COMBINED CYCLE GAS POWER PLANT FOR EFFICIENT ENERGY GENERATION

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Abstract-

The Combined Cycle power plant or combined cycle gas turbine generator generates electricity and waste heat is used to make steam to generate additional electricity via a steam turbine. The gas turbine is one of the most efficient way for the conversion of gas fuels to mechanical power or electricity. The use of distillate liquid fuels, usually diesel, is also common as alternate fuels. More recently, as simple cycle efficiencies have improved and as natural gas prices have fallen, gas turbines have been more widely adopted for base load power generation, especially in combined cycle mode, where waste heat is recovered in waste heat boilers, and the steam used to produce additional electricity. This system is known as a Combined Cycle.

Keywords: Cogeneration, CHP, HSRG, Recuperation, Combined Cycle.

I. INTRODUCTION

The basic principle of the Combined Cycle is simple, burning gas in a gas turbine (GT) produces not only power but also fairly hot exhaust gases. Routing these gases through a water-cooled heat exchanger produces steam, which can be turned into electric power with a coupled steam turbine and generator.

A combined-cycle gas turbine power plant consists of one or more gas turbine generators equipped with heat recovery steam generators to capture heat from the gas turbine exhaust. Steam produced in the heat recovery steam generator powers a steam turbine generator to produce additional electric power.

Use of the otherwise wasted heat in the turbine exhaust gas results in high thermal efficiency compared to other combustion based technologies. Combined-cycle plants currently entering service can convert about 50 percent of the chemical energy of natural gas into electricity. Additional efficiency can be gained in combined heat and power (CHP) applications (cogeneration), by bleeding steam from the steam generator, steam turbine or turbine exhaust to serve direct thermal loads.

The following figure shows a single shaft CC cycle block diagram in more detail.

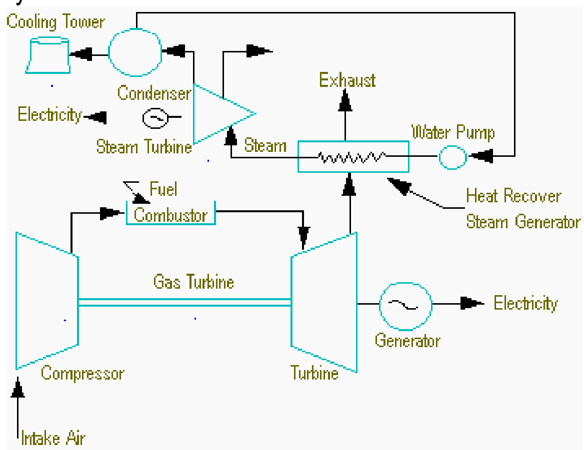

Fig. 1: single shaft CC cycle block diagram

II. MECHANISM

Combined cycle power plant as in name suggests, it combines existing gas and steam technologies into one unit, yielding significant improvements in thermal efficiency over conventional steam plant. In a CCGT plant the thermal efficiency is extended to approximately 50-60 per cent, by piping the exhaust gas from the gas turbine into a heat recovery steam generator. However the heat recovered in this process is sufficient to drive a steam turbine with an electrical output of approximately 50 per cent of the gas turbine generator. The gas turbine and steam turbine are coupled to a single generator. For startup, or 'open cycle' operation of the gas turbine alone, the steam turbine can be disconnected using a hydraulic clutch. In terms of overall investment a single-shaft system is typically about 5 per cent lower in cost, with its operating simplicity typically leading to higher reliability

Table. 1: analysis of the competitive standing of the various types of power plants

Type of Plant	Capital Cost ($/kW)	Heat Rate (kJ/kWh)	Net Efficiency	Reliability (%)	Completion (Months)
SCGT (2500°F/1371˚C Natural gas	300-350	7582-8000	45	97-99	10-12
SCGT oil fired	400-500	8322-8229	41	95-98	12-16
SCGT crude fired	500-600	10,662—11,250	32	90-95	12-16
Regenerative gas turbine natural gas fired	375-575	6824-7200	50	96-98	12-16
Combined-cycle gas turbine	600-900	6203-6545	55	95-98	22-24
Advanced gas turbine CCPP	800-1,000	5249-5538	65	94-96	28-30
Combined cycle coal gasification	1,200-1.400	6950-7332	49	90-95	30-36
Combined-cycle fluidized bed	1-200-1,400	7300-7701	47	90-95	30-36
Nuclear power	1,800-200	10.000-10550	34	92-98	48-60
	800-1.000	9749-10285	35	94-97	36-42
Diesel general or-diesel fired	400-500	7582-8000	45	96-98	12-16
Diesel generator-power plant oil fired	600-700	8124-8570	42	92-95	16-18

III. EFFICIENCY OF CCGT PLANT

Roughly the steam turbine cycle produces one third of the power and gas turbine cycle produces two thirds of the poweroutput of the CCPP. By combining both gas and steam cycles, high input temperatures and low output temperatures can be achieved. The efficiency of the cycles adds, because they are powered by the same fuel source. To increase the power system efficiency, it is necessary to optimize the HRSG, which serves as the critical link between the gas turbine cycle and the steam turbine cycle with the objective of increasing the steam turbine output. HRSG performance has a large impact on the overall performance of the combined cycle power plant.

The electric efficiency of a combined cycle power station may be as high as 58 percent when operating new and at continuous output which are ideal conditions. As with single cycle thermal units, combined cycle units may also deliver low temperature heat energy for industrial processes, district heating and other uses. This is called cogeneration and such power plants are often referred to as a Combined Heat and Power (CHP) plant. The efficiency of CCPT is increased by Supplementary Firing and Blade Cooling. Supplementary firing is arranged at HRSG and in gas turbine a part of the compressed air flow bypasses and is used to cool the turbine blades. It is necessary to use part of the exhaust energy through gas to gas recuperation. Recuperation can further increase the plant efficiency, especially when gas turbine is operated under partial load.

Table 1 depicts an analysis of the competitive standing of the various types of power plants, their capital cost, heat rate, operation and maintenance costs, availability, reliability, and time for planning. By examining the capital cost and installation time of these new power plants, it is obvious that the gas turbine is the best choice for peaking power. Steam turbine plants are about 50% higher in initial costs of $800-$1000/kW than combined-cycle plants, which are about $400-$900/kW. Nuclear power plants are the most expensive plants. The high initial costs and the long time in construction make such a plant unrealistic for a deregulated utility. Efficiency and heat rate are interchangeable, as they represent the efficient conversion of fuel to energy. The following relationship gives the easy conversion from heat rate to efficiency.

$$\text{Efficiency} = 3412.2/\text{BTU/kWh}$$
$$= 2544.4/\text{BTU/HPh} = 3600/\text{kJ/kWh}$$

In the area of performance, the steam turbine power plants have an efficiency of about 35% when compared with combined-cycle power plants, which have an efficiency of about 55%. Newer gas turbine technology will make combined-cycle efficiencies range between 60% and 65%. As a rule of thumb, a 1% increase in the efficiency could mean that 3.3% more capital can be invested. However, one must be careful that the increase in the efficiency does not lead to a decrease in the availability.

IV. FUELS FOR CCPT PLANTS

The turbines used in Combined Cycle Plants are commonly fuelled with natural gas and it is more versatile than coal or oil and can be used in 90% of energy applications. Combined cycle plants are usually powered by natural gas, although fuel oil, synthesis gas or other fuels can be used.

A. Natural gas

The naturally occurring gaseous fuel is known as natural gas. It is formed by decomposition of organic matter. It is obtained from wells dug in the oil-bearing regions before use; the natural gas is purified to remove objectionable impurities such as water, dust, grit, H_2S, CO_2, N_2 and higher hydrocarbons which can be easily liquefied. It is a very cheap & convenient fuel.

Composition:

- Methane (CH_4) = 70-90%
- Ethane (C_2H_6) = 5-10%
- Hydrogen = 3%
- CO & CO_2 = rest

Calorific value:

- 12000-14000 kcal/m3

B. Water Gas

Water gas is a mixture of combustible gases (CO & H_2). It contains little amount of non-combustible gases (CO_2& N_2). It can be prepared by passing alternatively steam and air through a bed of red hot coke or coal maintained at about 900 to 1000°C

Composition:

- Carbon monoxide = 44%
- Hydrogen = 48%
- Carbon dioxide = 4%
- Nitrogen = 4%

Properties of Water Gas:

- Water gas burns with non-luminous blue flame & hence is called blue water gas.
- The temperature of the flame reaches up to 1200°.
- Due to presence of CO, it is poisonous gas.
- Calorific value is about 2800 kcal/m3
- When mixed with hydro carbons, it is called carbureted water gas.

C. COAL GAS

It is obtained by destructive distillation of coal. Coal used should be rich in volatile matter (30 to 40%). The process is carried out in horizontal or vertical closed iron or silica retorts at 1350o C. The gaseous product obtained is a mixture of several combustible gases & is known as coal gas. Coke is the residue left behind.

Coal $\longrightarrow$ Coal gas + Coke

Composition:

- Methane = 32%
- Hydrogen = 47%
- Carbon monoxide = 7%
- Acetylene (C_2H_2) = 2%
- Ethylene (C_2H_4) = 3%
- Nitrogen (N_2) = 4%
- Carbon dioxide (CO_2) = 1%
- Other hydrocarbons = 4%

Properties coal gas:

- Colourless gas with a characteristic odour.
- Lighter than air.
- Slightly soluble in water.
- Burns with long smoky flame.
- Poisonous in nature.
- Calorific value is about 5000 kcal/m^3

D. OIL GAS

Oil gas is a mixture of hydrocarbons. Prepared by thermal cracking of kerosene oil. Kerosene oil consists of hydrocarbons ranging from $C_{11}H_{22}$ to $C_{16}H_{34}$.

Composition:

Composition of oil gas depends upon the nature of oil used.

- CH_4 = 25 – 30%
- H_2 = 50 – 60%
- CO = 10 – 15%
- CO_2 = 3%

Calorific value:

Calorific value of the gas is about 4500 – 5400 kcal/m^3

E. BIO GAS

Bio gas is produced by the degradation of biological matter by bacterial action (by anaerobic bacteria) in the absence of free oxygen. The cheapest & easily obtainable biogas is gobar gas. Gobar gas is produced by anaerobic fermentation of cattle dung.

Composition:

- Methane = 55%
- Carbon dioxide = 35%
- Hydrogen = 8%
- Nitrogen = 2%

Before using, gobar gas is passed through KOH solution to absorb maximum of CO_2.

Properties of Bio gas:

- It is colourless&odourless gas insoluble in water.
- It burns with non-luminous blue flame and gives a temperature of 540°C
- It is non-poisonous in nature as it does not contain carbon monoxide.
- Calorific value is about 12000 kcal/m^3

V. ENVIRONMENTAL IMPACTS

Although power plants are regulated by federal and state laws to protect human health and the environment, there is a wide variation of environmental impacts associated with power generation technologies. The purpose of the following section is to give consumers a better idea of the specific air, water, and solid waste releases associated with natural gas-fired generation.

A. Air emissions

At the power plant, the burning of natural gas produces nitrogen oxides and carbon dioxide, but in lower quantities than burning coal or oil. Methane, a primary component of natural gas and a greenhouse gas, can also be emitted into the air when natural gas is not burned completely. Similarly, methane can be emitted as the result of leaks and losses during transportation. Emissions of sulphur dioxide and mercury compounds from burning natural gas are negligible. The average emissions rates in the United States from natural gas-fired generation are: 1135 lbs/MWh of carbon dioxide, 0.1 lbs/MWh of sulphur dioxide, and 1.7 lbs/MWh of nitrogen oxides. Compared to the average air emissions from coal-fired generation, natural gas produces half as much carbon dioxide, less than a third as much nitrogen oxides, and one percent as much sulphur oxides at the power plant. In addition, the process of extraction, treatment, and transport of the natural gas to the power plant generates additional emissions.

B. Water Resource Use

The burning of natural gas in combustion turbines requires very little water. However, natural gas-fired boiler and combined cycle systems do require water for cooling purposes. When power plants remove water from a lake or river, fish and other aquatic life can be killed, affecting animals and people who depend on these aquatic resources.

C. Water Discharges

Combustion turbines do not produce any water discharges. However, pollutants and heat buildup in the water used in natural gas boilers and combined cycle systems. When these pollutants and heat reach certain levels, the water is often discharged into lakes or rivers. This discharge usually requires a permit and is monitored.

D. Solid Waste Generation

The use of natural gas to create electricity does not produce substantial amounts of solid waste.

VI. MERITS

A. Fuel efficiency

In conventional power plants turbines have a fuel conversion efficiency of 33% which means two thirds of the fuel burned to drive the turbine off. The turbines in combined cycle power plant have a fuel conversion efficiency of 50% or more, which means they burn about half amount of fuel as a conventional plant to generate same amount of electricity.

B. Low capita3l costs

The capital cost for building a combined cycle unit is two thirds the capital cost of a comparable coal plant.

C. Commercial availability

Combined cycle units are commercially available from suppliers anywhere in the world. They are easily manufactured, shipped and transported.

D. Abundant fuel sources

The turbines used in combined cycle plants are fuelled with natural gas, which is more versatile than a coal or oil and can be used in 90% of energy publications. To meet the energy demand now a day's plants are not only using natural gas but also using other alternatives like bio gas derived from agriculture.

E. Reduced emission and fuel consumption

Combined cycle plants use less fuel per kWh and produce fewer emissions than conventional thermal power plants, thereby reducing the environmental damage caused by electricity production. Comparable with coal fired power plant burning of natural gas in CCPT is much cleaner.

VII. ADVANTAGES OVER DIESEL PLANT:

1. The work developed per kg of air is large compared with diesel plant
2. Less vibrations due to perfect balancing.
3. Less space requirements.
4. Capital cost considerably less.
5. Higher mechanical efficiency.
6. The running speed of the turbine (40,000 to 100,000 r.p.m.) is considerably large compared to diesel engine (1000 to 2000 r.p.m.).
7. Lower installation and maintenance costs.
8. Poor quality fuels can be used.

VIII.ADVANTAGES OVER STEAM POWER PLANT:

1. No ash handling problem.
2. Low capital cost.
3. The gas turbine plants can be installed at selected load Centre as space requirement is considerably less where steam plant cannot be accommodated.
4. Fewer auxiliaries required/used.
5. Gas turbines can be built relatively quicker. They require much less space and civil engineering works and water supply.
6. The gas turbine plant as peak load plant is more preferable as it can be brought on load quickly and surely.
7. The components and circuits of a gas turbine plant can be arranged to give the most economic results in any given circumstances which is not possible in case of steam power plants.
8. For the same pressure and initial temperature conditions the ratio of exhaust to inlet volume would be only 3.95 in ease of gas turbine plant as against 250 for steam plant.
9. Above 550°C, the thermal efficiency of the gas turbine plant increases three times as fast the steam cycle efficiency for a given top temperature increase.
10. The gas turbine plants can work quite economically for short running hours.
11. Storage of fuel is much smaller and handling is easy

IX. CONCLUSIONS

Combined cycle power plants meet the growing energy demand, and hence special attention must be paid to the optimization of the whole system. Developments for gasification of coal and use in the gas turbine are in advanced stages.

Once this is proven, Coal as the main fuel can also combined cycle power plants meet the growing energy demand, be used in the combined cycle power plant. The advances in cogeneration-the process of simultaneously producing useful heat and electricity from the same fuel source-which increases the efficiency of fuel burning from 30% to 90%, thereby reducing damage to the environment while increasing economic output through more efficient use of resources.

REFERENCES

[1] ISBN (10): 81-224-2333-7, ISBN (13): 978-81-224-2333-4 / A-K-Raja New Age International Publisher.

[2] *Power Plant Engineering* By R. K. Rajput.

[3] *Gas Turbine Engineering Handbook*, by Meherwan P. Boyce ISBN: 978-0-7506-7846-9.

[4] *Gas Turbines: A Handbook of Air, Land, and Sea Applications*, Author Claire Soares, ISBN0750679697, 978075067969

[5] Antonio Mariani, BiagioMorrone and Andrea Unich (2012). *A Review of Hydrogen-Natural Gas Blend Fuels in Internal Combustion Engines, Fossil Fuel and the Environment*, Dr. Shahriar Khan (Ed.), ISBN: 978-953-51-0277-9, Intec.

[6] TaibIskandarMohamad (2010). *Compressed Natural Gas Direct Injection* (Spark Plug Fuel Injector), Natural Gas, PrimoÃ…Â¾ PotoÃ„Â nik (Ed.), ISBN: 978-953-307-112-1, Intec.

[7] Acwa Power Kirikkale Natural Gas Combined Cycle Power Plant Project Nontechnical Summary,Mgs Project Consultancy Engineering Trade Co. Gs Ankara – June/2014.

[8] Electricity Supply Board, *Aghada Combined Cycle Gas Turbine Power Plant Environmental Impact Statement* July 2004, Report P378250r6050001.