Poznan University of Technology

FACULTY OF MACHINES AND TRANSPORT

INCREASING THE PRODUCTION OF ELECTRIC ENERGY FROM NATURAL GAS USAGE

By

ALI ABDULHOSSEIN RESAN AL-MALIKI

A dissertation submitted to Poznan University of Technology in partial fulfillment

of the requirements for the degree of Master of Mechanical engineering

Supervisor:

Dr. Inż. Krzysztof Koper

ABSTRACT

About 70 % of all natural gas produced in Iraq is flared, rather than captured enough to provide electricity for millions of homes if it was captured and used. In addition, enough Liquefied petroleum gas (LPG) is lost through flaring in Iraq to fill more than two hundred thousand LPG cylinders per day; the value of all the natural gas flared in Iraq is thought to be $7 million per day. That does not include the opportunity cost of the oil, which is used to generate electricity instead of natural gas. If it was not used for power generation, this oil could be exported that is why Iraqi Oil Ministry announced that in 2022 all the associated natural gas would be used because the facilities allocated for its investment will be completed and it is estimated that the power demand will be reached 30,000MW in 2020 from 20,000MW in these days that why Iraq need to increasing the production of electric energy from natural gas usage in this study will propositions how to increase the production of electric energy by using combined cycle power plant (CCPP) which are more efficient in comparison with simple cycle power plant (SCPP) that use same amount of fuel (natural gas) and identify things that Iraqi Ministry of Electrics (MOE) should notes to develop the already founded power plants from simple cycle power plant (SCPP) to combined cycle power plant (CCPP) and to achieve the project's aims; the tasks was basic definitions of natural gas (what is NG ? how NG formed ? ….) , know basic information about the (SCPP) and (CCPP), introduction to Gas turbine power plant, basic knowledge about support systems and case study analysis from choosing the power plant among three potential sites where the gas turbines are already installed or planned to be installed in simple cycle and how one of them could be converted to a combined cycle plant and this study give what it is proposed to achieve this goals.

Keywords: natural gas, LPG, combined cycle, simple cycle, power plant, Gas turbine

STRESZCZENIE

Około 70% gazu ziemnego wyprodukowanego w Iraku jest wypalane, a nie wychwytywane po to, aby dostarczać energię elektryczną dla milionów domów. Ilość propano-butanu (LPG), która tracona jest przez wypalanie wystarczyłaby, aby wypełnić ponad dwieście tysięcy butli LPG dziennie, a wartość całego gazu wypalanego w Iraku wynosi 7 milionów dolarów dziennie. Nie obejmuje to kosztów ropy naftowej (jej frakcji olejowych), która jest wykorzystywana jako alternatywne paliwo do wytwarzania energii elektrycznej zamiast gazu ziemnego. Gdyby nie korzystać z jej zasobów do wytwarzania energii, można by eksportować tę ropę, dlatego Irackie Ministerstwo ds. Ropy Naftowej ogłosiło, że już w 2022 r. będzie możliwość wykorzystania całego związanego z wydobyciem ropy gazu ziemnego, ponieważ inwestycje w urządzenia do jego celowego spalania zostaną ukończone. Szacuje się, że zapotrzebowanie na moc w kraju wzrośnie do 30 000 MW w 2020 r. z dzisiejszych 20 000 MW, dlatego też Irak musi zwiększyć produkcję energii elektrycznej z gazu ziemnego. W pracy tej zaproponowano sposoby zwiększenia produkcji energii elektrycznej poprzez wykorzystanie elektrociepłowni (CCPP) której wydajność jest większa w porównaniu z prostą elektrownią (SCPP), które wykorzystują taką samą ilość paliwa (gaz ziemny). Kolejnym celem jest identyfikacja aspektów, które Irackie Ministerstwo Elektrykoenergetyki (MOE) powinno uwzględnić, aby rozwinąć już istniejące elektrownie z elektrowni o prostym cyklu (SCPP) do elektrociepłowni (CCPP). Praca przedstawia problematykę wykorzystania gazu ziemnego jako paliwa energetycznego, jego pochodzenie i ekonomikę wykorzystania, omawia schematy działania turbin i elektrowni gazowych oraz prezentuje studia przypadku, z których wywiedziono wnioski co do potencjału rozwoju energetyki gazowej w Iraku.

Słowa kluczowe: gaz ziemny, LPG, cykl prosty, cykl złożony, elektrownia, turbina gazowa

Acknowledgments

I have six women in my live my mother, my sister, my wife and my three daughters how support and encourage me to proceed in the way of knowledge ..

My father who was a brilliant engineer and inspired me to try to be like him ..

My friend Mr. MANKHI Tahseen Ali how help me to choose our wonderful university ..

My supervisor Dr. Inż. Krzysztof Koper how always show cooperation in overcoming the difficulties that have faced me since the first day I began my higher studies ..

Thank you all for everything, thank you for make my dream become reality

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms	Meaning
NG	Natural Gas
LPG	Liquefied petroleum gas
SCPP	Simple Cycle Power Plant
CCPP	Combined Cycle Power Plant
MOE	Iraqi Ministry of Electrics
MOO	Iraqi Ministry of Oil
HRSG	Heat Recovery Steam Generator
HPS	Hydropower stations
EPC	Engineering, Procurement, Construction
DCS	Distributed Control System
CCR	Center Control Room
DM	Demineralization
TCF	Trillion Cubic Feet
OPEC	Organization of Petroleum Export Countries
MW	Mega watt

1 NATURAL GAS

1.1 WHAT IS NATURAL GAS?

Natural gas is a naturally occurring hydrocarbon gas mixture consisting primarily of methane, but usually including varying quantities of other higher alkanes [1], and occasionally a minor percentage of carbon dioxide, nitrogen, hydrogen sulfide, or helium.

1.2 HOW IS NATURAL GAS FORMED?

Most natural gas was formed over time by two mechanisms: biogenic and thermogenic. Biogenic gas is formed by methanogenic organisms in marshes, bogs, landfills, and shallow sediments [2]. Deeper in the earth, at greater temperature and pressure, thermogenic gas is created from buried organic material.

1.3 NATURAL GAS USES

Used as a source of energy for cooking, heating, and electricity generation "Natural gas is a main source of electricity generation through the use of cogeneration, gas and steam turbines". It is also used as fuel for automobiles and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals. It is a non-renewable resource.

When gas is associated with petroleum production it may be considered a byproduct and be burnt as flare gas. The World Bank estimates that over 150 cubic kilometers of natural gas are flared or vented annually, before natural gas can be used as a fuel [3], it must be processed to remove impurities, including water, to meet the specifications of marketable natural gas. The by-products of this processing include: ethane, propane, butanes, pentanes, and higher molecular weight hydrocarbons, hydrogen sulfide (which may be converted into pure sulfur), carbon dioxide, water vapor, and sometimes helium and nitrogen [4].

The world's first industrial extraction of natural gas started at Fredonia, New York [5], United States in 1825.By 2009, Sixty-six thousand '66 000' km^3 (or 8%) had been used out of the total 850 000 km^3 of estimated remaining recoverable reserves of natural gas.

Based on an estimated 2015 world consumption rate of about three thousand and four hundred '3400' km^3 of gas per year, the total estimated remaining economically recoverable reserves of natural gas would last 250 years at current consumption rates. An annual increase in usage of 2–3% could result in currently recoverable reserves lasting significantly less, perhaps as few as 80 to 100 years.

In the 19th century and early 20th century, undesirable gas was usually burned off at oil fields.

Today, unwanted gas (or stranded gas without a market) associated with oil extraction often is returned to the reservoir with 'injection' wells while awaiting a possible future market or to re pressurize the formation, which can enhance extraction rates from other wells.

In regions with a high natural gas demand (such as the US), pipelines are constructed when it is economically feasible to transport gas from a wellsite to an end consumer [5].

Natural gas can be:

"Associated" (found in oil fields),

Or "non-associated" (isolated in natural gas fields),

And is also found in coal beds (as coalbed methane)

It sometimes comprises a noteworthy amount of ethane, propane, butane, and pentane - heavier hydrocarbons removed for commercial use prior to the methane being sold as a consumer fuel or chemical plant feedstock. Non-hydrocarbons such as carbon dioxide, nitrogen, helium (rarely), and hydrogen sulfide must also be removed before the natural gas can be transported.

Natural gas extracted from oil wells is called casing head gas (whether or not truly produced up the annulus and through a casing head outlet) or associated gas.

The natural gas industry is extracting an increasing quantity of gas from challenging resource types:

1.4 COUNTRIES WITH BIGGEST GAS RESERVES

There is some disagreement on which country has the largest proven gas reserves. Sources that consider that Russia has by far the largest proven reserves include the US CIA (47 600 km³), the US Energy Information Administration (47 800 km³) and OPEC (48 700 km³) However, BP credits Russia with only 32 900 km³ which would place it in second place, slightly behind Iran (33 100 to 33 800 km³, depending on the source) [6]. With Gazprom, Russia is frequently the world's largest natural gas extractor. Major proven resources (in cubic kilometers) are world 187 300 (2013), Iran 33 600 (2013), Russia 32 900 (2013), Qatar 25 100 (2013), Turkmenistan 17 500 (2013) and the United States 8500 (2013).

1.5 IRAQI NATURAL GAS RESERVES

Iraq has 126.7 trillion cubic feet (Tcf) of proven natural gas reserves which is 12th largest in the world. Iraq has 10 natural gas fields (non-associated) but about 70 percent of Iraq's natural gas reserves is associated natural gas.

Natural Gas Production, processing plants and Domestic Demand (million standard cu m) table 1.1.

Table 1.1 shows Iraqi gas production related data from year 2011 to year 2014 source MOE.

	2011	**2012**	**2013**	**2014**
Gross Production	18691.0	20496.0	21390.1	21853.1
Marketed Production	876.0	646.0	1179.0	904.4
Flaring	9612.0	11975.0	12431.8	12871.4
Reinjection	968.0	875.0	335.0	150.1
Shrinkage	7235.0	7000.0	7444.4	7927.2

1.6 COMPOSITION OF NATURAL GAS

Natural gas is a combustible mixture of hydrocarbon gases. While natural gas is formed primarily of methane, it can also include ethane, propane, butane and pentane. The composition of natural gas can vary widely, but below is a table 1.2 outlining the typical makeup of natural gas before it is refined.

Table 1.2 Typical composition of natural gas source MOE

Typical Composition of Natural Gas		
Methane	CH_4	70-90%
Ethane	C_2H_6	
Propane	C_3H_8	0-20%
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace

1.7 ENVIRONMENTAL EFFECTS

1.7.1 Effect of natural gas release

Natural gas is mainly composed of methane. After release to the atmosphere it is removed by gradual oxidation to carbon dioxide and water by hydroxyl radicals (-OH) formed in the troposphere or stratosphere, giving the overall chemical reaction [7].

$$\mathbf{CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O}$$

While the lifetime of atmospheric methane is relatively short when compared to carbon dioxide, with a half-life of about seven years, it is more efficient at trapping heat in the atmosphere, so that a given quantity of methane has 84 times the global-warming potential of carbon dioxide over a 20-year period and 28 times over a 100-year period. Natural gas is thus a more potent greenhouse gas than carbon dioxide due to the greater global-warming potential of methane. But because when it is burned, it produces more water than carbon dioxide by mole, in contrast to coal which produces mainly carbon dioxide, it produces only about half the carbon dioxide per kilowatt-hour that coal does. Current estimates by the EPA (United States Environmental Protection Agency) place global emissions of methane at 85 billion cubic meters (3.0×1012 cu ft) annually, or 3.2 per cent of global production. Direct emissions of methane represented 14.3 per cent by volume of all global anthropogenic greenhouse gas emissions in 2004 [8].

During extraction, storage, transportation, and distribution, natural gas is known to leak into the atmosphere, particularly during the extraction process. A Cornell University study in 2011 demonstrated that the leak rate of methane may be high enough to jeopardize its global warming advantage over coal. This study was criticized later for its over-estimation of methane leakage values. Preliminary results of some air sampling from airplanes done by the National Oceanic and Atmospheric Administration indicated higher-than-estimated methane releases by gas wells in some areas, but the overall results showed methane emissions in line with previous EPA estimates.

Natural gas extraction also releases an isotope of radon, ranging in activity from 5 to 200,000 becquerels per cubic meter of gas.

1.7.2 CO2 emissions

Natural gas is often described as the cleanest fossil fuel. It produces about 29% and 44% less carbon dioxide per joule delivered than oil and coal respectively and potentially fewer pollutants than other hydrocarbon fuels. However, in absolute terms, it comprises a substantial percentage of human carbon emissions, and this contribution is projected to grow [9]. According to the IPCC Fourth Assessment Report, in 2004, natural gas produced about 5.3 billion tons a year of CO2 emissions, while coal and oil produced 10.6 and 10.2 billion tons respectively. According to an updated version of the Special Report on Emissions Scenario by 2030, natural gas would be the source of 11 billion tons a year, with coal and oil now 8.4 and 17.2 billion respectively because demand is increasing 1.9 percent a year.

1.8 A WASTED RESOURCE TODAY

Today about 70 per cent of all natural gas produced in Iraq is flared, rather than captured enough to provide electricity for more than 15 million homes if it was captured and used. In addition, enough Liquefied petroleum gas (LPG) is lost through flaring in Iraq to fill around 250,000 LPG cylinders per day [10].

This flaring is a significant waste of Iraq's natural resources. Many parts of the country suffer from inadequate supplies of power. People are less comfortable in their homes, and there is less power available for businesses to grow and develop the economy. Iraq has to import LPG, rather than being self-sufficient or even exporting a surplus to generate revenue.

The value of all the natural gas flared in Iraq is thought to be $7 million per day. That does not include the opportunity cost of the oil which is used to generate electricity instead of natural gas. If it was not used for power generation, this oil could be exported.

1.9 PROCESSING: HOW DOES IT WORK?

Major transportation pipelines usually impose restrictions on the make-up of the natural gas that is allowed into the pipeline. Natural gas processing consists of separating all of the various hydrocarbons and fluids from the pure natural gas, to produce what is known as 'pipeline quality' dry natural gas. Associated hydrocarbons, known as 'natural gas liquids' (NGLs) can be very valuable by-products of natural gas processing. NGLs include ethane, propane, butane, isobutane, and natural gasoline [11]. These NGLs are sold separately and have a variety of different uses; including enhancing oil recovery in oil wells, providing raw materials for oil refineries or petrochemical plants, and as sources of energy. The actual practice of processing natural gas to pipeline dry gas quality levels can be quite complex, but usually involves four main processes to remove the various impurities:

- Oil and Condensate Removal
- Water Removal
- Separation of Natural Gas Liquids
- Sulfur and Carbon Dioxide Removal

In addition to those four processes above, heaters and scrubbers are installed, usually at or near the wellhead. The scrubbers serve primarily to remove sand and other large-particle impurities. The heaters ensure that the temperature of the gas does not drop too low. With natural gas that contains even low quantities of water, natural gas hydrates have a tendency to form when temperatures drop. These hydrates are solid or semi-solid compounds, resembling ice like crystals. Should these hydrates accumulate, they can impede the passage of natural gas through valves and gathering systems [11].

After processing, the pipeline quality natural gas is injected into gas transmission pipelines and transported to the end users. This often involves transportation of the gas over hundreds of miles, as the location of gas production is generally not the location where the gas is used.

2 COMBINED CYCLE POWER PLANT

2.1 SIMPLE CYCLE GAS TURBINE

Any stationary gas turbine that does not recover heat from the gas-turbine exhaust gases to preheat the inlet combustion air to the gas turbine or which does not recover heat from the gas-turbine exhaust gases to heat water or generate steam.

MOE has purchased total 72 units equal to 10,442MW of gas turbines from General Electric (GE) and Siemens that is called the Mega Deal. More than 90% of the Mega Deal gas turbines have been already installed as the simple cycle power stations by the end of 2015.

2.2 HOW COMBINED CYCLE POWER PLANT WORKS

2.2.1 INNER WORKINGS OF A COMBINED-CYCLE POWER PLANT

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

2.2.2 HOW A COMBINED-CYCLE POWER PLANT PRODUCES ELECTRICITY

This is how a combined-cycle plant works to produce electricity and captures waste heat from the gas turbine to increase efficiency and electrical output Fig. 2.1.

1. Gas turbine burns fuel.

    - The gas turbine compresses air and mixes it with fuel that is heated to a very high temperature. The hot air-fuel mixture moves through the gas turbine blades, making them spin.

    - The fast-spinning turbine drives a generator that converts a portion of the spinning energy into electricity.

2. Heat recovery system captures exhaust.

- A Heat Recovery Steam Generator (HRSG) captures exhaust heat from the gas turbine that would otherwise escape through the exhaust stack.

- The HRSG creates steam from the gas turbine exhaust heat and delivers it to the steam turbine.

3. Steam turbine delivers additional electricity.

    - The steam turbine sends its energy to the generator drive shaft, where it is converted into additional electricity.

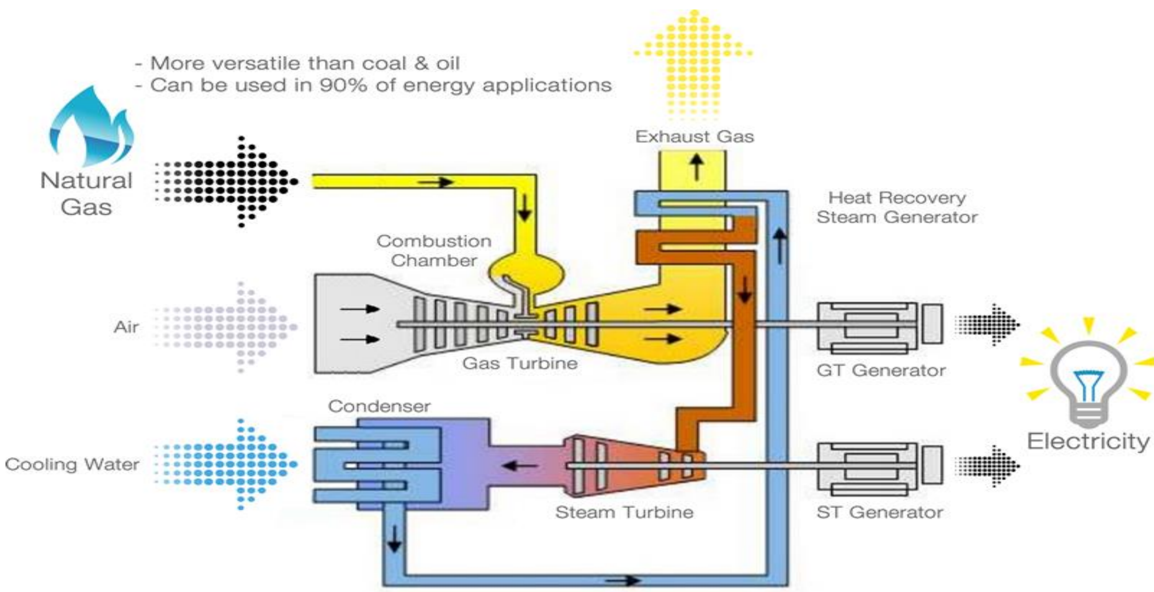


Figure 2.1: Combined-cycle power plant [12]

3 MAJOR COMPONENTS OF GAS POWER PLANT

A gas turbine is an internal combustion motive machine. From all points of view, it can be considered as a self-sufficient system: in fact, it is capable to aspirate and compress ambient air via its own compressor, to enrich the energetic power of air in its own combustion chamber and to convert this power into useful mechanical energy during the expanding process that takes place in its own turbine section. The resulting mechanical energy is transmitted via a coupling to a driven operating machine, which produces work useful for the industrial process in which the gas turbine belongs.

Major Components

This chapter briefly describes the following major components of the turbine:

- Air Inlet System
- Compressor
- Combustion Section
- Turbine
- Exhaust System
- Support Systems
- Base and Supports

3.1 AIR INLET SYSTEM

The air inlet system is specifically designed to modify the quality of air under various temperature, humidity, and contamination situations and make it more suitable for use.

3.2 COMPRESSOR

The gas turbine compressor is an axial flow design that efficiently compresses a large volume of air. The compressor consists of many individual stages operating in series.

3.3 COMBUSTION SECTION

The combustion system consists of liners into which fuel is added and burned with a portion of the compressed air. The excess compressed air is used to cool the products of combustion.

Fuel is injected into each liner by fuel nozzles that atomize the fuel for good burning. The fuel is ignited initially by electric igniters. Once the fire is started, the combustion process is self-sustaining as long as fuel and air are available.

3.4 TURBINE

Turbines are divided into three type's impulse, reaction, and a combination of the two, called impulse-reaction. The energy drop to each stage is a function of the nozzle area and airfoil configuration. Turbine nozzle area is a critical part of the design: too small and the nozzles have a tendency to "choke" under maximum flow conditions; too large and the turbine will not operate at its best efficiency [13]. It is important to note that approximately 3/4 to 2/3 of the turbine work drives the compressor, leaving approximately 1/4 to 1/3 for shaft horsepower.

3.4.1 Impulse-Type Turbine

In an impulse-type turbine, there is no net change in pressure between rotor inlet and exit; therefore, the blades' relative discharge velocity will be the same as its relative inlet velocity. The nozzle guide vanes are shaped to form passages that increase the velocity and reduce the pressure of the escaping gases.

There are two types of impulse turbines: a velocity-compounded impulse turbine (often called the Curtis turbine) and a pressure-compounded impulse turbine (called the Rateau turbine).

3.4.2 Reaction-Type Turbine

In a reaction-type turbine, the nozzle vanes only alter the direction of flow. The decrease in pressure and increase in velocity of the gas is accomplished by the convergent shape of the passage between the rotor blades.

Turbines may be either single-stage or multiple-stage. When the turbine has more than one stage, stationary vanes are located upstream of each rotor wheel. Therefore, each set of stationary vanes forms a nozzle vane assembly for the turbine wheel that follows. The rotor wheels may or may not operate independently of each other, depending upon the type of engine and the power requirements of the turbine. See handout for a more in depth discussion of turbine types [14].

Varying the amount of fuel injected into the combustion liners changes the energy from the combustion system, available to drive the turbine.

3.5 EXHAUST SYSTEM

The exhaust system is an internally insulated diffuser duct that directs the gas turbine exhaust flow from the power turbine exit to the HRSG or into a bypass stack, for a simple cycle turbine. The exhaust system gradually diffuses the exhaust flow for maximum pressure recovery of the exhaust flow thereby enhancing turbine performance.

3.6 SUPPORT SYSTEMS

Support systems consisting of lube oil, cooling water, ignition and fuel system, hydraulic oil, fire protection, and wash water are covered in more detail later.

3.7 BASE AND SUPPORTS

3.7.1 Turbine Base

The base that supports the gas turbine is a structural steel fabrication of welded steel beams and plate. Its prime function is to provide a support upon which to mount the gas turbine. Lifting trunnions and supports are provided, two on each side of the base in line with the two structural cross members of the base frame. Machined pads on each side on the bottom of the base facilitate its mounting to the site foundation. Two machined pads, atop the base frame are provided for mounting the aft turbine supports [14].

3.7.2 Turbine Supports

The following combustion turbine has rigid leg-type supports at the compressor end and supports with top and bottom pivots at the turbine end. On the inner surface of each support leg, a water jacket is provided, through which cooling water is circulated to minimize thermal expansion and to assist in maintaining alignment between the turbine and the load equipment. The support legs maintain the axial and vertical positions of the turbine, while two gib keys coupled with the turbine support legs maintain its lateral position. One gib key is machined on the lower half of the exhaust frame.

The other gib key is machined on the lower half of the forward compressor casing. The keys fit into guide blocks that are welded to the crossbeams of the turbine base. The keys are held securely in place in the guide blocks with bolts that bear against the keys on each side. This key and block arrangement prevents lateral or rotational movement of the turbine while permitting axial and radial movement resulting from thermal expansion. Figure 3.1 and 3.2 shows the major components discussed above.

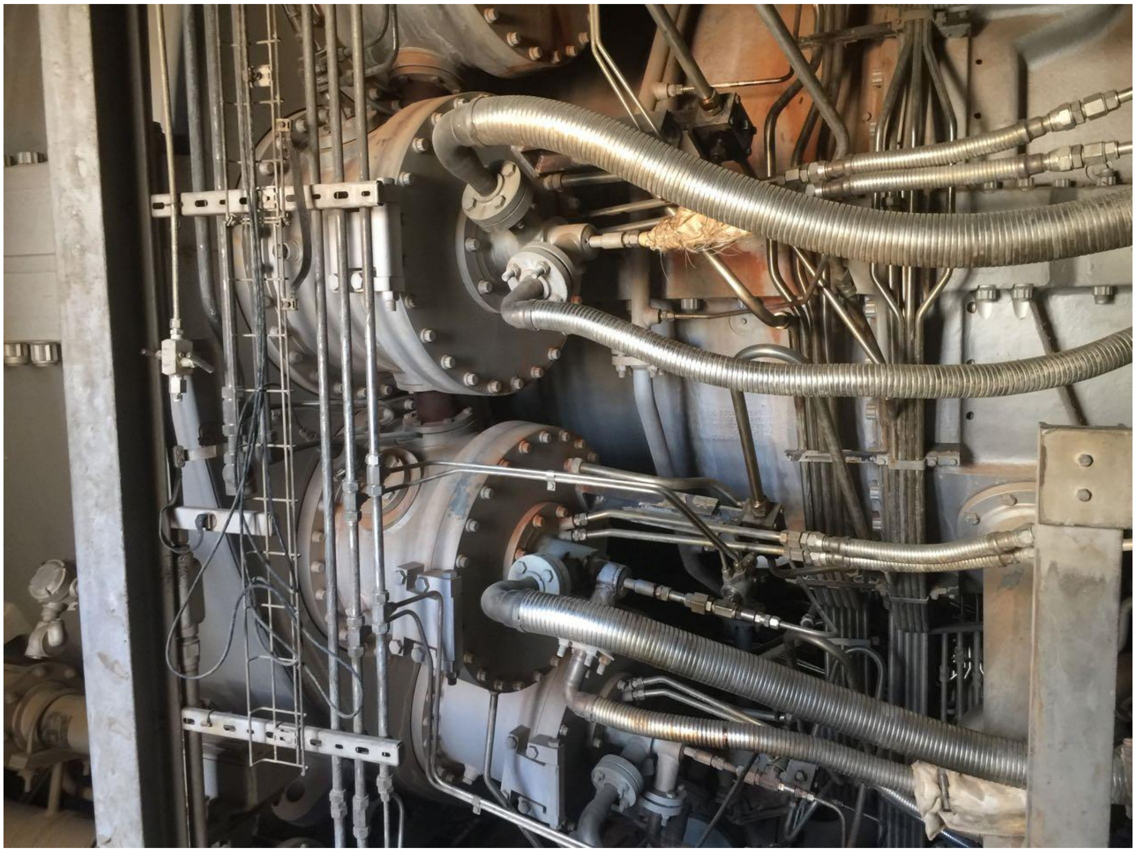


Figure 3.1: Gas Turbine view

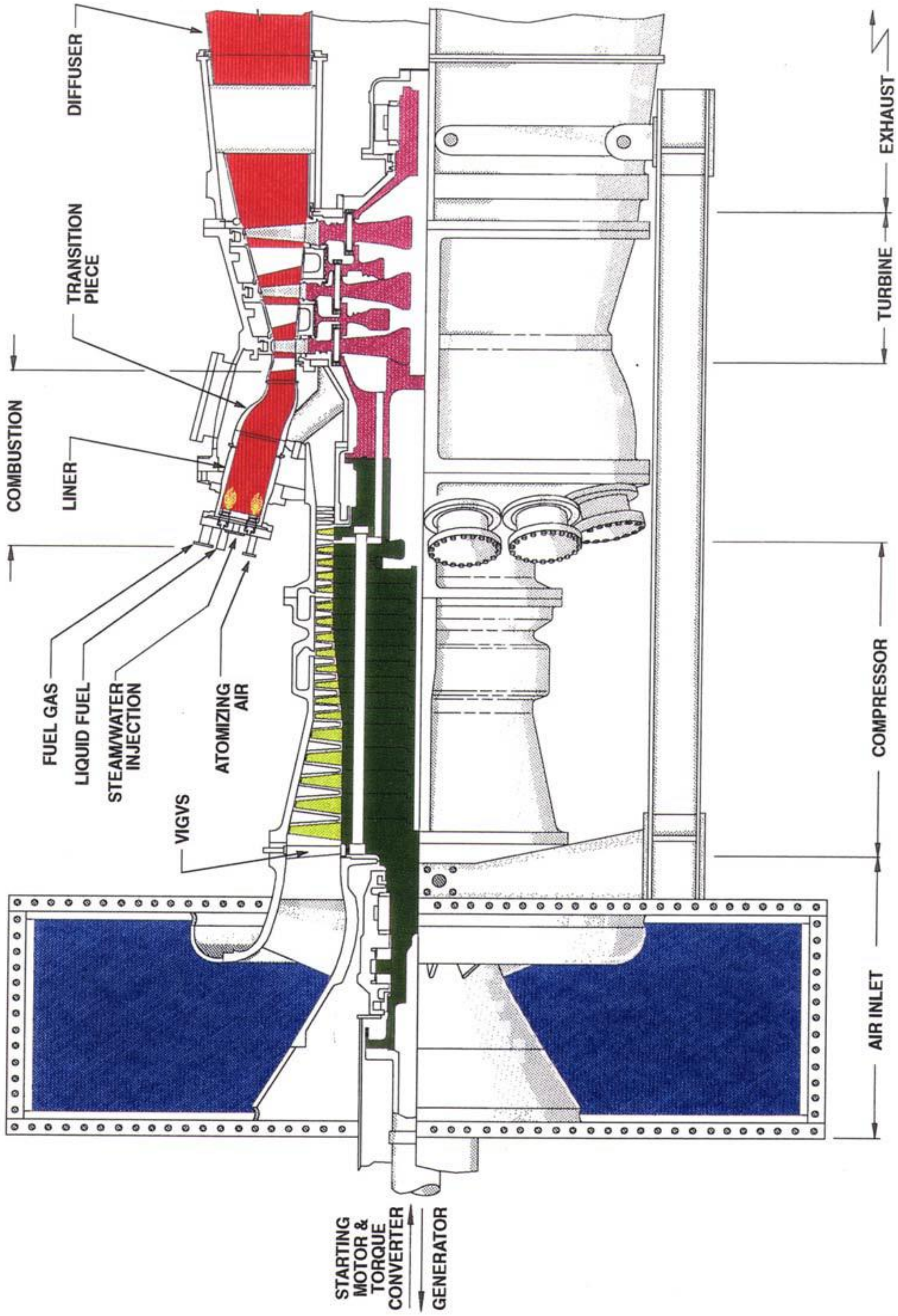


Figure 3.2: Gas Turbine Major Sections [15]

4.1 INTRODUCTION

This section describes the operation of the following combustion turbine support systems:

- Fuel Control System
- Liquid Fuel System
- Gas Fuel Control System
- Ignition System
- Fuel Gas System
- Lube Oil System

Even thought the support systems in this section maybe specific to G E turbine we will discuss them in general terms and concepts as to apply to all turbines. This course is meant to be general in nature and cover only the fundamentals.

4.2 FUEL CONTROL SYSTEM

The gas turbine fuel control system changes fuel flow to the combustors in response to the fuel stroke reference signal that responds to load changes on the generator. The reference signal may consists of two separate signals added together, one for liquid fuel flow and one for gas fuel flow; normally, gas flow + liquid flow = total fuel flow. Standard fuel systems are designed for operation with liquid fuel and/or gas fuel [16].

The heart of the fuel system is an electro- hydraulic, servo valve (servo) as shown in Figure 4.1. The servo valve is the interface between the electrical and mechanical systems and controls the direction and rate of motion of a hydraulic actuator based on the input current to the servo.

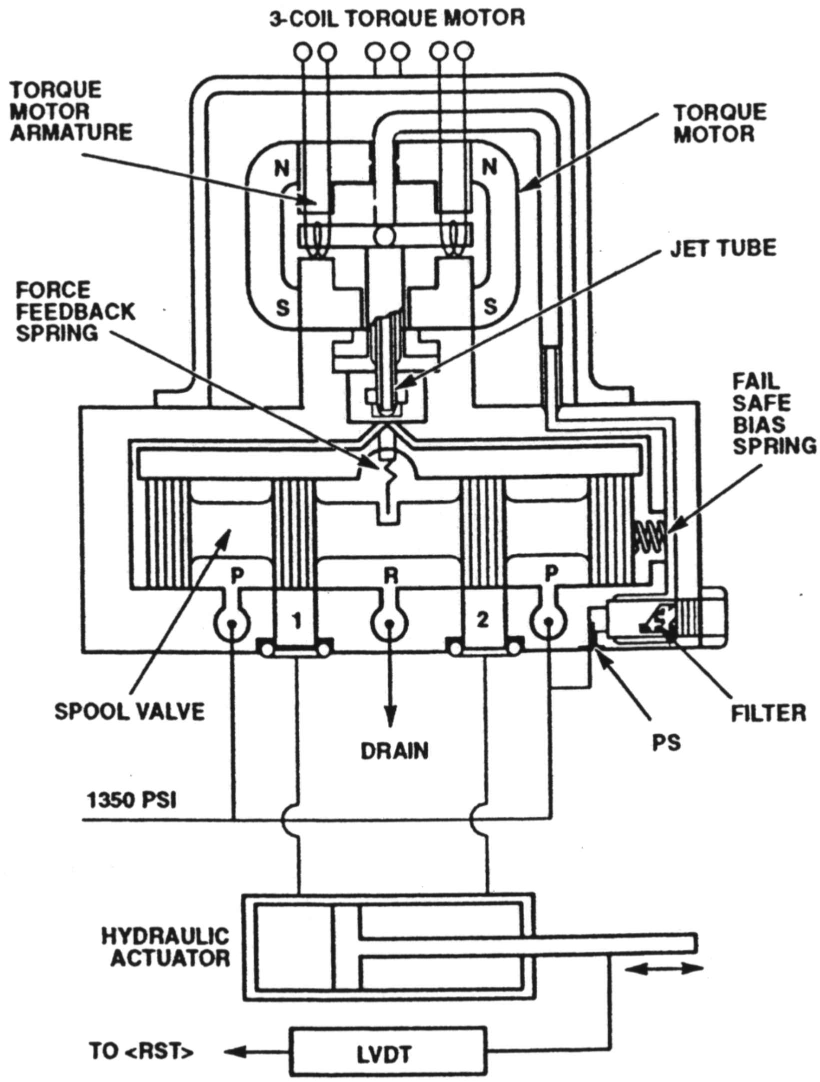


Figure 4.1: Electro-hydraulic Servo-valve [17]

If the hydraulic actuator is a double-action piston, the control signal positions the servo valve so that it ports high-pressure oil to either side of the hydraulic actuator. If the hydraulic actuator has spring return, hydraulic oil will be ported to one side of the cylinder and the other to drain. A feedback signal provided to (Figure 4.1) tells the control whether or not it is in the required position. The output is proportional to the position of the valve. As the valve moves, it causes the feedback signal to change.

Figure 4.2 shows the major components of the servo positioning loops. The digital-to-analog conversion is done by the control system; this represents called for fuel flow. The called for fuel flow signal is then compared to a feedback representing actual fuel flow. The difference is amplified and sent to the servo.

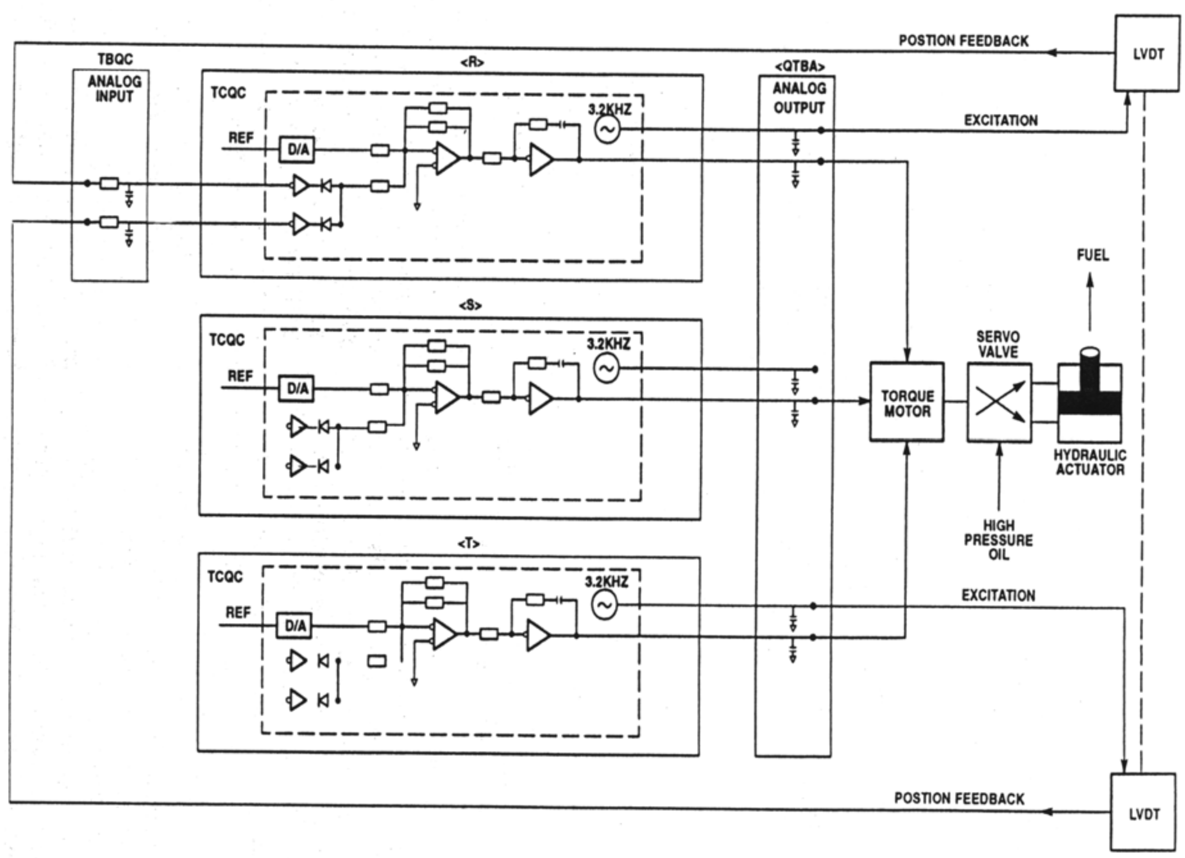


Figure 4.2: Servo Positioning Loops [18]

4.3 LIQUID FUEL SYSTEM

The liquid fuel system consists of fuel-handling components and electrical control components. Some of the fuel-handling components are primary fuel oil filter, fuel oil stop valve, fuel pumps, fuel bypass valve, fuel pump pressure relief valve, flow divider, combined selector valve/pressure gauge assembly, false start drain valve, fuel lines, and fuel nozzles.

The electrical control components are: liquid fuel pressure switch (upstream), fuel oil stop valve limit switch, liquid fuel pump bypass valve servo-valve, flow divider magnetic speed pickups, and system control cards. A diagram of the system showing major components is shown in Figure 4.3.

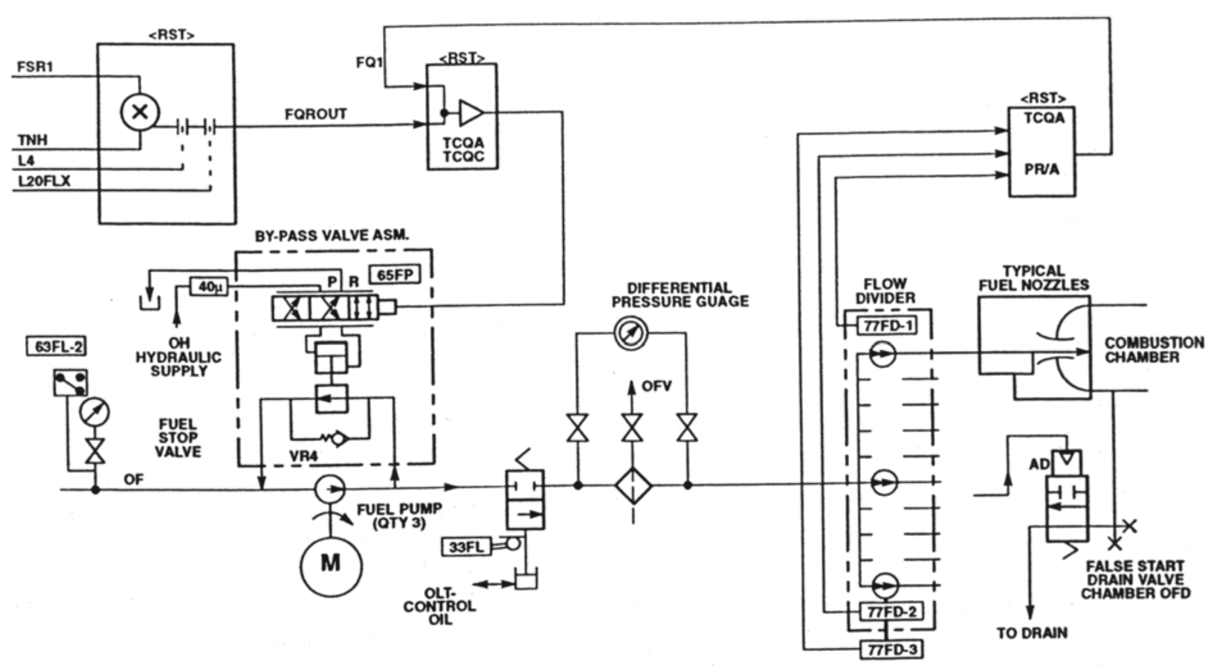


Figure 4.3: Liquid Fuel Control Schematic [19]

4.3.1 Fuel Bypass Valve

The fuel bypass valve is located between the inlet (low-pressure) and discharge (high-pressure) sides of the fuel pump. This valve bypasses excess fuel delivered by the fuel pump back to the fuel pump inlet, delivering to the flow divider the fuel necessary to meet the control system fuel demand. It is positioned by servo-valve, which receives its signal from the controllers.

4.3.2 Flow Divider

The flow divider, as its name implies, divides the single stream of fuel from the pump into several streams, one for each combustor. It consists of a number of matched high volumetric efficiency positive displacement gear pumps, again one per combustor. The flow divider is driven by the small pressure differential between the inlet and outlet [20]. The gear pumps are mechanically connected so that they all run at the same speed, making the discharge flow from each pump equal. Fuel flow is represented by the output from the flow divider magnetic pickups. These magnetic pickups, giving a pulse signal frequency proportional to flow divider speed, which is proportional to the fuel flow delivered to the combustion chambers.

4.4 GAS FUEL CONTROL SYSTEM

The following is a discussion of two types of gas control systems.

4.4.1 Type 1

The dry low NOx control system regulates the distribution of gas fuel to a multi-nozzle combustor arrangement. The fuel flow distribution to each fuel nozzle assembly is a function of combustion reference temperature and temperature control mode. By a combination of fuel staging and shifting of combustion modes from diffusion at ignition through premix at higher loads, low nitrous oxide (NOx) emissions are achieved.

Fuel gas (Figure 4.4) is controlled by the gas stop/speed ratio valve, the primary, secondary, and quaternary gas control valves, and the premix splitter valve.

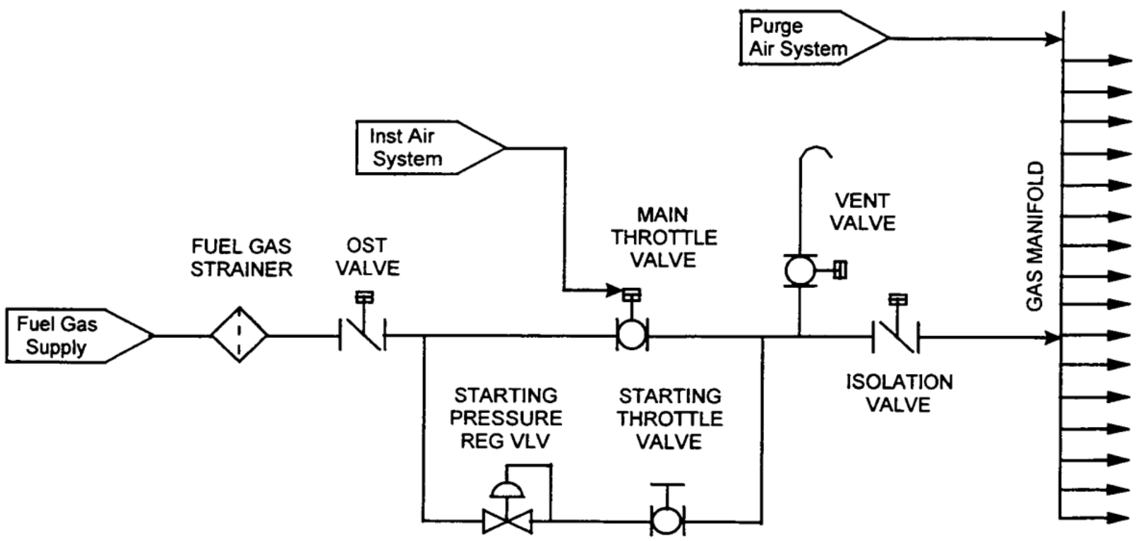
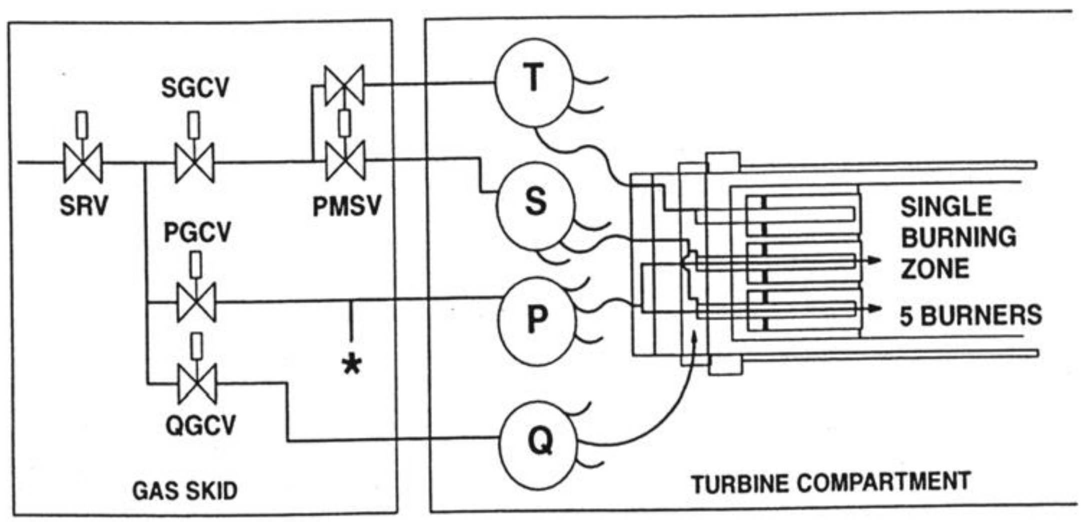


Figure 4.4: Simple Fuel Gas System [21]

The premix splitter valve controls the split between secondary and tertiary gas flow. All valves are servo controlled by signals from the control panel (Figure 4.5 and Figure 4.6).



SRV SPEED/RATIO VALVE
PGCV GAS CONTROL, PRIMARY
SGCV GAS CONTROL, SECONDARY
QGCV GAS CONTROL, QUATERNARY
PMSV PREMIX SPLITTER VALVE

T TERTIARY MANIFOLD, 1 NOZ. PREMIX ONLY
S SECONDARY MANIFOLD, 4 NOZ. PREMIX INJ.
P PRIMARY MANIFOLD, 4 NOZ. DIFFUSION INJ.
Q QUAT MANIFOLD, CASING. PREMIX ONLY
*PURGE AIR (PCD AIR SUPPLY)

Figure 4.5: DLN-Type1 Gas Fuel Control System [22]

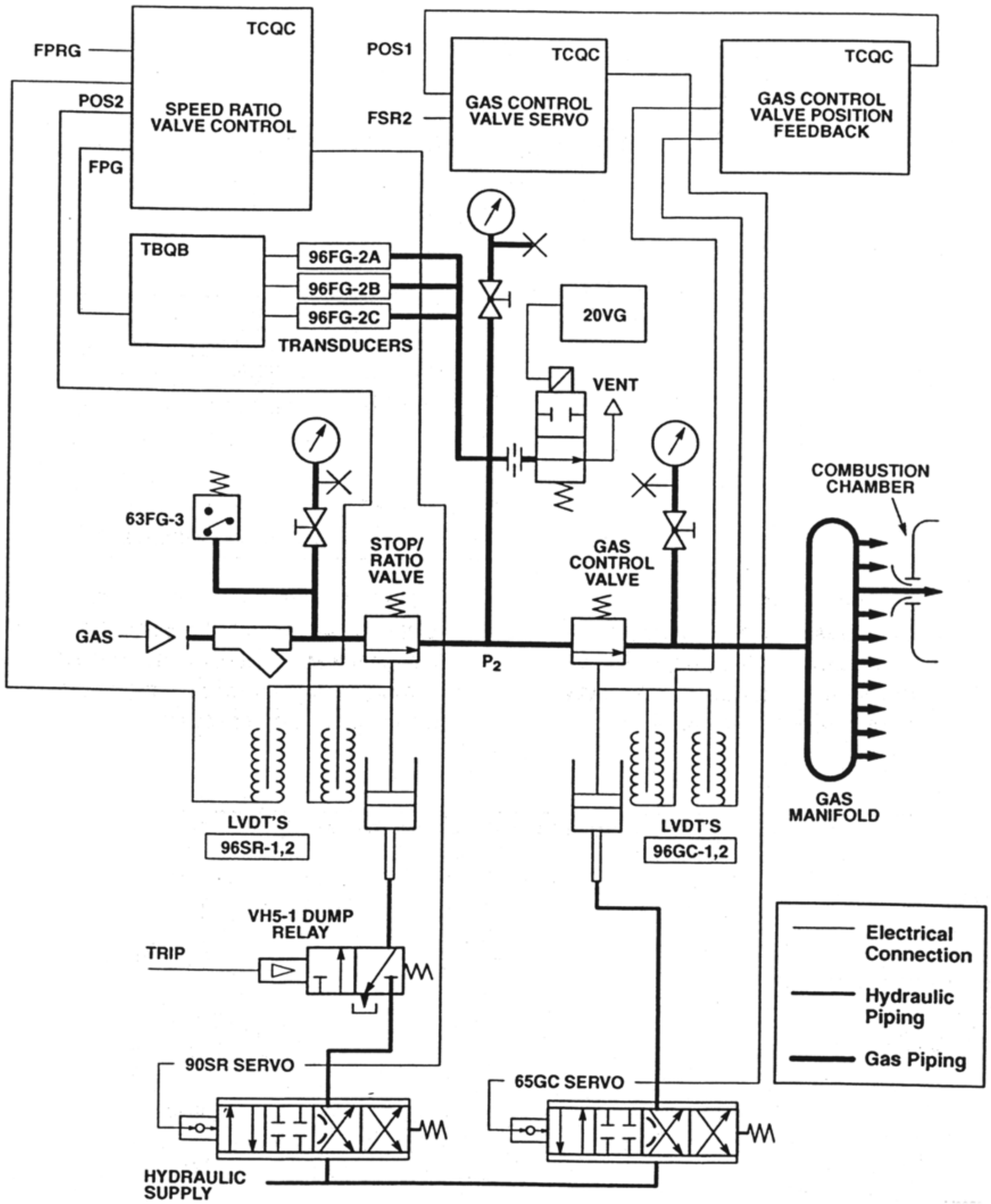


Figure 4.6: Gas Fuel Control System [22]

It is the gas control valve that controls the desired gas fuel flow in response to the total gas flow signal. To enable it to do this in a predictable manner, the speed ratio valve is designed to maintain a predetermined pressure at the inlet of the gas control valve as a function of gas turbine speed.

There are three main DLN combustion modes for this type system Primary, Lean-Lean, and Premix.

- Primary mode exists from light off to 81%-corrected speed, fuel flow to primary nozzles only.

- Lean-Lean is from 81% corrected speed to a pre-selected combustion reference temperature, with fuel to the primary and tertiary nozzles.

- In Premix operation, fuel is directed to secondary, tertiary, and quaternary nozzles. Minimum load for this operation is set by combustion reference temperature and IGV position.

The following describes the components that make up the gas fuel control system.

4.4.2 Gas Strainers

4.4.2.1 Y-Type Strainer

A Y-type strainer is provided in gas supply lines to remove any foreign particles from the gas fuel before it is admitted to the speed/ratio valve assembly. There is a blowdown connection on the bottom of the strainer body, which should be utilized periodically for cleaning the strainer screen. A high filtration, startup strainer basket needs to be left in the strainer until it stays clean for 48 hours of continuous operation, at which point, it should be removed and a more durable running strainer basket should be installed for continuous operation.

4.4.2.2 Duplex Strainer

The duplex strainer is designed as a single unit with two strainer baskets. A basket is isolated and individually removed for cleaning while fuel is filtered through the other one. There is no blowdown. A high filtration, startup strainer basket needs to be left in the strainer until it stays clean for 48 hours of continuous operation, at which point, it should be removed and a more durable running strainer basket installed for continuous operation.

4.4.3 Low-Pressure Switch

This pressure switch is installed in the gas piping upstream from the gas stop/ratio valve and control valve assembly and initiates an alarm on the enunciator panel whenever the gas pressure drops below a specified setting.

4.4.4 Pressure Gauges

Three pressure gauges, with hand valves, are installed in the fuel gas supply line. The upstream pressure gauge measures the pressure of the gas entering the stop/ratio valve, the intermediate pressure gauge measures P2 pressure ahead of the gas control valve, and the downstream gauge measures the pressure as the gas leaves the gas control valve.

4.4.5 Gas Fuel Vent Solenoid Valve

This solenoid valve vents the volume between the stop/ratio valve and the gas control valve when the solenoid is de-energized. The solenoid is energized and the vent valve closed when the master control protection circuit is energized. When a turbine start signal is given, the valve, therefore, will be closed, and remain closed until the turbine is shut down.

The vent is open when the turbine is shut down because the stop/ratio and gas control valves have metal plugs and metal seats and, therefore, are not leak-tight. The vent ensures that during the shutdown period, fuel gas pressure will not build up between the stop/ratio and gas control valves, and no fuel gas will leak past the closed gas control valve to collect in the combustors or exhaust.

4.4.6 Gas Control Valves

The position of the gas control valve plug is intended to be proportional to gas flow signal, which represents called for gas fuel flow.
Actuation of the spring-loaded gas control valve is by a hydraulic cylinder controlled by an electro-hydraulic servo-valve.

When the turbine is to run on gas fuel, the permissives for turbine purge complete must be met. This allows the gas control valve to open. The stroke of the valve is proportional to the gas flow signal.
The gas control valve stem position is sensed by the output of a linear variable differential transformer (LVDT) and fed back to an operational amplifier where it is compared to the gas flow input signal [23]. If the feedback is in error with input signal, the operational amplifier in the controller will change the signal to the hydraulic servo-valve to drive the gas control valve in a direction to decrease the error. In this way, the desired relationship between position and gas flow signal is maintained and the control valve correctly meters the gas fuel. See Figure 4.7.

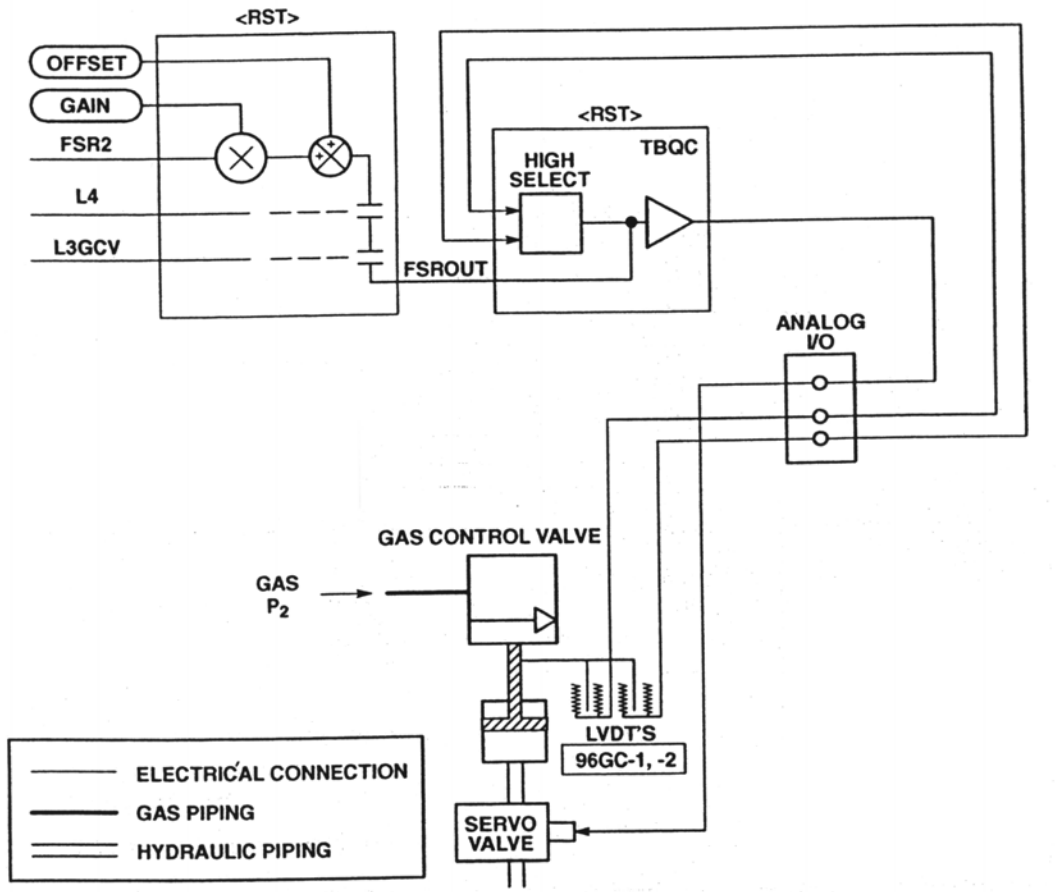


Figure 4.7: Gas Control Valve Control Schematic [23]

4.4.7 Stop/Speed Ratio Valve

The speed ratio/stop valve is a dual function valve. It serves as a pressure-regulating valve to hold a desired fuel gas pressure ahead of the gas control valve and it also serves as a stop valve.

As a stop valve, it is an integral part of the protection system. Any emergency trip or normal shutdown will move the valve to its closed position shutting off gas fuel flow to the turbine. This is done by either dumping hydraulic oil from the Stop/Speed Ratio Valve hydraulic trip relay or driving the position control closed electrically.

The stop/speed ratio valve has two control loops. There is a position loop similar to that for the gas control valve and there is a pressure control loop. See Figure 4.8.

The stop/speed ratio valve provides a positive stop to fuel gas flow when required by a normal shutdown, emergency trip, or a no-run condition [24]. Hydraulic trip dump valve is located between the electro-hydraulic servo- valve and the hydraulic actuating cylinder. This dump valve is operated by the low-pressure control oil trip system. If permissives are met, the trip oil is at normal pressure and the dump valve is maintained in a position that allows servo-valve to control the cylinder position. When the trip oil pressure is low (as in the case of normal or emergency shutdown), the dump valve spring shifts a spool valve to a position, which dumps the high-pressure hydraulic oil in the speed ratio/stop valve actuating cylinder to the lube oil reservoir. The closing spring atop the valve plug instantly shuts the valve, thereby shutting off fuel flow to the combustors.

In addition to being displayed, the feedback signals and the control signals of both valves are compared to normal operating limits, and if they go outside of these limits there will be an alarm.

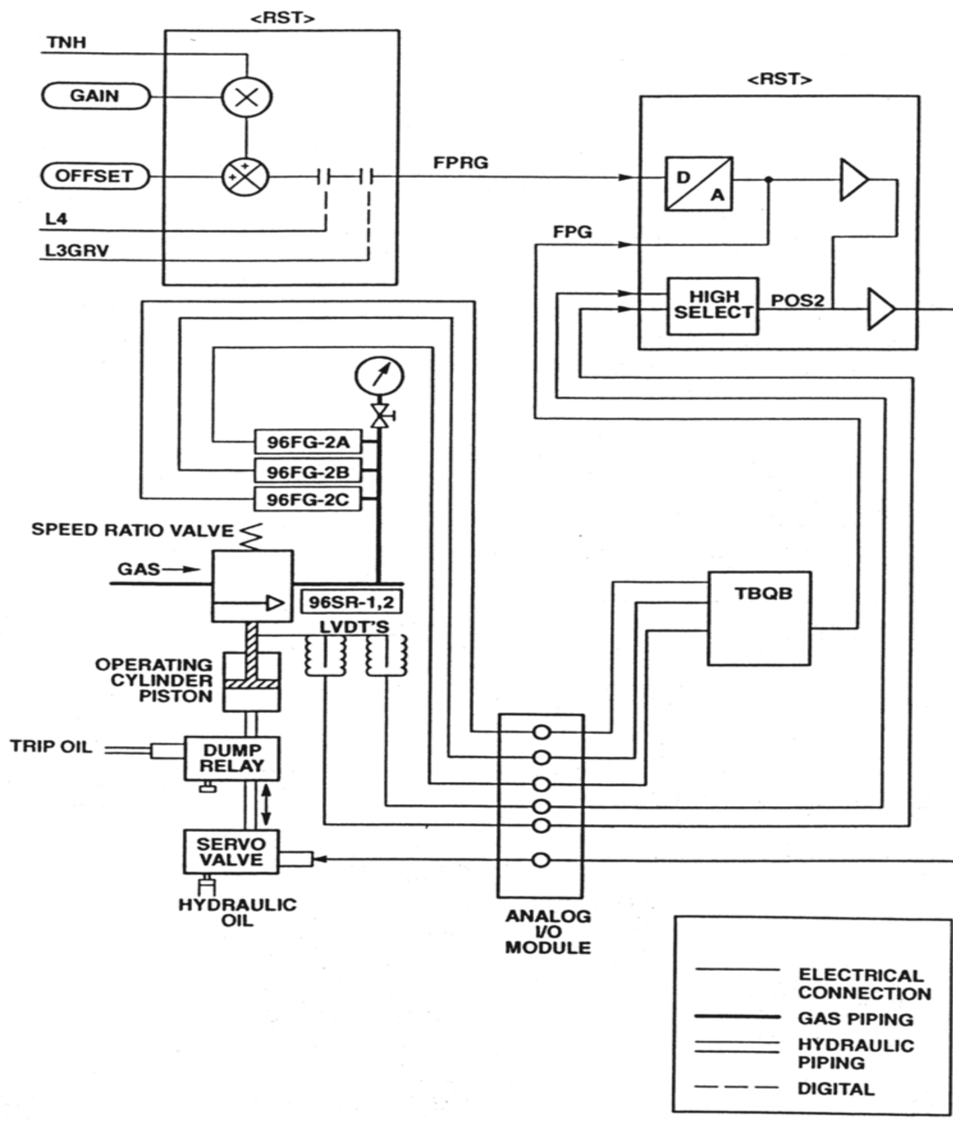


Figure 4.8: The stop/speed ratio valve [24]

4.4.8 Premix Splitter Valve

The Premix splitter valve (PMSV) regulates the split of secondary/tertiary gas fuel flow between the secondary and tertiary gas fuel manifolds. The valve is referenced to the secondary fuel passages; i.e., 0% valve stroke corresponds to 0% secondary fuel flow.

4.5 TYPE 2

The dry low Nox on Type 2 control system regulates the distribution of fuel delivered to a multi-nozzle, total premix combustor arrangement. The fuel flow distribution to each combustion chamber fuel nozzle assembly is calculated to maintain unit load and fuel split for optimal turbine emissions.

The Type 2 combustion system consists of six fuel nozzles per combustion can, each operating as a fully premixed combustor, five located radially, one located in the center. The center nozzle, identified as PM 1, (PreMix 1), two outer nozzles located adjacent to the crossfire tubes, identified as PM2, (PreMix 2), and the remaining three outer nozzles, identified as PM3, (PreMix 3) [25]. Another fuel passage, located in the airflow upstream of the premix nozzles, circumferentially around the combustion can, is identified as the quaternary fuel pegs (Figure 4.9).

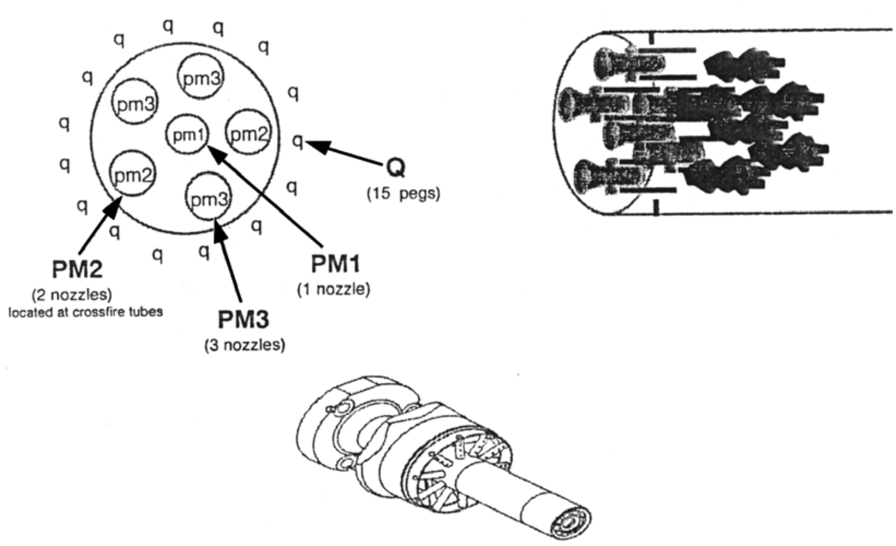


Figure 4.9: Type 2 Fuel Nozzle Arrangement [25]

The fuel flow to the six fuel nozzles and quaternary pegs are controlled by four independent control valves, each controlling flow split and unit load. The gas fuel system consists of the gas fuel stop/ratio valve, gas control valve one, (PM1), gas control valve two, (PM2), gas control valve three, (PM3), and gas control valve four, (Quaternary or Q) (Figure 4.10).

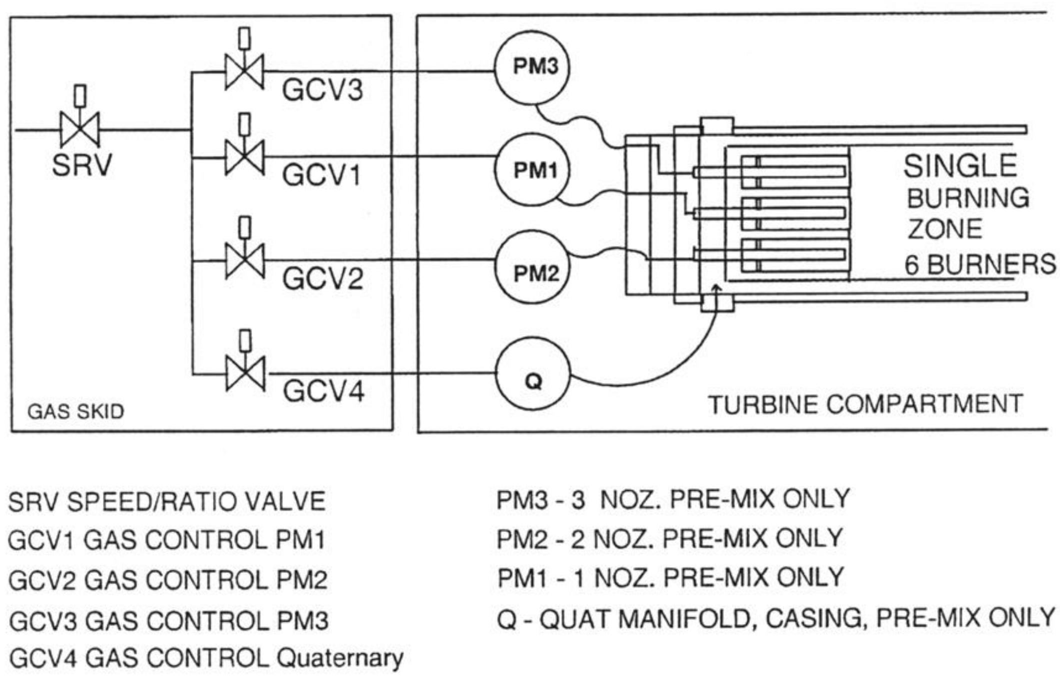


Figure 4.10: Type 2 Gas Fuel System [26]

The stop/ratio valve (SRV) is designed to maintain a predetermined pressure, at the inlet of the gas control valves. Gas control valves one through four, (GCV1-4), regulate the desired gas fuel flow delivered to the turbine in response to total fuel flow signal from the fuel control system. The flow control philosophy is performed in a cascading routine, scheduling a percentage flow reference for a particular valve, and driving the remainder of the percentage to the next valve reference parenthetically downstream in the control software [26].

4.6 GAS FUEL OPERATION

The fuel system operation is fully automated, sequencing the combustion system through a number of staging modes before reaching full load. Figure 4.11 represents typical operation sequence, from firing to full load fuel flow staging associated with a DLN-2.6 operation, and a typical shutdown fuel staging sequence from full load to unit flame out at part speed.

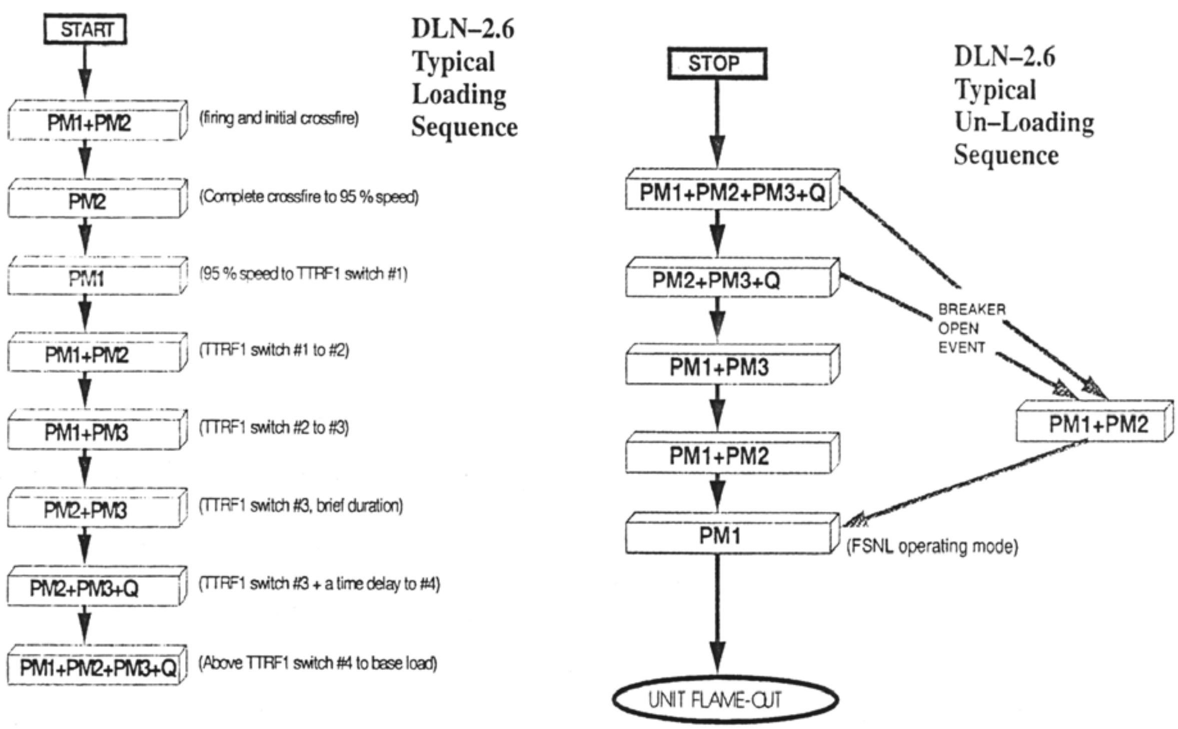


Figure 4.11: DLN 2.6 Fuel Modes for Start-up and Shutdown [27]

As shown, the primary controlling parameter for fuel staging is the calculated combustion reference temperature, which is discussed later. Other operations influencing parameters available to the operator are the selection of IGV temperature control "on" or "off', and the selection of inlet bleed heat "on" or "off." To achieve maximum exhaust temperature, as well as an expanded load range for optimal emission, IGV temperature control should be selected ON, and inlet bleed heat should be selected ON [27].

The operational mode is displayed on the main display. Operational mode is defined as “the sum of the nozzles being delivered fuel,” therefore, if PM1 and PM3 are fueled, the unit is in Mode 4. Likewise, if PM2 and PM3 are fueled, the unit is in Mode 5. When the quaternary passages are fueled, a *Q* is added to the mode number.

4.6.1 Chamber Arrangement

Most gas turbines have multiple combustors; for example, the 7F machine employs 14 combustors. There are two spark plugs and four flame detectors in selected chambers with crossfire tubes connecting adjacent combustors.

Each combustor consists of a six-nozzle/end cover assembly, forward and aft combustion casings, flow sleeve assembly, multi-nozzle cap assembly, liner assembly, and transition piece assembly. A quaternary nozzle arrangement penetrates the circumference of the combustion can, porting fuel to casing injection pegs located radially around the casing.

4.6.2 Combustion Reference Temperature

The combustion reference temperature signal is generated by a calculation in the control software. This calculated temperature represents a reference for combustor mode sequencing and fuel split scheduling, but not unit load control. It should be noted that is a calculated temperature *not* a true indication of actual machine firing temperature, only a reference for mode transition sequencing.

4.6.3 Inlet Guide Vane Operation

The combustor emission performance is sensitive to changes in fuel to air ratio. The combustor was designed according to the airflow regulation scheme used with inlet guide vane (IGV) temperature control [28]. Optimal combustor operation is crucially dependent upon proper operation along the predetermined temperature control scheme. Controlled fuel scheduling will be dependent upon the state of IGV temperature control.

4.6.4 Inlet Bleed Heat (IBH)

Operation of the gas turbine with reduced minimum IGV settings can be used to extend the Premix operating region by 20-30% of base load. Reducing the minimum IGV angle allows the combustor to operate at a firing temperature high enough to achieve optimal emissions [29].

Inlet bleed heating, through the use of recirculated compressor discharge airflow, is necessary when operating with reduced IGV angles. Inlet heating protects the compressor from stall by relieving the discharge pressure and increasing the inlet air stream temperature. Other benefits include

anti-icing protection due to increased pressure drop across the IGV's.

The inlet bleed heat system regulates compressor discharge bleed flow through a control valve and into a manifold located in the compressor inlet air stream. The control valve varies the inlet heating airflow as a function of IGV angle. At minimum IGV angles, the inlet bleed flow is controlled to a maximum of 5.0% of the total compressor discharge flow. As the IGV's are opened at higher loads, the inlet bleed flow will proportionally decrease until shut off.

The IBH control valve is monitored for its ability to track the command set- point. If the valve command set-point differs from the actual valve position by a prescribed amount for a period of time, an alarm will annunciate to warn the operator. If the condition persists for an additional amount of time, the inlet bleed heat system will be tripped and the IGV's minimum reference will be raised to the default value.

The IBH system monitors the temperature rise in the compressor inlet airflow. This temperature rise serves as an indication of bleed flow. Failure to detect a sufficient temperature rise in a set amount of time will cause tile inlet bleed heat system to be tripped and an alarm annunciated.

4.6.5 Flame Detection

Reliable detection of the flame location in the system is critical to the control of the combustion process and to the protection of the gas turbine hardware. Flame detectors in separate combustion chambers around the gas turbine are mounted to detect flame in all modes of operation. The signals from these flame detectors are processed in control logic and used for various control and protection functions.

4.7 IGNITION SYSTEM

Two spark plugs located in different combustion chambers are used to ignite fuel flow. These spark plugs are energized to ignite fuel during startup only, at firing speed. Flame is propagated to those combustion chambers without spark plugs through crossfire tubes that connect adjacent combustion chambers around the gas turbine.

4.8 CONTINGENCY OPERATION

4.8.1 Unit Trip

In case of a unit trip, the gas fuel system will be shut down by deactivating the dump valves on the SRV and GCV's. This allows the hydraulic fluid, which activates the valve open to be ported to drain, while fluid is ported from hydraulic supply to close the valve with assistance from the spring force.

4.8.2 False Start

During a false start, where flame is not established in the monitored combustion chambers after time delay, the stop ratio valve and gas control valves are shut and the unit is run through a second unit purge cycle. At the end of this purge cycle, fuel is admitted and firing is again attempted. If the second attempt is unsuccessful in maintaining flame, the unit is tripped and the stop ratio valve and gas control valves close.

4.9 FUEL GAS CONTROL SYSTEM

The Stop/Speed Ratio Valve (SRV) and Gas Control Valves (GCVs) work in conjunction to regulate the total fuel flow delivered to the gas turbine. This arrangement uses four separate Gas Control Valves to control the distribution of the fuel flow to a multi-nozzle combustion system [30].

The GCVs control the desired fuel flow in response to a control system fuel command. The response of the fuel flow to GCVs' commands is made predictable by maintaining a predetermined pressure upstream of the GCVs. The GCVs' upstream pressure is controlled by modulating the SRV based on turbine speed as a percentage of full speed.

In this combustion system there are four gas fuel system manifolds: Premix 1 (PM1), Premix 2 (PM2), Premix 3 (PM3), and Quarternary (Q). Each com- bustion chamber has a total of six fuel nozzles. The PM 1 gas fuel delivery system consists of one diffusion type fuel nozzle for each combustion chamber [31]. The PM2 gas fuel delivery system consists of two premix type fuel nozzles for each combustion chamber. The Quarternary gas fuel delivery system consists of injection pegs located in each combustion casing. The PM3 gas fuel delivery system consists of three premix type fuel nozzles for each combustion chamber. The GCVs regulate the percentage of the total fuel flow delivered to each of the gas fuel system manifolds.

The GCVs and SRV are actuated by hydraulic cylinders moving against spring- loaded valve plugs. Three coil servo valves are driven by electrical signals from the control system to regulate the hydraulic fluid in the actuator cylinders.

4.9.1 Gas Control Valves

The plugs in the GCVs are contoured to provide the proper flow area in relation to valve stroke. The combined position of the control valves is intended to be proportional to FSR. The GCVs use a skirted valve disc and venturi seat to obtain adequate pressure recovery. High-pressure recover, occurs at valve pressure ratios substantially less than the critical pressure ratio. The result is that the flow through the GCVs is independent of the pressure drop across the valves and is a function of valve inlet pressure, and valve area only [32].

The control system's fuel command is the percentage of maximum fuel flow required by the control system to maintain either speed, load, or another set- point. Figure 4.12 is a gas control valve schematic.

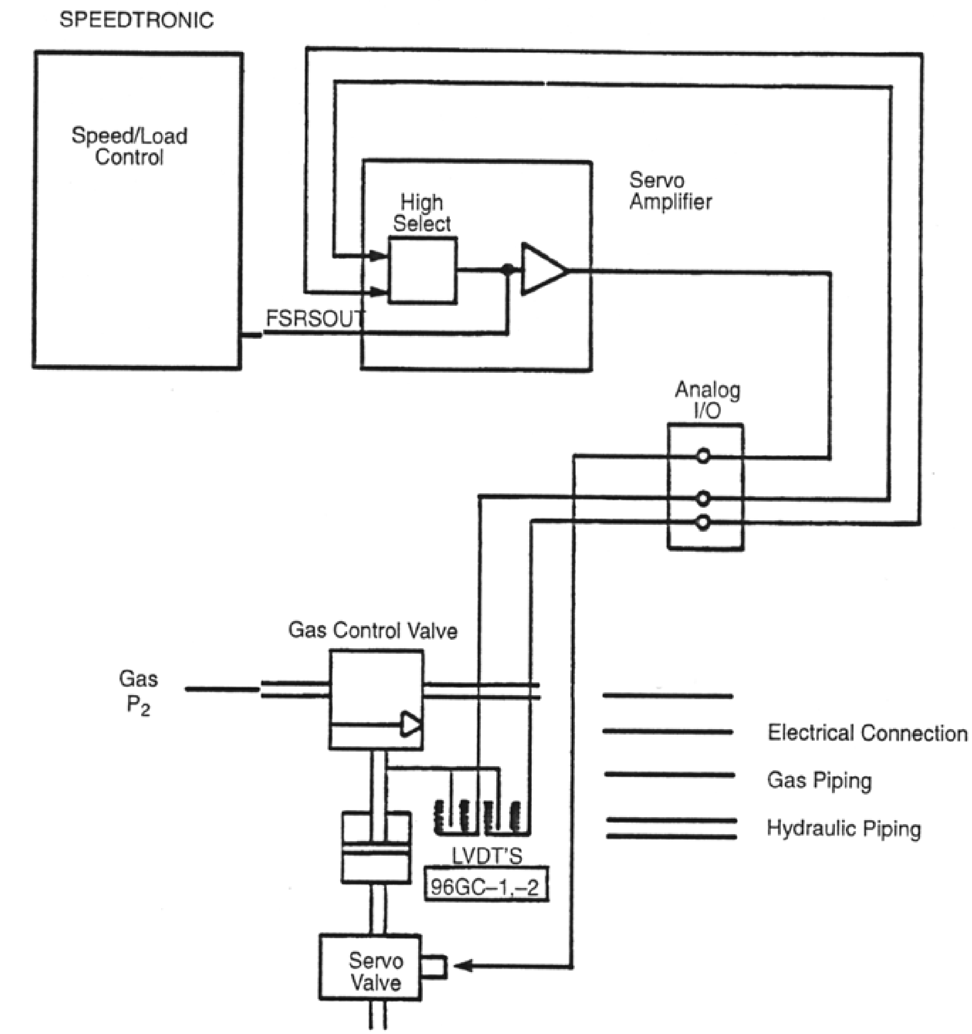


Figure 4.12: Gas Control Valve Control Schematic [32]

The SRV and GCVs are equipped with hydraulically-actuated, spring-return dump valves. The dump valves are held in their normal operating state by a supply of hydraulic oil referred to as trip oil.

4.9.2 Stop/Speed Ratio Valve

The SRV serves two functions. First is its operation as a stop valve, making it an integral part of the protection system. An emergency trip or normal shutdown will trip the valve to its Closed position, preventing gas fuel flow to the turbine. The SRV also operates as a pressure-regulating valve. The control system uses the SRV to regulate the pressure upstream of the GCVs.

While the SRVs position control loop is considered an inner control loop, the pressure control loop is considered an outer control loop (Figure 4.13).

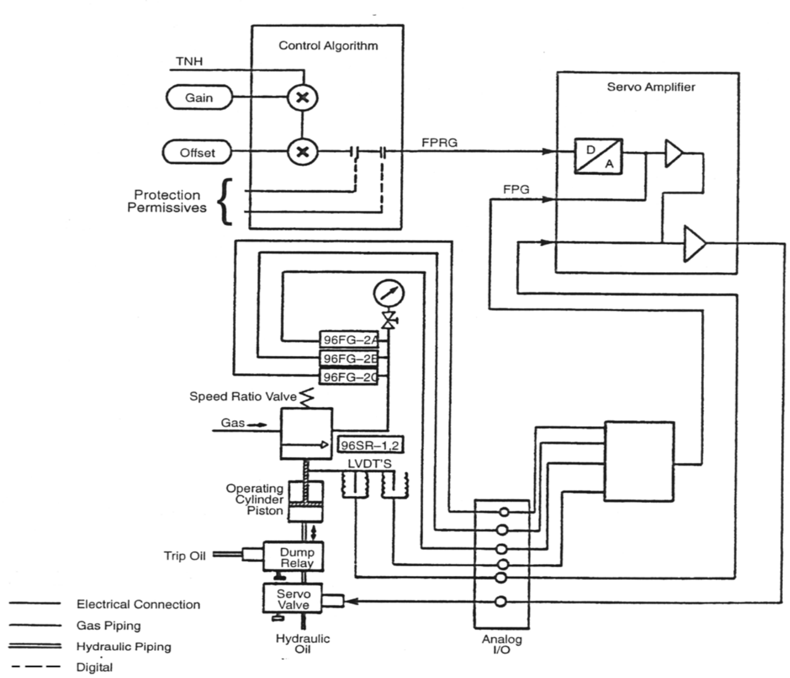


Figure 4.13: Speed Ratio/Stop Valve Control Schematic [32]

The SRV will be closed automatically on flame failure, failure to ignite on startup, or actuation of the fire detection equipment. Following a unit trip, the master protective and ignition permissive circuits are used to prohibit starting until the conditions are acceptable.

4.10 LUBE OIL SYSTEM

The function of the lubricating oil system (see Figure 4.14) is to provide an uninterrupted supply of filtered oil at the required temperature and pressure to meet the lubricating requirements of the combustion turbine bearings it may also provide lubrication to the following: electric generator/ exciter, and starting package bearings. Lubricating oil from the bearing supply header may supply cooling to the turbine trunnion supports and the main supply to the generator seal oil system.

The oil to meet the requirements of the combustion turbine unit is furnished by a common system complete with reservoir, pumps, cooler, filters, and control valves. The system is designed to provide a force fed supply of lubricating oil at temperatures and pressures that is required for normal turbine operations [33]. The combustion turbine is safeguarded with respect to loss of lubricating oil pressure or high oil temperatures. In the event that oil temperatures or pressures exceed designed limits, the system will alarm, or if serious enough, trip the combustion turbine. The starting device and turning gear may be interlocked so that the unit cannot be rotated without the required oil pressure.

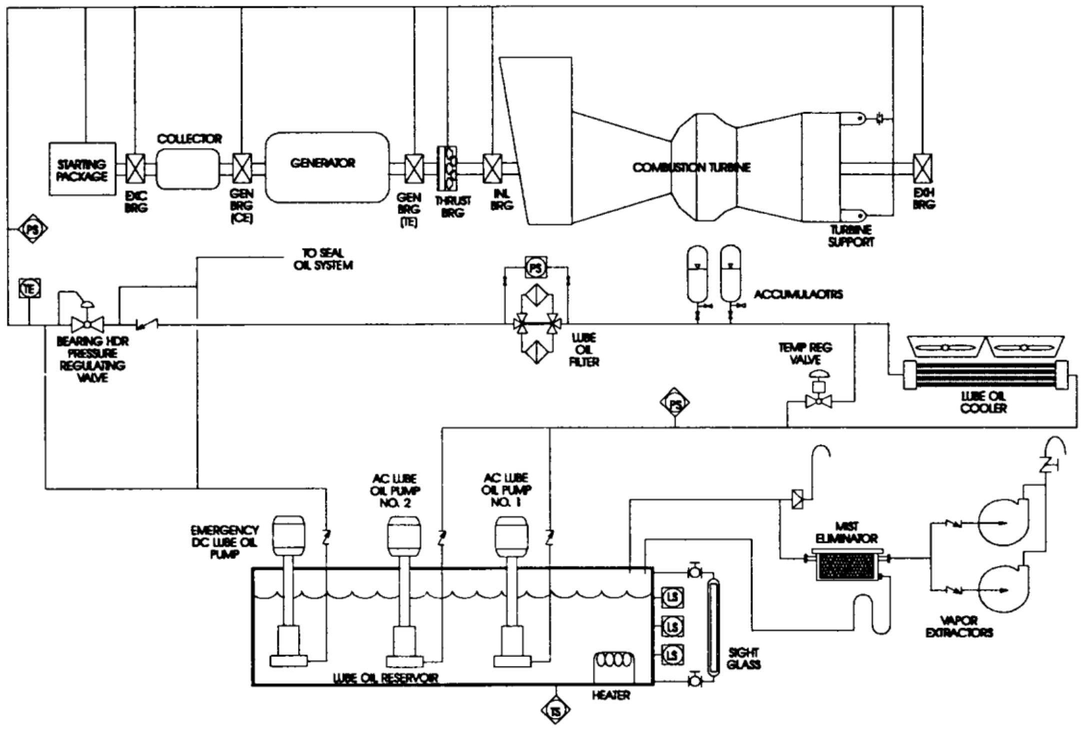


Figure 4.14: Simplified Lubricating Oil System [33]

Clean filtered lubricating oil is supplied from the lubricating oil reservoir to the bearings by:

- An AC lubricating oil pump, under all normal turbine operating conditions.
- A back-up AC lubricating oil pump may also be used, when the primary AC lubricating oil pump is not operational.
- In an emergency, a DC lubricating oil pump is used on a, loss of AC pump discharge pressures or low bearing header pressure.

5 PROBLEMS SETTING AND GOAL OF THE STUDY

5.1 INTRODUCTION

One of the most important sources of natural energy lost in Iraq it is the associated natural gas, which is excessive wasted as a result of oil extraction operations and even with the simple quantity used as fuel for power plants it is used to produce less energy than if it was used correctly and because Iraq owns and contracts to build power stations in large quantities, the following objectives must be considered to achieve the best results and to maintain energy sources at the same time.

5.2 RESEARCH AIMS AND OBJECTIVES

5.2.1 Aims

1- Propositions of increase the production of electric energy by using (CCPP).

2- Identify things that we should know to develop the already founded power plants from (SCPP) to (CCPP).

5.2.2 Tasks

To achieve the project‘s aims; the following research objectives have been identified:

- Basic definitions of natural gas (what is NG? how NG formed?....).
- Know basic information about the (SCPP) and (CCPP).
- Introduction to Gas turbine power plant.
- Basic knowledge about support systems.
- Case study analysis and conclusions.

6 CASE STUDY

6.1 INTRODUCTION

Today about 70 % of all natural gas produced in Iraq is flared, rather than captured enough to provide electricity for more than 15 million homes if it was captured and used. In addition, enough Liquefied petroleum gas (LPG) is lost through flaring in Iraq to fill around 250,000 LPG cylinders per day [34].

This flaring is a significant waste of Iraq's natural resources. Many parts of the country suffer from inadequate supplies of power. People are less comfortable in their homes, and there is less power available for businesses to grow and develop the economy. Iraq has to import associated natural gas, rather than being self-sufficient or even exporting a surplus to generate revenue.

The value of all the natural gas flared in Iraq is thought to be $7 million per day. That does not include the opportunity cost of the oil, which is used to generate electricity instead of natural gas. If it was not used for power generation, this oil could be exported that is why Iraqi Oil Ministry announced that in 2022 all the associated natural gas would be used because the facilities allocated for its investment will be completed [35].

For Iraqi people, the Iraqi government at its maximum effort has been rehabilitating, building and upgrading the infrastructures, which were destructed or exhausted in the periods of the wars and economic sanction since such periods ended. The power sector is one of those infrastructures, which are essential for the life of Iraqi people and is needed to be improved immediately.

As for the electricity situation, it is estimated that the power demand will be reached 30,000MW in2020 from 20,000MW in 2015.

As one of solutions to enhance the power supply, we wants to convert the existing simple cycle gas turbine (SCGT) power stations to the combined cycle gas turbine (CCGT) power stations [36], to improve the sustainability performance for Natural gas and increase the production of electric energy and what we should notes when built new power plants.

In this study, one site selected (Amara) for Add-On Project with the consideration of suitability and priority of other candidate sites (i.e. Bagdad, Nasiriyah,… and Najibyah). In addition, the feasibility study of Add-On Project for selected gas turbine power station was carried out.

6.2 FINANCIAL SITUATION IN IRAQ

This study will save amounts of money budget because we will have more energy from same amount of fuel if we applied it on all old and new gas power plant, as we know Iraqi Government has currently faced financial stringency because of the less national budget due to the slump of crude oil price and the increase of costs/expenses for cleaning operation by Iraqi army against terrorism table 6.1.

The World Bank and the International Monetary Fund (IMF) decided to provide Iraq with financial supports. However, those financial supports are not enough and each ministry in the Iraqi Government has to find out appropriate solutions to cover such situation.

Table 6.1 National Budget of Iraq and Planned Oil Price/Export Amount source MOE

	2015	2016
National Budget	$ 105 B	$ 88.2 B
Expected Oil Price	$ 56 BPD	$ 45 BPD
Expected Export Volume	3.3 M BPD	3.6 M BPD

6.3 OUTLINE OF ADD-ON PROJECT (REPOWERING)

6.3.1 Basic Concept:

The principle of the combined cycle is firstly to recover the exhausted gas and generate the steam by the heat recovery steam generator (HRSG) and secondly to combine the steam and generate the electricity by the steam turbine generator (STG) [37]. After completing the gas turbine cycle (simple cycle), the temperature of the exhausted gas from the gas turbine which is wasted in the simple cycle is still high enough to generate the steam. By recycling this exhausted gas, the overall net efficiency of the combined-cycle may achieve at more than 50 % from the simple-cycle at around 35 % - 40 %. This recycling of the waste entropy can expand the power capacity without increasing the fuel consumption and the environmental load [38]. Especially, to add the HRSG and STG on the existing/operating simple-cycle power plant is called (Add-On) also known as repowering.

6.3.2 Site Selection

The study has initially considered many potential sites where the gas turbines are already installed or planned to be installed in simple cycle and one of them could be converted to a combined cycle plant but the selection goes to site of Amara Power Plant Figure 6.1 because of the availability of information, table 6.2 show the site of our study.

Table 6.2 study site

Site	**Amara**
Governorate	Missan
Gas Turbines No.	4 units x 125 MW
SCPP	In operation

Note: the site utilize four gas turbines of General Electric (GE) make, Frame 9 E type.

Figure 6.1: Amara Gas Turbine Power Plant

Figure 6.2: Location of Gas Turbine Power Plant

The power stations at Amara have been completed and the gas turbines in simple cycle mode are in commercial operation Figure 6.2 and Figure 6.3.

The other sites like Najibyah in Al-basrah has been ruled out for Add-On because there is no enough information about enough land available for the equipment needed for the adaptation into CCPP. As the site of Amara have adequate extra land Figure 6.3 and they have been compared. The site of Amara has been selected for this study because

Figure 6.3: Show Available Area for Add-On Plant

of the vicinity of the water (Tigris river) which safeguards availability of the water to the power plant, in the essential quantity and with lower pumping costs.

Plant Configuration:

- Site : Amara area in Missan Governorate
- Capacity : 500MW (4 x 125MW) + 250MW (by this project)
- Main Fuel : Natural available

Amara site have four (4) GTGs of about 125 MW ISO rating, this study describes feasibility of the 4/4/1x1 configuration Figure 6.4.

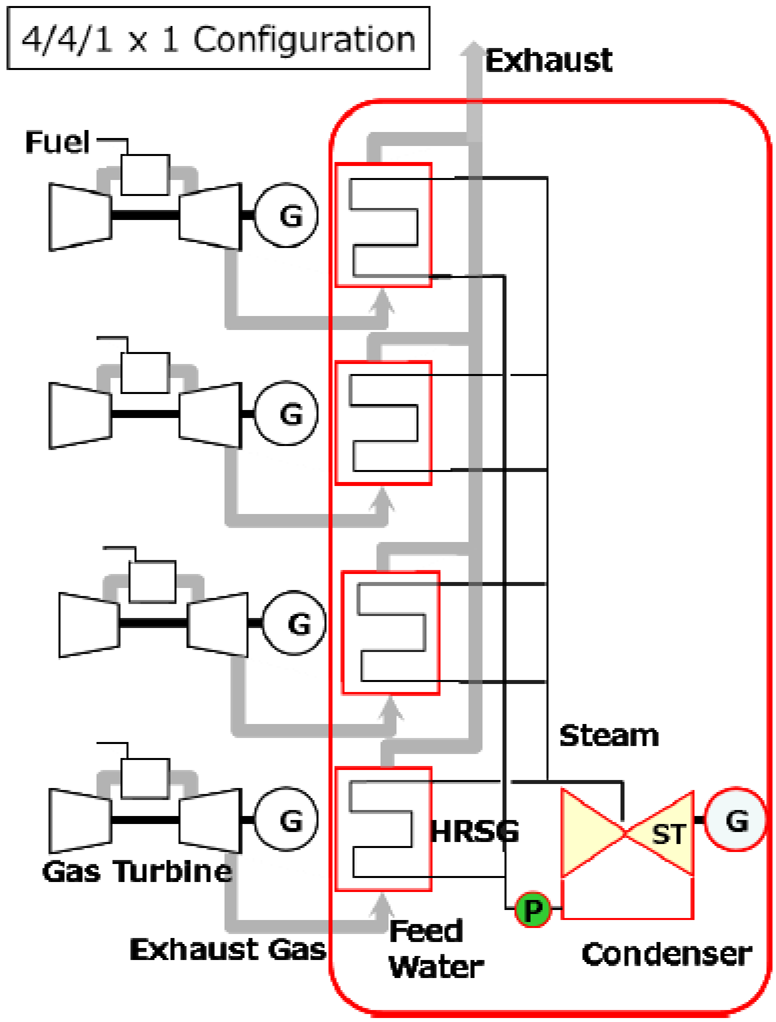


Figure 6.4: Suggest Plant Configuration

6.3.3 Technology Advantages of American, German and Japanese Companies

The main purpose of the Add-On project is to increase the output comparing with simple cycle and to attain the higher efficiency to reduce the fuel consumption. In this regards, American leading equipment companies have many experiences to optimize the steam cycle in accordance with specific condition such as in Iraq and to develop the equipment model. Moreover, the utilization of steam exhaust from existing Gas Turbine efficiently is one of the important parts of which many American leading equipment companies including companies who do not manufacture Gas Turbine have accumulated their technology for a long time. Therefore, American leading equipment companies are expected to contribute a lot toward optimization of model and cycle like this project.

6.4 OUTLINE OF ENERGY GENERATION AND DISTRIBUTION IN IRAQ

The electricity demand in Iraq has been rapidly increasing however the electricity supply has not met such demand. Considering the situation in Iraq and current circumstances around MOE, it is understood that the Add-On project for Amara Gas Turbine Power Station is very appropriate solution because this is the project which is possible to realize and materialize under the current situation and circumstances in Iraq.

6.4.1 Electricity Supply and Demand:

The actual generation output at the end of 2013 was around 11,000MW against the demand16,000MW. In 2013, the electricity supply form the national grid to Iraqi people was around 16 hours per day. And, it was increased up to around 12,000MW in 2014, however it is expected that the demand in 2018 will be over 20,000MW.

Power Stations:

The design capacity of the power station in the whole country in 2013 was around 22,000MW which are steam (6,000MW), gas (11,700MW), Hydro (1,800MW) and Diesel (2,400MW). According to MOE's explanation in the Iraqi Power Conference in London in June 2014, it is expected to add 17,000 MW until 2018 by followings and accordingly the total design capacity will be around 39,000MW in 2018.

- Under Construction : 12,000MW
- Add On (combined) : 5,000MW

6.4.2 Transmission Capacity:

The transmission network in Iraq is made by 400kV line called (super grid) and 132kV line connected to 33/11 kV distribution network. The table 6.3 shows the transmission capacity in 2013 and the plan to be added.

Table 6.3 Transmission Capacity, Source MOE

	2013	2015 (to be added)	2020 (to be added)
400kV Substations	29	25	
400kV Overhead Lines	5,100km	900km	3,000km
132kV Substations	219	64	91
132kV Overhead Lines	12,600km	3,300km	3,500km

6.5 CURRENT CIRCUMSTANCES (MOE) HAS FACED

6.5.1 Lack of Budget

The national budget of Iraq heavily relies on the amount and its price of exporting of crude oil because around 90% of national revenue is come from the revenue of exporting of crude oil. The Table 6.4 shows the national budget of Iraq and the planed oil price/export volume [39].

Table 6.4 National Budget of Iraq and Planned Oil Price/Export Amount, source MOE

	2011	2012	2013	2014(*)	2015	2016
National Budget	$82.6B	$100B	$118.5B	---	$105B	$88.2B
Expected Oil Price	$76.5 BPD	$85 BPD	$90 BPD	---	$56 BPD	$45 BPD
Expected Export Volume	2.2M BPD	2.6M BPD	2.9M BPD	---	3.3M BPD	3.6M BPD

(*) The national budget of year 2014 was not finally concluded.

Due to trend of decreasing of oil price recently, the amount of national budget is very much negatively affected and the allocation of yearly budget to ministries for reconstruction and development projects has been decreased accordingly. As reference, the oil price as of January 2016 is around USD30 BPD.

6.5.2 Financial Situation in Iraq

As mentioned above, Iraqi Government has suffered two kinds of negative impact and has been facing the situation of financial stringency at the moment. Therefore, in order to cover the negative financial situation, the World Bank and the International Monetary Fund (IMF) decided to provide the country with financial supports. However those financial supports are not enough and each ministry is in the situation that ministry cannot implement by Iraqi national budget and they have to find out suitable solutions such as utilizing foreign finance arranged by foreign institutes on their reconstruction and development projects to be proceeded with the implementation of the necessary projects.

6.6 GAS TURBINE POWER PLANT IN SOUTH OF IRAQ

The table 6.5 shows the list of existing / planned gas turbine power stations in south of Iraq which are planned to be combined by Add-On project (Add-On Project).

Table 6.5 List of Gas Turbine Power Stations in South of Iraq, source MOE

Governorate (City):	**Power Station:**	**Capacity:**
Basrah (Basrah)	Rumaila	1,460 MW (5 unites of 292MW)
	Shat Al- Basrah	1,250 MW (10 units of 125MW)
	Najibyah	500 MW (4 units of 125MW)
Missan (Amara)	Amara	500 MW (4 units of 125MW)
Thi Qar (Nasiriyah)	Nasiryah	500 MW (4 units of 125MW)
Mothanna	Semawa	500 MW (4 units of 125MW)

6.7 CANDIDATE SITE FOR ADD-ON PROJECT

There are two candidates of gas turbine power station for the Add-On project in the south of Iraq, which are Najibiya (Basrah Governorate) and Nasiriyah (Thi Qar Governorate). The figure 6.5 shows the location of candidates of gas turbine power stations.

Figure 6.5: Location of Candidate Gas Turbine Power Station

Amara:

Amara is a city of Missan Governorate. Missan Governorate is located in the southern eastern part of Iraq and on the border of Iraq and Iran. It is also located on the bank of the Tigris River. It is almost400km away from Baghdad. The area of Missan Governorate is 16,072 km^2 and its population is approximately 1,050,000. There are (1) university, (6) hospitals and 80 medical centers in Missan Governorate.

Nasiriyah:

Nasiriyah is a city of Thi Qar Governorate in Iraq. The best part of the area of the Thi Qar Governorate is situated next to the Euphrates River and Gharraf. The area of Thi Qar Governorate is13,626 ㎢ and its population is approximately 2,000,000. It has a good net of roads and transportation linking to the neighboring governorate as. There are (2) universities, (11) hospitals and (138) medical centers.

Najibyah :

Najibyah is located in Basrah Governorate which is 3rd governorate in Iraq regarding population and considered as the economic capital of Iraq. The capital of Basrah Governorate is Basrah city, is about590km away from Baghdad and located on the Shatt al-Arab river in southern Iraq between Kuwait and Iran. The area of the Basrah Governorate is 19,070 ㎢ and its population approximately2,750,000. There are (1) university which is Basrah University, (17) hospital and (121) medical centers.

6.8 BACKGROUND AND OBJECTIVE

For the Iraqi people, the Iraqi government at its supreme effort has been rehabilitating, building and improve the infrastructures, which were destructed or exhausted in the times of the former regime's wars and economic sanction since such periods ended. The Oil and electric power sectors is two of those infrastructures, which are vital for the life of the people in Iraq, and is needed to be developed immediately.

The Ministry of Electricity, Iraq (MOE) has been executing a lot of projects which rehabilitate and newly install the power stations, substations, transmission lines, distribution lines and other necessary projects to increase the power supply resources and provide enough electricity for all through the country.

As one of solutions to increase the electric power supply and for sustainability of NG "and widely in Iraq", we should plans to convert the existing simple cycle power plant (SCPP) to the combined cycle power plant (CCPP).

The principle of the combined cycle as a first step recover the heat from exhausted gas and generate the steam by the heat recovery steam generator (HRSG) and then to combine the steam and generate the electricity by the steam turbine generator (STG). After completing the gas turbine cycle (simple cycle), the temperature of the exhausted gas from the gas turbine which is wasted in the simple cycle is still high enough to generate the steam (energy). By recycling this exhausted gas, the overall net efficiency of the combined-cycle may achieve at more than 50% from the simple-cycle at around 35%-40%. This recycling of the waste enthalpy can expand the power capacity without increasing the fuel consumption and the environmental load. Especially, to add the HRSG and STG on the existing/operating simple-cycle power station is called (Add-On) also known as repowering or bottoming.

MOE has purchased total seventy two units equal to 10,442MW of gas turbines from General Electric (GE) and Siemens that is called the Mega Deal. More than 90% of the Mega Deal gas turbines have been already installed as the simple cycle power stations by the end of 2015.

Based on the conceptual plan of the combined cycle conversion mentioned above, MOE has been discussing with the IPP developers to realize the projects. However, it is assumed that the total cost in IPP paid by MOE as tariff should exceed the total cost in investing by MOE’s own for EPC even though MOE would utilize the foreign finance on the projects. Therefore it is highly recommended to MOE that MOE would consider the EPC to be financed by foreign institutes (EPC+Finance) besides the IPP as alternative. As the recommendation of the EPC+Finance, in May 2015, MOE’s expectation for the feasibility study for the Add-On project (Add-On Project) was shown.

MOE had provisionally shortlisted three (3) sites in the south region of Iraq where SCGT power stations either exists or are planned, out of which one of the most suitable sites to be converted to a CCGT power station. Among three (3) candidate sites, Nasiriyah (Thi Qar Governorate) has been selected by the discussion with MOE for this feasibility study.

Under this Add-On Project, individual HRSG will be installed behind each of the existing gas turbines. The exhaust from each gas turbine will be led to the HRSG via individual diverter damper installed in by pass stack. The proposed arrangement will allow simple cycle as well as combined cycle operation of the plant. The diverter dampers along with the guillotine dampers for all four (4) gas turbines shall be installed for safe maintenance of the HRSG while the gas turbine is operating in simple cycle mode. The HRSG will be of horizontal design employing natural circulated evaporator sections. The HRSG comprises of HP and LP drums together with respective economisers, evaporators and super- heaters.

Steam from the four (4) HRSGs will be connected to one (1) number HP/LP steam turbine having down flow exhaust arrangement exhausting the steam into a water cooled condenser (WCC), thus constituting an Add-On Block of 4-4-1 configuration.

Generator of steam turbine will be connected to a dedicated step-up transformer for power evacuation at 400kV level using existing 400kV GIS.

Contents and Technical feasibility

6.9 SITE SELECTION

In this study has initially considered three potential sites where the gas turbines are already installed or planned to be installed in simple cycle and one of them could be converted to a combined cycle plant table 6.6.

Table 6.6 simple cycle gas power plant

Site	Amara	Nasiriyah	Najibyah
Governorate	Missan	Thi Qar	Basrah
Gas Turbines number	4 units x 125 MW	4 units x 125 MW	4 units x 125 MW
Simple Cycle PS	In operation	Planned, Not started	In operation

All three (3) sites utilize four (4) gas turbines of GE make, Frame 9 E type or plan to install.

The power stations at Amara and Najibyah have been completed and the gas turbines in simple cycle mode are in commercial operation. At Nasiriyah site, the gas turbines have not been yet installed however the EPC “Engineering, Procurement, Construction" contractor has been selected and the installation works are expected to commence in early 2016 and be completed in 25 months from thereafter.

The site of Najibyah has been ruled out for Add-On because there is no extra land available for accommodating the equipment needed for the conversion into combined cycle. The sites of Nasiriyah and Amara have adequate extra land and they have been compared with following terms table 6.7.

Table 6.7 Comparison of Nasiryah and Amara sites

No	Description	Nasiryah Power Station	Amara Power Station
1	Current situation	?	All 4 Gas Turbine Generator (GTG) installed and in operation.
2	Availability of sufficient area to install Add-On facilities	Layout drawing shows that the area is available. EPC current layout drawing for Simple Cycle may be adjusted to accommodate a combined cycle with 4/4/1 configuration,	Area is available.
3	Temporary yard & laydown area required during construction	Area available adjacent to the site.	Area available adjacent to the site.
4	Grid capacity to accept 250 MW coming from Add-On	Yes	Yes
5	Ground bearing capacity (impact on the foundation costs)	?	Piling required
6	Seismic Classification (impact on the foundation and structural costs)	Seismic Code UBC97 Seismic Importance Factor 1 Horizontal acceleration 0.2 g	Seismic Code UBC97 Seismic Importance Factor 1 Horizontal acceleration 0.2 g
7	Cooling Water		
7.a	Water source and availability around the year	River Water (Euphrates river), available through all year	River Water (Tigris river Branch), available through all year.
7.b	Water quality	Require treatment	Require treatment
7.c	Distance of the water source from the site	100-200m from Euphrates River bank beside the plant	5 to 6 km Tigris River to the west of plant

Note: The above site information mentioned in Table-2 has been provided by MOE

No	Description	Nasiriyah Power Station	Amara Power Station
8	Whether the existing facilities have extra capacity (like water treatment/DM plant, Water storage tanks, Fire water reserve, compressed Air etc.)	Partially (refer to interface description)	No
9	Interfaces with existing facilities		
9.a	HV Switchyard extension (spare bay)	Yes	Yes
9.b	Availability of sufficient area in CCR to accommodate new control system/DCS	Available	Available

Note: The above site information mentioned in Table-2 has been provided by MOE and the missing information it because I could not reach it

The site of Amara has been selected because I was work in the site and I have information on the subject and the river water (Tigris) relatively close which ensures availability of the water to the Power Station, in the required quantity and with reasonable pumping costs.

Furthermore the time schedule expected for the implementation of the SCGT power stations in Nasiriyah site (around two years) with many unknown information to reach.

6.10 EXISTING FACILITIES

Currently the simple cycle power station at Amara has already been erected and four gas turbines are already in work supply electric power. The SCGT Power Station is designed with four GE gas turbines and generators Frame 9E (MS 9001 EA), outdoor installation type, having Non Dry Low Nox (Non-DLN) combustors with capabilities to fire crude oil as main fuel, light distillate oil and natural gas as back-up. The natural gas, although currently available, is planned by the Ministry of Oil, Iraq (MOO) to be brought at site at beginning of year 2017.

The SCGT power station will also have common and auxiliary systems as briefly described here below:

Fuel facilities include an unloading station for light diesel oil, storage tanks and fuel forwarding system for both crude oil & light diesel oil. Fuel gas station is also envisaged with all necessary equipment for conditioning of gas before firing in the gas turbine combustors.

Raw water to the plant is supplied from the Tigris River. Water treatment and storage facilities include: pretreatment of the river water with clarification and sludge removal. Reverse osmosis and EDI type water treatment plant for demineralized water supply for SCGT consumers and water injection in gas turbine combustors. Service water, fire water and potable water system also envisaged for plant usage. Effluents treatment and sewage treatment are installed for treatment of waste water and plant sewage respectively.

Other mechanical systems considered are compressed air, firefighting system and auxiliary boiler.

Electrical power evacuation is by means of four (4) step-up transformers one each for each gas turbine, 400 KV and 132 KV gas insulated switchgears (GIS) located indoors. Electrical power distribution has unit auxiliary transformers (UAT), MV power distribution system, LV power distribution system, emergency power supply system and emergency diesel generator.

Gas turbines are installed outdoor having their own compartments/enclosures. The SCGT power station includes central electrical and control building, GIS buildings, administration building, fire station, canteen, warehouse, bachelor house and workshop building.

6.11 COMBINED CYCLE CONFIGURATION

The conversion of a SCGT power station to a CCGT power station is realized by adding the HRSG that utilizes the heat of the exhaust gases for generating steam which is utilized in operating a steam turbine and generator to generate electricity [40].

The steam from each HRSG can be connected to four sets of smaller sized steam turbines or the steam output from each of the four HRSGs can be combined together to supply the steam to a common piping header which then feeds one larger sized steam turbine. The way the GTG/HRSG units are grouped in order to supply steam to the steam turbine and the number of steam turbine determine the configuration of the combined cycle.

In consideration with the following advantages, the 4/4/1x1 configuration mentioned below will be more recommendable in this feasibility study than the 2/2/1x2 configuration mentioned below.

The bigger capacity STG unit has better efficiency than 2 STG of smaller capacity for the same steam parameters.

Lower capital costs due to saving on the cost of the steam turbine and generator, their foundation and STG building, step up transformer, electrical power distribution equipment's and cabling.

Suitable for base load

The plot area requirement is less (the available site area in Nasiriyah is limited).

Reduced construction area during the construction at site.

4/4/1x1 configuration:1 block comprising of four (4) gas turbines, four (4) heat recovery steam generators and one (1) steam turbine generator.

2/2/1x2 configuration: 2 blocks each comprising of two (2) gas turbines, two (2) heat recovery steam generators and one (1) steam turbine generator

As Amara site have four (4) GTGs of about 125 MW ISO rating, this study describes feasibility of the 4/4/1x1 configuration with the consent of below Figure 6.6.

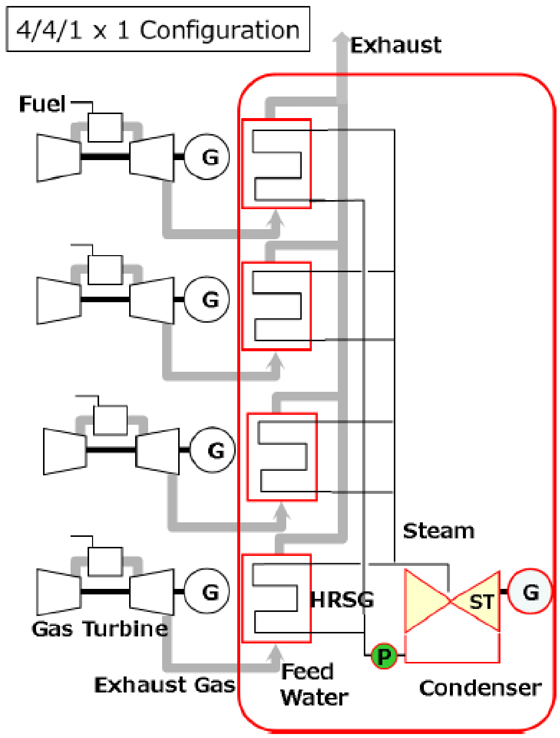


Fig. 6.6 Combined Cycle Configuration

6.12 DESIGN BASIS FOR THE ADD-ON PROJECT

The design conditions utilised for the Add-On project have been considered as follows:

Fuel

Main fuel considered for Add-On project is natural gas while crude oil and light fuel oil are back up fuels.

This is because the fuel gas is available at Amara site in early 2017 and the cost of the natural gas is expected to be lower than crude oil and light fuel oil. Further as per information from MOE, the fuel gas is envisaged to be used as main fuel from 2017. Thus the Add-On project will be starting the commissioning and the commercial operation with fuel gas.

Raw Water

The source of raw water for the Add-On project is the water from the Tigris River.

This solution is the same as for the simple cycle project and the Add-On project shall have a series of treatments in order to produce the water at different chemical and physical properties as required by the Add-On project equipment.

Cooling System

The main cooling system for steam condenser and closed cooling circuit exchangers is envisaged to be wet type Induced draft Cooling Towers. The cooling water will be clarified river water with the cycles of concentration of 2.5

Gas Turbines

1- Performance Summary

The summary performances of the gas turbines in simple cycle are considered as follows: For details of gas turbine performance data estimated by GE.

2- Power Augmentation

The gas turbines installed in Amara are not provided with power augmentation means such as evaporative cooling, fogging, chillers, etc.

Site Design Conditions

(1) Ambient conditions:

Ambient minimum temperature:	0°C
Ambient maximum temperature:	55 °C
Ambient barometric pressure:	1.0094 bar(a)
Relative Humidity, Minimum:	10 %
Relative Humidity, Maximum:	98 %

(2) Site Seismicity

Site Seismicity is classified as per UBC97 code:

Seismic Importance Factor:	1
Horizontal Acceleration:	0.2 g

(3) Wind Speed

Maximum wind speed is 160 km/h, Applicable Code IBC 2000

Wind exposure: C

Electrical Grid Conditions

The frequency of the transmission system will be nominally 50 Hz, and will normally be controlled within 49.5 Hz to 50.5 Hz. However, the plant equipment shall be capable to operate within the following exceptional conditions:

- The units will remain synchronized to the transmission system at transmission system frequencies within the range 47.5 Hz to 52 Hz for a duration of 60 minutes;
- The units will remain synchronized to the transmission system at transmission system frequencies within the range 47 Hz to 47.5 Hz for a duration of 5 seconds required each time the frequency is below 47.5 Hz;
- The units remain synchronized to the transmission system during rate of change of transmission system frequency of values up to and including 0.5 Hz per second;

The Gas Turbines are capable to operate with Automatic Generation Control (AGC), Load Frequency Control (LFC) and all Net Dependable Capacity (NDC) application functions as well as speed droop.

Noise Limitation

The limit of any measured sound pressure level anywhere in the work area shall not exceed 85 dB (A) at 1 meter distance from the noise source.

Effluents discharge

Aqueous emissions from the plant shall be treated and discharged in accordance with the following quality limits.

Aqueous discharges shall be segregated into storm drains, process effluent and domestic sewage streams. Process effluents shall be provided with an appropriate monitoring and treatment system to ensure that the discharge limits are not exceeded.

6.13 PURPOSE AND ADVANTAGES OF ADD-ON

The Add-On projects are also known as bottoming cycle and it aims to:

(1) Reduce consumption of natural gas that's mean improve the sustainability NG

because we will got more energy from same amount of fuel.

(2) Raise the capacity of the power station so to benefit the consumers in the area/region, preventing possibility of power cuts in those areas affected by power shortages

(3) Increase the efficiency of the existing power station which means increasing the use of the fuel intrinsic energy therefore reducing the cost of the energy produced
The following table provided the benefit of Add-On in terms of increase in output and efficiency of the plant table 6.8.

Table 6.8 Anticipated Performance Gain after Add-On

S. No.	**Configuration**	**Simple cycle (4xGE9E GTs)**	**Combined Cycle (4GTs - 4HRSGs - 1ST)**	**Increase**
1	Gross Power Output (kW)	444,800	654,700	**209,900**
2	Gross Efficiency (%)	32.2	47.4	**15.2**

Note:

i) The Power Output and Efficiency are at site ambient temperature 15 ºC, relative

humidity 35% and pressure 1.0094bar.

ii) The above performance parameters are at Natural Gas.

iii) SCGT performance data has been taken from GE document "Performance data"

provided by MOE and the same is the basis for combined cycle anticipated performance.

(4) Fighting global warming by reducing the specific CO2 as they improve the efficiency of the

existing SCGTs, as such it correspond to CDM (Clean Development Mechanism) as the increase of the output power is brought without increasing of fuel consumption table 6.9.

Table 6.9 Reduction in Specific CO2 Emission after Add-On

Parameter	**Simple Cycle (SCGT)**	**Combined Cycle (CCGT)**
CO_2 production (tons / KW / year) @8150 Hrs. of operation per Year	5.36	3.64

7 CONCLUSIONS AND FUTURE WORK

1- Today about 70 % of all natural gas produced in Iraq is flared, rather than captured enough to provide electricity for more than 15 million homes if it was captured and used. In addition, enough Liquefied petroleum gas (LPG) is lost through flaring in Iraq to fill around 250,000 LPG cylinders per day.

2- Natural gas is a naturally occurring hydrocarbon gas mixture consisting primarily of methane, but usually including varying quantities of other higher alkanes, and occasionally a minor percentage of carbon dioxide, nitrogen, hydrogen sulfide, or helium.

3- Liquefied petroleum gas (LPG) most commonly, mixes including both propane and butane.

4- MOE has purchased total 72 units equal to 10,442MW of gas turbines from General Electric (GE) and Siemens that is called the Mega Deal and Iraq needs more thousands of MW in near future that is why it is proposed to use combined cycle power plant (CCPP) instead of simple cycle power plant (SCPP).

5- As one of solutions to improve the enhance the power supply in Iraq, it is proposed to convert the existing simple cycle gas turbine (SCGT) power stations to the combined cycle gas turbine (CCGT) power stations, to improve the sustainability performance for natural gas and increase the production of electric energy. and to modify the existent or built new power plants the MOE need to note the following point .

- Current situation.
- Availability of sufficient area to install Add-On facilities.
- Temporary yard & laydown area required during construction.
- Grid capacity to accept 250 MW coming from Add-On.
- Ground bearing capacity (impact on the foundation costs).

- Seismic Classification (impact on the foundation and structural costs).
- Cooling Water.
  - Water source and availability around the year.
  - Water quality.
  - Distance of the water source from the site.
- Whether the existing facilities have extra capacity (like water treatment/DM plant, Water storage tanks, Fire water reserve, compressed Air etc.)
- Interfaces with existing facilities.
  - HV Switchyard extension(spare bay).
  - Availability of sufficient area in CCR to accommodate new control system/DCS.

8 REFERENCES

[1] Kunz, O., & Wagner, W. (2012). The GERG-2008 wide-range equation of state for natural gases and other mixtures: an expansion of GERG-2004. Journal of chemical & engineering data, 57(11), 3032-3091.

[2] MacDonald, G. J. (1990). Role of methane clathrates in past and future climates. Climatic Change, 16(3), 247-281.

[3] Sovacool, B. K. (2009). Reassessing energy security and the Trans-ASEAN natural gas pipeline network in Southeast Asia. Pacific Affairs, 82(3), 467-486.

[4] Gupta, V. R., & Clark, C. J. (1990). U.S. Patent No. 4,929,789. Washington, DC: U.S. Patent and Trademark Office.

[5] Evans, W. C., White, L. D., & Rapp, J. B. (1988). Geochemistry of some gases in hydrothermal fluids from the southern Juan de Fuca Ridge. Journal of Geophysical Research: Solid Earth, 93(B12), 15305-15313.

[6] Sweeny, A. (2010). Black Bonanza: Canada's Oil Sands and the Race to Secure North America's Energy Future. John Wiley & Sons.

[7] De Anil, K. (2003). Environmental chemistry. New Age International.

[8] Shah, Y. T. (2017). Chemical Energy from Natural and Synthetic Gas. CRC Press.

[9] Mokhatab, S., & Poe, W. A. (2012). Handbook of natural gas transmission and processing. Gulf professional publishing.

[10] Burleson, E. (2012). Climate change and natural gas dynamic governance. Case W. Res. L. Rev., 63, 1217.

[11] Brooks, R. (2013, July). Modeling the North American market for natural gas liquids. In 32nd US Association of Energy and Economics (USAEE) Conference, Anchorage (pp. 28-31).

[12] Moore, J. H. (1997). U.S. Patent No. 5,649,416. Washington, DC: U.S. Patent and Trademark Office.

[13] Moodley, R. (2016). Design and evaluation of a single stage axial flow turbine rotor for a micro turbojet engine (Doctoral dissertation, University of Johannesburg).

[14] Zia, J., Sevincer, E., Chen, H., Hardy, A., Wickersham, P., Kalra, C., & Vandeputte, T. (2013). High-potential working fluids for next generation binary cycle geothermal power plants (No. DOE/EE0002769-3). General Electric Global Research.

[15] Ertesvåg, I. S., Kvamsdal, H. M., & Bolland, O. (2005). Exergy analysis of a gas-turbine combined-cycle power plant with precombustion CO 2 capture. Energy, 30(1), 5-39.

[16] Fritsche, D. (2005). Origin and control of thermoacoustic instabilities in lean premixed gas turbine combustion (Doctoral dissertation).

[17] Hayner, P. F., & Zenny, O. (1959). U.S. Patent No. 2,896,588. Washington, DC: U.S. Patent and Trademark Office.

[18] Byers, J. O., & Haner, L. (1998). U.S. Patent No. 5,787,915. Washington, DC: U.S. Patent and Trademark Office.

[19] Cohen, J. M., Rey, N. M., Jacobson, C. A., & Anderson, T. J. (1998, June). Active Control of Combustion Instability in a Liquid–Fueled Low–NOx Combustor. In ASME 1998 International Gas Turbine and Aeroengine Congress and Exhibition (pp. V003T06A020-V003T06A020). American Society of Mechanical Engineers.

[20] Sims, B. G., & O'Neill, D. H. (1994). Testing and evaluation of agricultural machinery and equipment: Principles and practices (Vol. 110). Food & Agriculture Org..

[21] Kurz, R., & Brun, K. (2001). Degradation in gas turbine systems. Journal of Engineering for Gas Turbines and Power, 123(1), 70-77.

[22] Beroun, S., & Martins, J. (2001). The development of gas (CNG, LPG and H2) engines for buses and trucks and their emission and cycle variability characteristics (No. 2001-01-0144). SAE Technical Paper.

[23] Miller, N. T. (2006). U.S. Patent No. 7,069,137. Washington, DC: U.S. Patent and Trademark Office.

[24] Johnston, J. B. (1987, May). Performance and Reliability Improvements for Heavy Duty Gas Turbines. In ASME 1987 International Gas Turbine Conference and Exhibition (pp. V005T15A001-V005T15A001). American Society of Mechanical Engineers.

[25] Shimizu, N., Kuroda, M., Kirikami, S., Sato, I., & Arai, O. (1991). U.S. Patent No. 5,016,443. Washington, DC: U.S. Patent and Trademark Office.

[26] Martin, B. J. (1977). U.S. Patent No. 4,013,223. Washington, DC: U.S. Patent and Trademark Office.

[27] Hoeft, R. F., Janawitz, J., & Keck, R. (1993). Heavy duty gas turbine operating and maintenance considerations. General Electric Company, Gas Turbine Division.

[28] Meegahapola, L., & Flynn, D. (2015). Characterization of gas turbine lean blowout during frequency excursions in power networks. IEEE Transactions on Power Systems, 30(4), 1877-1887.

[29] Daiber, P. C. (1996). Performance and Reliability Improvements for the MS5001 Gas Turbines. GE Power Systems, Atlanta.

[30] Marra, J. (2015). Advanced Hydrogen Turbine Development. Siemens Energy, Inc., Orlando, FL (United States).

[31] Alexander, M. J., Schroder, M. S., Crawley, B. D., Smith, G. R., Steffen, M. J., Maters, J. C., & Snider, D. A. (2008). U.S. Patent Application No. 12/331,824.

[32] Diduck, V. J. (2000). U.S. Patent No. 6,025,788. Washington, DC: U.S. Patent and Trademark Office.

[33] Kobayashi, Y., & Mori, A. (1984). U.S. Patent No. 4,480,602. Washington, DC: U.S. Patent and Trademark Office.

[34] Burleson, E. (2012). Climate change and natural gas dynamic governance. Case W. Res. L. Rev., 63, 1217.

[35] Ehrman, M. U. (2006). Competition is a Sin: an Evaluation of the Formation and Effects of a Natural Gas OPEC.

[36] Gamage, G. D. (2011). Assessing the effectiveness of wind power and cogeneration for carbon management of electric power systems (Doctoral dissertation, UNIVERSITY OF CALGARY).

[37] Chen, L., Dhar, V., Guo, J., Hill, M., Kim, H. J., Mustafaoglu, O., ... & Sundararaman, R. (2006). Design toward integration of CO2 capture and fuel conversion technologies for a 500 MWe Coal-Based power plant.

[38] Poullikkas, A. (2005). An overview of current and future sustainable gas turbine technologies. Renewable and Sustainable Energy Reviews, 9(5), 409-443.

[39] Al-Moumen, M. M., & Rothwell, G. (2009). Developing Iraq‘s Oil industry to maximize government net revenues ‘ (Doctoral dissertation, PhD thesis, Stanford University).

[40] Eveloy, V., Rodgers, P., & Popli, S. (2014). Trigeneration scheme for a natural gas liquids extraction plant in the Middle East. Energy Conversion and Management, 78, 204-218.