \right) \times 2.509105 \times 4.76 \dots \dots \dots (10)$$

The firing temperature at T3, is calculated based on the formulae below:

$$W_{fuel} \times LHV \times \eta_{comb} = C_{pmix} (W_2 + W_{fuel}) (T_3 - T_2)$$

$$T_3 = \left(\frac{\left(\frac{F}{A} \right) \times LHV \times \eta_b}{Cp_{mix}} \right) + T_2 \dots \dots \dots (11)$$

Where Cp_{mix} is calculated based on specific heat of air at the combustor inlet temperature, T_2 and methane at the ambient temperature, T_{amb}

$$\tilde{x}_{fuel} = \frac{N_f}{N_f + 4.76N_a}$$

$$\tilde{x}_{air} = 1 - \tilde{x}_{fuel}$$

$$MW_{mix} = \tilde{x}_{air}MW_{air} + \tilde{x}MW_f$$

$$Cp^o_{mix} = \sum \tilde{x}Cp^o = \tilde{x}Cp^o_{air} + \tilde{x}Cp^o_{fuel}$$

$$C_{pmix} = \frac{Cp^o_{mix}}{MW_{mix}}$$

Where

N_f = moles of fuel

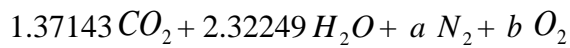
N_a = moles of air

Heat supplied into the combustor

$$Q_{in} = W_{fuel} \times LHV \dots\dots\dots(12)$$

Combustion Product

The product that would be formed with excess air combustion process



Where

$$a = \left(\frac{\% \text{ Excess Air}}{100} + 1 \right) 9.435734$$

$$b = \left(\frac{\% \text{ Excess Air}}{100} + 1 \right) 2.509105$$

Based on the product equation, specific heat of gas exits from the combustor chamber can be determined.

$$N_{product} = 1.37143 + 2.32249 + a + b$$

$$\tilde{x}_{CO_2} = \frac{1.37143}{N_{product}}$$

$$\tilde{x}_{H_2O} = \frac{2.32249}{N_{product}}$$

$$\tilde{x}_{N_2} = \frac{a}{N_{product}}$$

$$\tilde{x}_{O_2} = \frac{b}{N_{product}}$$

$$MW_{product} = \frac{1.37143(44) + 2.32249(18.02) + a(28.01) + b(32)}{N_{product}}$$

Therefore the value of specific heat at the firing temperature is

$$Cp_{gas}(T_3) = \frac{\tilde{x}_{CO_2} Cp^o_{CO_2} + \tilde{x}_{H_2O} Cp^o_{H_2O} + \tilde{x}_{N_2} Cp^o_{N_2} + \tilde{x}_{O_2} Cp^o_{O_2}}{MW_{product}}$$

Turbine

$$P_t = C_{p_{gas}} \times (T_3 - T_4) \dots \dots \dots (13)$$

Pressure ratio across the turbine

$$r_t = \frac{P_4}{P_3}$$

Where

$$P_4 = \frac{P_1}{(1 - 0.03)}$$

$$P_3 = P_2 \times (1 - 0.02)$$

Using the assumed polytropic efficiency of the turbine, η_p and expansion ratio, the efficiency of the turbine may be calculated

$$\eta_t = \frac{(1 - r_t^{\eta_p(1-y)/y})}{(1 - r_t^{(1-y)/y})} \dots\dots\dots(14)$$

From the isentropic efficiency, we are able to determine the turbine exhaust temperature

$$T_4 = \left[1 - \eta_t \left(1 - \frac{1}{r_t^{(1-y)/y}} \right) \right] T_3 \dots\dots\dots(15)$$

Final Calculation

m_{fuel} is obtained from daily monitoring on site. With know mass of fuel, the air mass flow rate can be calculated from the air to fuel ratio. However, the value should not exceed the mass flow rate design of Taurus 60.

$$m_{air} = m_{fuel} \times \frac{A}{F}$$

The output power exerts by the generator is

$$P_{generator} = (m_{air})W_{comp} + (m_{air} + m_{fuel})W_{tur} \dots\dots\dots(19)$$

Fuel consumption per hour

$$FC = W_{fuel} \times 3600 \dots\dots\dots(20)$$

While the overall efficiency of the gas turbine is

$$\eta_{overall} = \eta_{turbine} \times \eta_{compressor} \dots\dots\dots(21)$$

The heat rate of the gas turbine operation is

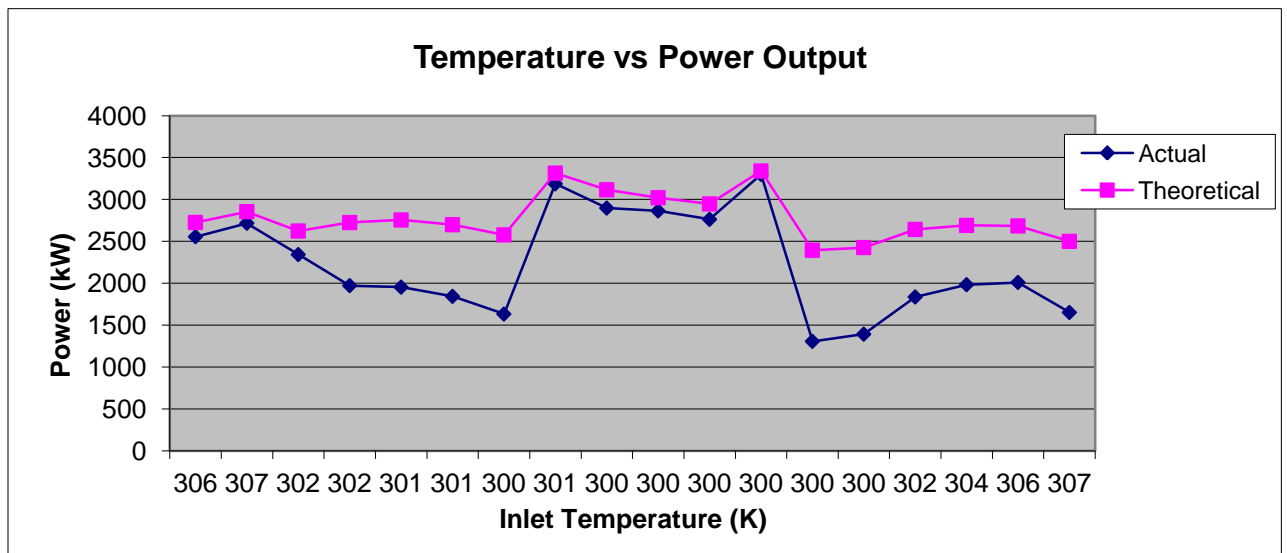
$$Heat\ Rate = \frac{3600}{\eta_{overall}} \dots\dots\dots(22)$$

4.3 Result

Comparison Actual Performance with Theoretical

T1 (K)	Power _{actual} (kW)	P _{gen} (kW)
306.4833	2556	2725.7734
306.5944	2717	2854.5497
301.8722	2343	2624.0587
301.7056	1972	2724.8947
301.0944	1954	2755.8061
300.5944	1844	2699.4651
300.3722	1633	2577.6921
300.5389	3187	3314.9654
299.5944	2898	3115.8318
300.4833	2864	3021.1920
300.4278	2763	2946.8407
300.4833	3300	3340.3479
299.7056	1307	2394.3834
299.9833	1393	2426.6522
302.0944	1837	2642.7410
303.9833	1983	2691.0746
306.2056	2010	2684.8574
306.8167	1652	2500.3251

Table 3: Power generated by Taurus 60 at specific inlet temperature.



Graph 1: Comparison between actual and theoretical output.

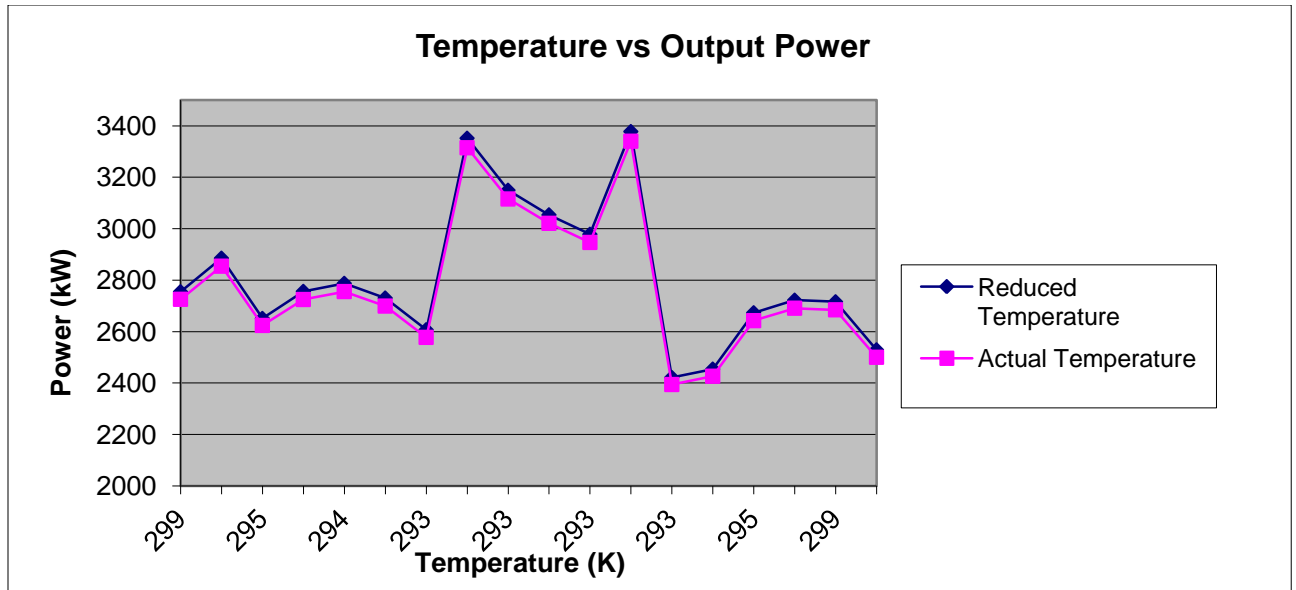
$$Deviation = \frac{|2268.2941 - 2780.0806|}{2268.2941} \times 100\% = 22.56\%$$

Comparison of power output with reduced inlet temperature

T1 (K)	P _{gen} (kW)	T1-7(K)	P _{gen} (kW)
306.4833	2725.7734	299.4833	2755.1289
306.5944	2854.5497	299.5944	2885.6405
301.8722	2624.0587	294.8722	2651.4060
301.7056	2724.8947	294.7056	2756.5028
301.0944	2755.8061	294.0944	2787.7656
300.5944	2699.4651	293.5944	2730.6864
300.3722	2577.6921	293.3722	2607.3742
300.5389	3314.9654	293.5389	3352.0112
299.5944	3115.8318	292.5944	3149.7724
300.4833	3021.1920	293.4833	3054.0883
300.4278	2946.8407	293.4278	2978.6775
300.4833	3340.3479	293.4833	3377.9162
299.7056	2394.3834	292.7056	2421.7262
299.9833	2426.6522	292.9833	2454.4325
302.0944	2642.7410	295.0944	2673.3476
303.9833	2691.0746	296.9833	2722.3306
306.2056	2684.8574	299.2056	2716.0889
306.8167	2500.3251	299.8167	2529.2426

Table 4: Powers generated using actual and reduced inlet temperature.

$$Increase = \frac{|2780.0806 - 2811.3410|}{2780.0806} \times 100\% = 1.12\%$$



Graph 2: Comparison between the output power with actual and reduced inlet temperature.

4.4 Discussion

Based on observation, we can see that the theoretical power generated deviates from the actual data. This becomes more apparent as we take into account the specific heat variation with temperature at each stage of gas turbine process.

As stated before, gas turbine operates based on load demand and the variation of power output is controlled by the fuel gas valve opening which is usually automated. It is difficult to know the exact mass flow rate at every stage and it is also difficult to accurately determine the excess air use in the combustion chamber. So for this calculation, excess air of 300% is assumed so that other value like the ratio of fuel to air can be calculated. Once the ratio had been determined, other related value can be calculated.

By using this assumption, we may be able to calculate the variation of mass flow rate of air into the compressor based on load demand thus enable us to determine the actual

compressor work. Less compressor ratio means the compressor has to do more work in order to provide sufficient mass flow rate of air into the combustor as per load demand.

Based on the calculation also, we can see that by lowering the inlet temperature, the power generated by the gas turbine will actually increase. In this calculation, the inlet temperature had been decrease by 7°C from the original inlet temperature.

4.5 Computer Program – Visual Basic

With the equation formulate in the previous section, we can use it to write the code to create an appropriate computer program that can predict the output power of the gas turbine if the user change the input parameter. There are several steps taken to come out with the program.

Step 1: Creating the Command

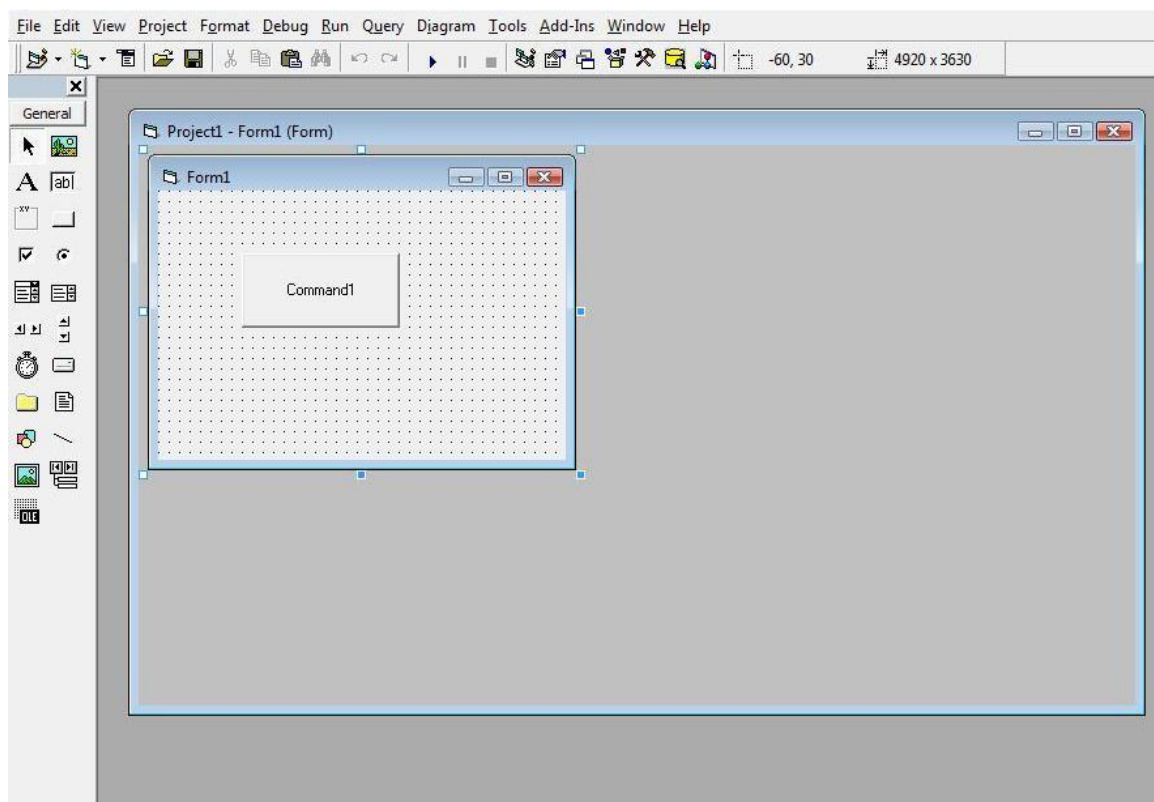


Figure 7: Starting button to start the program

Step 2: Writing the Code

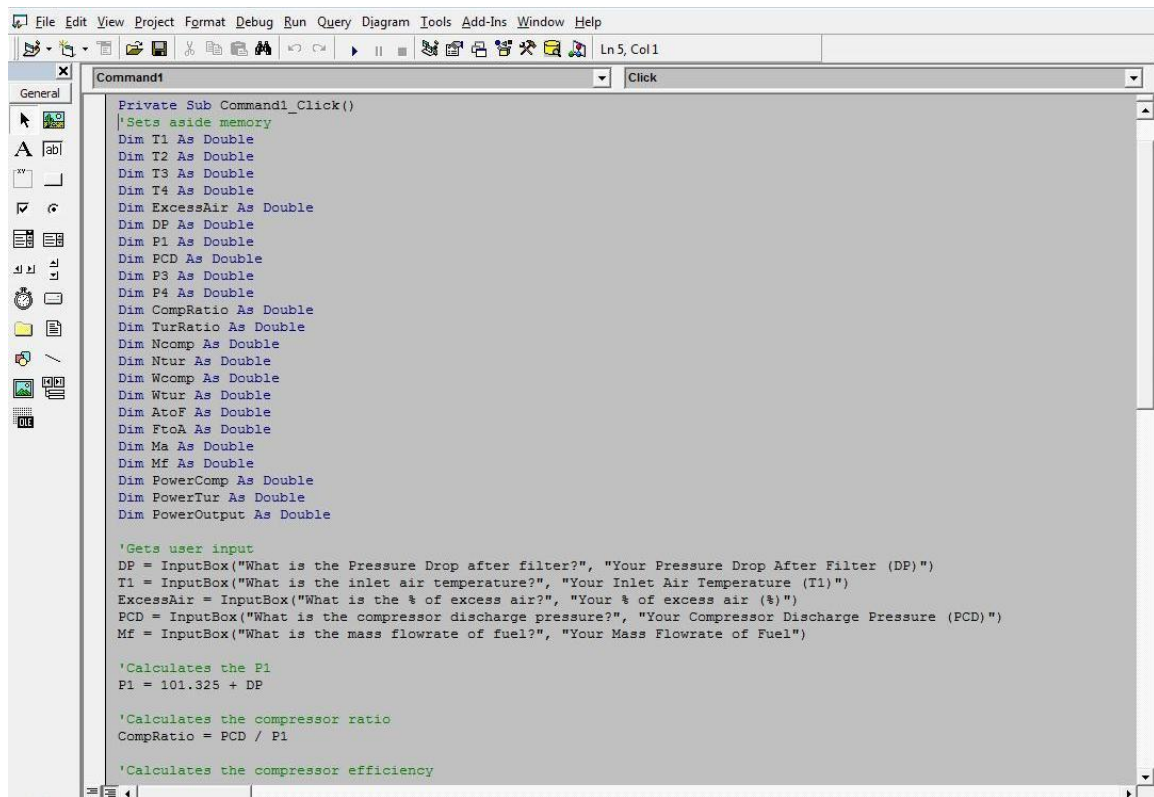


Figure 8: The code writing.

Code

```
Private Sub Command1_Click()  
'Sets aside memory  
Dim T1 As Double  
Dim T2 As Double  
Dim T3 As Double  
Dim T4 As Double  
Dim ExcessAir As Double  
Dim DP As Double  
Dim P1 As Double  
Dim PCD As Double  
Dim P3 As Double  
Dim P4 As Double  
Dim CompRatio As Double  
Dim TurRatio As Double  
Dim Ncomp As Double  
Dim Ntur As Double  
Dim Wcomp As Double  
Dim Wtur As Double
```

Dim AtoF As Double
Dim FtoA As Double
Dim Ma As Double
Dim Mf As Double
Dim PowerComp As Double
Dim PowerTur As Double
Dim PowerOutput As Double

'Gets user input

DP = InputBox("What is the Pressure Drop after filter?", "Your Pressure Drop After Filter (DP)")

T1 = InputBox("What is the inlet air temperature?", "Your Inlet Air Temperature (T1)")

ExcessAir = InputBox("What is the % of excess air?", "Your % of excess air (%)")

PCD = InputBox("What is the compressor discharge pressure?", "Your Compressor Discharge Pressure (PCD)")

Mf = InputBox("What is the mass flowrate of fuel?", "Your Mass Flowrate of Fuel")

'Calculates the P1

$P1 = 101.325 + DP$

'Calculates the compressor ratio

$CompRatio = PCD / P1$

'Calculates the compressor efficiency

$Ncomp = ((CompRatio ^ 0.2857) - 1) / ((CompRatio ^ 0.3247) - 1)$

'Calculates the compressor discharge temperature T2

$T2 = (((CompRatio ^ 0.2857) - 1) / Ncomp + 1) * T1$

'Calculates the specific compressor work

$Wcomp = 1.395 * (T2 - T1)$

'Calculates the Air to Fuel ratio

$AtoF = ((ExcessAir / 100) + 1) * 2.509105 * 4.76$

'Calculates the Fuel to Air ratio

$FtoA = 1 / AtoF$

'Calculates the T3

$T3 = ((FtoA * 43043 * 0.999) / 1.0623) + T2$

'Calculates the P3

$P3 = PCD * 0.98$

'Calculates the P4
 $P4 = P1 / 0.97$

'Calculates the turbine ratio
 $TurRatio = P3 / P4$

'Calculates the turbine efficiency
 $Ntur = (1 - (TurRatio ^ 0.2223)) / (1 - (TurRatio ^ 0.2498))$

'Calculates the T4
 $T4 = (1 - Ntur * (1 - (1 / (TurRatio ^ 0.2498)))) * T3$

'Calculates the specific turbine work
 $Wtur = 1.333 * (T3 - T4)$

'Calculates the mass flowrate of air
 $Ma = Mf * AtoF$

'Calculates the power of compressor
 $PowerComp = Ma * Wcomp$

'Calculates the power of turbine
 $PowerTur = (Ma + Mf) * Wtur$

'Calculates the power output
 $PowerOutput = (PowerTur - PowerComp) * 0.995$

'Informs the user of the result
MsgBox "The Power Output is " & PowerOutput & " kW.", vbInformation,
"Your Power Output"
End Sub

Step 3: Running the Code

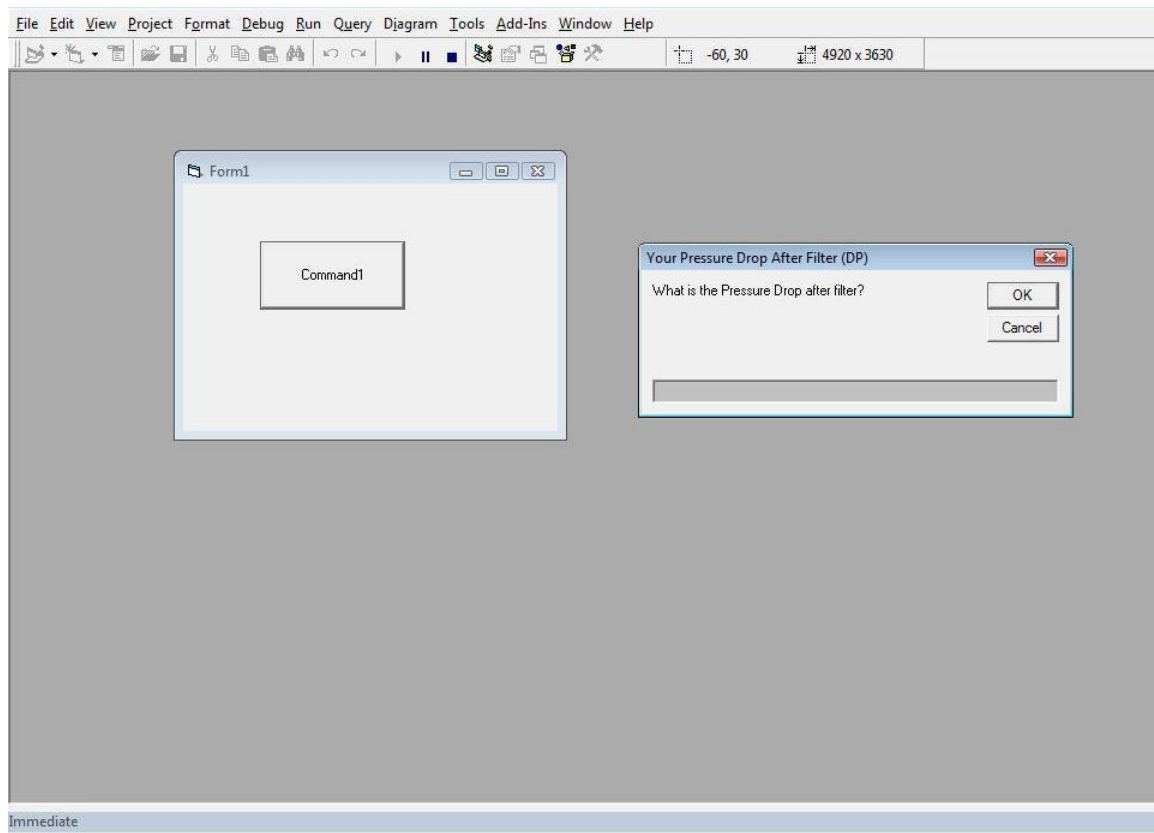


Figure 9a: Input of pressure drop across inlet air filter.

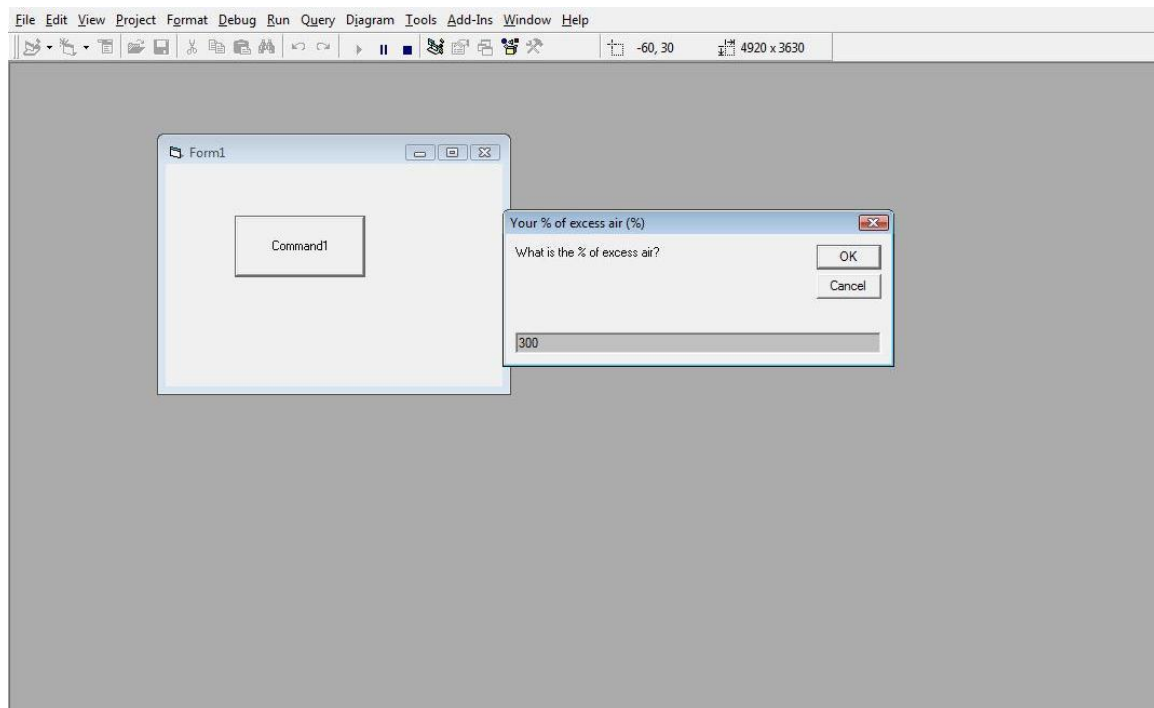


Figure 9b: Input of percentage of excess air used

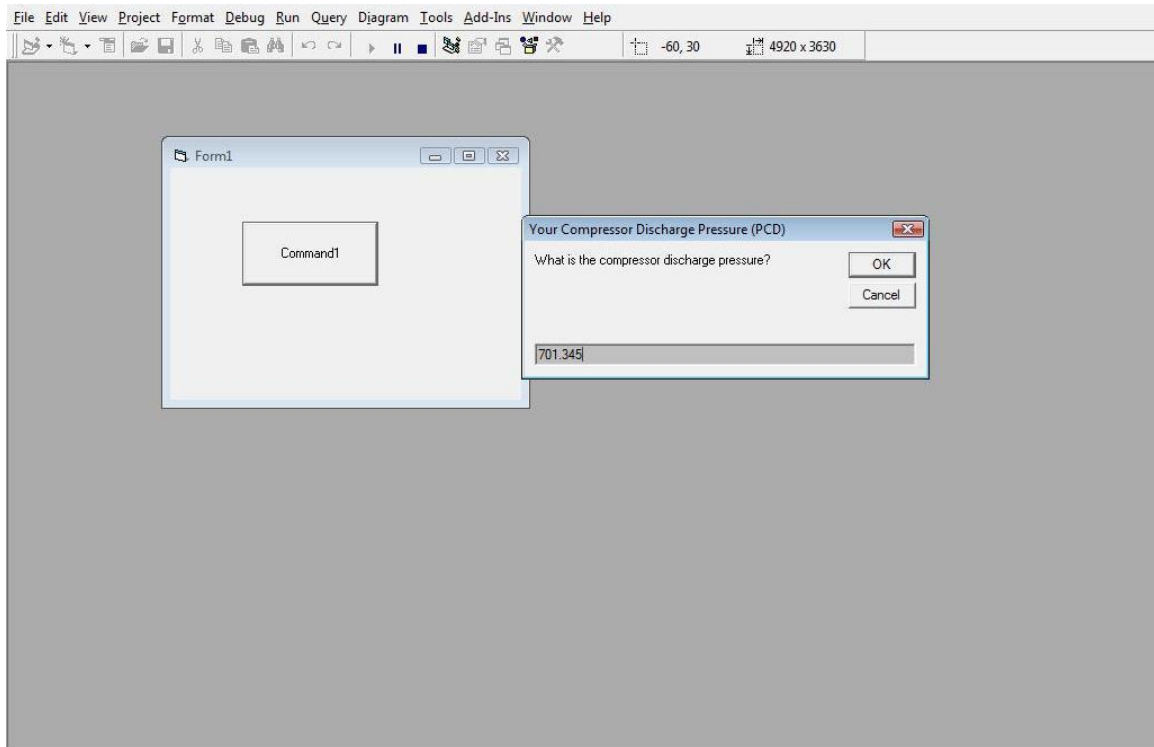


Figure 9c: Input of compressor discharge pressure

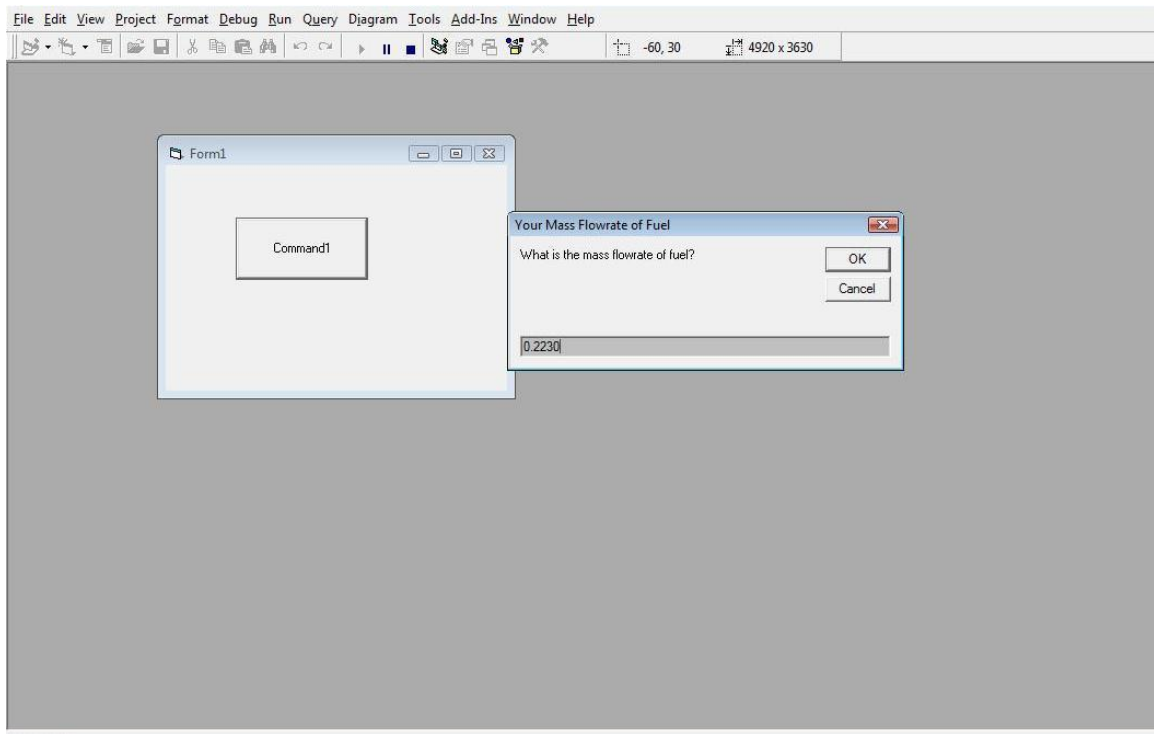


Figure 9d: Input of the mass flowrate of fuel.

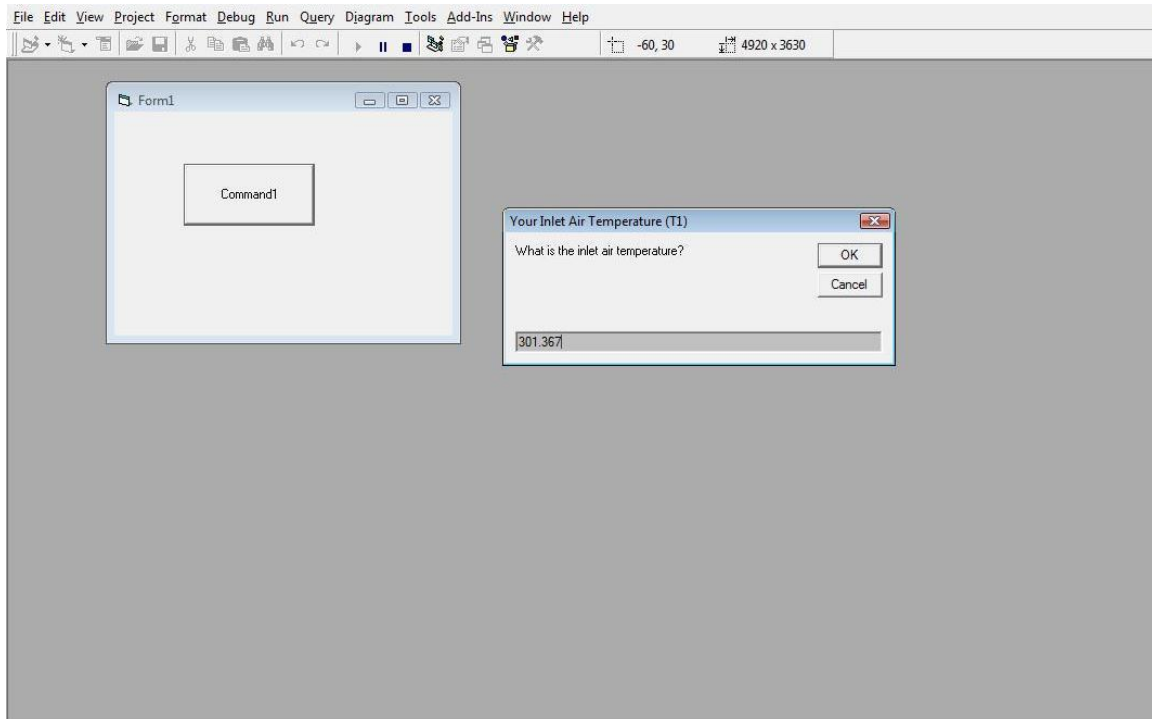


Figure 9e: Input of inlet air temperature.

Step 4: End result

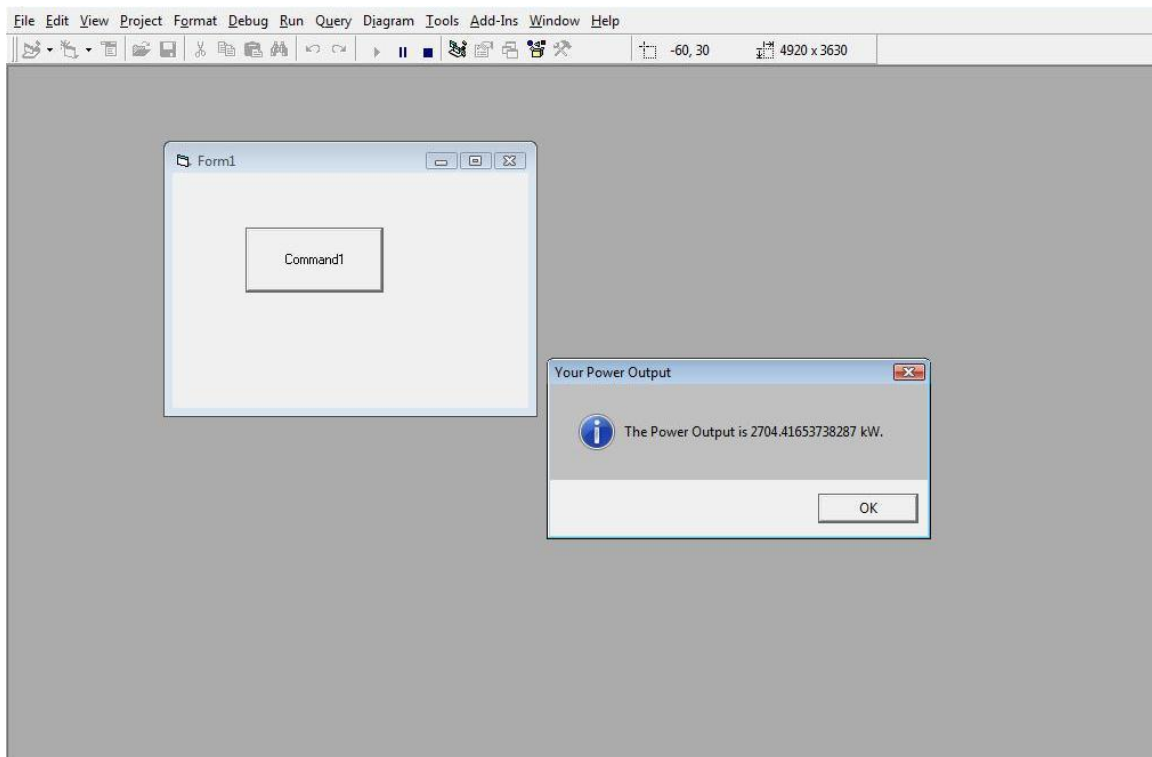


Figure 10: The predicted output power of the gas turbine.

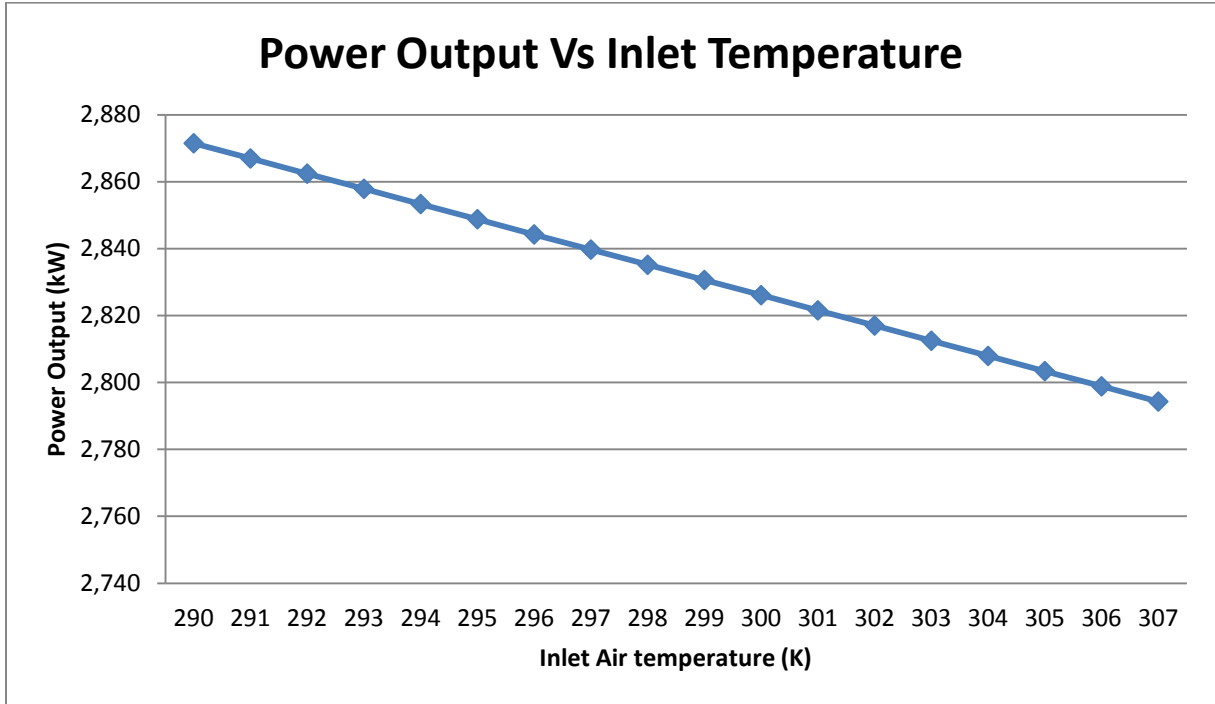
4.6 Parametric Study

For the parametric study, the analysis on how the input parameters affect the output power and the overall efficiency of the gas turbine was done. The input parameters are:

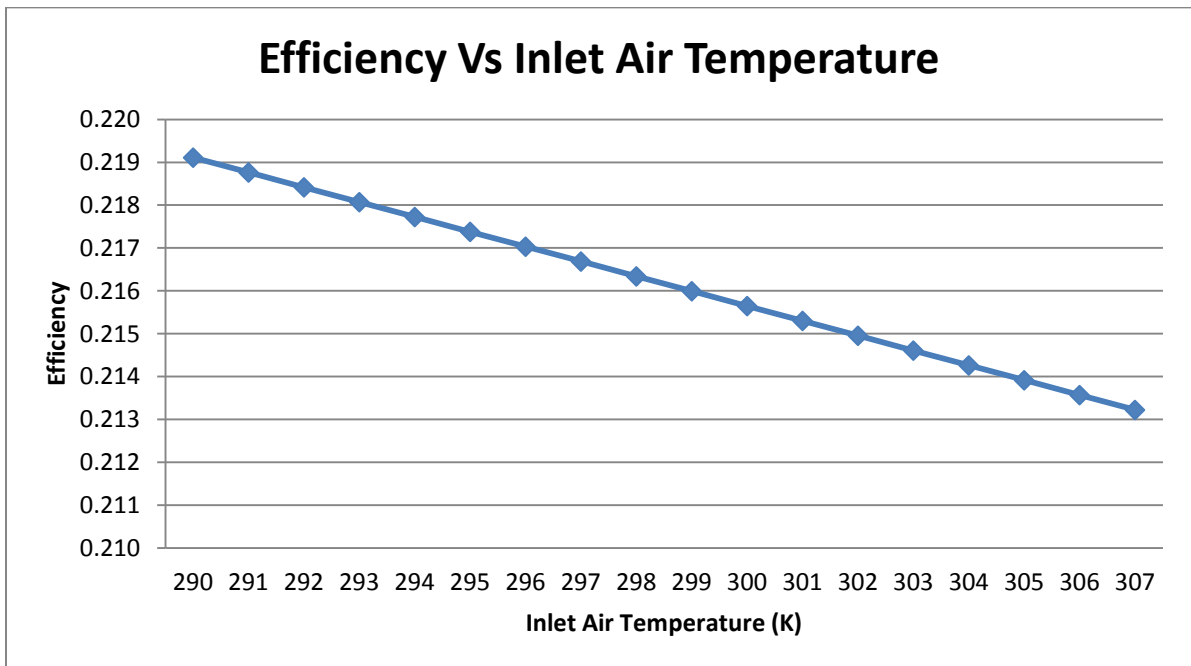
1. Inlet air temperature
2. Compressor pressure discharge
3. Pressure drop
4. Fuel mass flowrate
5. Percentage of excess air

The analysis was done one by one for all the inputs. One of the parameters is varies within certain range while others is kept constant. The graphs are plotted for all the calculation and analysis was done base on it.

1. Inlet Air Temperature



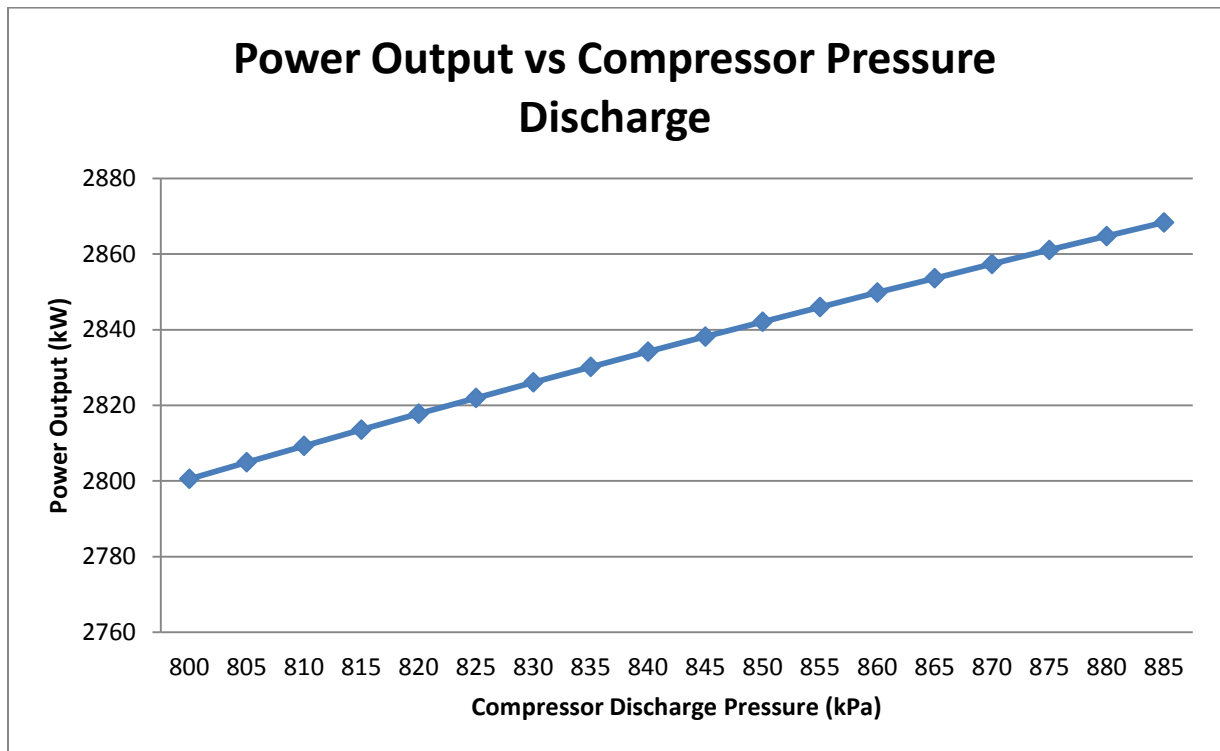
Graph 3: Power Output vs Temperature.



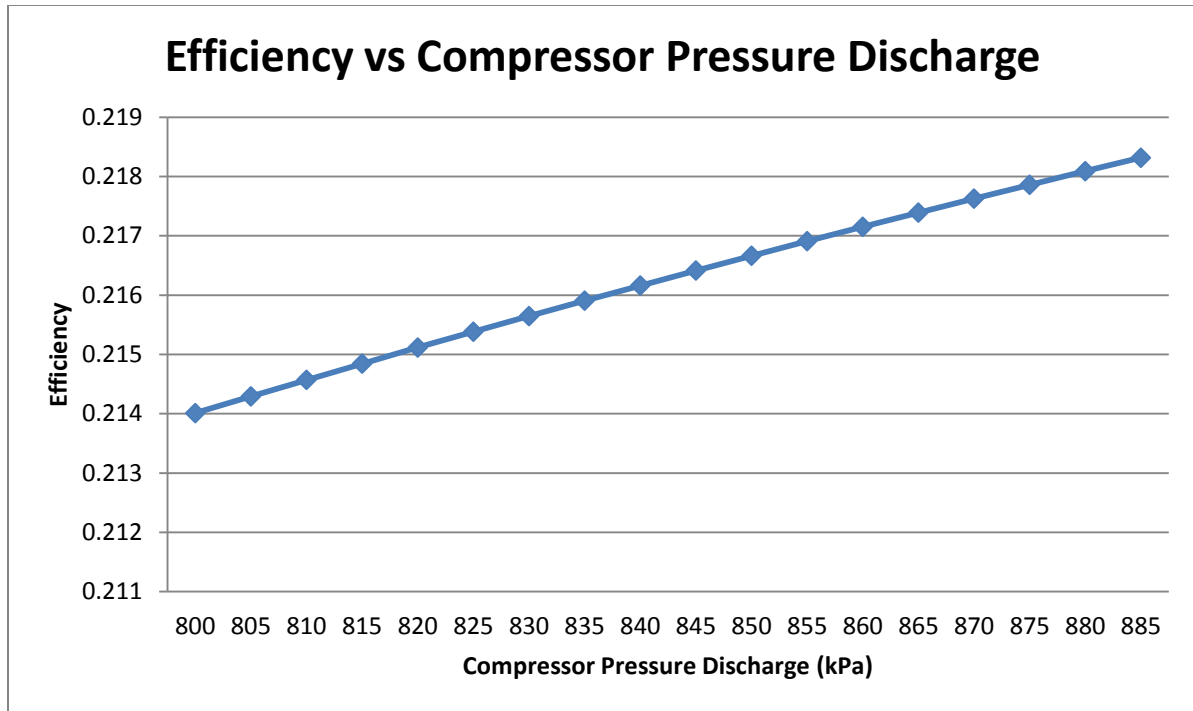
Graph 4: Overall efficiency vs Inlet air temperature

From the graph, by varying the inlet temperature while other inputs parameters are kept constant, there are changes in the output power and efficiency of the gas turbine operation. As the inlet air temperature gets higher, both the output power and efficiency of the gas turbine decrease. This shows that the lower the inlet temperature, the higher the output power and overall efficiency will be.

2. Compressor Pressure Discharge



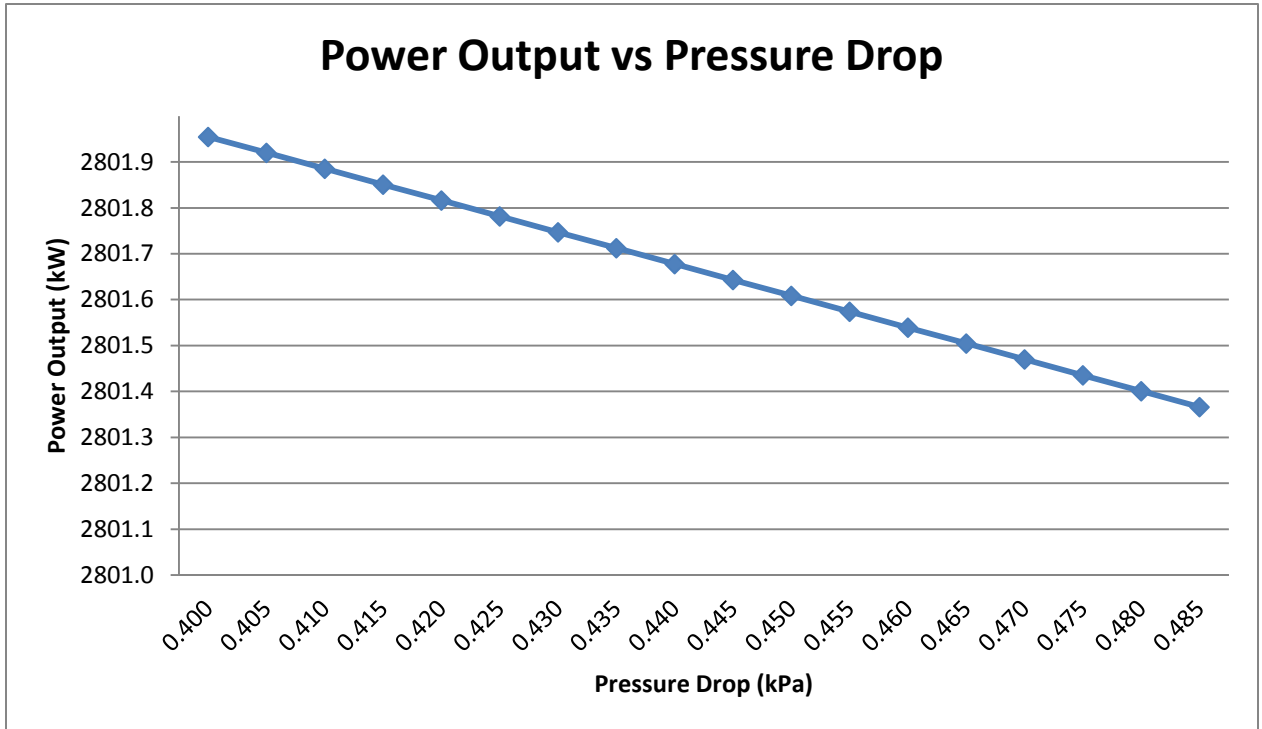
Graph 5: Power output vs Compressor Pressure Discharge



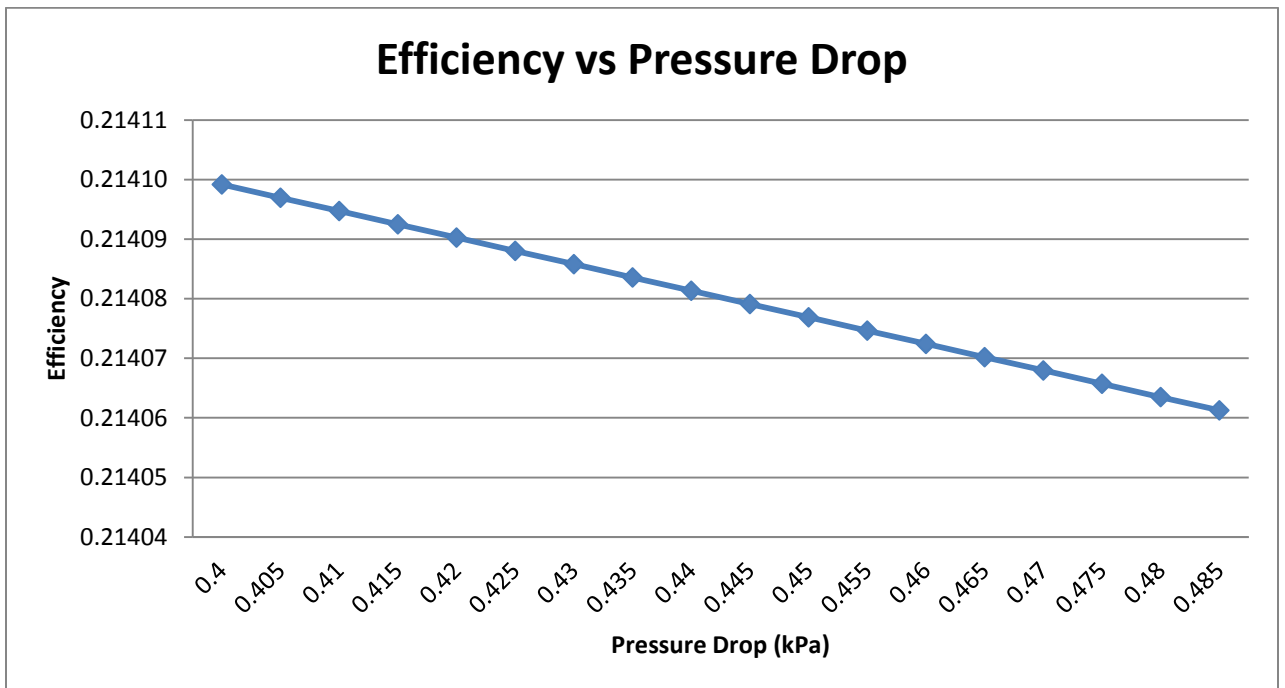
Graph 6: Efficiency vs compressor pressure discharge.

This time, the compressor pressure discharge is varied while other input parameters are kept constant. As the compressor pressure discharge gets higher, both the output power and efficiency of the gas turbine increase. This shows that the higher the compressor pressure discharge, the higher the output power and overall efficiency will be.

3. Pressure Drop



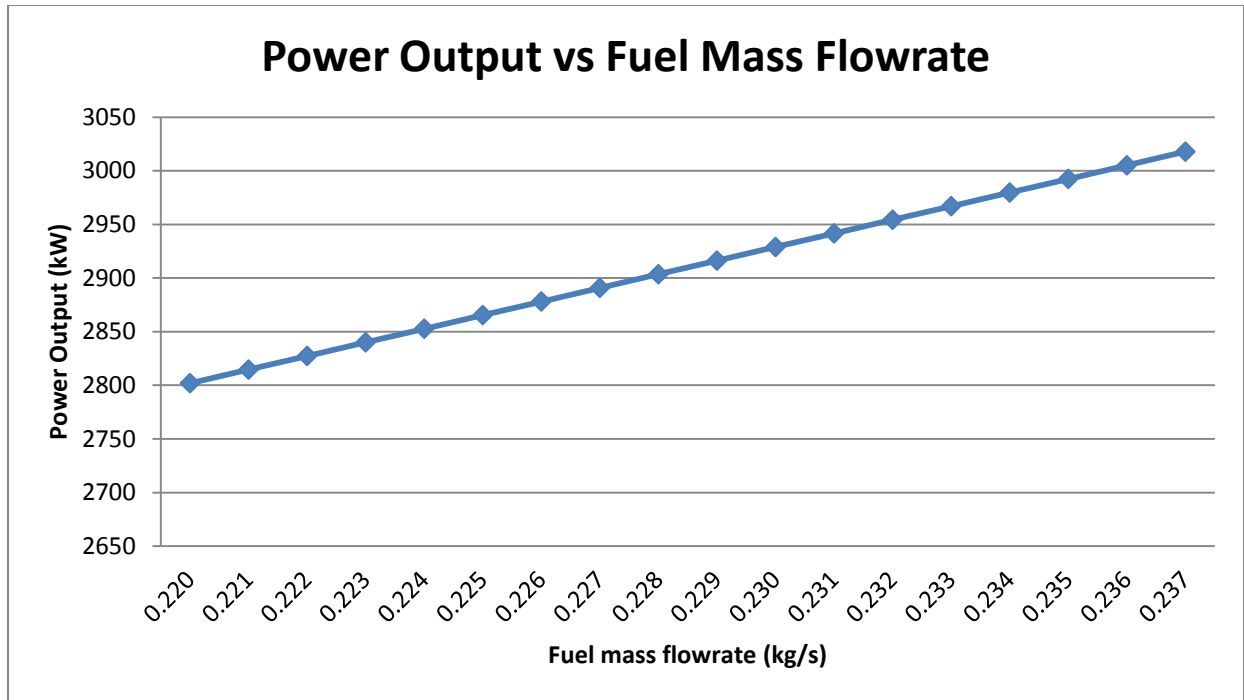
Graph 7: Power Output vs Pressure Drop



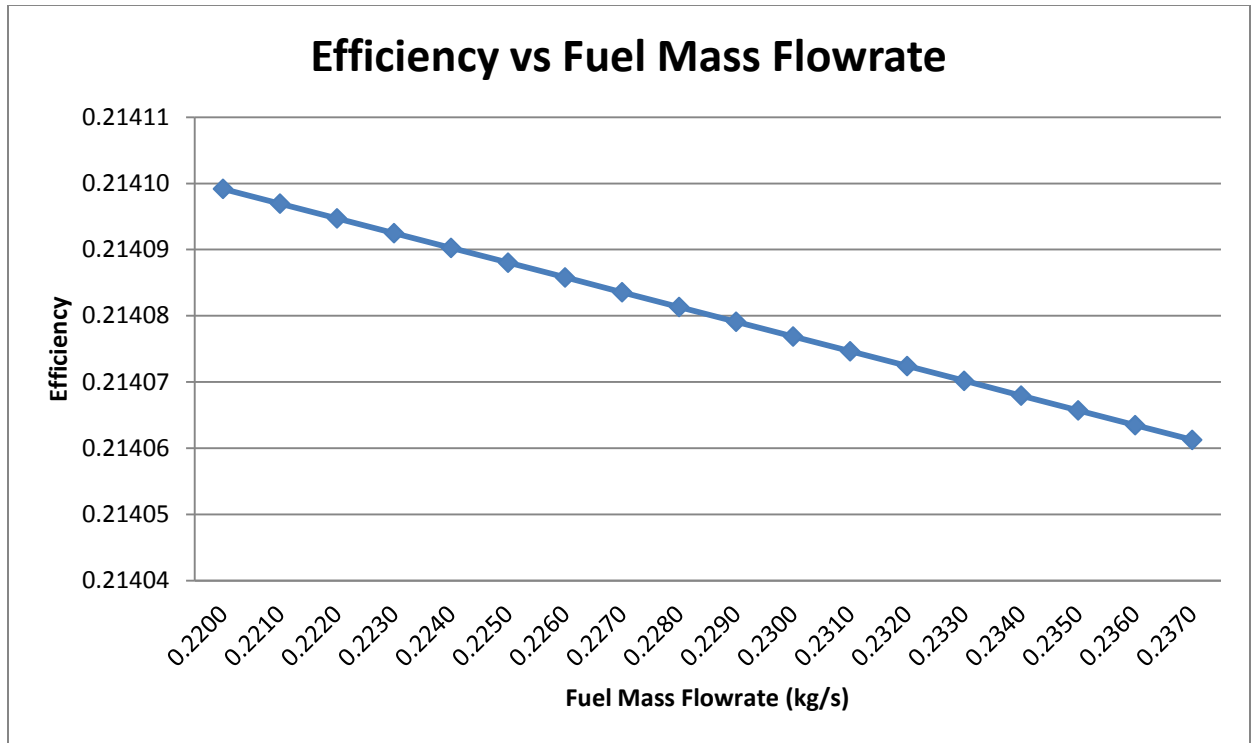
Graph 8: Efficiency vs Pressure Drop

This time, the pressure drop is varied while other input parameters are kept constant. As the pressure drop gets higher, both the output power and efficiency of the gas turbine decrease. This shows that the lower the pressure drop, the higher the output power and overall efficiency will be.

4. Fuel Mass Flowrate



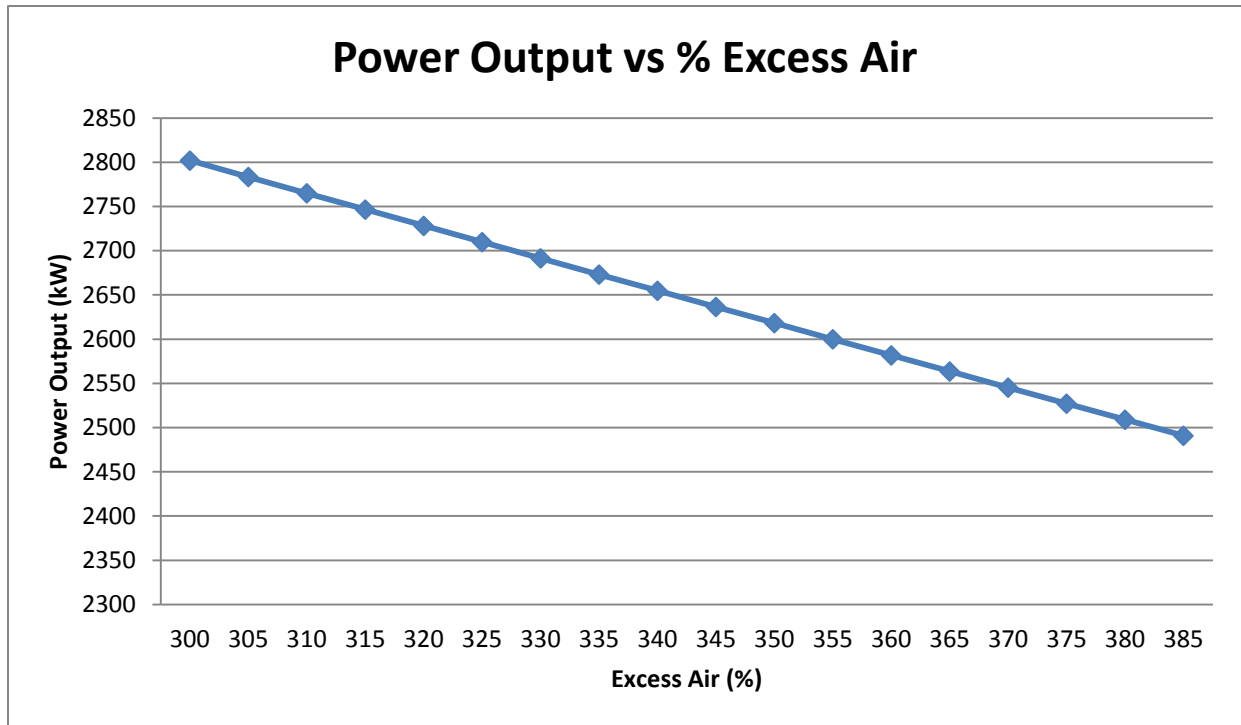
Graph 9: Power Output vs Fuel mass flowrate



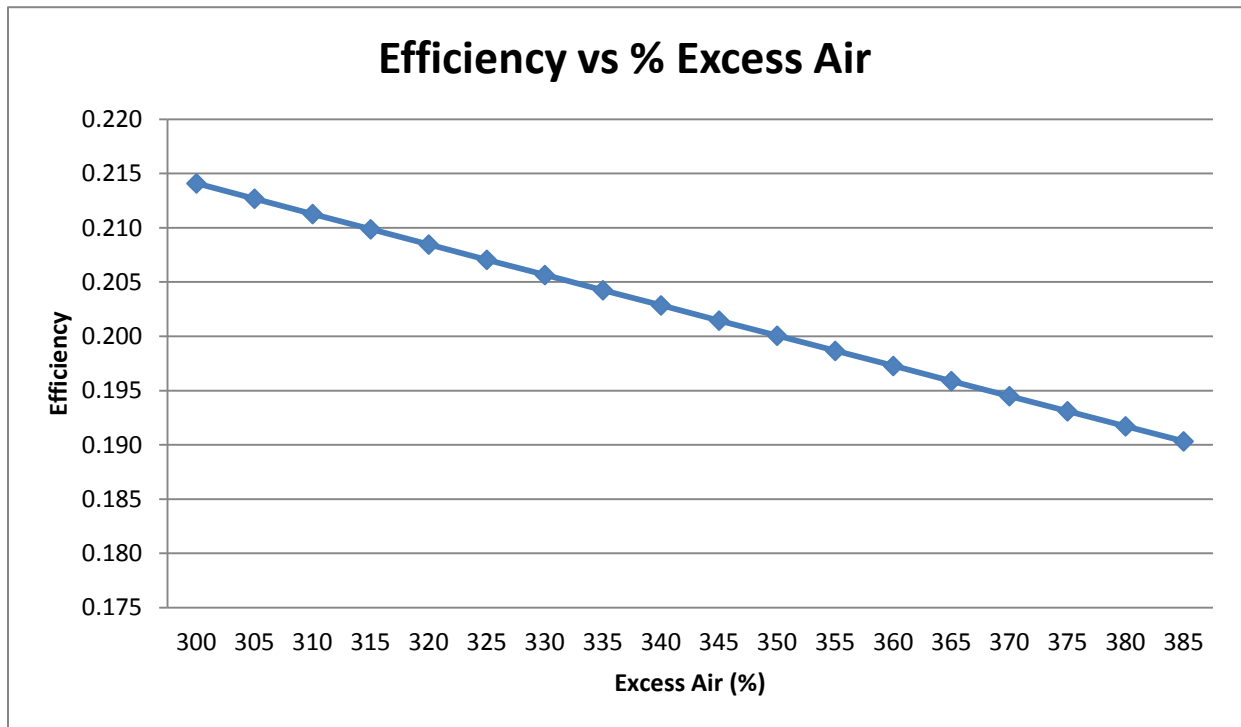
Graph 10: Efficiency vs Fuel mass Flowrate

This time, the fuel mass flowrate is varied while other input parameters are kept constant. For this case, as the fuel mass flowrate increases, the power output of the gas turbine increase but the efficiency of the gas turbine decrease. The decrease is due to the higher consumption of the fuel. This shows that, with higher fuel mass flowrate, we get gain in power output but lose in the gas turbine efficiency.

5. Percentage of excess air



Graph 11: Power Output vs % of excess air



Graph 12: Efficiency vs Percentage of excess air.

This time, the percentage of excess air is varied while other input parameters are kept constant. As the percentage of excess air gets higher, both the output power and efficiency of the gas turbine increase. This shows that the higher the percentage of excess air, the lower the output power and overall efficiency will be.

CHAPTER 5

CONCLUSION

Based on the result obtained, we can see that there is deviation between the actual power and theoretical power generated by gas the turbine. The result also proved that by lowering the inlet temperature, we can actually increase the output power of the gas turbine package. So ways can be find to reduce the inlet temperature in order to increase the power output and the efficiency of the gas turbine. By using the calculation formulated to find the output power of the gas turbine, a computer program can be created to predict the effects of changing the parameters, in this case the mass flowrate of fuel, the inlet air temperature, the compressor pressure discharge, the pressure drop after filter and percentage of excess air used. The computer program will predict the output power of the gas turbine base on the code design.

There are many ways to cool down the inlet air temperature that is available right now but further study is needed to choose and develop the most appropriate system for the gas turbine generator in UTP.

Recommendation

In order to ensure the smoothness of the project and increase the efficiency some recommendation are to be followed.

1. Proper planning of project management to ensure each milestone can be achieved within the intended time.

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