Chapter One

Introduction

1-1 Introduction:

The generation of electric power has become even more important over recent years. Due to the rising consumption and growing environmental awareness, new requirements have to be met. The power supply has to be constantly adapted to the stochastic requirements of the consumers, for the consumers of electric energy expect that they can use this energy at all times and in any quantity desired. However, the electric power cannot be stored in appreciable amounts. This means that it has to be produced at the time when it is needed. Differences between generation and consumption result in deviations from the adjusted target values of the network frequency and power delivered to customers.

The continued quest for higher thermal efficiencies has resulted in rather innovative modifications to conventional power plants, which is called the combined gas–vapor cycle, or just the combined cycle. It's more popular modification involves a gas power cycle topping a vapor power cycle; the combined cycle of greatest interest is the gas-turbine cycle topping a steam turbine cycle, which has a higher thermal efficiency than either of the cycles executed individually. The basic principle of the Combined Cycle is simple: burning gas in a gas turbine (GT) produces not only power - which can be converted to electric power by a coupled generator but also fairly hot exhaust gases. Routing these gases through a water-cooled heat exchanger produces steam, which can be turned into electric power with a coupled steam turbine and generator.

A combined cycle power plant uses both a gas and a steam turbine together to produce up to 50% more electricity from same fuel traditional simple cycle plant The waste heat from gas turbine is routed to the nearby steam turbine , which generates extra power [1].

1-2 problem statement:

Time consumed and high cost of the process To determine the performance of combined cycle power plant or its components through the available methods in order to develop an experimental prototype. Efforts needed to be concentrating on increasing the efficiency of the power plants and increase the power output while also cutting down on the fuel used.

1-3 Research importance:

The energy analysis carried out by power plant through a computer simulation or modeling is considered as the most economical solution for analyzing the energy and also helps in the future designs of power plants.
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1-4: Objectives:

- How to get the thermo economic optimization of heat recovery steam generator of combined cycle of gas turbine power plant.
- Investigate effectiveness of heat recovery steam generators.
- How to reduce the cost in terms of fuel consumption.

1-5: Methodology:

Research methodology of my work is given steps by steps as:

- An exhaustive Literature Review is under progress in the area of combined cycle .
- Visit the power plant and know the temperature and pressure inlet , Inlet and outlet temperature of gas turbine , Mass flow rate of air , Mass flow rate of fuel , A/F ratio , Compressor ratio, Condenser pressure , Mass flow rate of steam , Inlet temperature of steam turbine , Inlet and outlet pressure of steam turbine.
- Calculate the efficiency of the power station
- Simulation studies of gas turbine – combined cycle power plant for gas turbine.
- The result are obtained the result are shown in the form of graph.
- study how to make an optimization and choose the most appropriate way of optimization to use it in the study and calculate the optimum values for the parameters.

1.6 Scope of Work:

Scope of Work in this research are:

- calculate the efficiency of combined cycle by using MATLAB program.
- Calculate the less cost to produce MW.
- Study the effective of heat recovery steam generator in reducing cost.

Chapter Two

Theoretical Background and Literature Review

2-1 Theoretical Background :

A combined cycle power plant including a gas turbine, a steam turbine, and a heat recovery steam generator. The power plant also includes a feed-water heater positioned downstream of the steam turbine and a fuel moisturization system in communication with the heat recovery steam generator.

This type of power plant is being installed in increasing numbers round the world where there is access to substantial quantities of natural gas. A Combined Cycle Power Plant produces high power outputs at high efficiencies (up to 66%) and with low emissions. In a Conventional power plant we are getting 33% electricity only and remaining 67% as waste. By using combined cycle power plant we are getting 68% electricity.

A combined cycle power plant utilizes a gas turbine and a steam turbine in combination to produce power. The power plant is arranged such that the gas turbine is thermally connected to the steam turbine through a heat recovery steam generator ("HRSG"). The HRSG is a non-contact heat exchanger that allows feed water for the steam generation process to be heated by otherwise wasted gas turbine exhaust gases.

2-2 Working principle of CCGT plant:

as shown in Fig.2.1 Ambient air is filtered and led to the compressor of the gas turbine, where it is compressed and fed to the combustor .In the combustor the compressed air is heated up, to the turbine inlet temperature. And expanding in the turbine.

After expansion the flue is led to the HRSG. Steam is generated in the HRSG by heat transfer from the flue to the feed-water.

The steam generated is passed through the super heater. Superheated steam then flows through the turbine. After doing work in the turbine the pressure of steam is reduced. Steam leaving the turbine passes through the condenser which is maintained the low pressure of steam at the exhaust of turbine.

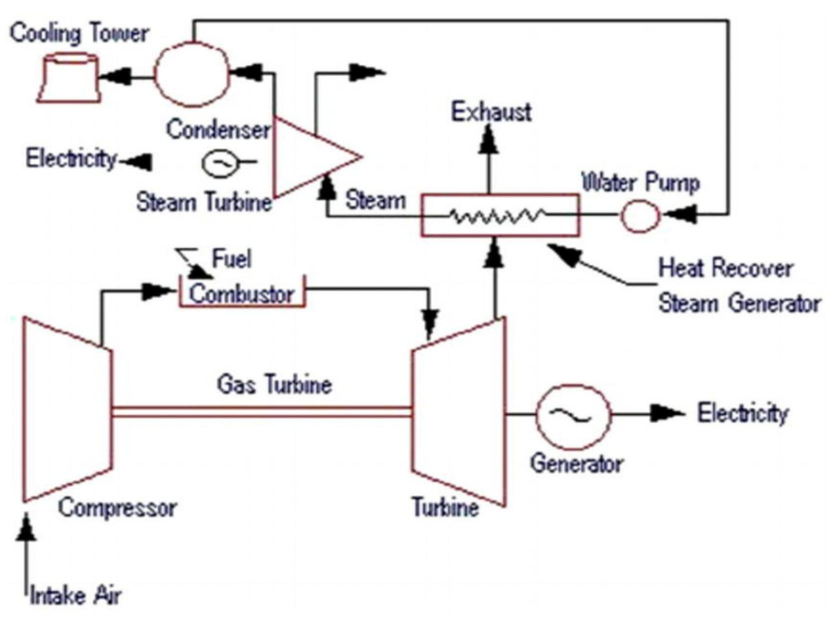


Fig.2.1 A schematic diagram of combined cycle power plant

2-3 Main components of combined cycle power plants :

The major components that make up a combined cycle are compressor , gas turbine HRSG, and steam turbine as shown in Fig.2.1.

2-3-1 : Compressor:

A compressor is a device, which pressurizes a working fluid There are three types of compressors. The positive displacement compressors are used for low flow and high head, centrifugal compressor are medium flow and medium head, and axial flow compressor for high flow and low head. Nearly all gas turbine plants producing over 5 MW have axial flow compressors .

In an axial flow compressor air passes from one stage to the next with each stag raising the pressure slightly. By producing low pressure increases on the order of 1.1 to 1.4, very high efficiencies can be obtained. The use of multiple stages permits overall pressure increase up to 40:1. The rule of thumb for a multiple stage gas turbine compressor would be that the energy raise per stage would be constant rather than pressure raise per stage.

The compressor produces 30:1 pressure in 22 stages.

The centrifugal compressor is slightly less efficient than the axial flow compressor, but it has a higher stability. A higher stability that it’s operating range is greater (surge to choke margin) [2].

2-3-2 Combustor :

All gas turbine combustors perform the same function; they increase the temperature of the high-pressure gas. The gas turbine combustor uses very little of its air (10%) in the combustion process. The rest of the air is used for cooling and mixing. The new combustors are also used circulating steam for cooling purposes .The air from the compressor must be diffused before it enters the combustor. The velocity of the air leaving the compressor is about 122 to 183 (m/sec) and the velocity in the combustor must be maintained below 15.2 (m/sec). Even at these low velocities care must be taken to avoid the flame to be carried on downstream. The combustor is a direct-fired air heater in which fuel is burned almost stoichiometrically with one third or less of the compressor discharge air. Combustion products are then mixed with the remaining air to arrive at a suitable turbine inlet temperature. Despite the many design differences in combustors[2].

all gas turbine combustion chambers have three features :

(1) a recirculation zone.

(2) a burning zone (with a recirculation zone which extends to the dilution region).

(3) a dilution zone.

The air entering a combustor is divided so that the flow is distributed between three major regions:

(1) Primary Zone.

(2) Dilution Zone.

(3) Annular space between the liner and casing.

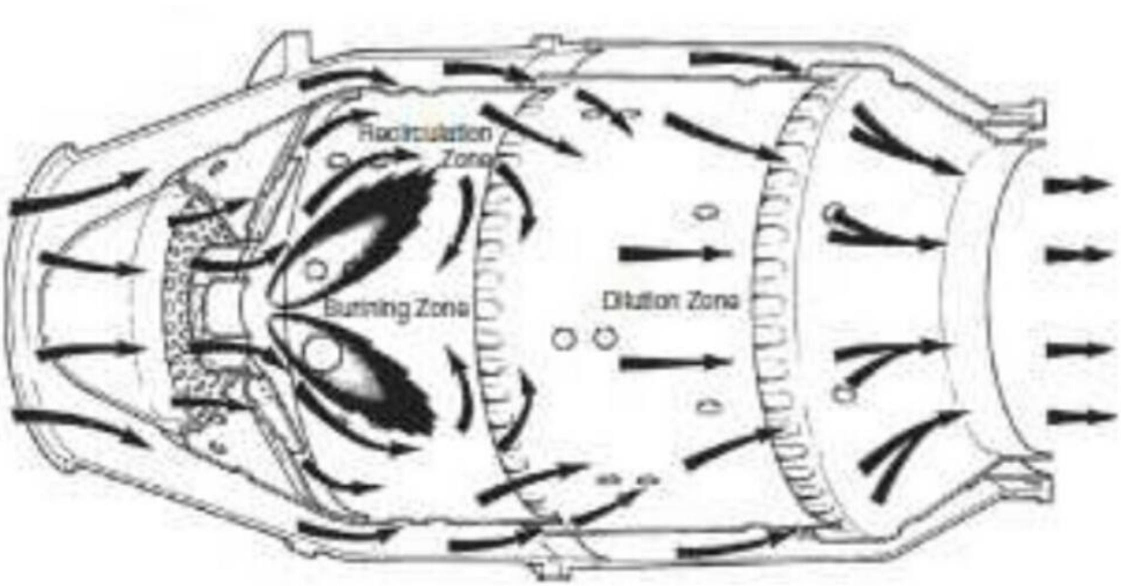


Fig.2-2 A typical combustor

Combustor performance is measured by efficiency, the pressure decrease encountered in the combustor, and the evenness of the outlet temperature profile. The combustion efficiency is a measure of combustion completeness. The combustioncompleteness affects fuel consumption directly, since the heating value of any unburned fuel is not used to increase the turbine inlet temperature. Normal combustion temperatures range from 1871 0C to 1927 0C. At this temperature, unburned fuel is not used to increase the turbine inlet temperature. Normal combustion temperatures range from 1871 0C to 1927 0C. At this temperature , the volume of nitric oxide in the combustion gas is about 0.01%. If the combustion temperature is lowered, the amount of nitric oxide is substantially reduced.[2]

2-3-3 Gas turbine :

There are two types of turbine used in gas turbine

I. Axial flow turbine.

II. Radial flow turbine .

The axial flow turbine, like its counter parts the axial flow compressor, has flow which inter and leaves in the axial direction. Most axial flow turbine consist of more than one stage: the front stages are usually impulses (zero reaction) and the later stages have about 50% reaction. The impulses stages produces about twice output of a 6 comparable 50% reaction stage, while the efficiency of an impulses stage is less than that of 50% reaction stages [2].

The high temperatures that are now available in the turbine section are due to improvements of the metallurgy of the blades in the turbines. The developments of directionally solidified blades as well as the new single crystal blades, with the new coatings, and the new cooling schemes, are responsible for the increase in firing temperatures. The high-pressure ratio in the compressor also causes the cooling air used in the first stages of the turbine to be very hot. The temperatures leaving the gas turbine compressor can reach as high as 649 0C. Thus, the present cooling schemes need revisiting and the cooling passages are in many cases also coated. The cooling schemes are limited in the amount of air they can use, before there is a negative effort in overall thermal efficiency due to an increase in the amount of air used in cooling. The rule of thumb in this area is that if you need more than 8% of the air for cooling you are loosing the advantage from the increase in the firing temperature [2].

The new gas turbines being designed for the new millennium are investigating the use of steam as a cooling agent for the first and second stages of the turbines. Steam cooling is possible in the new combined cycle power plants, which is the base of most of the new High Performance Gas Turbines (HPGT). Steam as part of the cooling as well as part of the cycle power will be used in the new gas turbines in the combined cycle mode. The injection of about 5% of steam by weight of air amounts to about 12% more power. The pressure of the injected steam must be at least 4 bar above the compressor discharge. The way of steam injected must be done very carefully so as to avoid compressor surge. By using the steam cooling the firing temperature reaches up to 1649 0C.

Since 1950, turbine bucket material temperature capability has advanced approximately 472 0C. The importance of this increase can be appreciated by noting that an increase of 56 0C in turbine firing temperature can provide a corresponding increase of 8–13% in output and 2–4% improvement in simple-cycle efficiency.

Advances in alloys and processing, while expensive and time-consuming, provide significant incentives through increased power density and improved efficiency. In the late 1990s, single-crystal blades were introduced in gas turbines. These blades offer additional creep and fatigue benefits through the elimination of grain boundaries. In single-crystal material, all grain boundaries are eliminated from the 7 material structure and a single crystal with controlled orientation is produced in an airfoil shape. By eliminating all grain boundaries and the associated grain boundary strengthening additives, a substantial increase in the melting point of the alloy can be achieved, thus providing a corresponding increase in high-temperature strength. The transverse creep and fatigue strength is increased, compared to equiaxed or DS structures. The advantage of single-crystal alloys compared to equiaxed and DS alloys in low-cycle fatigue (LCF) life is increased by about 10% [2].

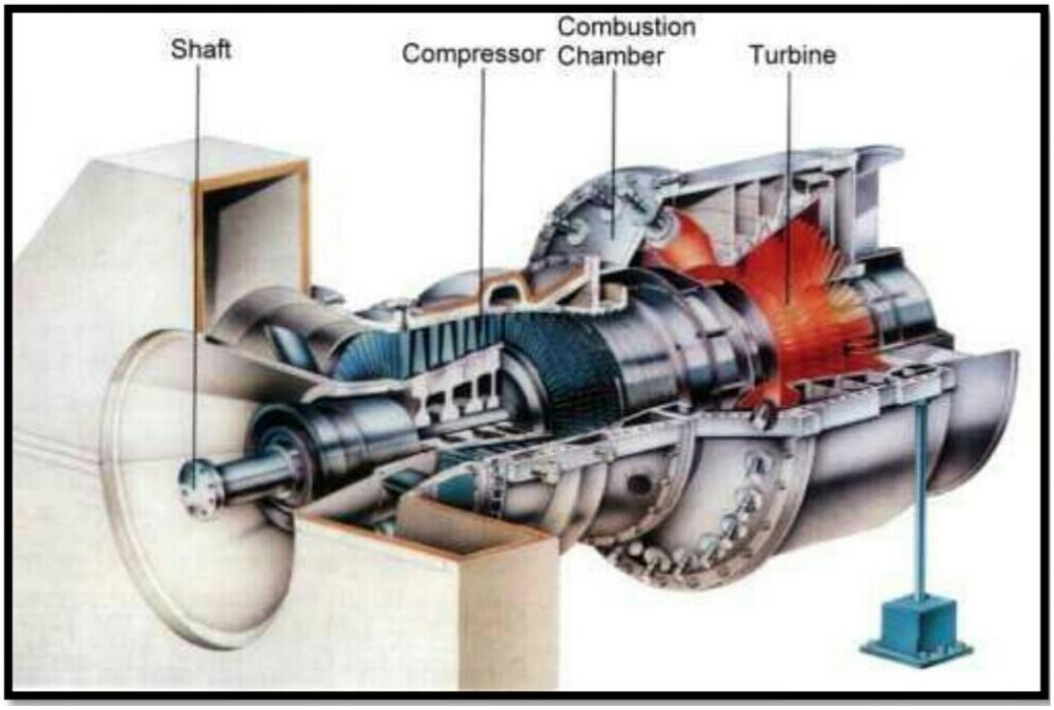


Figure (2-3): Gas turbine of combined cycle.

2-3-4 Heat recovery steam generator (HRSG) :

The gas turbine exhaust gases enter the Heat Recovery Steam Generator (HRSG), where the energy is transferred to the water to produce steam. There are many different configurations of the HRSG units. Most HRSG units are divided into the same amount of sections as the steam turbine. In most cases, each section of the HRSG has a Pre-heater, an Economizer and Feed-water, and then a Super heater.

The steam entering in the steam turbine is superheated.

The most common type of an HRSG in a large Combined Cycle Power plant is the drum type HRSG with forced circulation. These types of HRSGs are vertical; the exhaust gas flow is vertical with horizontal tube bundles suspended in the steel structure.

The steel structure of the HRSG supports the drums. In a forced circulation 8 HRSG, then the steam water mixture is circulated through evaporator tubes using a pump. These pumps increase the parasitic load and thus detract from the cycle efficiency. In this type of HRSG the heat transfer tubes are horizontal, suspended from un-cooled tube supports located in the hot gas path. Some vertical HRSGs are designed with evaporators, which operate without the use of circulation pumps [2].

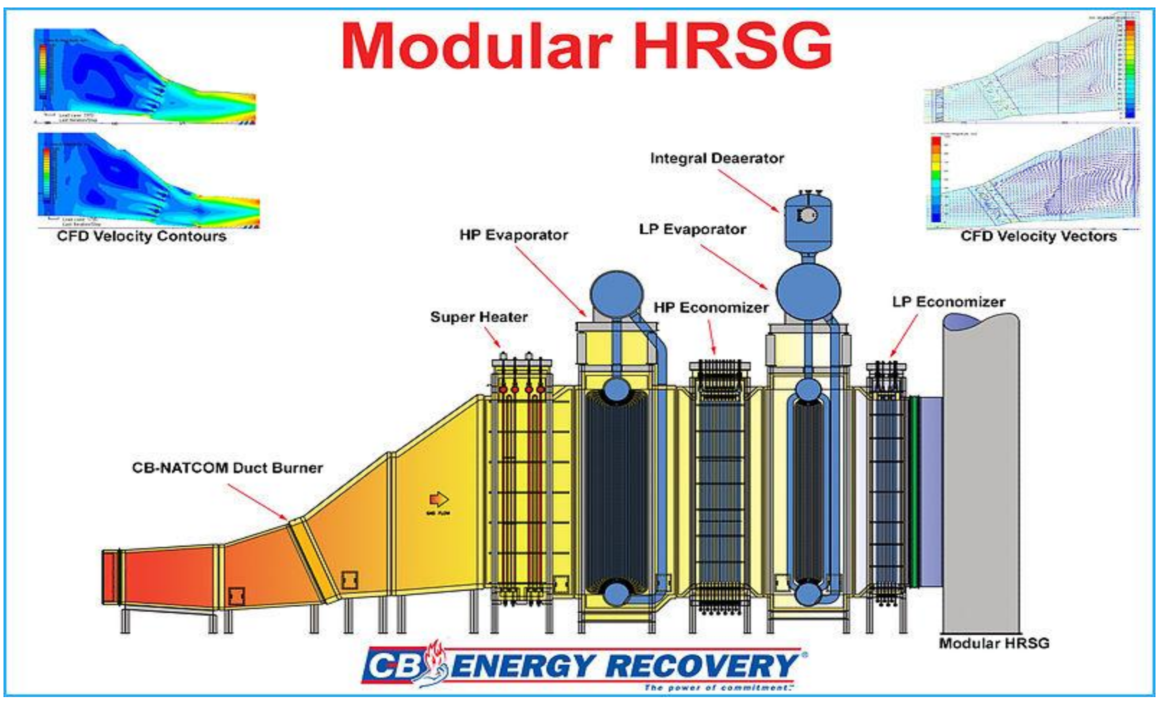


Figure (2-4): Heat recovery steam generator

2-3-4-1 Components of HRSG :

HRSGs consist of three major components. They are the Evaporator, Superheated, and Economizer. The different components are put together to meet the operating requirements of the unit.

1- Evaporator Section:

The most important component would, of course, be the Evaporator section, since without this coil or coils, the unit would not be an HRSG. Throughout our discussion. we will refer to a main heat transfer com as a "section". When the section is broken into more than one segment, i e., such as for a change in tube size. material, extended surface, location, etc., we will refer to the segments as coils. So an evaporator section may consist of one or more coils. In these coils, the effluent water), passing through the tubes is heated to the saturation point for the pressure it is flowing [3].

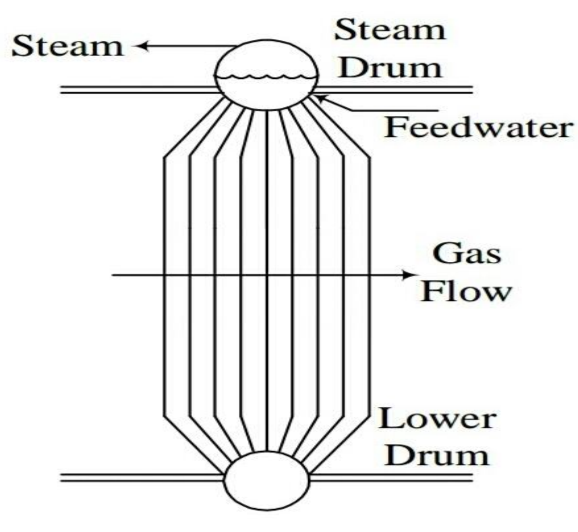


Figure (2-5):Evaporator Section

2- superheated section:

The Superheated Section of the HRSG is used to dry the saturated vapor being separated in the steam drum. In some units it may only be heated to little above the saturation point where in other units it may be superheated

to a significant temperature for additional energy storage, The Superheater Section is normally located in the hotter gas stream, in front of the evaporator[3].

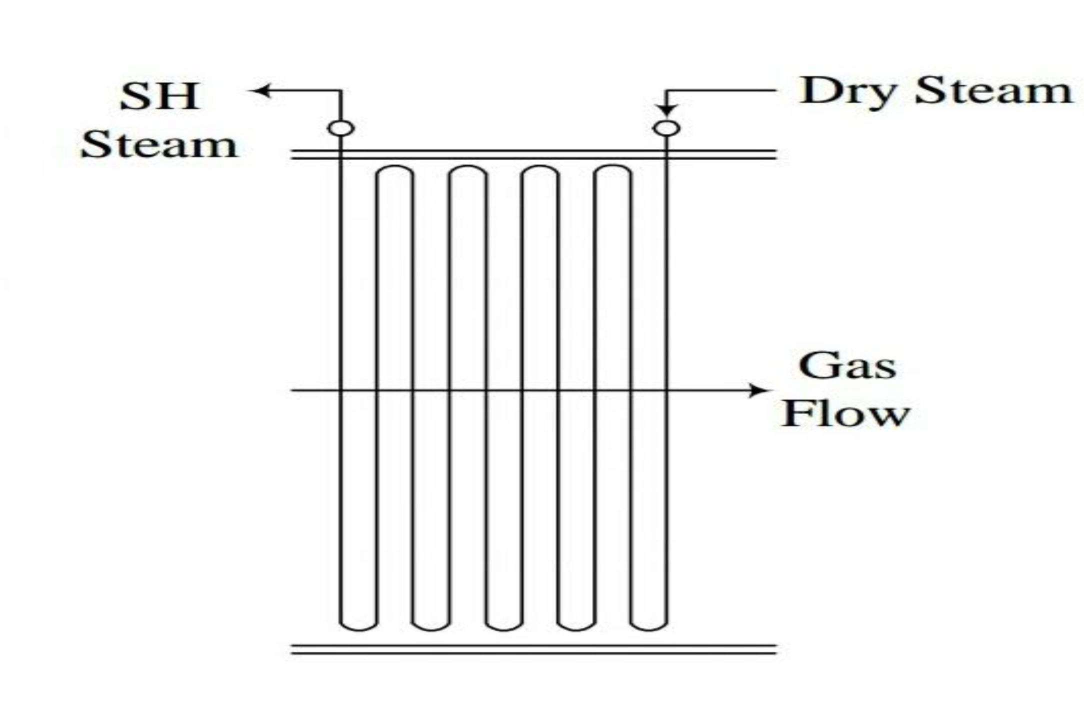


Figure (2-6): superheated section

3- Economizer Section:

The Economizer Section, sometimes called a pre-heater or preheat coil is used to preheat the feed-water being introduced to the system to replace the steam being removed from the system via the super heater or steam outlet and the water loss through blow down. It is normally located in the colder gas downstream of the aporator. Since the evaporator inlet and outlet temperatures are both close to the saturation temperature for the system pressure, the amount of heat that may be removed from the flue gas is limited due to the approach to the evaporator, known as the pinch which is discussed later, whereas the economizer inlet temperature is low allowing the flue gas temperature to be taken lower[3].

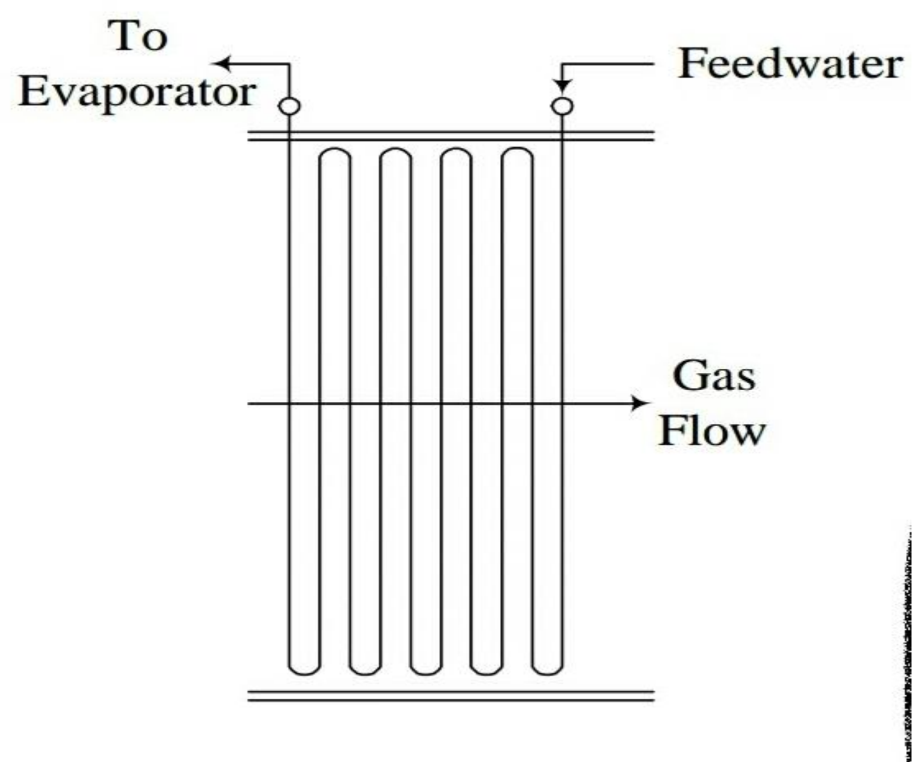


Figure (2-7): Economizer Section

2-3-5Steam turbine :

The steam turbines in most of the large power plants are at a minimum divided into two major sections: the High Pressure section (HP) and the Low Pressure section (LP). In some plants, the HP section is further divided into a High Pressure section and an Intermediate Pressure section (IP). The HRSG is also divided into sections corresponding with the steam turbine. The LP steam turbine's performance is further dictated by the condenser back pressure, which is a function of the cooling and the fouling .

The efficiency of the steam section in many of these plants varies from 30–40 % To ensure that the steam turbine is operating in an efficient mode, the gas turbine exhaust temperature is maintained over a wide range of operating conditions .This enables the HRSG to maintain a high degree of effectiveness over this wide range of operation .

In a combined cycle plant, high steam pressures do not necessarily convert to a high thermal efficiency for a combined cycle power plant. Expanding the steam at higher steam pressure causes an increase in the moisture content at the exit of the steam turbine. The increase in moisture content creates major erosion and corrosion problems in the later stages of the turbine. A limit is set at about 10% (90% steam quality) moisture content. [6]

The advantages for a high steam pressure are that the mass flow of the steam is reduced and that the turbine output is also reduced. The lower steam flow reduces the size of the exhaust steam section of the turbine thus reducing the size of the exhaust stage blades. The smaller steam flow also reduces the size of the condenser and the amount of water required for cooling. It also reduces the size of the steam piping and the valve dimensions. This all accounts for lower costs especially for power plants which use the expensive and high-energy consuming air-cooled condensers [2].

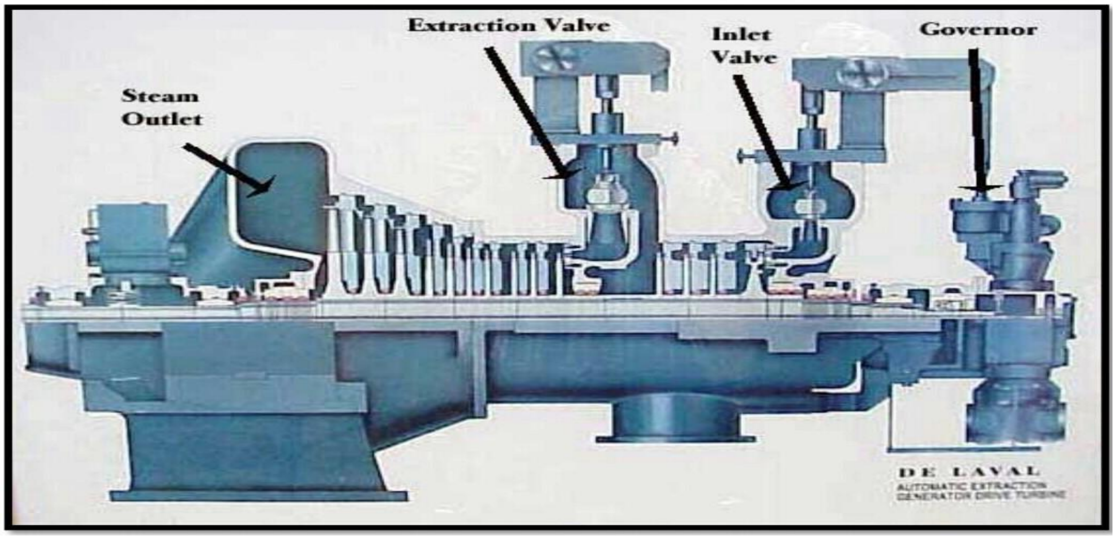


Figure (2-8): Steam turbine of combined cycle.

2-3-6 Condenser:

The use of a condenser in a power plant is to improve the efficiency of the power plant by decreasing the exhaust pressure of the steam below atmosphere. Another advantage of the condenser is that the steam condensed may be recovered to provide a source of good pure feed water to the boiler and reduce the water softening capacity to a considerable extent. A condenser is one of the essential components of a power plant.

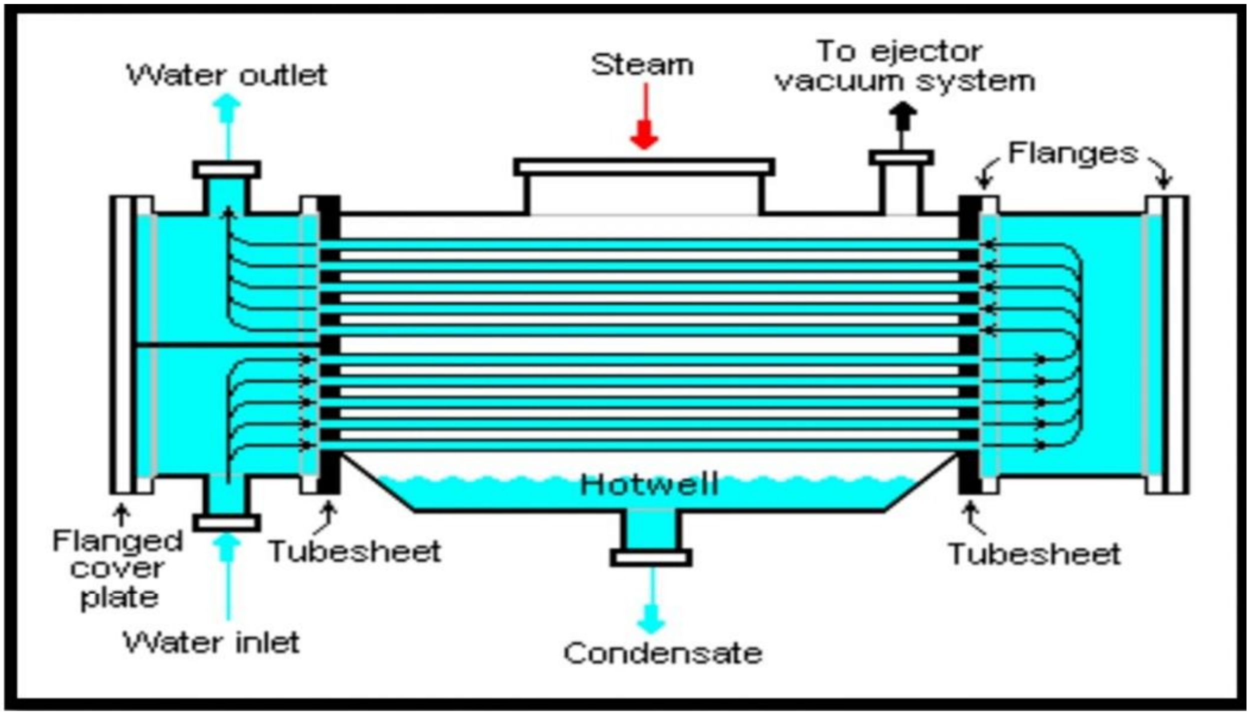


Figure (2-9): Power plant condenser

2-3-7 Cooling Tower :

The importance of the cooling tower is felt when the cooling water from the condenser has to be cooled. The cooling water after condensing the steam becomes hot and it has to be cooled as it belongs to a closed system. The Cooling towers do the job of decreasing the temperature of the cooling water after condensing the steam in the condenser [4].

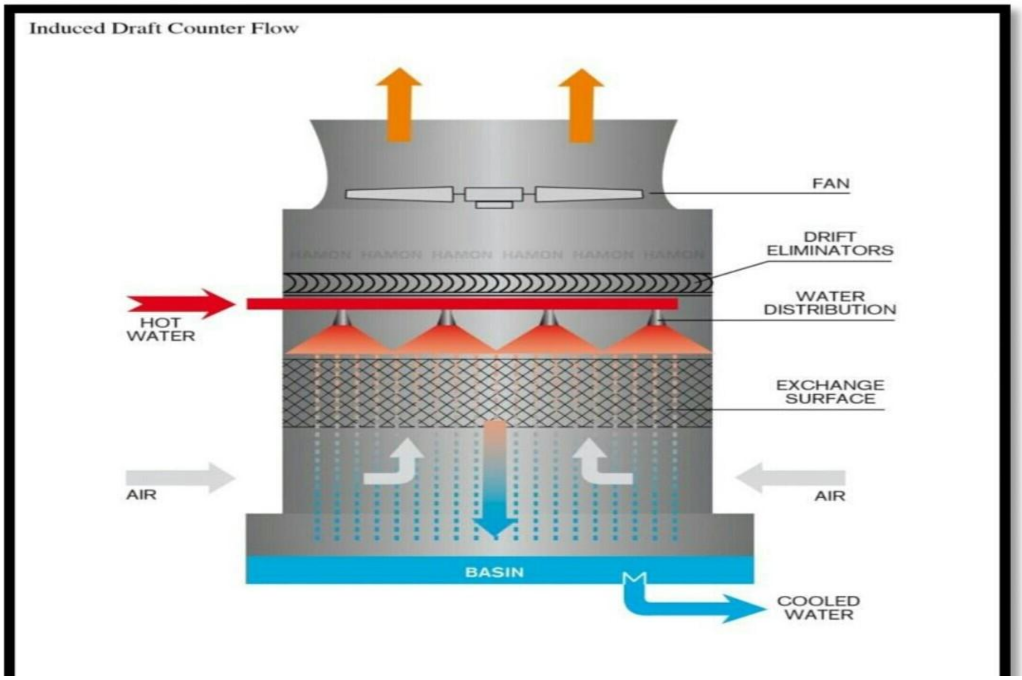


Figure (2-10): power plant cooling tower

2-3-8 Dearator :

Most power plants with a steam cycle have a dearator prior to the HRSG. If high amount of oxygen is presence in the feedwater this may cause corrosion of equipment and piping. If additional carbon dioxide also is presence, then the ratio of corrosion will increase. Therefore removal of these non-condensing gases is important.

Dearation is an important process that removes dissolved gases from the feedwater before it enters the HRSG. Dearation is a continuous process due to water losses and air leakages into the system. The concentration of oxygen should not exceed 20ppm in the feedwater. The feedwater tank is placed under the Dearator, and function as a buffer in feedwater , the dearation process is illustrated. Boiler feedwater is sprayed in a thin film at upper part of the dearator and is heated . by hot dearation steam injected at lower level. This reduces the solubility of the dissolved gasses, and the amount of the gases in the feedwater is reduced. The gases are vented out at the top, and the dearated water is pumped to the HRSG [5].

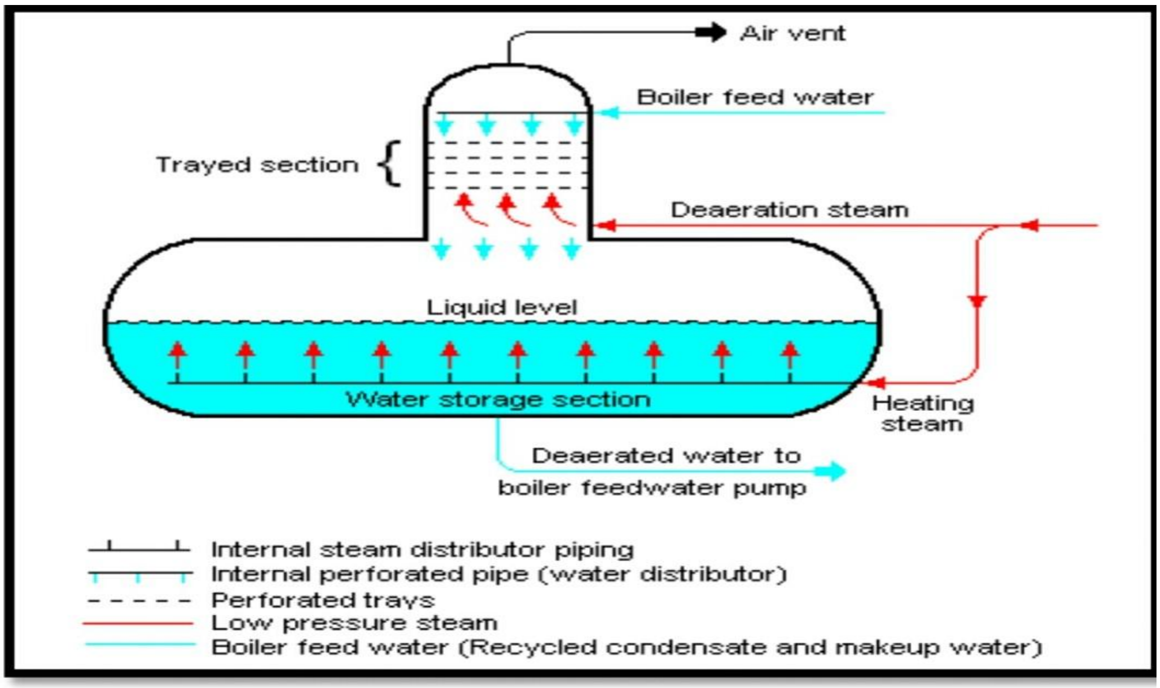


Figure (2-11): Dearator

2-4 Literature studies:

Literature studies will be performed in order to obtain knowledge about the general structure of a power plant system, its dynamics and the components included. There will also be access to older versions of the power system which is going to be used as reference. Further, earlier developed power system components can be obtained through the Power System Library.

2-4-1 Optimization of combined cycle power plant:

1) Optimization of Combined Cycles for Offshore Oil and Gas Installations by Alexander SvaeSletten (2013) on his second Master thesis from Norwegian University of Science and Technology.

a. Objectives of study:

This study aims to optimizing the design developed on the project work Process simulation of combined cycles for offshore applications.

b. Discussion about study:

The design parameters for the system developed in the project work were optimized in MATLAB using a connection between MATLAB and a Microsoft Excel spread sheet linked with GT PRO. The thesis includes the development of an objective function and a screening of the potential

MATLAB optimization methods. After the optimization methods were decided upon, adjustments were made to them in an attempt to improve the optimized solution, and a brief comparison of the different optimization methods was carried out. Finally, the best solution was compared to that of the project work, both in respect to the individual design parameters and total system performance.

Through this study it has become apparent that the selection of objective function is of paramount importance, the optimized solution will only be as good as the selected function. In terms of the optimization methods, there were fairly small differences between the various algorithms, though the pattern search with a MADSPositiveBasis2N search algorithm seemed to be a good option for obtaining the best possible solution. In comparison to the design developed in the project work, there were noticeable improvements to be had in terms of power production and weight savings.

c. Results of study:

The main components of the optimized solution were 493 kg lighter (Fuel) and able to produce an additional 268 kW when compared to the project work, corresponding to a 2.6 % improvement in the value of the efficiency. This may not sound like much, but the cumulative savings over the lifetime of an installation may become quite significant. Overall it appears to be quite advantageous to optimize the design of combined cycles for offshore oil and gas installations. Once a suitable objective function is established a quite good optimized solution can be realized in relatively short time. It does not appear to be necessary with many adjustments to the optimization parameters, though adjustments can be made if a better solution is sought after.

The optimum solutions for different parameters shown in the study are:

1)Optimum steam temperature is **488.69** ℃**.**

2)Optimum steam condenser pressure is **0.04856 bar.**

3)Optimum pinch point temperature difference is **33.251**℃**.**

4)Optimum drop pressure on HRSG is **34.996 mbar.**

2-4-2 Simulation of combined cycle power plant:

1) Combined-Cycle Plant Simulation Toolbox for Power Plant Simulator by AbdolhamidSalehi, et al (2008), Department of Electrical Engineering, School of Engineering Shiraz University, Shiraz, Iran.

a. Objectives of study:

This study aims to develop Simulation Toolbox of simulating Combined Cycle power Plant by using C++ Programming language, MATLAB® Toolbox and SIMULINK® Simulator.

b. Discussion about study:

This study addresses the development of a set of system component simulation modules combined with a control structure in a common software framework for a typical combined cycle power plant. The simulation toolbox was designed for educational purposes using SIMULINK® based on Object Oriented Programming (OOP) and the C programming language. The simulation toolbox will be utilized to assess the long-time behavior of control systems and the overall plant performance following system disturbances. The developed simulation tool is able to use all MATLAB® toolboxes for research and education studies.

This paper discusses the development of a physical simulation toolbox for a typical combined cycle power plant with standard configuration. The heart of a plant simulation is its modeling block, which for a power plant is comprised of highly nonlinear and complex algebraic, and differential equations. Various approaches such as modular technique and Object Oriented Programming (OOP) could be utilized for this purpose.

c. Results of study:

The power plant modeled in the SIMULINK® environment based on OOP and the C-programming language, to create a new toolbox for constructing plant simulation. An important feature of this environment is building the Dynamic Link Library (DLL) of m-files and c-files of the block diagrams of this toolbox using a Visual C++ program linked with the MATLAB®. The developed simulation tool is able to use all MATLAB® toolboxes for research studies.

2)Off-design Simulations of Offshore Combined Cycles OysteinFlatebo (2012), Master thesis from Norwegian University of Science and Technology.

a. Objectives of study:

This study aims to present an off-design simulation of offshore combined cycles in Norwegian, by using GTMASTER and GTPRO simulators.

b. Discussion about study:

First, this thesis gives a description of combined cycles from a thermodynamic and technical point of view. A study of existing offshore combined cycles is performed, and some of the implications of using combined cycles offshore are discussed. In the study, also off-design performance regarding the gas turbine and steam cycle is presented. Further, the simulation tool GTPRO is used to model two CC plants, one designed for offshore installations, and one designed to achieve high efficiency. As part of the design process a sensitivity analysis is performed to find a good trade-off between efficiency and weight for the offshore plant. The model showed good agreements compared with the existing offshore plants, with a power output of 50.3MW, plant efficiency of 50.3%, and similar weight of the skids. The high efficient plant, based on the same gas turbine, and the same assumptions produced 53.1MW.

This model gained 2.4MW more in power output, however with a penalty of 209 ton in extra weight.

To review the plants performance and operability, off designsimulations were performed in GTMASTER. Both part load and changing ambient temperature were investigated. The results showed that both plants had similar behavior in performance at off-design, and that the GT strongly dictates the behavior of the steam cycle. At part load the relative SC efficiency increases, resulting in general high plant efficiency. At 60% GT load, the relative gas turbine efficiency is 81% compared to the relative plant efficiencies of about 90%. The difference in efficiency between the high efficient plant and the offshore plant remains constant at part load.

c. Results of study:

The result from the simulations of ambient temperature is that none of plants will achieve higher plant gross efficiency at changing ambient temperature. The best plant efficiency occurs at design point. However, both plants have a long interval with approximately 100 % plant efficiency. From 15 to 0°C, the relative SC gross efficiency drops with 5 % and the relative GT efficiency increase with 2%. However, the power output changes for both the GT and ST. From 28°C to about 0°C the power output increase almost linearly for the SC and GT.

2-4-3 Various previous studies about combined cycle power plant:

Effect of Operating Parameters on the Performance of Combined Cycle Power Plant by Mohamed Islam, et al (2014).

a. Objectives of study:

This study focuses on summarizing Effect of Operating Parameters on the Performance of Combined Cycle Power Plant.

b. Discussion about study:

The performance of gas-steam combined cycle power plant depends on various operating parameters. The power output and efficiency both depends on operation of topping as well bottoming cycle but mainly depends on topping cycle which is Brayton cycle in this study. Besides the power output and efficiency there are different losses which occur in different components of plant. These are based on first and second law of thermodynamics. The second law approach (Exergy analysis) gives better understanding of different losses and optimization of system for higher power output and efficiency.

c. Results of study:

The major operating parameters which influence the combined cycle performance :and the effects these operating parameters can be summarized as follows

1)The turbine inlet temperature (TIT): significantly affects the performance of combined cycle. It should be kept on higher side for minimizing the exergy losses and increase efficiency.

2) The compressor pressure ratio: should be optimum for maximum performance of combined cycle.

3) Pinch point temperature: The decrease in pinch point temperature the more heat transfer in steam bottoming cycle thus improving the combined cycle performance.

4) The ambient temperature: The ambient temperature also affects the combined cycle performance. The decrease in ambient temperature will make an increase in efficiency.

5) Pressure levels: The increase in number of pressure levels improves the combined cycle performance.

Chapter Three

Methodology

3-1 Plant Overview

3-1-1 General :

The Garri Complex Power Station is located about 70 km north of Khartoum City, the capital of Sudan. The contract titled Sudan Garri Power Station Plant 1 was generally executed by Harbin Power Engineering Co .Ltd (HPE) . The supervisor committee (consultant) was Lahmeyer International Germany. The Garri Complex Power Station belongs to National Electrical Corporation (NEC) of Sudan . The complex consist of four plants, two existing (plant-1and plant-2), one is under construction (plant-4) and one future plant (plant-3) (see figure3.1).

Figure 3.1: Layout for Garri Power Plant

Plant one consist of six units comprising of two sets of combined cycle units, including four gas turbines with type of PG6581B and rated capacity of 38MW, two units of steam turbine with rated capacity of 36MW. Total installed capacity is 224 MW. The Heat Recovery Steam Generator (HRSG) is made by Harbin Boiler Works (China). The steam turbine type L36-6.70 is also the product of Nanjing Turbine & Electrical Machinery Group Co .Ltd . Each has a capacity of 36MW equipped with brushless excitation and digital excitation regulator SVR-2000A .The water used for all plant comes from Nile River, where a water pre-treatment station is installed to purify the dirty water by chemical dosing, and then water is delivered to the Site through a common 15 km pipeline. The waste water after treatment through a new waste water treatment plant is going back to NILE River with an acceptable quality. For Light Diesel Oil (LDO) tanks have been installed and are receiving LDO by existing pipes from Khartoum Refinery Company (KRC) or unloading station.

There is a big electrical substation with a voltage degree of 220kV, and 6 bays as well as one coupler are ready to send electricity to grid.

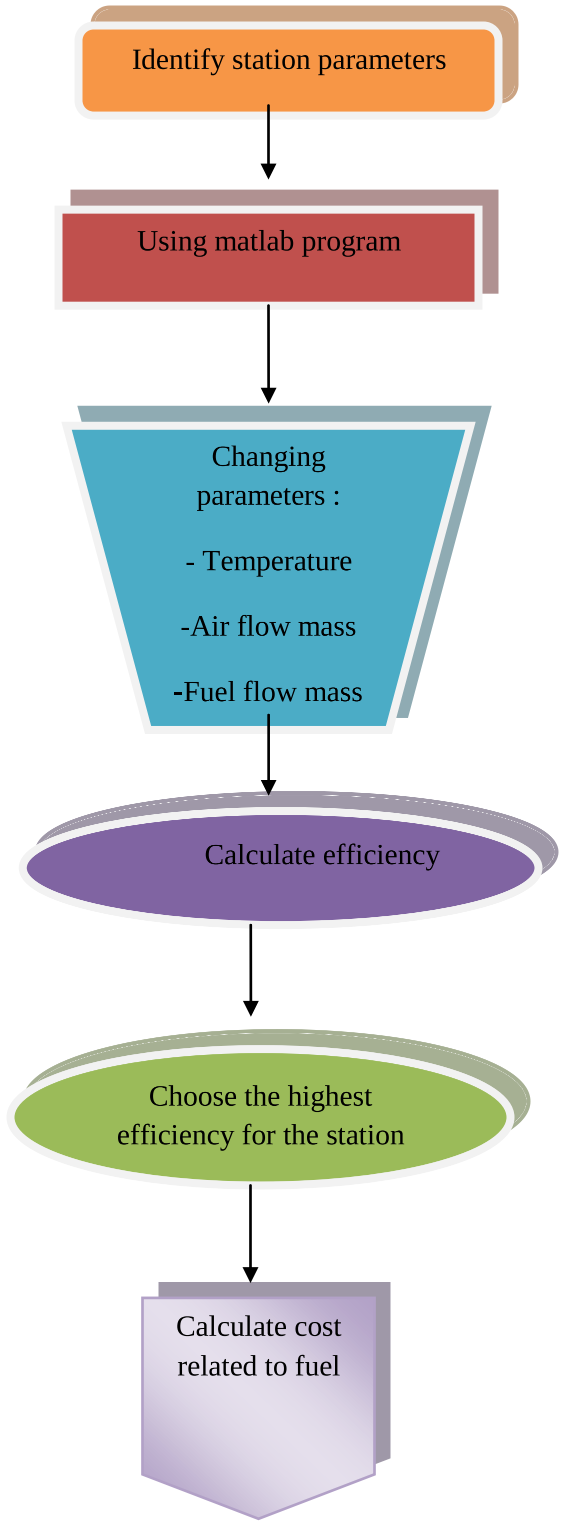
There are two control centers, one located in substation where communication is available with Local Dispatching Center (LDC) through Supervisory Control And Data Acquisition (SCADA) system and local control & protection systems are also put in. Another control room called Central Control Room (CCR) is on the 3rd floor of steam turbine hall.

The general control system Distributed Control System (DCS) is Freelance . 2000 produced by ABB Company, it has an ability to communicate with other controllers, such as Programmable Logic Controller (PLC) servicing for River-side and water demineralization Station, as well as controller (MARK VI). So all the running parameters including Gas Turbine, Steam Turbine, LDO system, Demi - water plant & Rive-side can be shown on the 10 sets of Operation Station (OS).

For electrical arrangement, the power generated by gas turbine steps up through main transformer to the 220kV grid, same time steps down through a unit auxiliary transformer to 6 . 3kv medium voltage for house load system. The power generated by steam turbine is directly stepping up through main transformer to 220kVgrid. An emergency diesel generator is also available here in this plant for any emergency case in order to ensure the essential load. A newly - installed demi - water station is controlled by PLC Siemens Simapic S7-300 to generate enough capacity of demineralised water for HRSG, steam turbine and other customers.

Other main ancillary systems consist of air compressor system, firefighting system, potable water generation plant, waste water treatment plant, heating ventilation and air conditioning (HVAC) system, DC system, Uninterruptible Power Supplies system (UPS), etc.

3-2 Methodology steps:



Flow chart (3-1) :Methodology steps

3-3 GARRI station of Sudan power plant:

GARRI station power plant of Sudan is one of the major sources of electric power in Sudan. It builds north of Khartoum in Garri city. It contain tow combined cycle gas turbine station, every station had two blocks which any block consist tow gas turbines and one steam turbine. GARRI generation is approximately 60 MW of power to generate electricity.

The data of this project are based on the document of GARRI Power Plant Station of Sudan. And below we will present the layout of one block on GARRI and its generation and also efficiency on this chapter.

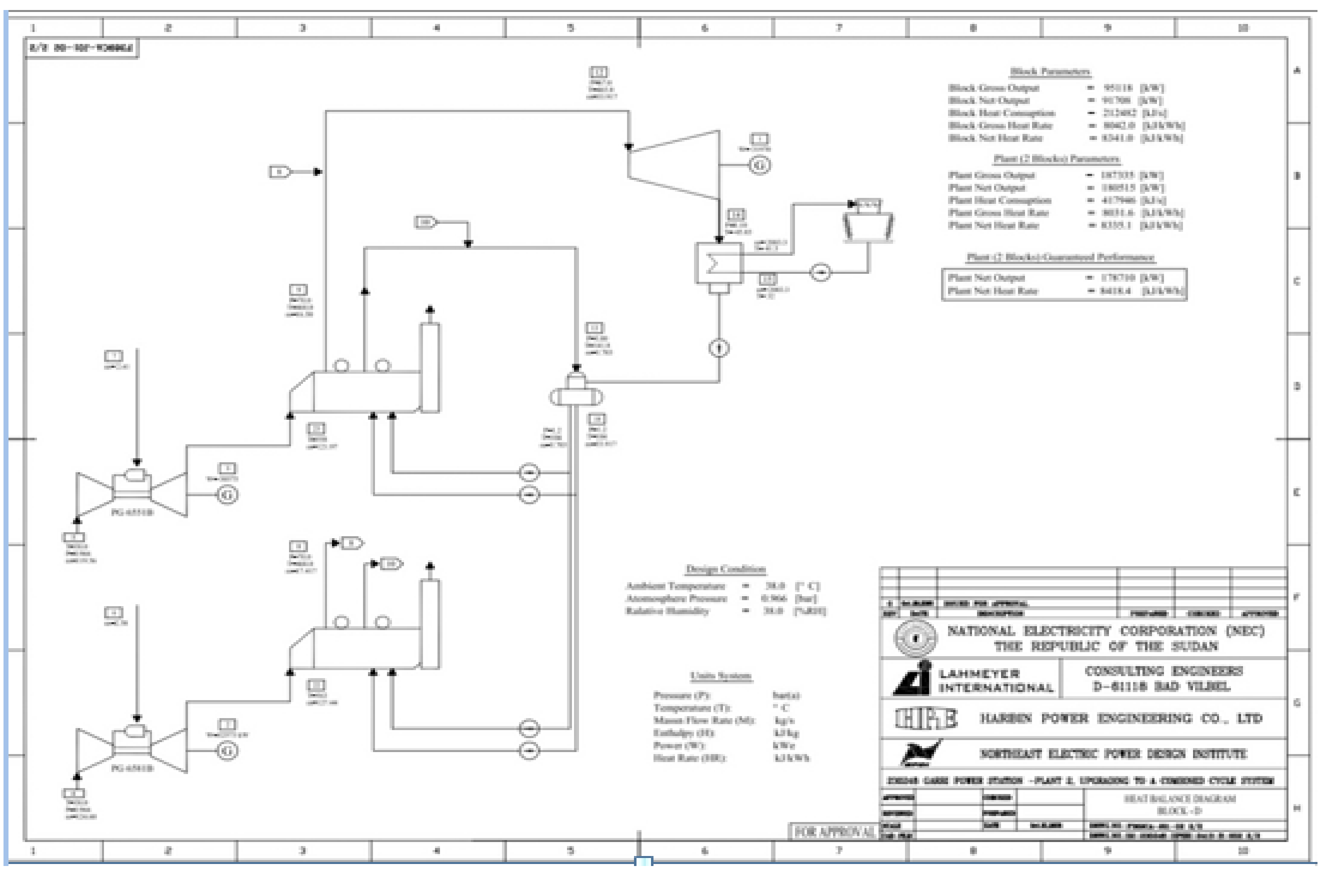


Figure (3-2): layout of one block 1 of GARRI plant

3-3-1 Actual data of GARRI station process:

Next it is shown different tables of data of the process which my project is based. The real data is extract of the combined cycle of GARRI process, so much the produced total energy, as the auxiliary one used, and the total efficiency of the cycle. Table (4.1) shows the performance of Block 1 of GARRI power plant which explains the net efficiency of block with losses and without losses, net generation, and net heat rate and fuel consumption.

ITEM	UNIT	PLANT 1 BLOCK 1			
		GT1	GT2	ST1	Block 1
Gross Generation	kWh	580,363.64	580,363.64	197,800.00	1,358,527.27
Station Service	kWh	27,000.00	0.00		27,000.00
Net Generation	kWh	553,363.64	580,363.64	197,800.00	1,331,527.27
Service Hour	hr	24.00	24.00	24.00	
No. of Start	time	498	1,308	197	
No. of Start	time	0.00	0.00	0.00	
Operating Hours	hr	69,422.77	67,037.00	992.52	
Planned Outage	hr	0.00	0.00	0.00	
Forced Outage	hr	0.00	0.00	0.00	
Forced Derating	hr	0.00	0.00	0.00	
Standby (RS/D)	hr	0.00	0.00	0.00	
Availability	%	100.00	100.00	100.00	100.00
Capacity Factor	%	76.52	76.52	25.19	59.46
hcgo Consumption	ton	0.00	180.58		180.58
FO Consumption	ton	180.10	0.00		180.10
FO Consumption	Litre	214,404.76	0.00		214,404.76
Fuel Oil Cost					
Gross Generation	MWh	580.36	580.36	197.80	1,358.53
Gross Generation Cost	Ton/MWh	0.31	0.31		0.27
Gross Generation Cost	SDG/KWh	0.68	0.68		0.58
Gross Heat Rate	kJ/kWh	14,231.09	14,040.63		12,077.70
Net Heat Rate	kJ/kWh	14,925.46	14,040.63		12,322.60
Specific Heat Rate	kg/kWh	0.31	0.31		0.27
Gross Efficiency	%	25.30	25.64		29.81
Net Efficiency	%	24.12	25.64		29.21

Table(3-1): performance of Block1 of GARRI power Plant

3-4 Thermodynamics of combined-cycle power plants :

Figure (3.3) shows the layout to typical combined cycle power plant. Combined cycle could have various arrangements depending upon the alterations in gas cycle and steam cycle arrangements. In the shown layout there is simple gas turbine cycle; compression of air occurs between states 1 and 2. Subsequently heat addition and expansion occurs in combustion chamber and gas turbine through processes 2-3 and 3-4 respectively. Exhaust gases from gas turbine enter into heat recovery steam generator (HRSG) at state 4 and leave at state 5. Steam generated at state 6 from HRSG is send to steam turbine for expansion and thus steam turbine work output augments work output of gas turbine. Expanded steam enters condenser at state 7 and condensate is sent back to HRSG at state 12 after passing it through dearator. For ma, mf and ms being flow rates of air, fuel and steam respectively thermodynamic analysis is carried out as under.

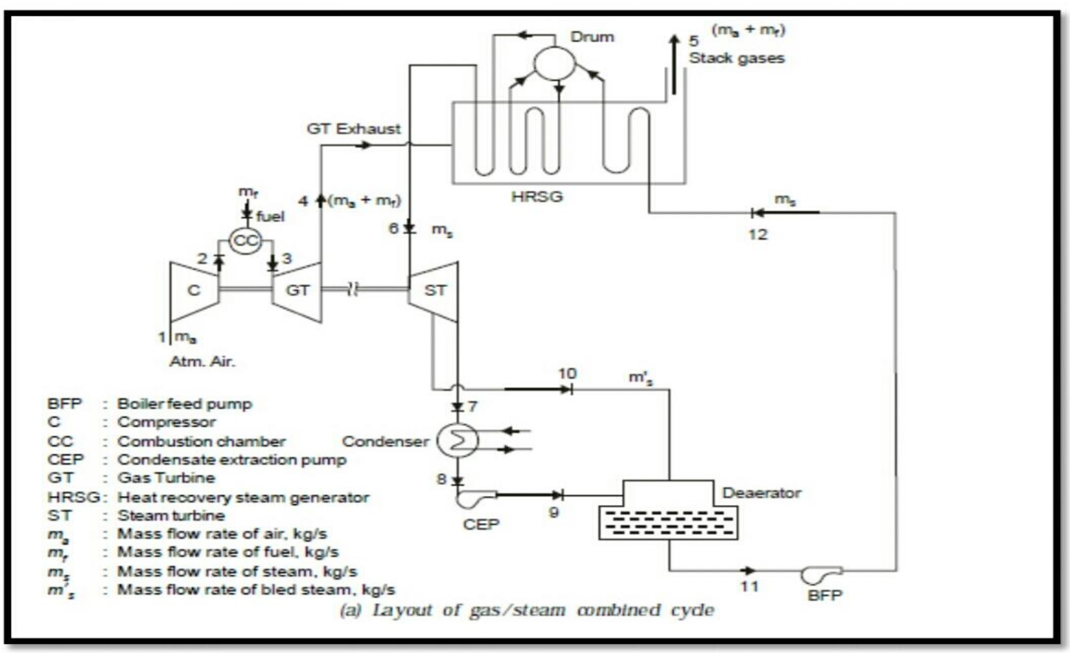


Figure (3-3) : layout of combined cycle

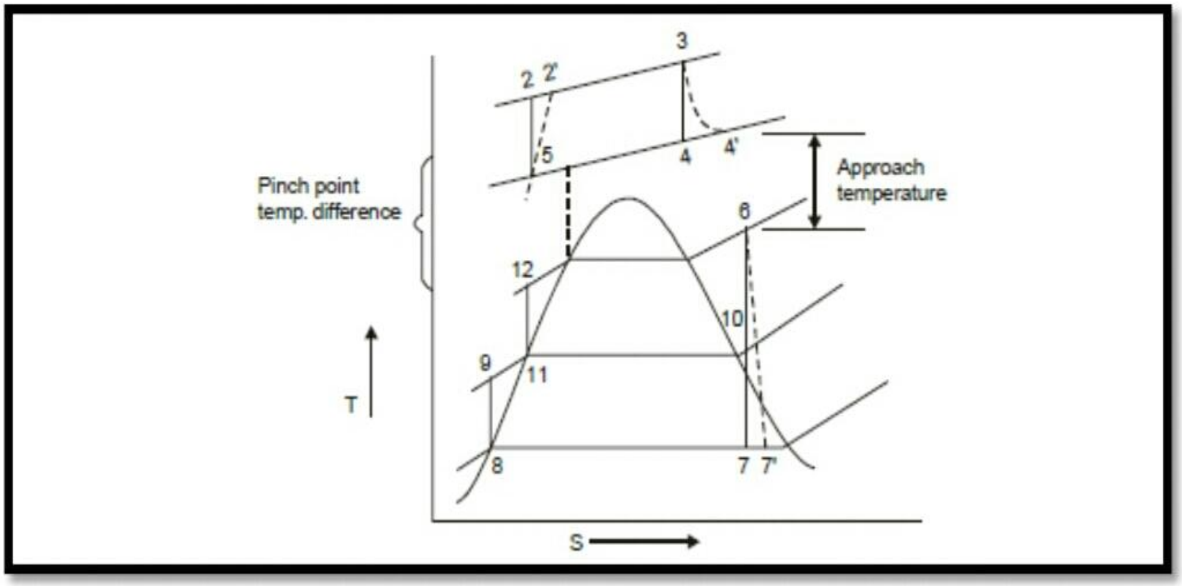


Figure (3-4): T-S diagram representation of combined cycle

3-5 Thermodynamic analysis:

Thus the work requirement in compressor,

$$rp = \frac{p2}{p1} \ldots\ldots\ldots\ldots\ldots\ldots[1]$$

$$\frac{T2s}{T1} = r_p^{\gamma-1/\gamma} \ldots\ldots\ldots\ldots\ldots\ldots[2]$$

$$WC = maCPa(T2 - T1) \ldots\ldots\ldots[4]$$

Heat addition in combustion chamber, for fuel having calorific value

$$Qadd = mf \times CV……… [5]$$

Energy balance upon combustion chamber yields,

$$(ma \times CPa\ T2) + (mf \times CV) = (ma + mf)\ cpgT3\ ……[6]$$

Work available from gas turbine,

$$\frac{T3}{T4S} = r_p^{\gamma-1/\gamma}\ …….[7]$$

$$WGT = (ma + mf)\ CPg\ (T3 - T4)…….[9]$$

Net work from gas cycle,

$$WGas\ cycle = WGT - WC…….[10]$$

Work available from steam turbine, for bled steam mass flow rate for dearation being ms,

$$\{ms' (h10) + (ms - ms') (h9)\} = ms(h11) \ldots\ldots.[11]$$

$$WST = \{ms(h6 - h7) + (ms - ms') (h7 - h10)\} \ldots\ldots[12]$$

Pump works,

$$WCEP = (ms - ms') (h9 - h8) \ldots\ldots\ldots....[13]$$

$$WBFP = ms(h12 - h11) \ldots\ldots\ldots\ldots\ldots\ldots[14]$$

Net work available from steam cycle,

$$WSeam\ cycle = WST - WCEP - WBFP \ldots\ldots.[15]$$

Hence total work output from combined cycle,

$$WCombined = WGas\ cycle + WSteam\ cycle \ldots\ldots.[16]$$

Thermal efficiency of combined cycle,

$$\eta combined = WCombined \div Qadd \ldots\ldots\ldots\ldots..[17]$$

Thermal efficiency of gas cycle,

$$\eta Gas\ cycle = WGas\ cycle \div Qadd \ldots\ldots\ldots\ldots\ldots\ldots..[18]$$

3-6 MATLAB Program :

MATLAB (Matrix-Laboratory) is a leading program in engineering and sports applications produced by Math works MATLAB allows mathematical manipulation of matrices, mathematical graphing, implementation of various algorithms, creation of graphical user interfaces, and communication with programs written in other languages, including C- C ++, Java, and Fortran. The program is used with many other applications and utilities such as Simulink , Is a leading program in engineering applications and sports production company Math Work uses the software with many other applications and utilities such as Simulink. The additions produced by the company are divided into two special additions to the Matlab and special additions to Smyolink . The additions of the Matlab are called Toolbox boxes. These boxes are different from each other, The scientific treatment of it contains within it software lessons that lead to the solution of scientific issues in the specialty that was created for The tool such as Simulink, Is a leading program in engineering applications and sports production company Math Worx uses the software with many other applications and utilities such as Simulink. The additions produced by the company are divided into two special additions to the Matlab and special additions to Smyolink. The additions of the Matlab are called Toolbox boxes. These boxes are different from each other, The scientific treatment of it contains within it software lessons that lead to the solution of scientific issues in the specialty that was created for The tool such as image processing tool, they are addressing specialized image analysis and writing algorithms to arrange pixels and so on. You can learn the free Matlab here The additions to the Smolink are called block blocks that apply physical or mathematical theories to your model, which is created to give you a simulation of your model. If your model is subjected to these physical or mathematical theories in real reality, we will take a mass as in the Smolink program, And spacecraft and payment systems called (Aerospace Blockset) aircraft manufacturers benefit from these blocks Subjecting their planes to air certain factors Ka atmospheric pressure and its impact on the structure of the plane by default and see the results on the computer performance of their aircraft aided simulation software Smeulenk and this block. Doctors and medical engineers also use this program to draw nucleic acids that have complex and overlapping forms.

Matlab allows you to draw 3D shapes after typing mathematical equations in a given window. After drawing the shapes the color and size of the body can be changed by a special tool bar. When drawing complex shapes, certain parts can be made semi-transparent so that the user can see the other parts behind them. This program is also used to draw two-dimensional diagrams and to solve difficult math equations [7].

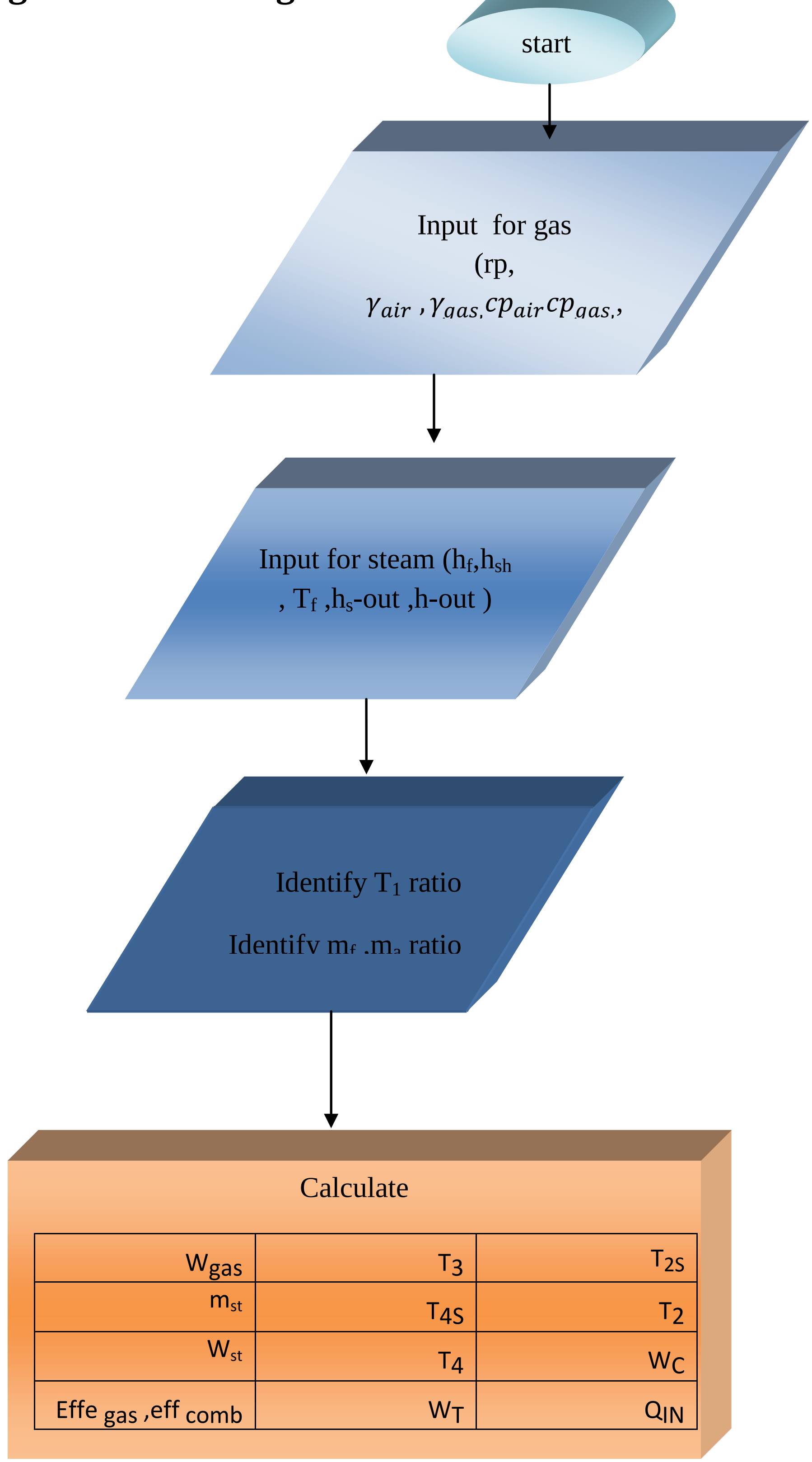
3-7 Simulation of combined cycle power plant with MATLAB simulator:

We made a script file for MATLAB program through it we can calculates the efficiency of combined cycle ,work in compressor and work in gas turbine , work in steam cycle and efficiency of gas cycle and efficiency Steam cycle, and net power.

After that calculate the cost of MW , and select low cost.

This program calculates all these values at inlet temperature of 15 $^\circ$c to 45 $^\circ$c , air flow rate of 190 kg/s to 290 kg/s by step 10 kg/s , and a fuel flow rate of 2.5kg/s to7.5 kg/s.

3-7-1 Building MATLAB Programmer:



Flow chart (3-2): Building Matlab Programmer

Chapter Four

Results and Discussion

Chapter Four: Results and Discussion:

4-1: Effect of different parameters on plant thermal efficiency:

4-1-1: Effect of Air inlet temperature and air flow rate:

Effect of Air inlet temperature and air flow rate on efficiency when fuel flow rate **2.5** kg/s.

		ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
mf	**T1**	***190***	***200***	***210***	***220***	***230***	***240***	***250***	***260***	***270***	***280***	***290***
2.5	288	0.2431	0.226	0.2089	0.1919	0.1748	0.1577	0.1406	0.1236	0.1065	0.0894	0.0723
	293	0.244	0.227	0.21	0.1929	0.1759	0.1589	0.1419	0.1248	0.1078	0.0908	0.0738
	298	0.2449	0.228	0.211	0.194	0.177	0.1601	0.1431	0.1261	0.1091	0.0921	0.0752
	303	0.2459	0.2289	0.212	0.1951	0.1781	0.1612	0.1443	0.1274	0.1104	0.0935	0.0766
	308	0.2468	0.2299	0.213	0.1961	0.1793	0.1624	0.1455	0.1286	0.1118	0.0949	0.078
	313	0.2477	0.2309	0.214	0.1972	0.1804	0.1636	0.1467	0.1299	0.1131	0.0962	0.0794
	318	0.2486	0.2318	0.2151	0.1983	0.1815	0.1647	0.1479	0.1312	0.1144	0.0976	0.0808

Table (4-1): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=2.5 kg/s.

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

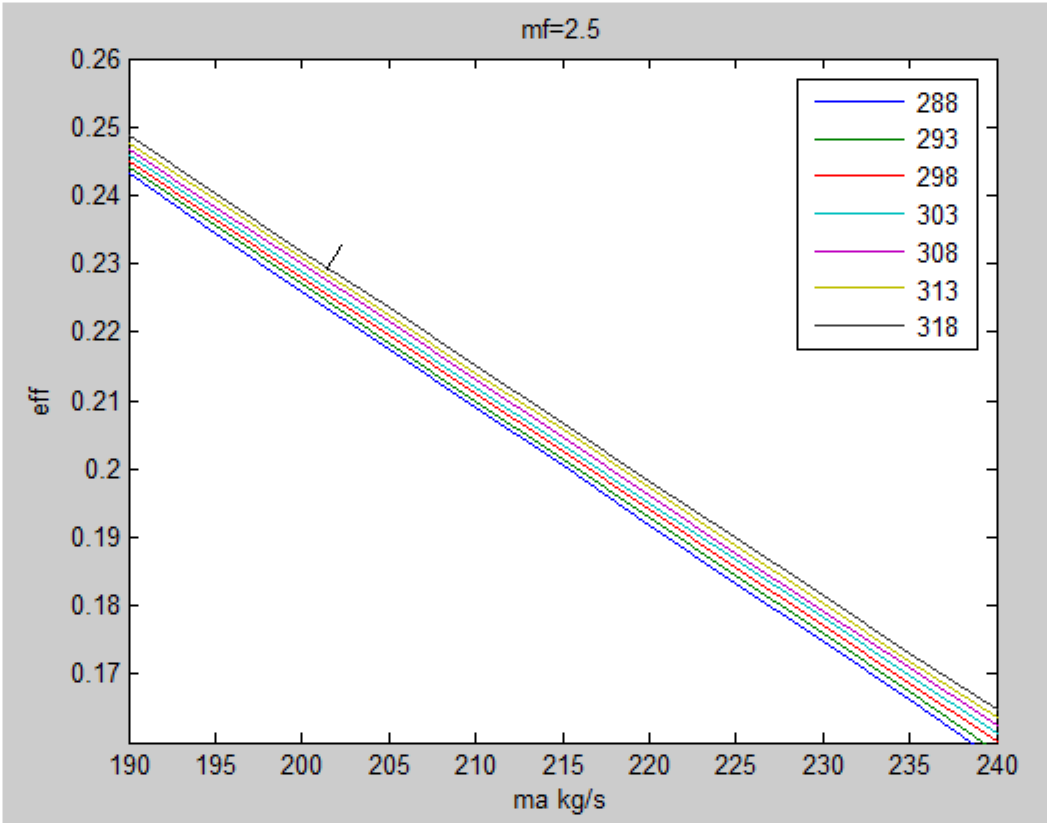


Figure (4-1): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=2.5 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
3	288	0.2971	0.2829	0.2687	0.2545	0.2402	0.226	0.2118	0.1975	0.1833	0.1691	0.1549
	293	0.2979	0.2837	0.2695	0.2553	0.2412	0.227	0.2128	0.1986	0.1844	0.1702	0.156
	298	0.2987	0.2845	0.2704	0.2562	0.2421	0.228	0.2138	0.1997	0.1855	0.1714	0.1572
	303	0.2995	0.2853	0.2712	0.2571	0.243	0.2289	0.2148	0.2007	0.1866	0.1725	0.1584
	308	0.3002	0.2862	0.2721	0.258	0.244	0.2299	0.2158	0.2018	0.1877	0.1736	0.1596
	313	0.301	0.287	0.2729	0.2589	0.2449	0.2309	0.2169	0.2028	0.1888	0.1748	0.1608
	318	0.3018	0.2878	0.2738	0.2598	0.2458	0.2318	0.2179	0.2039	0.1899	0.1759	0.1619

Table (4-2): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=3 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

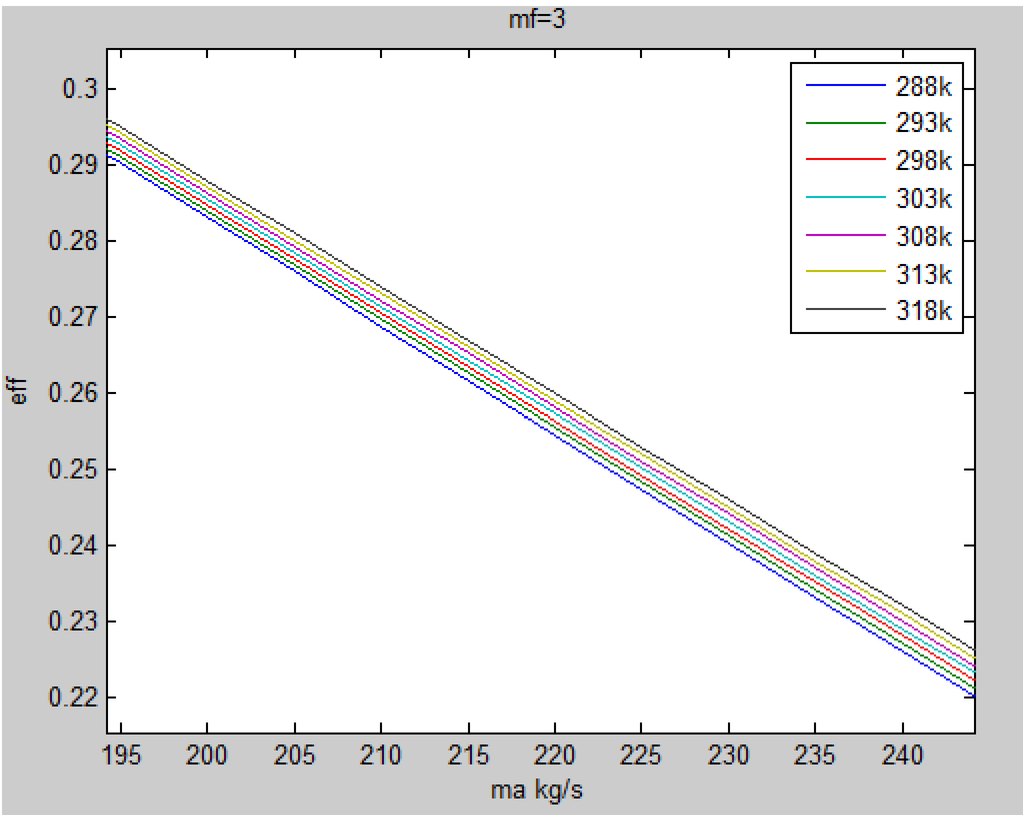


Figure (4-2): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=3 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
3.5	288	0.3358	0.3236	0.3114	0.2992	0.287	0.2748	0.2626	0.2504	0.2382	0.226	0.2138
	293	0.3364	0.3243	0.3121	0.2999	0.2878	0.2756	0.2635	0.2513	0.2391	0.227	0.2148
	298	0.3371	0.325	0.3128	0.3007	0.2886	0.2765	0.2643	0.2522	0.2401	0.228	0.2158
	303	0.3377	0.3256	0.3136	0.3015	0.2894	0.2773	0.2652	0.2531	0.241	0.2289	0.2168
	308	0.3384	0.3263	0.3143	0.3022	0.2902	0.2781	0.2661	0.254	0.242	0.2299	0.2178
	313	0.3391	0.327	0.315	0.303	0.291	0.279	0.2669	0.2549	0.2429	0.2309	0.2189
	318	0.3397	0.3277	0.3157	0.3038	0.2918	0.2798	0.2678	0.2558	0.2438	0.2318	0.2199

Table (4-3): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=3.5 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

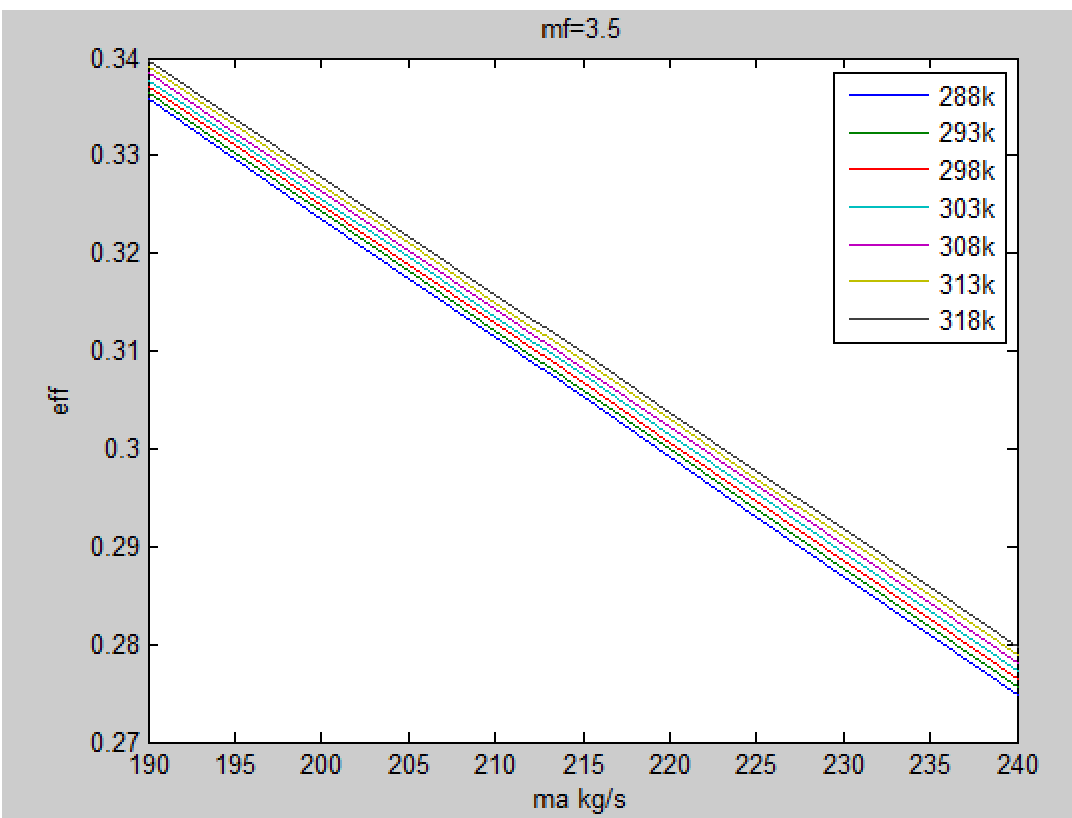


Figure (4-3): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=3.5 kg/s

4	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
	288	0.3647	0.354	0.3434	0.3327	0.322	0.3114	0.3007	0.29	0.2794	0.2687	0.258
	293	0.3653	0.3547	0.344	0.3334	0.3227	0.3121	0.3015	0.2908	0.2802	0.2695	0.2589
	298	0.3659	0.3553	0.3447	0.334	0.3234	0.3128	0.3022	0.2916	0.281	0.2704	0.2598
	303	0.3665	0.3559	0.3453	0.3347	0.3241	0.3136	0.303	0.2924	0.2818	0.2712	0.2607
	308	0.367	0.3565	0.3459	0.3354	0.3248	0.3143	0.3037	0.2932	0.2826	0.2721	0.2615
	313	0.3676	0.3571	0.3466	0.3361	0.3255	0.315	0.3045	0.294	0.2835	0.2729	0.2624
	318	0.3682	0.3577	0.3472	0.3367	0.3262	0.3157	0.3053	0.2948	0.2843	0.2738	0.2633

Table (4-4): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=4 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

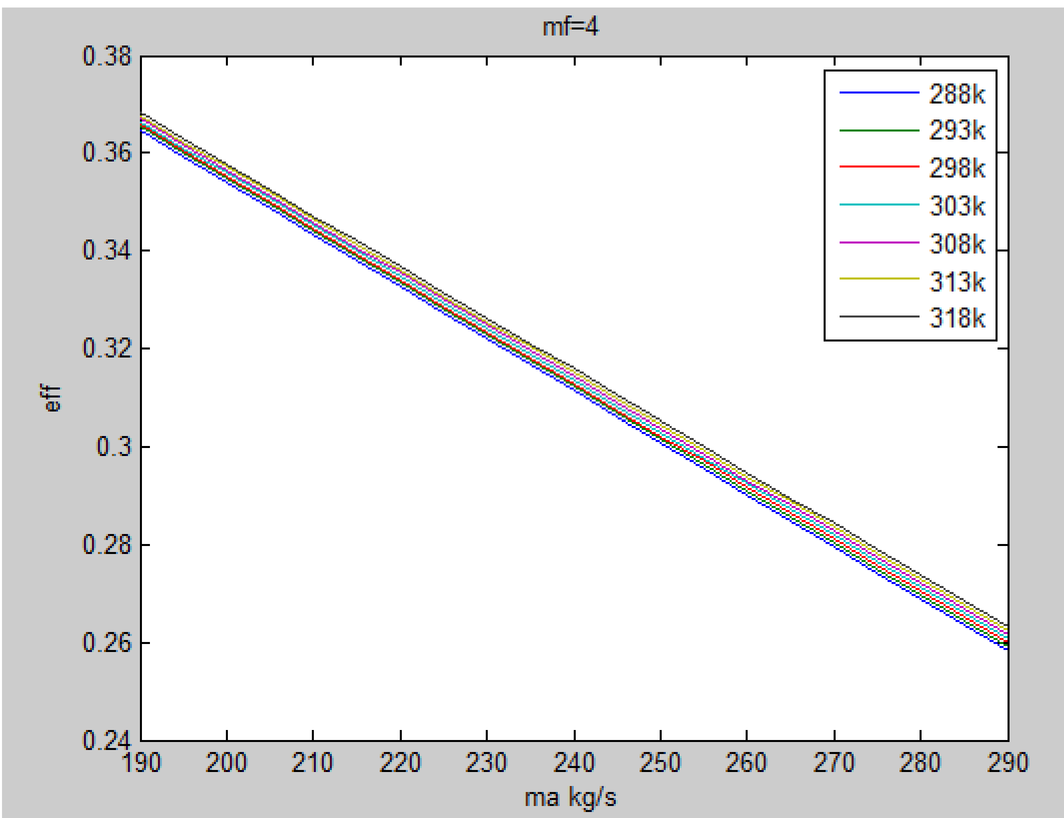


Figure (4-4): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=4 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
4.5	288	0.3872	0.3778	0.3683	0.3588	0.3493	0.3398	0.3303	0.3208	0.3114	0.3019	0.2924
	293	0.3878	0.3783	0.3688	0.3594	0.3499	0.3405	0.331	0.3216	0.3121	0.3026	0.2932
	298	0.3883	0.3788	0.3694	0.36	0.3505	0.3411	0.3317	0.3223	0.3128	0.3034	0.294
	303	0.3888	0.3794	0.37	0.3606	0.3512	0.3418	0.3324	0.323	0.3136	0.3042	0.2947
	308	0.3893	0.3799	0.3705	0.3612	0.3518	0.3424	0.333	0.3237	0.3143	0.3049	0.2955
	313	0.3898	0.3805	0.3711	0.3618	0.3524	0.3431	0.3337	0.3244	0.315	0.3057	0.2963
	318	0.3903	0.381	0.3717	0.3624	0.353	0.3437	0.3344	0.3251	0.3157	0.3064	0.2971

Table (4-5): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=4.5 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

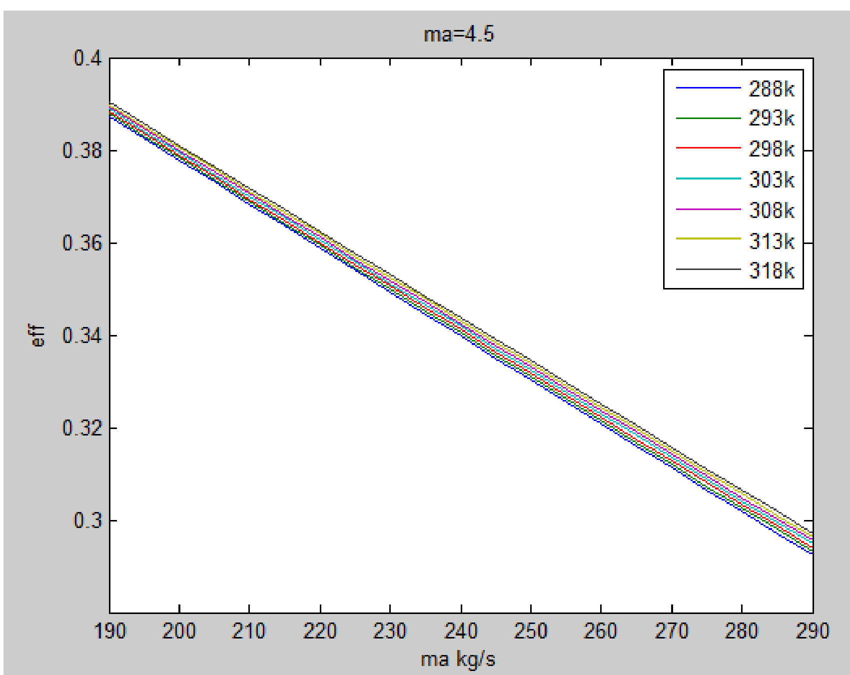


Figure (4-5): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=4.5 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
5	288	0.4053	0.3967	0.3882	0.3797	0.3711	0.3626	0.354	0.3455	0.337	0.3284	0.3199
	293	0.4057	0.3972	0.3887	0.3802	0.3717	0.3632	0.3547	0.3461	0.3376	0.3291	0.3206
	298	0.4062	0.3977	0.3892	0.3807	0.3722	0.3638	0.3553	0.3468	0.3383	0.3298	0.3213
	303	0.4067	0.3982	0.3897	0.3813	0.3728	0.3643	0.3559	0.3474	0.3389	0.3305	0.322
	308	0.4071	0.3987	0.3902	0.3818	0.3734	0.3649	0.3565	0.348	0.3396	0.3312	0.3227
	313	0.4076	0.3992	0.3907	0.3823	0.3739	0.3655	0.3571	0.3487	0.3403	0.3318	0.3234
	318	0.408	0.3997	0.3913	0.3829	0.3745	0.3661	0.3577	0.3493	0.3409	0.3325	0.3241

Table (4-6): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=5 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

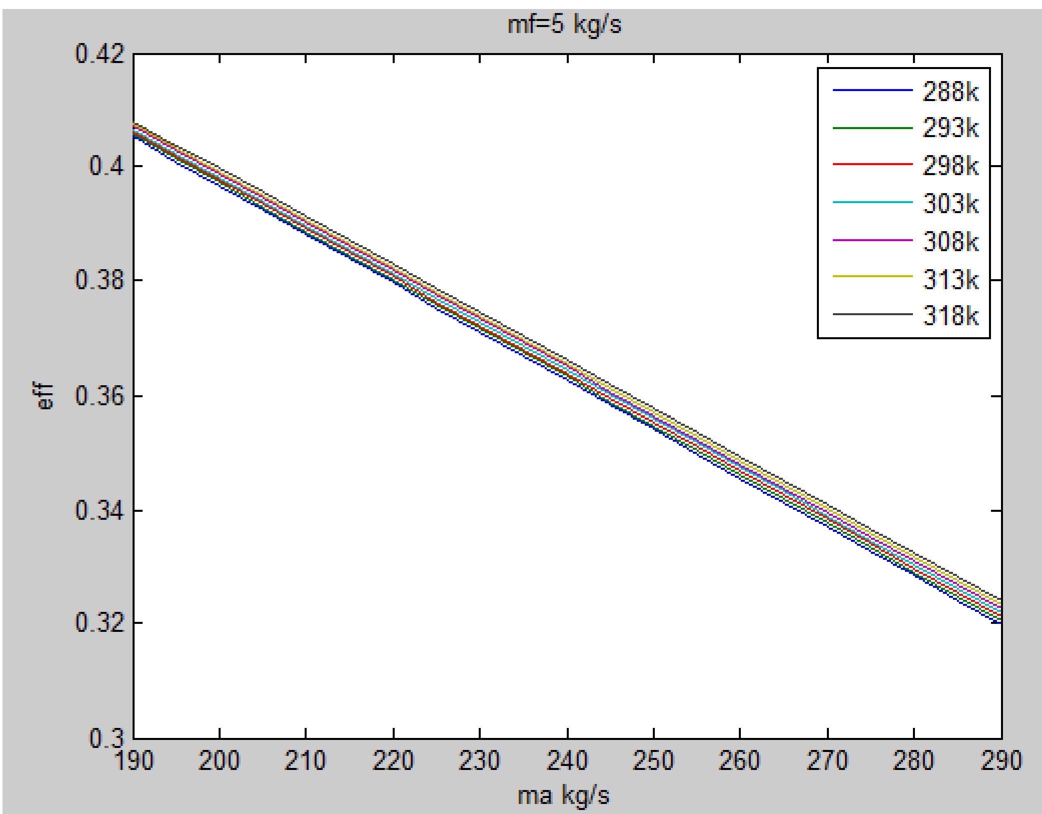


Figure (4-6): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=5 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
5.5	288	0.42	0.4122	0.4045	0.3967	0.389	0.3812	0.3734	0.3657	0.3579	0.3502	0.3424
	293	0.4204	0.4127	0.405	0.3972	0.3895	0.3817	0.374	0.3663	0.3585	0.3508	0.343
	298	0.4208	0.4131	0.4054	0.3977	0.39	0.3823	0.3746	0.3668	0.3591	0.3514	0.3437
	303	0.4213	0.4136	0.4059	0.3982	0.3905	0.3828	0.3751	0.3674	0.3597	0.352	0.3443
	308	0.4217	0.414	0.4063	0.3987	0.391	0.3833	0.3757	0.368	0.3603	0.3526	0.345
	313	0.4221	0.4145	0.4068	0.3992	0.3915	0.3839	0.3762	0.3686	0.3609	0.3533	0.3456
	318	0.4225	0.4149	0.4073	0.3997	0.392	0.3844	0.3768	0.3691	0.3615	0.3539	0.3463

Table (4-7): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=5.5 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

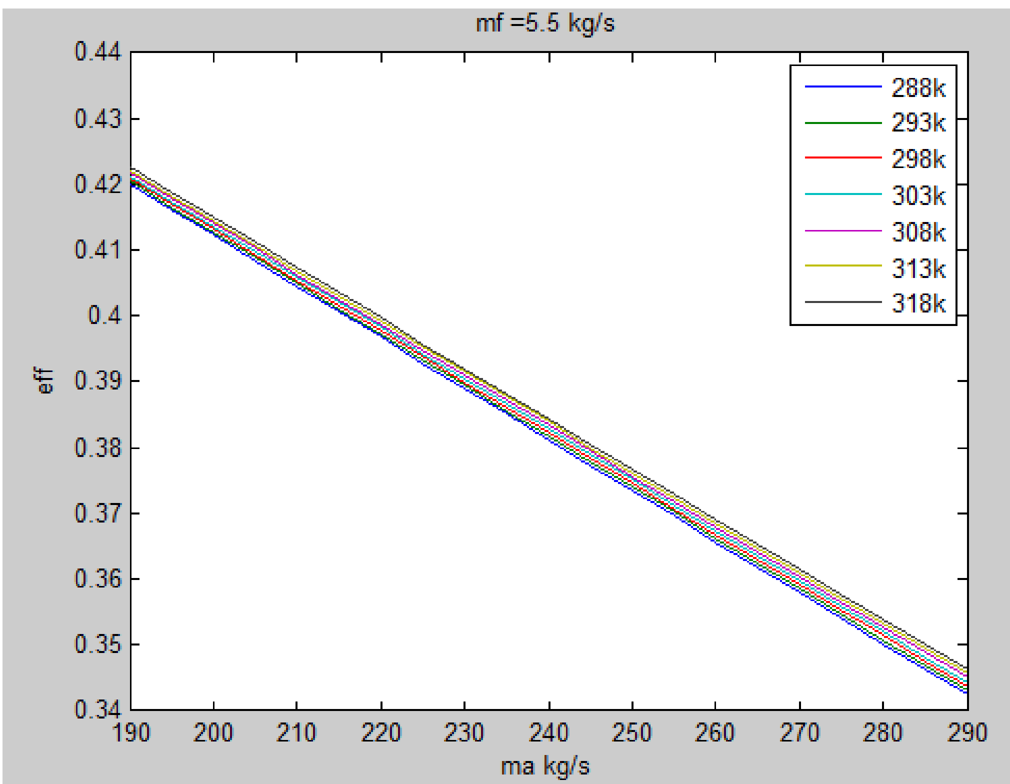


Figure (4-7): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=5.5 kg/s

6	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
	288	0.4323	0.4252	0.4181	0.411	0.4038	0.3967	0.3896	0.3825	0.3754	0.3683	0.3612
	293	0.4327	0.4256	0.4185	0.4114	0.4043	0.3972	0.3901	0.383	0.3759	0.3688	0.3617
	298	0.4331	0.426	0.4189	0.4118	0.4048	0.3977	0.3906	0.3836	0.3765	0.3694	0.3623
	303	0.4335	0.4264	0.4193	0.4123	0.4052	0.3982	0.3911	0.3841	0.377	0.37	0.3629
	308	0.4338	0.4268	0.4198	0.4127	0.4057	0.3987	0.3916	0.3846	0.3776	0.3705	0.3635
	313	0.4342	0.4272	0.4202	0.4132	0.4062	0.3992	0.3922	0.3851	0.3781	0.3711	0.3641
	318	0.4346	0.4276	0.4206	0.4136	0.4066	0.3997	0.3927	0.3857	0.3787	0.3717	0.3647

Table (4-8): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=6 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

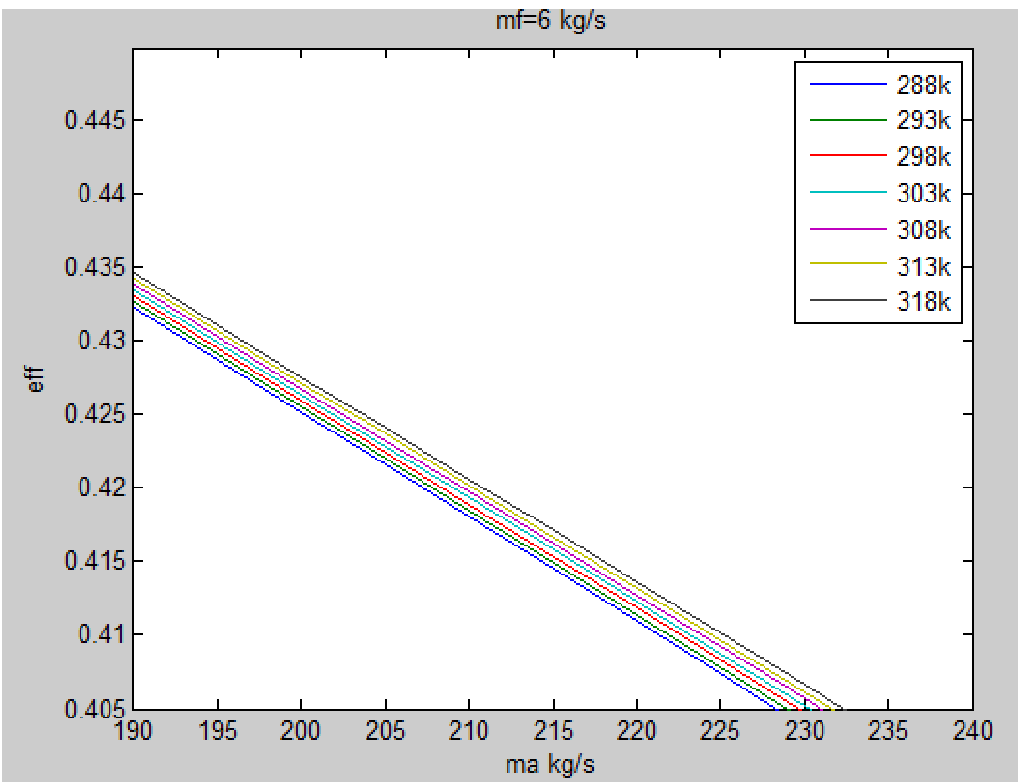


Figure (4-8): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=6 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
6.5	288	0.4427	0.4361	0.4296	0.423	0.4164	0.4099	0.4033	0.3967	0.3902	0.3836	0.377
	293	0.443	0.4365	0.43	0.4234	0.4169	0.4103	0.4038	0.3972	0.3907	0.3841	0.3776
	298	0.4434	0.4369	0.4303	0.4238	0.4173	0.4108	0.4042	0.3977	0.3912	0.3846	0.3781
	303	0.4438	0.4372	0.4307	0.4242	0.4177	0.4112	0.4047	0.3982	0.3917	0.3852	0.3787
	308	0.4441	0.4376	0.4311	0.4246	0.4182	0.4117	0.4052	0.3987	0.3922	0.3857	0.3792
	313	0.4445	0.438	0.4315	0.4251	0.4186	0.4121	0.4056	0.3992	0.3927	0.3862	0.3797
	318	0.4448	0.4384	0.4319	0.4255	0.419	0.4126	0.4061	0.3997	0.3932	0.3867	0.3803

Table (4-9): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=6.5 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

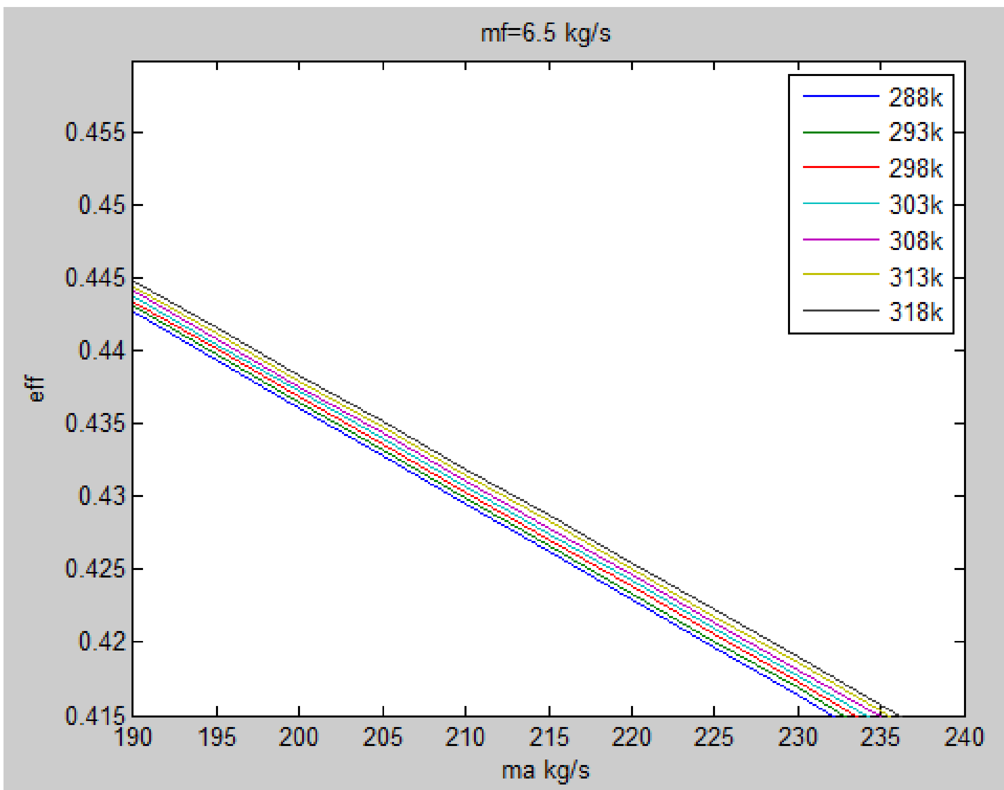


Figure (4-9): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=6.5 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
7	288	0.4516	0.4455	0.4394	0.4333	0.4272	0.4211	0.415	0.4089	0.4028	0.3967	0.3906
	293	0.4519	0.4459	0.4398	0.4337	0.4276	0.4215	0.4155	0.4094	0.4033	0.3972	0.3911
	298	0.4523	0.4462	0.4401	0.4341	0.428	0.422	0.4159	0.4098	0.4038	0.3977	0.3916
	303	0.4526	0.4465	0.4405	0.4345	0.4284	0.4224	0.4163	0.4103	0.4042	0.3982	0.3921
	308	0.4529	0.4469	0.4409	0.4348	0.4288	0.4228	0.4168	0.4107	0.4047	0.3987	0.3926
	313	0.4533	0.4472	0.4412	0.4352	0.4292	0.4232	0.4172	0.4112	0.4052	0.3992	0.3932
	318	0.4536	0.4476	0.4416	0.4356	0.4296	0.4236	0.4176	0.4116	0.4056	0.3997	0.3937

Table (4-10): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=7 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

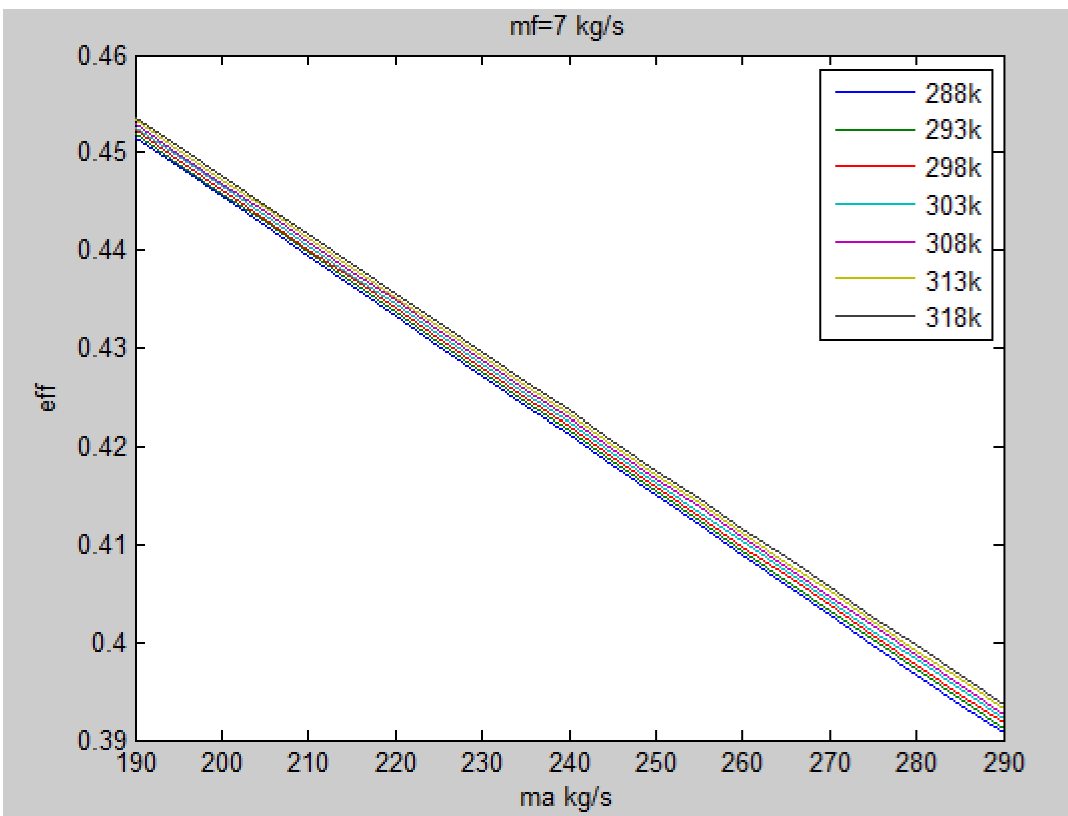


Figure (4-10): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=7 kg/s

	T1	ma1	ma2	ma3	ma4	ma5	ma6	ma7	ma8	ma9	ma10	ma11
7.5	288	0.4593	0.4536	0.4479	0.4423	0.4366	0.4309	0.4252	0.4195	0.4138	0.4081	0.4024
	293	0.4596	0.454	0.4483	0.4426	0.4369	0.4313	0.4256	0.4199	0.4142	0.4086	0.4029
	298	0.4599	0.4543	0.4486	0.443	0.4373	0.4317	0.426	0.4203	0.4147	0.409	0.4034
	303	0.4603	0.4546	0.449	0.4433	0.4377	0.432	0.4264	0.4208	0.4151	0.4095	0.4038
	308	0.4606	0.4549	0.4493	0.4437	0.4381	0.4324	0.4268	0.4212	0.4156	0.4099	0.4043
	313	0.4609	0.4553	0.4497	0.444	0.4384	0.4328	0.4272	0.4216	0.416	0.4104	0.4048
	318	0.4612	0.4556	0.45	0.4444	0.4388	0.4332	0.4276	0.422	0.4164	0.4108	0.4052

Table (4-11): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=7.5 kg/s

As we see in this table that efficiency increase by increase temperature , it also increase by decrease in air flow rate.

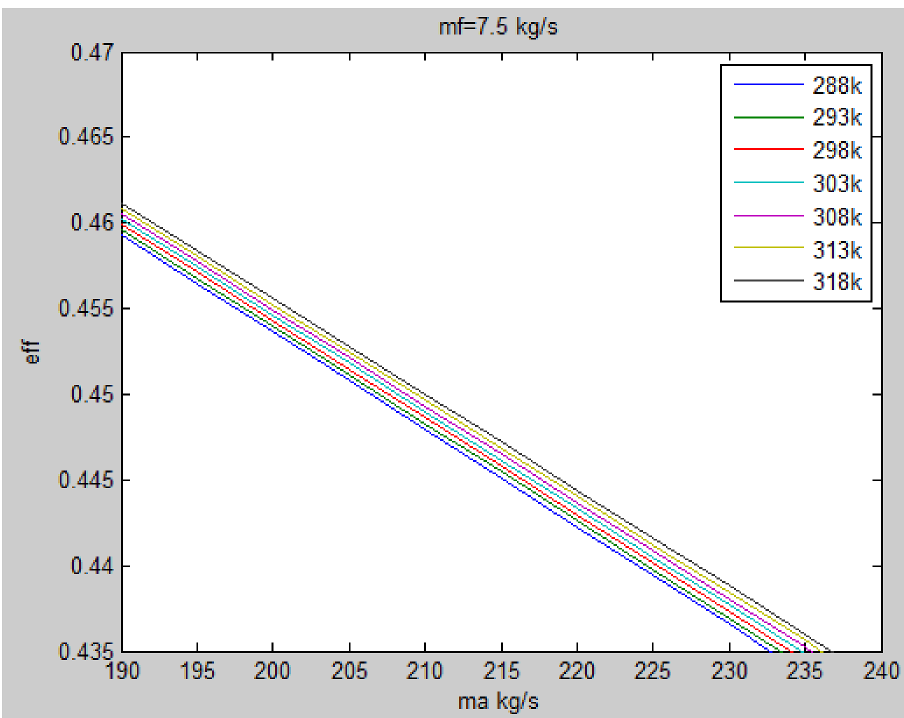


figure (4-11): Effect of Air inlet temperature and air flow rate on plant efficiency when mf=7.5 kg/s

Table(4-12): Demonstrates the highest efficiency for any fuel flow rate according to the MATLAB program in the following circumstances.

NO	m_f kg/s	T_i ˚C	m_a Kg/s	$2.W_g$ MW	W_s MW	W_{net} MW	eff
1.	2.5	318	190	41.558	11.898	53.456	**0.2486**
2.	3	318	190	57.544	20.311	77.855	**0.3018**
3.	3.5	318	190	73.552	28.724	102.276	**0.3397**
4.	4	318	190	89.52	37.137	126.657	**0.3682**
5.	4.5	318	190	105.508	45.55	151.058	**0.3903**
6.	5	318	190	121.496	53.936	175.432	**0.408**
7.	5.5	318	190	137.482	62.375	199.85.	**0.4225**
8.	6	318	190	153.47	70.788	244.258	**0.4346**
9.	6.5	318	190	169.458	79.201	248.659	**0.4448**
10.	7	318	190	185.446	87.641	273	**0.4536**
11.	7.5	318	190	201.44	96.72	298.16	**0.4612**

Table(4-12): Demonstrates the highest efficiency for any fuel flow rate according to the MATLAB program

In this table Demonstrates the highest efficiency for any fuel flow rate according to the MATLAB program in the following circumstances. And found the highest efficiency is 46.12% when : fuel flow rate 7.5 kg/s , inlet temperature 318k , air flow rate 190 kg/s , then the two gas turbine generated 201.44 MW, and steam turbine generated 96.92 MW , over all generated 298.16 MW.

Table(4-13): Demonstrates the cost of MW of the highest efficiency for any fuel flow rate according to the MATLAB program.

No	Mf Kg/s	Mf Ton/h	Cost mf SD /h	W_{net} MW	Cost of MW SD/M W.h	eff
1	2.5	18	6778.26	53.456	126.7	0.2486
2	3	21.6	8133.9	77.855	104.4	0.3018
3	3.5	25.2	9489.5	102.276	92.7	0.3397
4	4	28.8	10845.2	126.657	85.6	0.3682
5	4.5	32.4	12200.86	151.058	80.7	0.3903
6	5	36	13556.52	175.432	77.2	0.408
7	5.5	39.6	14912.2	199.857	74.2	0.4225
8	6	43.2	16267.8	244.258	72.5	0.4346
9	6.5	46.8	17623.47	248.659	70.8	0.4448
10	7	50.4	18979.12	273	69.5	0.4536
11	7.5	54	20334.78	298.16	68.2	0.4612

Table(4-13) : Demonstrates the cost of MW of the highest efficiency for any fuel flow rate

Power station used HCGO fuel which cost about 376.57 SDG per Ton.

Table(4-14): Effect of heat recovery steam generation of economic by study comparison between cost net gas turbine work and cost combined Cycle work

No	Mf Ton/h	Cost mf SD /h	**Cost of** 2 wg **MW SD/M W.h**	**Cost of** **w $_{net}$ MW SD/M W.h**	**Cost difference**
1	18	6778.26	163.1	126.7	36.4
2	21.6	8133.9	141.35	104.4	36.95
3	25.2	948 9.5	129.017	92.7	36.317
4	28.8	10845.2	121.148	85.6	35.548
5	32.4	12200.86	115.639	80.7	34.939
6	36	13556.52	111.58	77.2	34.38
7	39.6	14912.2	108.46	74.2	34.26
8	43.2	16267.8	105.999	72.5	33.499
9	46.8	17623.47	103.999	70.8	33.199
10	50.4	18979.12	102.34	69.5	32.84
11	54	20334.78	100.947	68.2	32.747

Table(4-14) : Effect of heat recovery steam generation of economic

In this table ,there is a significant difference in the cost of production of mw without the use of HRSG high cost.

HRSG is a free energy that depends on the cost of construction and maintenance only.

HRSG by reduction can be 40% of the selling price by gas generation only.

Chapter five

Conclusion and Recommendations

Chapter five : Conclusion and Recommendations

5-1 Conclusion:

The first thing is to say that the goal or objective of the project has been successfully achieved. With the designed plant it has been possible to simulate the combined cycle power plant.

The effects of major operating parameters can be summarized as follows:

1) The decrease in air inlet temperature (ambient temperature) will make an increase in efficiency and power output on gas cycle.

2) The decrease in air mass flow rate will make a decrease in efficiency and increase in power output.

3) The turbine inlet temperature should be kept on higher side for maximizing power output, but in other side it minimizes the thermal net efficiency.

4) The increase in live steam pressure will make an increase in efficiency and power output.

5) The increase in live steam temperature will make an increase in efficiency and power output.

6) The increase in steam mass flow will make an increase in efficiency and power output.

5-1-1 optimum operating:

By using the actual operating parameters of GARRI combined cycle power plant and through MATLAB programs, the maximum efficiency of GARRI combined cycle power plant was founded equals **46.12%**, the optimum operating parameters were derived, which are:

- Air inlet temperature (ambient temperature) is **318 K**.
- Mass flow rate of fuel (LPG) is **7.5 Kg/s**.
- Air mass flow rate is **190 Kg/s**.
- Compressor pressure is **920 KPa**.
- Turbine inlet temperature is **1980 K.**
- Live steam pressure is **6700 KPa**.
- Live steam temperature is **556 C**.
- Mass flow rate of steam is **62 Kg/s**.
- Condenser pressure is **10 KPa.**

5-2 Recommendation:

1. Applying simulation by using MATLAB program for its precise numerical analysis and change the compressor pressure ratio.
2. Make studies how to benefit from the high exhaust temperature form heat recovery steam generator by stack.
3. Designing simulation software by using a specific programming language for studying thermal power plants.

References:

1\ Applied Thermodynamics ,third addition copyright @(2009 , 2006 , 2003) New age international (p) Ltd, by Onkar Singh.

2\ Documents Unit of Garri

3\ (P.K.Nag), Power plant Engineering, Third Edition
copyright @ 2006.

4\A. El-Hadik, " The Impact of Atmospheric Conditions on Gas Turbine Performance," Journal of Engineering for Gas turbine and power, vol. 112, pp. 590-596, October 199

5\ Y. A. Çengel and M. A. Boles, Thermodynamic An Engineering Approach, 5th edition, McGraw-Hill, 2006.

6\J. Horlock, Combined power plants including Combined Cycle Gas Turbine (CCGT) Plants, perrgamon press, 1992

7\ Wikipedia .org

Appendixes

Garri Power station

Heat Recovery Steam Generation Pipes

```matlab


close all
clc

%%%%%%%%%%%%%%%% GAS TURBINE CYCLE %%%%%%%%%%%%%%%

rp=10;
gama_air = 1.4;
Cp =1.005;
eff_c = 0.85;

T1 = (15:5:45)+273;
ma = 190:5:290;
CV = 43000;
mf = 2.5:0.5:7.5;
Cpg = 1.15;
gama_gas = 1.333;

%%%%%%%%%%% STEAM TURBINE DATA  %%%%%%%%%%%%%%%%%

% FOR HIGH PRESSURE 67 BAR AND TEMP 465C DEGREE:

hf = 1257.13;
hsh = 3328.26;
Tf = 283.888+273;
dt= 25; %%%%%%  assume deffrent at heat recovery
T5= Tf +dt;

% FOR LOW PRESSURE 0.1 BAR :
hs_out = 2098;
h_out = 2005.4;

```

MATLAB code

```matlab
for i=1:7
    for j=1:21
        for k =1:11

            T2s(i)= T1(i)* rp^((gama_air -1)/ gama_air);

            T2(i)  = ((T2s(i)-T1(i))/eff_c)+T1(i);

            Wc(i,j)= ma(j)* Cp *(T2(i)-T1(i));

            Qin(k)= mf(k)*CV;

            T3(i,j,k)=  ((ma(j)*Cp*T2(i))+(mf(k)*CV))/((ma(j)+mf(k))*Cpg);

            T4s(i,j,k)= T3(i,j,k)/ rp^((gama_gas -1)/ gama_gas);

            T4(i,j,k)= T3(i,j,k)-( T3(i,j,k)-T4s(i,j,k) )*eff_c;

            Wt(i,j,k)= ( ma(j)+mf(k)  )* Cpg *( T3(i,j,k)-T4(i,j,k) );

            W_gas(i,j,k)= Wt(i,j,k)- Wc(i,j);

           eff_gas(i,j,k)= W_gas(i,j,k)/Qin(k);

           m_st(i,j,k)=  ( ma(j)+mf(k))*Cpg*( T4(i,j,k)-T5)/(hsh - hf);

           W_st(i,j,k)= m_st(i,j,k)*(hsh - h_out);

           eff_combined (i,j,k)= (W_gas(i,j,k)*2+ W_st(i,j,k))/(Qin(k)*2);

```

MATLAB code

```
for i=1:7
    for j=1:21
        for k =1:11

            T2s(i)= T1(i)* rp^((gama_air -1)/ gama_air);

            T2(i)  = ((T2s(i)-T1(i))/eff_c)+T1(i);

            Wc(i,j)= ma(j)* Cp *(T2(i)-T1(i));

            Qin(k)= mf(k)*CV;

            T3(i,j,k)= ((ma(j)*Cp*T2(i))+(mf(k)*CV))/((ma(j)+mf(k))*Cpg);

            T4s(i,j,k)= T3(i,j,k)/ rp^((gama_gas -1)/ gama_gas);

            T4(i,j,k)= T3(i,j,k)-( T3(i,j,k)-T4s(i,j,k) )*eff_c;

            Wt(i,j,k)= ( ma(j)+mf(k) )* Cpg *( T3(i,j,k)-T4(i,j,k) );

            W_gas(i,j,k)= Wt(i,j,k)- Wc(i,j);

           eff_gas(i,j,k)= W_gas(i,j,k)/Qin(k);

           m_st(i,j,k)= ( ma(j)+mf(k))*Cpg*( T4(i,j,k)-T5)/(hsh - hf);

           W_st(i,j,k)= m_st(i,j,k)*(hsh - h_out);

           eff_combined (i,j,k)= (W_gas(i,j,k)*2+ W_st(i,j,k))/(Qin(k)*2);

```

MATLAB code

Assumptions

CV =43000kj/kg

γ air = 1.4

γ gas = 1.333

Tin = 15 ℃– 45 ℃

r_P = 10

η_C = 83%

η_T = 83%

m_a = 190 – 290 Kg/s

m_f = 2.5 – 7.5 Kg/s

ambient Pressure = 0.966 bar

Turbine pressure = 67 bar

Condenser pressure = 0.1 bar