ADVANCED CONTROL ENGINEERING
REPORT

POWER CONTROL OF GAS POWER PLANT

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Abstract

In this project paper we tend to area unit discussing regarding the advances in system component technologies, modern state-of-the-art power plant control systems are being developed by incorporating such advanced technologies as extensive digitization of high-speed control circuits, interconnection with other equipment over open interfaces, and a repertory of diverse multiplexed systems. Here major focus is given to the gas power plant working with respect to its efficiency and control system with respect to it. For example: Based on Hitachi Integrated Autonomic Control System (HIACS), Hitachi, Ltd. has developed and deployed a wide range of leading-edge power plant control systems including gas turbine control systems, steam turbine control systems, and generator excitation control systems.

Keywords: gas power plant; HIACS; range of leading edge; steam turbine; control systems.

Contents

Chapter 1

Introduction

Natural gas is the eco-friendliest which has the capability to produce 30% of electricity which is regarded as a main resource. The main part of the model is turbine, where a burning gas at power plant heats up the air through 100's of propellants inside the turbine.

Spinning magnets through a winded coil is the main principle involved. Here mechanical energy is converted into electrical energy which is more efficient in nature.

Coal has 33% of carbon which is very much harmful to the environment whereas gas power plant has 60% less carbon content. Toxic content is more in coal which has the partnered application with wind and solar energy. The use of gas turbine in power generation industry is more recent in the last two decades than its use in other fields as early as in 1875. The major progress has been achieved in three directions: increase in capacities of gas turbine units (50-100 MW), increase in efficiency (38%) and drop in capital cost. Natural Gas produces 30 percent of USA electricity and expected to grow, and 15 percent of Australia's electricity Natural gas has become the number one choice of large new power plants of United States of America. Burning natural gas at the power plant heats up the air needed speed up about hundreds of propellers like blades in the turbine. Turbine is connected by a shaft to a generator that makes an electric current.

Chapter 2

History of Gas Turbine Power Plant

In 1791 John Barber, an Englishman was the first to patent a design that used the thermodynamic cycle of the modern gas turbine. His design contained the basics of the modern gas turbine. It had a compressor, a combustion chamber, and a turbine. The main difference in his design is that the turbine was equipped with a chain-driven reciprocating type of compressor. He intended its use for jet propulsion.

In 1939 Gas turbine first successfully ran at the Swiss National Exhibition at Zurich. The early gas turbines built in the 1940s and even 1950s had simple-cycle efficiencies of about 17 percent. This was because of low compressor and turbine efficiencies and low turbine inlet temperature due to metallurgical limitations at the time. In 1949 the first gas turbine for an electric utility was installed in Oklahoma as part of a combined-cycle power plant. It was built by General Electric and produced 3.5 MW of power. In the past, large coal and nuclear power plants dominated the base-load electric power generation. However, natural gas-fired turbines now dominate the field because of their: black start capabilities, higher efficiencies, lower capital costs, shorter installation times, better emission characteristics, and abundance of natural gas supplies. The world's largest gas turbine is a behemoth. Named Harriet, GE's 500,000 bhp gas turbine cost around $1 billion to develop and has the potential to run an entire 600-megawatt steam power plant all by its lonesome.

Gas turbine systems operate on the thermodynamic cycle known as the Brayton cycle, named after George Brayton (1830–1892), the American engineer who developed it. In 1872 George Brayton applied for a patent for his Ready Motor. Today the term Brayton cycle is generally associated with the gas turbine even though Brayton never built anything other than piston engines. Like other internal combustion power cycles, The Brayton cycle is an open system, though for thermodynamic analysis it is conventionally assumed that the exhaust gases are reused in the intake, enabling analysis as a closed system. Ideal Brayton cycle consist of 4 cycles.

They are mentioned below:

1. Isentropic process - Ambient air is drawn into the compressor, where it is pressurized.

2. Isobaric process - The compressed air then runs through a combustion chamber, where fuel is burned, heating that air—a constant-pressure process, since the chamber is open to flow in and out.

3. Isentropic process - The heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.

4. Isobaric process - Heat Rejection (in the atmosphere).

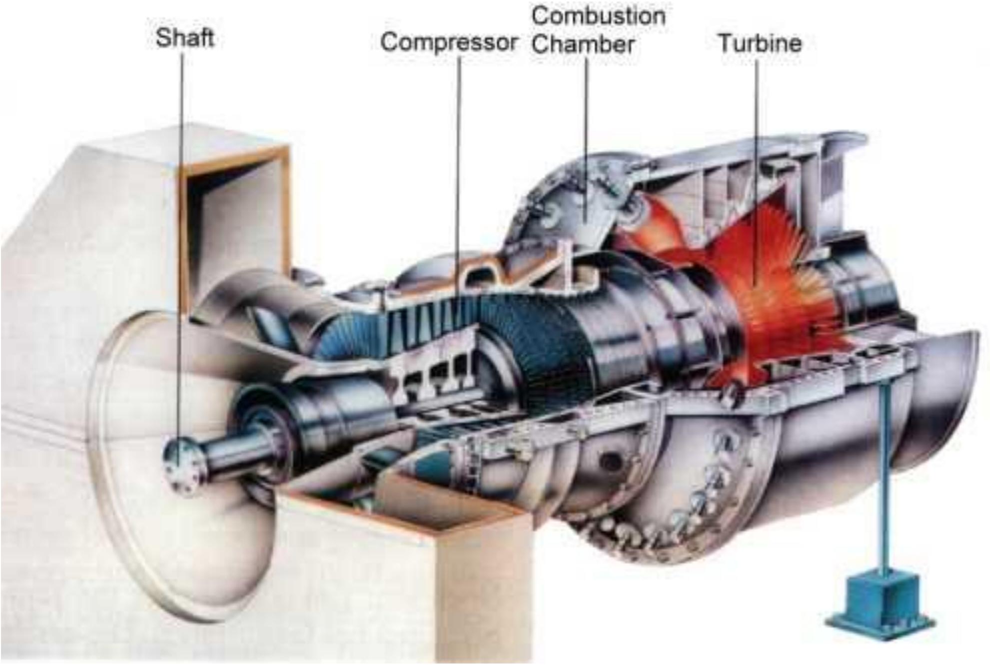


Fig 2.1: Gas Turbine internal image[1]

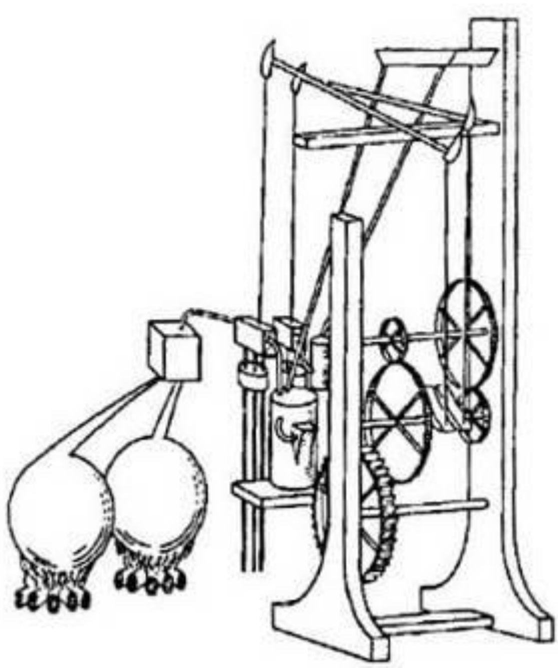


Fig 2.2: Sketch of John Barber's gas turbine, from his patent[2]

Chapter 3

Systems of Gas Power Plant

a. Simple Gas turbine Open cycle power station.

By spinning magnets through a wire coil, it converts the mechanical energy of the turbine into electricity that's why it's called a generator. This type of power plant is called a simple cycle gas turbine because there is only one turbine and one generator. Some of the characteristics are given below:

- Operate When Demand is High
- Peak Demand
- Operate for Short / Variable Times
- Designed for Quick Start-Up
- Not designed to be Efficient but Reliable
- Not Cost Effective to Build for Efficiency

b. Combined cycle power plant

It combines a gas turbine and a steam turbine used in a coal power plant but instead of using coal or even more gas to create steam a combined cycle plant uses the exhaust heat from the gas turbine to boil water into steam. The steam then drives a second turbine which spins a second generator producing even more electricity. This two-step combined cycle process is highly efficient converting as much as 50% of the energy contained in natural gas into electricity. Some of the characteristics are given below:

- Operate for Peak and Economic Dispatch
- Designed for Quick Start-Up
- Designed to Efficient, Cost-Effective Operation
- Typically Has Ability to Operate in SC Mode

In short, we can say combined cycle power plants are typically used daily to supply steady baseload power while open cycle power plants ideal during high peak demand like on hot summer days.

Comparison

Coal fired steam turbines are only 33% efficient and this is one of the main reasons why gas fired power plants are better for the environment. Natural gas starts out with a lower carbon content than coal and with more efficient power plants it can produce electricity with about 60% less carbon dioxide than coal fired power plants. Also, natural gas plants do not release many of the toxic substances like mercury that comes from burning coal. Modern natural gas plants can get going in just 15 mins that makes them ideal for backing up renewables since they can switch on and off faster than most other conventional plants and partner with wind and solar energy as the wind changes or clouds move across the sky.
Besides helping the environment natural gas plants also make financial sense.

According to united states energy information administration when you consider the construction and fuel costs natural gas plants are the cheapest kind of new power generation we can build right now. So, from efficiency to affordability to helping the environment it's easy to see that natural gas is playing a bigger role in supplying our electricity needs. Working principle of gas turbine power plant: The combustion (gas) turbines being installed in many of today's natural-gas-fueled power plants are complex machines, but they basically involve three main sections:

- The compressor, which draws air into the engine, pressurizes it, and feeds it to the combustion chamber at speeds of hundreds of miles per hour.
- The combustion system typically made up of a ring of fuel injectors that inject a steady stream of fuel into combustion chambers where it mixes with the air. The mixture is burned at temperatures of more than 2000 degrees F. The combustion produces a high temperature, high pressure gas stream that enters and expands through the turbine section.
- The turbine is an intricate array of alternate stationary and rotating aero foil-section blades. As hot combustion gas expands through the turbine, it spins the rotating blades. The rotating blades perform a dual function: they drive the compressor to draw more pressurized air into the combustion section, and they spin a generator to produce electricity.

Chapter 4
Heavy duty gas turbines and Brayton cycle

Industrial heavy-duty gas turbines (HDGT) are specially designed gas turbines for power generation which are specified by their long life and higher availability compared other types of gas turbines. HDGTs are composed of three major components: multistage axial flow compressors, can-annular combustors and axial flow turbines. Air with atmospheric conditions is drawn to the compressor after passing air filters at the entrance. The multistage compressor increases speed, pressure and temperature of the air before it reaches the combustor and inlet to the high-pressure turbine parts. Each compressor stage comprises a row of rotor blades and stator vanes. Of importance is a row of stator vanes at the inlet (variable inlet guide vanes, VIGVs) whose angle may be changed by the control system during operation. As illustrated in Fig. 1, the compressed air with high pressure and temperature will follow its way to the combustor. The combustor is in essence a heater in which fuel is burnt to increase the temperature at constant pressure. Roughly one third of the compressor discharge air is mixed with the fuel to be burnt, while the remaining air is mixed with combustion products to become the turbine inlet flow which is now at turbine inlet temperature (TIT). The flow is then expanded in 2–4 turbine stages which drive compressor and generator. Finally, the flow is guided through the exhaust duct to a second environment which can be surrounding ambient conditions or a heat recovery steam generator (HRSG) in combined cycle plants (CCP). In addition to air/gas dynamics passing through major components of the gas turbine, there are other equipment's which are of interest in the gas turbine model like exhaust gas thermocouple and its radiation shield and the fuel valve system and valve positioner. An estimation of these equipment parameters is done as well.

4.1 Elements of Gas turbine power plant:

1) **L.P air compressor:** Atmospheric air is drawn in and passed through the air filter. It then flows into the low-pressure compressor. Major percentage of power developed (66%) by the turbine is used to run the compressor. The power required to run the compressor can be reduced by compressing the air in two stages, i.e., in low pressure and high-pressure compressor and by incorporating an intercooler between the two.

2) **Intercooler:** Intercooler is used to reduce work of the compressor and increase the efficiency. The energy required to compress air is proportional it the air temperature at inlet. Therefore, if intercooling is carried out between the stages of compression, total work can be reduced.

3) **H.P. Compressor:** From the intercooler, the compressed air enters the high-pressure compressor, where it is further compressed to a high pressure. Then it is passed into the regenerator.

4) **Regenerator:** In the simple open cycle system, the heat of the turbine exhaust gases goes as waste. To make use of this heat a regenerator is provided. In the regenerator the heat of the hot exhaust gases from the turbine is used to preheat the air entering the combustion chamber.

5) **Combustion chamber:** Hot air from regenerator flows to the combustion chamber. Fuel (natural gas or coal gas or kerosene or gasoline) is injected into the combustion chamber and burns in the steam of hot air. The products of combustion, comprising a mixture of gases as high temperature and pressure are passed to the turbine.

6) **Gas turbines:** Products of combustion are expanded in high pressure turbine and then in low pressure turbine. The part of the work developed by the gases passing through the turbines is used to run the compressor and the remaining (about 34%) is used to generate electric power.

7) **Open cycle and closed cycle system:** When the heat is given to the air by mixing and burning the fuel in the air and the gases coming out of the turbine are exhausted to the atmosphere, the cycle is known as “open cycle system”. If the heat to the working medium (air or any other suitable gas) is given without directly burning the fuel in the air and the same working medium is used again and again, the cycle is known as “closed cycle system”.

8) **Reheating combustion chamber:** The output of the plant can be further improved by providing a reheating combustion chamber between high pressure and low-pressure turbines. In this, fuel is added to reheat the exhaust gases of high pressure turbine. The addition of the regenerator, intercooler and reheating combustion chamber increases the overall efficiency of the plant.

9) **Valve Positioner and Fuel System Lag:** The valve positioner moves the actuator to a valve position corresponding to the set point. The valve positioner and its connection to the valve actuator and valve system is presented. Due to the fact that HDGTs are able to operate with liquid and gas fuel, the fuel system models are essentially two different systems with similar blocks. In larger HDGTs both fuel systems are supplied with inner loop feedback which senses the current position of the valve and eliminates the error between setpoint and position signal. Therefore, only one time constant will appear, which is in the valve positioner block the positioner time constant can be found in the manufacturer data or similar available data for older units. Moreover, in liquid fuel systems, there is a bypass way from the fuel pump output to the pump section. Bypass path is presented in Rowen’s model by the feedback loop gain Kf. The value of Kf is explicitly calculated to force the overall valve positioner-fuel system loop gain to unity.

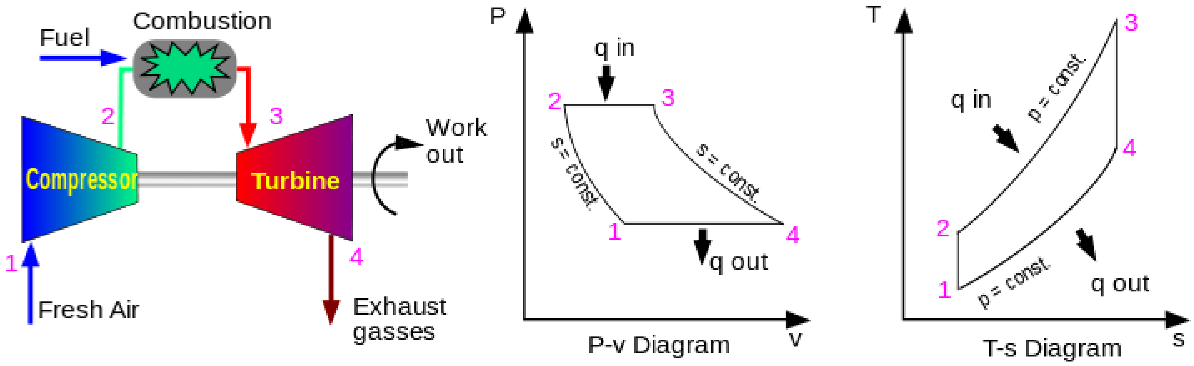
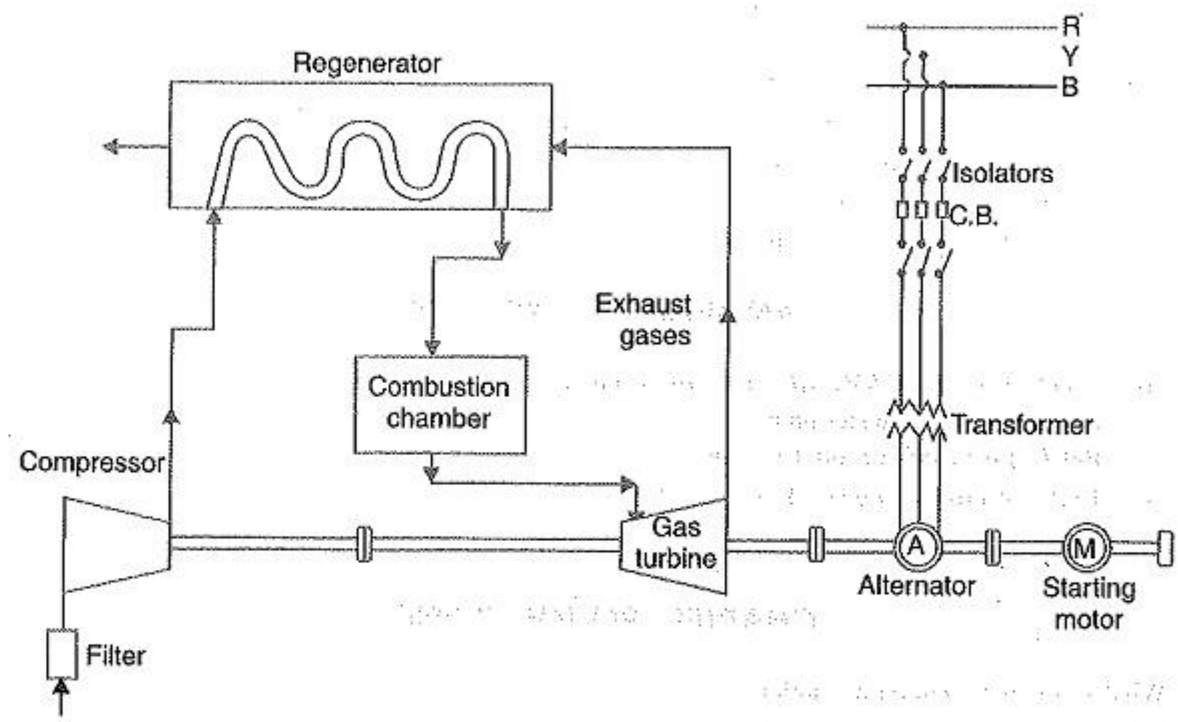


Fig 3.1. Idealized Brayton Cycle[3]



Schematic arrangement of gas turbine power plant.
Fig. 2.9

Fig 3.2. Schematic Diagram for gas turbine plant for simple cycle[4]

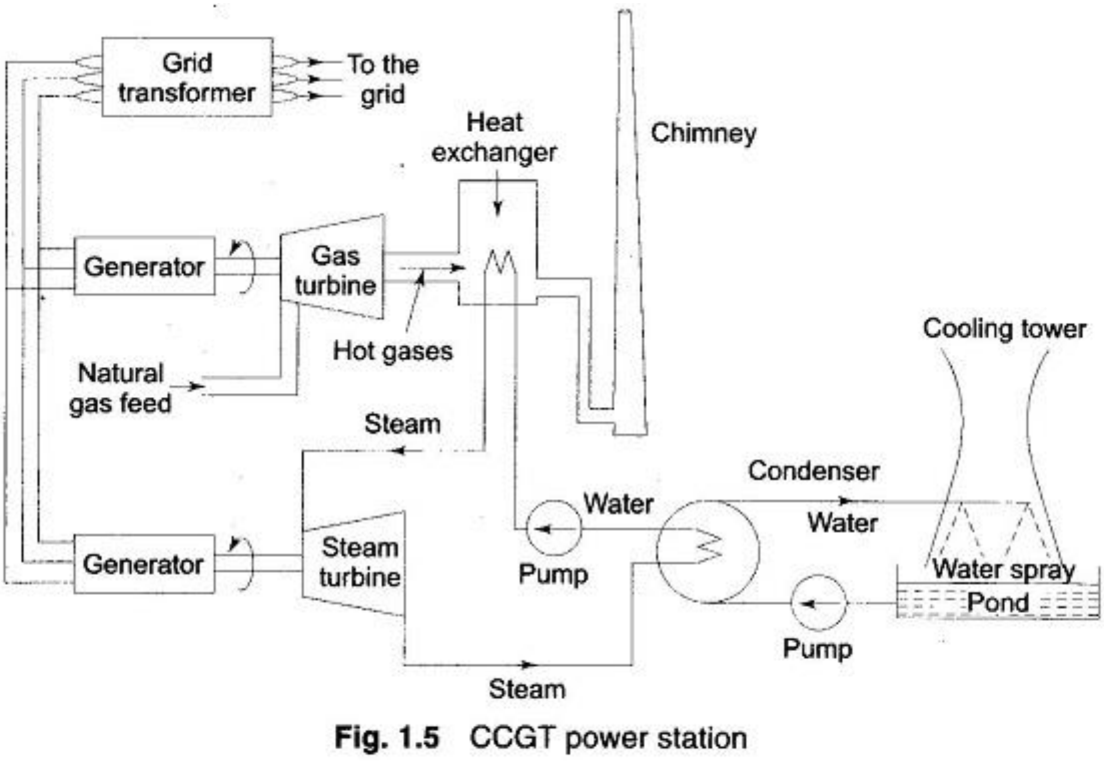


Fig 3.3. Schematic Diagram for combined cycle gas turbine[5]

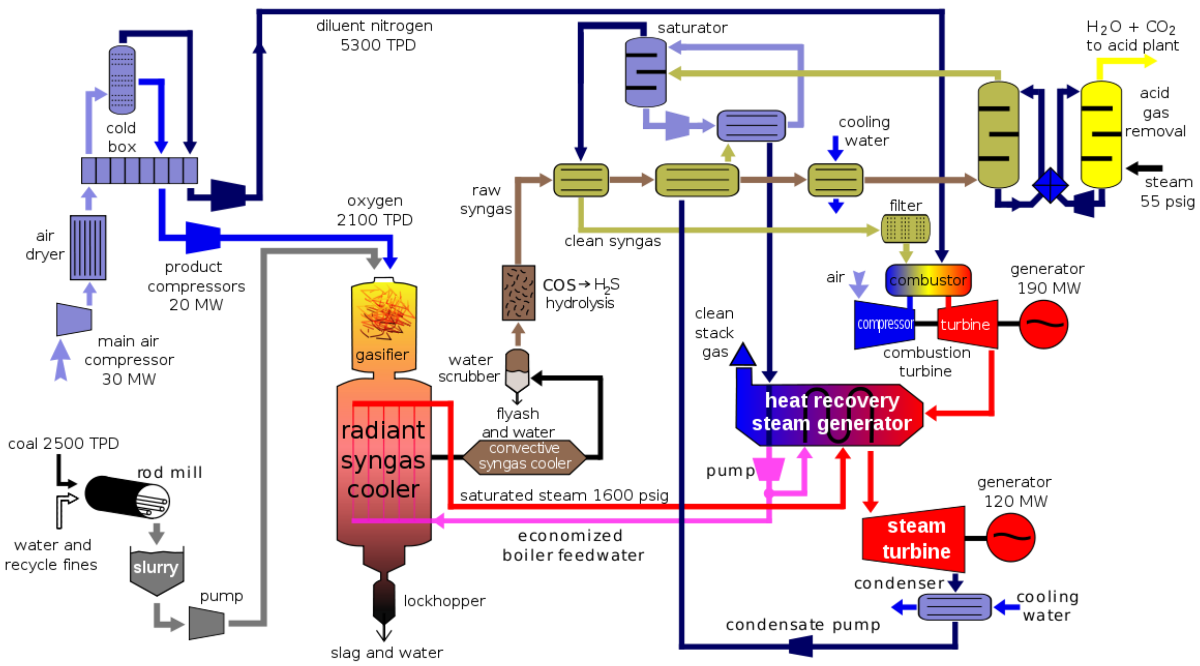


Fig 3.4. Power Generation Diagram[6]

Chapter 5

Gas Turbine (Applications): single-phase

Direct drive and mechanical drive

With land-based industries, gas turbines can be used in either direct drive or mechanical drive application. With power generation, the gas turbine shaft is coupled to the generator shaft, either directly or via a gearbox "direct drive" application. A gearbox is necessary in applications where the manufacturer offers the package for both 60 and 50 cycle (Hertz, Hz) applications. The gear box will use roughly 2 percent of the power developed by the turbine in these cases.

Power generation applications extend to offshore platform use. Minimizing weight is a major consideration for this service and the gas turbines used are generally "aero derivatives" (derived from lighter gas turbines developed for aircraft use).

For mechanical drive applications, the turbine module arrangement is different. In these cases, the combination of compressor module, combustor module and turbine module are termed the gas generator. Beyond the turbine end of the gas generator is a freely rotating turbine. It may be one or more stages. It is not mechanically connected to the gas generator, but instead is mechanically coupled.

The stationary part of the turbine assembly consists of a row of contoured vanes set at a predetermined angle to form a series of small nozzles which direct the gases onto the blades of the turbine rotor. For this reason, the stationary vane assembly is usually called the turbine nozzle, and the vanes are called nozzle guide vanes.

Exhaust module:

The gas turbine's hot gases exit via the exhaust section or module. Structurally, this section supports the power turbine and rear end of the rotor shaft. The exhaust case typically has an inner and outer housing. Hollow struts locate its position. The inner housing typically has a cone shape or cover that encloses a chamber for cooling the thrust bearing at the end of the shaft. When we consider aircraft engine applications, we note that turboshaft engines (such as those used in helicopters) do not develop thrust with the use of the exhaust duct, as they must be capable of stationary hover. So, helicopters use divergent ducts that dissipate energy in exhaust gases. On fixed wing aircraft, the exhaust duct could be convergent in design. That would accelerate exhaust gases and produce thrust which adds additional power to the engine. Combined thrust and shaft horsepower give equivalent shaft horsepower (ESHP).

Other Gas Turbine Systems

Cooling system:

Air for cooling the hot sections of the turbine are drawn (bleed air) from various stages in the compressor. Most OEMs prefer to use air only for cooling, even if they have a combined cycle operation and therefore a source of steam derived from water that is boiler feed water quality. Steam cooling can be very effective, both in closed loop and open loop configurations, as some OEMs, such as MHI have proven. If the steam quality stays uniform, deposits will not form on the insides of fine laser drilled cooling holes in the turbine airfoils. However, if there is a divergence in required water/ steam quality, this could prove a problem. Other OEMs, such as Rolls Royce prefer not to worry about this possibility, however remote. They configure their designs so that they only need air cooling. Air "spent" on cooling will cost the OEM in terms of nominal efficiency, so some designers are less keen to spend more than they absolutely have to. In power generation machinery that generally operates at base load, this may not be of major concern. It is, in applications with severe swings in load and/ or speed.

Bearing and lubrication system:

Basically, sleeve bearings locate the turbine modules concentrically around the shaft(s) during operation and when the turbine is not running. They provide the rotor with support. The thrust developed by the overall rotor is absorbed by thrust bearings at the end of the rotor. One arrangement of key bearing positions. Oil flow to the bearings is regulated. The bearings in the hot section require far more oil flow than those in the cooler compressor section. Thermocouples or RTDs measure oil flow temperature. Sudden temperature rises in the oil trigger an alarm or shutdown. The section on design development refers to varying design philosophies between OEMs. The lubrication system is one area where it shows as much as anywhere else. Certain OEMs have a preference for greater lubrication flows than others, at a given temperature range.

Chapter 6

Electric Power System

Electric power is an essential ingredient for many of the modern society's fundamental functions. There are many possible ways of power generation, like with renewable energy sources such as hydro, wind and solar power, or with fossil fuels such as gas and coal. Electric energy has the great advantage of being an energy carrier which is rather simple to convert into other types of energy forms with reasonably low losses. Further, the transportation of electric energy can be provided with transmission nets in a reliable way and with low losses, both long and short distances. Generally, the power grid can be subdivided into generation, transmission, distribution and usage. A simple overview is showed in Figure 3.1. The transmission efficiency can be further improved by controlling the voltage levels between and within these different zones with voltage transformers.

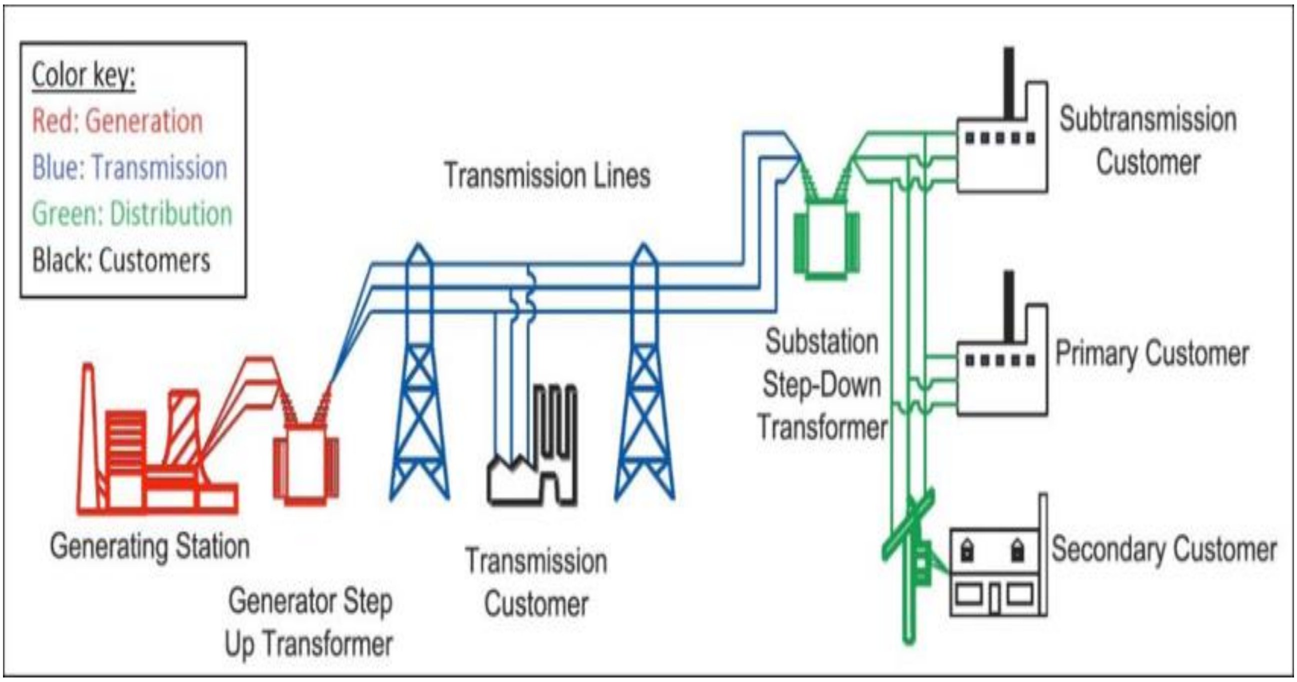


Fig 6: Power Generation[7]

Chapter 6

Advantages of Gas Turbine Power Plant

• Natural gas is very suitable fuel and where this is available cheap, it is an ideal source of power in gas turbine.
• Gas turbine plant is smaller in size and weight compared to an equivalent steam power plant. For smaller capacities the size of the gas turbine power plant is appreciably greater than a highspeed diesel engine plant; but for larger capacities it is smaller in size than comparable diesel plant. If size and weight are main considerations such as in ships, aircraft engines and locomotives, gas turbines are more suitable.
• The initial cost is lower than an equivalent steam plant.
• It requires less water as compared to a steam plant. It can be started quickly and can be put on load in a very short time.
• Maintenance cost is low.
• It does not require heavy foundations and buildings.
• Any poor quality and wide variety of fuels from natural gas to residual oil or powered coal can be used.
• The running speed of the turbine (40,000 to 100,000 rpm) is considerably large compared with diesel engine (1000 to 2000 rpm).
• The exhaust of the gas turbine is free from smoke.
• Storage of fuel requires less area and handling is easy.
• It is simple in construction. There is no need for boiler, condenser and other accessories as in the case of steam power plants.
• Gas turbine plants can be used in water scarcity areas.
• Less pollution and less water are required.
• Cheaper fuel such as kerosene, paraffin, benzene and powdered coal can be used which are cheaper than petrol and diesel.

Chapter 7

Disadvantages of Gas Turbine Power Plant

• 66% of the power developed is used to drive the compressor. Therefore, the gas turbine unit has a low thermal efficiency.
• The running speed of gas turbine is in the range of (40,000 to 100,000 rpm) and the operating temperature is as high as 1100 – 1260 ° C. For this reason, special metals and alloys have to be used for the various parts of the turbine.
• High frequency noise from the compressor is objectionable.
• Gas turbines are expensive and high speeds and high operating temperatures. Also, designing and manufacturing gas turbines is a tough problem from both the engineering and materials standpoint. Also, tend to use more fuel when they are idling. They prefer a constant rather than a fluctuating load. Applications of Gas turbine power plants:
• Gas turbines are used to drive pumps, compressors and high-speed cars.
• Aircraft, jets and ships.
• Power generation (used for peak load and as stand- by unit).
• Gas turbine power plants are used to supply peak loads in steam or hydro-plants.
• They are used as standby plants for hydroelectric power plants.
• Gas turbines are used in jet, aircraft and ships.

Chapter 8

Applications of Gas Turbine Power Plant

- Gas turbines are used to drive pumps, compressors and high speed cars.
- For Power generation.
- Gas turbine power plants are used to supply peak loads in steam or hydro-plants.
- They are used as standby plants for hydro-electric power plants.
- Gas turbines are used in jet, aircraft and ships

Fig 8: Gas turbine used in Jet[8]

Chapter 8

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