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Customization of Gas Turbine Power Plant Using Cumulative Pressure Apparatus Based on Pascal's Law

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Abstract: This paper shows an improvisation for gas turbine power plants. It incorporates a hydraulic compressor to compress air prior to combustion. The aim is to reduce in-house consumption of the power generated in the turbine, thus increasing the overall efficiency of the power plant. The proposed compressor could also be used in different scenarios.

1 Introduction

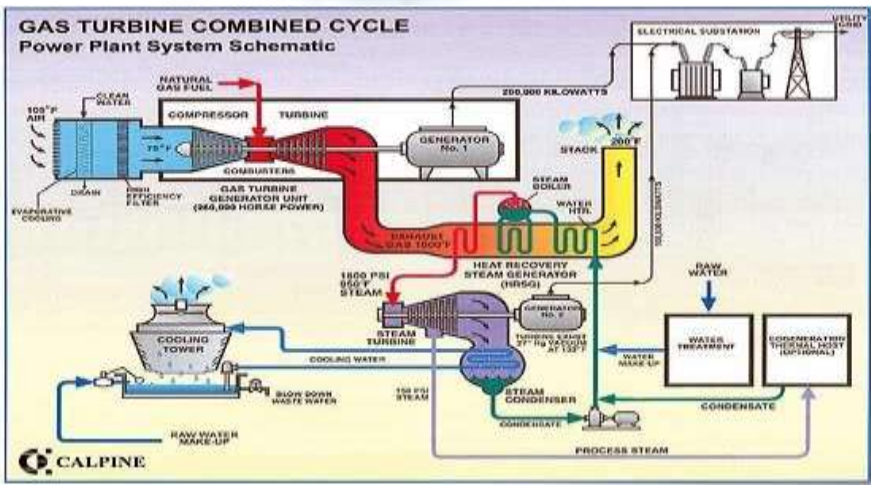
Although Gas Turbine Power Plants have great potential, they are used mainly as backup for thermal and other power plants as the output efficiency is low due to the diverting of most of the energy produced, into running the compressor and other equipment. Thus to increase the overall efficiency of the power plant the compression process can be achieved through a different and more efficient and less power consuming process.
If such a process exists, it should be

1. Less or zero energy consuming
2. Easy to follow and operate
3. Easy to construct
4. Less or zero maintenance
5. Zero or less emissions
6. Less noisy operation
7. One time easy investment
8. Less hazardous
9. Reliable

And most importantly, giving the desired output.

2 General working of gas Turbine Power plants

The actual working of gas turbine power plant is discussed as follows.
The main equipment of a Gas Turbine power plant are



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2.1 Compressor

The compressor sucks in air form the atmosphere and compresses it to pressures in the range of 15 to 20 bar. The compressor consists of a number of rows of blades mounted on a shaft. This is something like a series of fans placed one after the other. The pressurized air from the first row is further pressurized in the second row and so on. Stationary vanes between each of the blade rows guide the air flow from one section to the next section. The shaft is connected and rotates along with the main gas turbine.

2.2 Combustor

This is an annular chamber where the fuel burns and is similar to the furnace in a boiler. The air from the compressor is the Combustion air. Burners arranged circumferentially on the annular chamber control the fuel entry to the chamber. The hot gases in the range of 1400 to 1500 °C leave the chamber with high energy levels. The chamber and the subsequent sections are made of special alloys and designs that can withstand this high temperature.

2.3 Turbine

The turbine does the main work of energy conversion. The turbine portion also consists of rows of blades fixed to the shaft. Stationary guide vanes direct the gases to the next set of blades. The kinetic energy of the hot gases impacting on the blades rotates the blades and the shaft. The blades and vanes are made of special alloys and designs that can withstand the very high temperature gas. The exhaust gases then exit to exhaust system through the diffuser. The gas temperature leaving the Turbine is in the range of 500 to 550 °C. The gas turbine shaft connects to the generator to produce electric power. This is similar to generators used in conventional thermal power plants.

The auxiliary parts of a gas turbine power plant are:-

2.4 Air Intake System

Air Intake System provides clean air into the compressor. During continuous operation the impurities and dust in the air deposits on the compressor blades. This reduces the efficiency and output of the plant. The Air Filter in the Air Intake system prevents this.

A blade cleaning system comprising of a high pressure pump provides on line cleaning facility for the compressor blades.

The flow of the large amount of air into the compressor creates high noise levels. A Silencer in the intake duct reduces the noise to acceptable levels.

2.5 Exhaust System

Exhaust system discharges the hot gases to a level which is safe for the people and the environment. The exhaust gas that leaves the turbine is around 550 °C. This includes an outlet stack high enough for the safe discharge of the gases.

Silencer in the outlet stack reduces the noise to acceptable levels. In Combined Cycle power plants the exhaust system has a 'diverter damper' to change the flow of gases to the Heat Recovery Boilers instead of the outlet stack.

2.6 Starting System

Starting system provides the initial momentum for the Gas Turbine to reach the operating speed. This is similar to the starter motor of your car. The gas turbine in a power plant runs at 3000 RPM (for the 50 Hz grid - 3600 RPM for the 60 Hz grid). During starting the speed has to reach at least 60 % for the turbine to work on its on inertia. The simple method is to have a starter motor with a torque converter to bring the heavy mass of the turbine to the required speed. For large turbines this means a big capacity motor. The latest trend is to use the generator itself as the starter motor with suitable electrics. In situations where there is no other start up power available, like a ship or an off-shore platform or a remote location, a small diesel or gas engine is used.

2.7 Fuel System

The Fuel system prepares a clean fuel for burning in the combustor. Gas Turbines normally burn Natural gas but can also fire diesel or distillate fuels. Many Gas Turbines have dual firing capabilities.

A burner system and ignition system with the necessary safety interlocks are the most important items. A control valve regulates the amount of fuel burnt. A filter prevents entry of any particles that may clog the burners. Natural gas directly from the wells is scrubbed and cleaned prior to admission into the turbine. External heaters heat the gas for better combustion.

For liquid fuels high pressure pumps pump fuel to the pressure required for fine atomization of the fuel for burning. These are the main Auxiliary systems in a Gas Turbine Power Plant. Many other systems and subsystems also form part of the complex system required for the operation of the Gas Turbine Power Plant.

3.1 Performance

More than Fifty percent of the energy converted is used by the compressor. Only around 35 % of the energy input is available for electric power generation in the generator. The rest of the energy is lost as heat of the exhaust gases to the atmosphere.
Three parameters that affect the performance of a of gas turbine are

1. The pressure of the air leaving the compressor.
2. The hot gas temperature leaving the Combustion chamber.
3. The gas temperature of the exhaust gases leaving the turbine.

3.2 ISO Ratings of Gas Turbine Power Plant

The performance of gas turbines depend on the ambient conditions prevailing in a place. ISO has developed ratings that specify input conditions while specifying Gas Turbines.
The same Gas Turbine performs differently in high altitudes. It performs differently in winter and in summer in the deserts. This has to do nothing with the Gas Turbine itself, but is due to the ambient atmospheric conditions.
To eliminate misunderstandings, the gas turbine output and performance is specified at Standard conditions called the ISO ratings. These are specified as per ISO standards 3977-2 (Gas Turbines - Procurement - Part 2: Standard Reference Conditions and Ratings).
The Standard conditions are explained below.

3.3 Ambient temperature, Relative Humidity, and Elevation

The three standard conditions specified in the ratings are Ambient Temperature - 15 °C, Relative Humidity of 60 % and Ambient
Pressure at Sea Level.
These conditions affect the air density. How does air density affect the Gas Turbine output and performance?
The compressor section compresses only a fixed volume of air for each rotation of the blades. The mass of the air depends on the air density. So at sea levels one rotation sucks in more kg of air than at high altitudes.
The work done by the gas turbine i.e.: the heat energy to mechanical energy conversion depends on the mass of the hot gases, the specific heat and the Temperature difference. The mass of the hot gases depend on the mass of the air that is taken in. This means at sea level the Gas turbine gives more output than at high altitudes.

3.4 Inlet and Exhaust Losses

The standard conditions specify that Inlet and Exhaust losses as Zero.
The intake system and the exhaust system offer resistance to the flow of air and the exhaust gases. The energy to overcome these resistances comes from the Gas Turbine. This reduces the net output of the Gas Turbine. The configuration and layout of the intake and exhaust systems varies from plant to plant and accordingly the losses. These losses reduce the actual output of the Gas Turbine from the rated value.

3.5 Base Load Operation at 100 % rated power

The standard considers that the Gas Turbine operates at 100 % rated load. The efficiency quoted at the standard ratings are for this 100 % Load. Efficiency of the gas turbine at part load operations is different from that at 100 % load. If you buy a machine rated at 100 MW and operate it at 75 MW you will not get the rated efficiency.
The performance of a plant operating as a base load plant is different than a peaking load plant. This is mainly due to the frequent starts and stops that lead to deterioration of the performance.

3.6 Corrections

All the manufacturers provide correction factors for deviations from the various standard ratings discussed above. If the actual conditions are known the output and efficiency at the standard ratings is corrected to the actual conditions. Consider these corrections when specifying, purchasing and operating Gas Turbine power plants. Understanding of the ISO ratings and the actual plant conditions is essential when specifying and buying a Gas Turbine. Also this can be used to compare the performance of Gas Turbines.

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3.7 Stoichiometric Ratio of Natural Gas and Air

The air to fuel ratio is the property of fuel and chemical composition of the fuel that defines the value for this ratio. Most of the fuels we use in internal combustion engines are hydrocarbons, and their burning will obviously result in the release of hydrogen and carbon as residuals, along with heat and pressure. Let us have a look at the oxidation reaction of methane (natural gas) as a fuel.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

The atomic weights of the atoms that make up octane and oxygen are Carbon (C) = 12.01
Oxygen (O) = 16
Hydrogen (H) = 1.008
So 1 molecule of methane has a molecular weight of: 1 * 12.01 + 4 * 1.008 = 16.042
One oxygen molecule weighs: 2 * 16 = 32
The oxygen-fuel mass ratio is then: 2 * 32 / 1 * 16.042 = 64 / 16.042
So we need 3.99 kg of oxygen for every 1 kg of fuel
Since 23.2 mass-percent of air is actually oxygen, we need: 3.99 * 100/23.2 = 17.2 kg air for every 1 kg of methane.
So the stoichiometric air-fuel ratio of methane is 17.2.

4.1 Principle

The first thing that comes to mind when thinking of fluid pressure is Pascal's law

4.2 Statement

Pascal's law or the principle of transmission of fluid-pressure is a principle in fluid mechanics that states that pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure ratio (initial difference) remains the same
Utilizing this theory there are many devices in day-to-day application such as hydraulic jack, hydraulic seed crusher, air brake, oil brake, hydraulic fork lift etc…
This principle is stated mathematically as:

$$\Delta P = \rho g(\Delta h)$$

Where
ΔP Is the hydrostatic pressure (given in Pascal in the SI system), or the difference in pressure at two points within a fluid column, due to the weight of the fluid;
ρ is the fluid density (in kilograms per cubic meter in the SI system);
g is acceleration due to gravity (normally using the sea level acceleration due to Earth's gravity in meters per second squared)
Δh is the height of fluid above the point of measurement, or the difference in elevation between the two points within the fluid column (in meters in SI).
The intuitive explanation of this formula is that the change in pressure between two elevations is due to the weight of the fluid between the elevations. Note that the variation with height does not depend on any additional pressures. Therefore Pascal's law can be interpreted as saying that any change in pressure applied at any given point of the fluid is transmitted undiminished throughout the fluid.

4.3 Operation

Since we have arrived at the principle, we should also be clear about the operation
This method which we are going to adopt should be easy to follow, i.e., the laymen should understand the procedure and it should not call for any additional training thus saving time and resources.
Also any new process meant to replace the existing process, should give the desired results, or else should not be followed.
This process can actually save precious power generated by many folds. This may be called as an optimization process, where we make use of cumulative pressure in terms of Pascal's law.

4.4 Experimental setup

The setup consists of high pressure cylindrical chamber made of double walled copper or alloy steel (pressure of 16-20 bar). The cylinder is flanked on both sides by pipes of similar material. This cylinder is filled with the working fluid and is connected to pistons on either sides to ensure maximum compression ratio. In this cylinder is the gas to be compressed. This cylinder has inlet and outlet valves to facilitate the easy inflow and out flow of gas (air). The cylinder is made air tight by employing suitable means. This setup is included in place of air compressor.

4.5 Working

The air to be compressed enters the Pascal compressor. The partial vacuum is created so that air can enter freely. Now, a suitable load is applied at the lesser diameter end of pipe. This force is transmitted throughout the entire volume of fluid and thus the pistons are pushed inwards and the air is compressed. This compressed air is stored in a pressurized container and it is mixed with compressed natural gas (cng). This air cng mixture is sent to the gas combustion chamber, where the gas is combusted to high temperatures. Since pressure directly proportional to temperature, the pressure increases considerably. This high pressure temperature gas travels on to the turbine vanes. There it is expanded through a joule Thompson expansion valve. The gas expands there and rotates the turbine blades. Thus power is generated which is transmitted through transmission lines to the power grid.

5. Applications advantages and disadvantages

Gas turbine power plants are used to supply peak loads in steam or hydro-plants and are used as standby plants for hydro-electric power plants. They are also used in jet, aircraft and ships.
Natural gas is very cheap and is an ideal source of fuel when available in abundance. Gas turbine power plants are compact in size compared to other power plants of equivalent capacity. The initial cost is lower than an equivalent steam plant. Initial installation cost is very low and it requires minimal water for operation. The maintenance cost is also low and the quality of fuel need not be standard. 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.

The main disadvantage of the gas turbine power plant is that the major workload developed is used to drive the compressor. Also the setup requires special metals and alloys for different components since operating temperature and speeds are high.

Conclusion

In this paper the following pointers were explained and suggested.

1. The working of gas turbine power plants were explained.
2. A replacement for the conventional compressor was proposed based on Pascal's law.
3. This alternative uses a cumulative pressure hydraulic compressor to compress the inlet air to achieve the air to fuel ratio.
4. The major advantage of this setup is that it uses minimal power generated to run and hence the overall efficiency is improved.
5. This setup is noise- and pollution-free.
6. Maintenance and labor costs are low.
7. The maximum power used in-house would be to run the cooling apparatus as the heat generated in the hydraulic compressor would be high.
8. The initial investment, however, is very high.
9. Compression can only be done in pulses and the method requires that multiple setups need be used to achieve the required level of compression.
10. This method is versatile in that it can be used to compress air in various scenarios.

As the saying goes **If engineering is the application of science for human benefit, then the engineer must be a student of not only the application of science but of human benefit as well.**

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