Description and Optimization of Gas Turbine Generator Sets

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Abstract. Form this article, the author mainly interprets the principle and composition of gas turbine generator set, as well as discusses how to improve efficiency and treat exhaust gases, which including compressor interstage waste heat utilization for power generation, auxiliary catalytic technology and gas-steam turbine combined cycle. Taking the Rankine cycle based on compressor interstage waste heat as an example, it discusses how to recover and utilize the compressor interstage waste heat; through the analysis of the waste heat recovery system, it is concluded that the auxiliary catalytic technology plays an vital role in the operation of internal combustion engines; the analysis of the principle of the gas turbine combined cycle and the comparison of two kinds of combined cycles result in the conclusion that the gas-steam turbine combined cycle is a highly efficient and feasible means of optimizing the efficiency of the system. After exploring the three aspects, the author of this essay has finally come up with three reliable paths for optimizing gas turbine generator sets.

Keywords: Gas turbine; waste heat utilization; gas turbine combined-cycle; catalytic technology.

1. Introduction

With the development of the economy, science and technology, the global demand for energy has been increasing. Despite the emergence of many new forms of energy access, the burning of fossil fuels cannot be replaced. This is because these new energy sources are affected by the natural environment and are characterized by instability, so the basis of global energy sources is still fossil energy. Therefore, the improvement of the efficiency of gas turbine generator sets is still the top priority for improving energy utilization.

The CO_2 emissions from thermal power plants account for more than 40%of the total global CO_2 emissions, 70%of which are generated by coal-fired power plants [1], and other emissions generated by plants which rely on coal fired. Bring a heavy burden and impact on the environment. Therefore, how to tackle these exhaust gases is still a major challenge that requires to be given priority to.

In China, after natural gas is extracted, it is often compressed to high pressure by compressors and afterward carried to other areas over long distances. The single compressor has the disadvantages of high outlet temperature and power consumption, so it generally adopts multi-stage compressor and inter-stage cooling for the compressed gas. In the process of interstage cooling, low-grade waste heat is released [2], which is one of the focuses of thermal energy recovery in internal combustion engines. Considering the compressor interstage waste heat recycling for power generator sets is an essential way to save energy and reduce emissions in internal combustion engines.

According to research data, the fuel energy utilization rate of internal combustion engines is actually only 20% to 30%, while the remaining 70%to 80%of the energy is not converted into mechanical work but dissipated into the environment in the form of heat energy. Therefore, the technology of waste heat utilization will be the focus of future development of internal combustion engine operation. Waste heat recovery systems generally include heat exchanger, the devices of waste heat recovery (e.g, waste heat boilers), and heat energy conversion equipment (e.g, chillers).And in order to improve the operating efficiency of these devices, it is necessary to rely on heat capture technology, the technology of heat transport and the technology of heat conversion. Among the technologies for waste heat utilization, catalytic technology is of high value and feasibility.

Gas-steam combined cycle generator technology is a popular and innovated technology at present, and has been adopted in large quantities worldwide. It is a technique that combines the gas thermal cycle with the vapour-cycling by processing the exhaust air and waste heat from the gas cycle to

rotate a steam turbine, which ultimately drives the generator set to generate electricity. This technology is able to greatly improve the efficiency of the generating unit while being environmentally friendly, and is therefore an efficient and viable means of optimizing the generator set.

In this paper, we investigate ways to improve the efficiency of the generator set and to reduce energy consumption (green friendliness) from two perspectives, that is to say the treatment of waste heat and exhaust gases.

2. Description of gas turbine generator sets

A gas turbine consists of components such as a compressor, combustion chamber, turbine and return heaters [3]. The principle of gas turbine generator set is to convert the energy of fuel into electricity by driving the generator through the gas turbine coupling. The gas turbine generator set is mainly composed of two parts, gas turbine and the generator, and mainly includes four processes: compression, combustion, expansion and exhaust. Firstly, the outside atmosphere enters the engine through the air inlet and is compressed for the first time in the axial flow compressor, after that the air enters the centrifugal compressor for the second compression. After two compression processes, high pressure air enters the combustion chamber, mixes with the atomized fuel, and burns fully under the suitable oil/gas mixing ratio to create high temperature gas. The high-temperature air enters the turbine and impacts the blades on the turbine, contribute to the turbine to rotate at high speed. The rotation of the turbine drives a generator to produce electricity. This series of processes transforms the energy of the fuel into serviceable work, i.e. electrical energy, and at the same time realizes the start-up of the gas turbine and the generation of electricity. Gas turbines play a significant role in modern industrial and military fields due to their high efficiency, lightweight and powerful output. Therefore, it is crucial to learn the optimization of gas turbine generator set.

3. Optimisation of gas turbine generator sets

3.1. Utilisation of waste heat between compressor stages for power generation

As an example, the proposed organic Rankine cycle (ORC) generator set is based on waste heat between compressor stages (Figure 1).

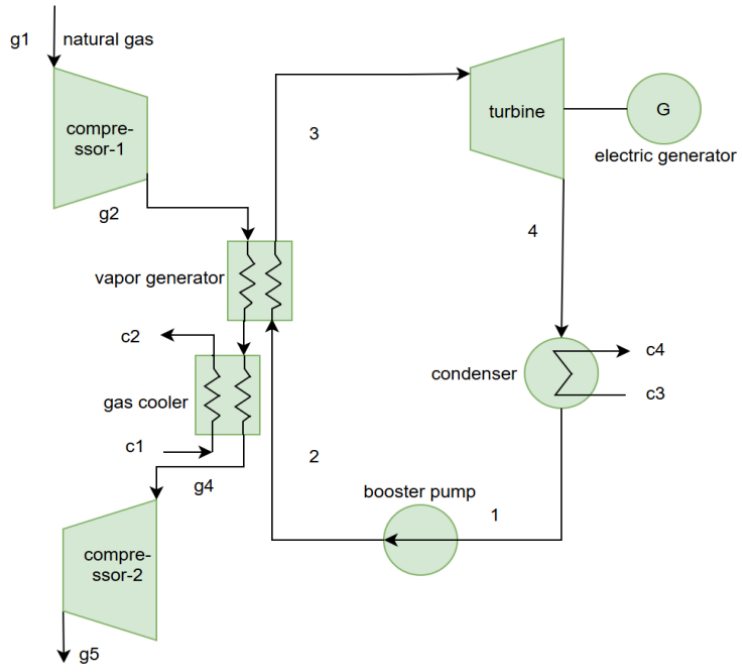


Fig 1. Flowchart of Rankine cycle generator set based on waste heat between compressor stages [2].

Firstly, the natural gas passes through the first compressor and afterward warms up and pressurises, then enters the steam generator and liberates heat to heat the organic matter transported from the booster pump from liquid to gaseous state; after that, the high-temperature and high-pressure gaseous organic matter pours into turbine to expand and do work to drive the generator to rotate and generate electricity, on the other hand, the low-pressure matter condenses into liquid state in the condenser, and then enters into the steam generator again after the booster pump raises the pressure. On the other hand, the low-pressure mass is condensed to a liquid state in the condenser and re-entered into the steam generator after the pressure is raised by the booster pump to accomplish the ORC process. The gas from the steam generator requires going through the gas cooler to reduce the temperature and then transported to the second compressor to soar the pressure, and finally reach the target pressure. This is the entire process of the cycle.

Through this cycle, the residual heat from the compressor stages can be recovered and utilized to generate electricity from the residual heat. This not only reduces the temperature of the compressor gas, but also cutting down the power consumption of the compressor, but also makes use of the waste heat to generate electricity again, thereby achieving an increase in resource utilization and optimization of the generator set.

3.2. Catalytic technology

Assisted catalysis is a key technology in waste heat utilization [4]. Through the use of assisted catalytic technology, energy utilization and the machine efficiency can be improved on the one hand, and exhaust gases can be treated of the other hand to achieve green development. Catalytic technology refers to the use of catalysts to accelerate chemical reactions in order to achieve a more efficient utilization of waste heat generated by internal combustion engines. To name only an example, the heat generated by the catalytic reaction is further used to heat the working medium in the heat exchanger, which can enhance the thermal efficiency of the entire system. In addition, assisted catalytic systems can play a crucial role in reducing pollutant emissions. By optimizing the composition and structure of the catalyst, it can effectively convert carbon monoxide, nitrogen oxides, unburned hydrocarbons and other noxious substances in the gas, which helps to respond to the call for energy conservation and emission reduction and the requirements of environmental protection. In the selection of catalysts, the requirements of high temperature resistance, corrosion resistance and high activity must be taken into account. Commonly used catalytic materials include precious metals, such as platinum, palladium and rhodium [5], which is able to retain good catalytic properties while resisting high temperatures and have good chemical stability.

3.3. gas turbine combined-cycle

A gas turbine combined-cycle(GTCC), also known as a gas-steam turbine combined cycle, is a method of combining two cycles by using the waste heat and exhaust gases from a gas turbine cycle to a vapour-cycling. In this combined cycle, gas is used as a high-temperature process and steam is used as a low-temperature process. The gas from the gas turbine cycle is used in the vapour-cycling as a heat source. In this way the two cycles are combined to compose electricity from a generator. Research data have demonstrated that this improves the efficiency of the entire cycle. In the gas-steam combined cycle, which is generally composed of generator, compressor, combustion chamber, waste heat boiler and other parts, waste heat utilization and exhaust reignition type are the two most commonly used ways of power generator sets, and the following figure shows the workflow diagram of these two ways of power generation (Figure 2).

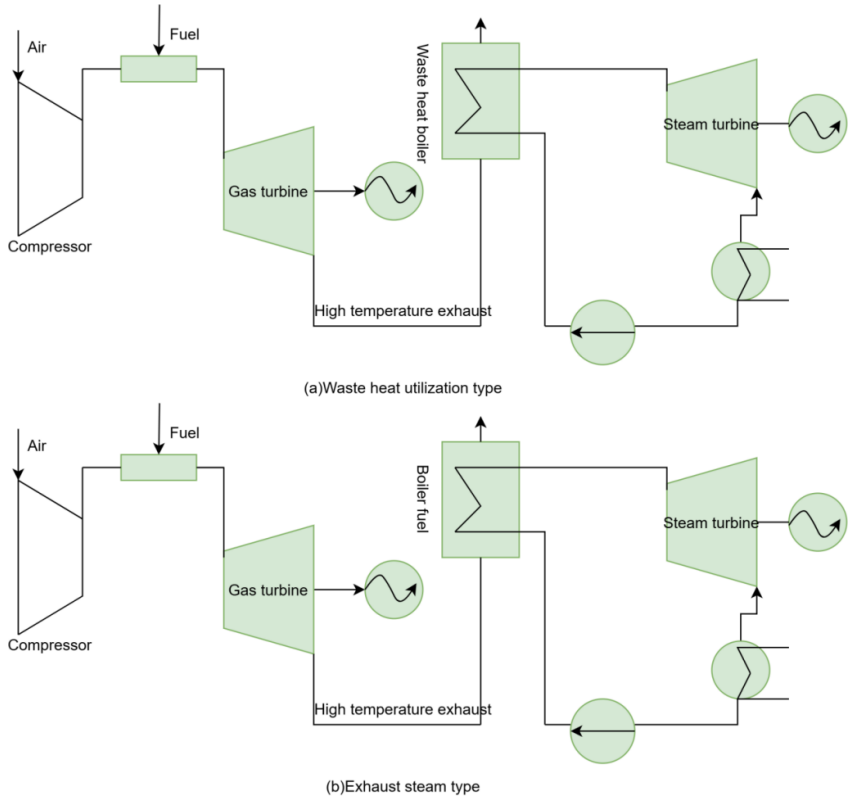


Fig 2. Waste heat utilization type and exhaust reignition type.

Regarding the beginning process of the entire gas turbine combined cycle, the flow is roughly like this: The outside air is firstly poured into the compressor, where it is compressed twice and afterward transformed into the required high-pressure air. The high-pressure air then enters the combustion chamber, where it mixes with the atomized fuel and burns. The heat released from the combustion eventually drives the generator, while the exhaust gases with high heat will enter the waste heat boiler and become the heat source for the vapour-cycling. In this way the exhaust gas from the gas turbine cycle becomes the heat source for the vapour-cycling, which can generate electricity again. The above is the operation mode of the combined cycle. As for the two forms of waste heat utilization and exhaust reignition type, their respective characteristics are illustrated in detail in Table 1:

Table 1. The difference between waste heat utilization type and exhaust steam reignition type.

	System control	Large proportion of the output	The steam turbine run independent
Waste heat utilization type	simple	gas turbine	×
Exhaust steam reignition type	complex	Steam turbine	√

Data interpret that the gas-steam combined cycle is 10-20% more efficient than a single cycle, up to nearly 60%.The combined cycle has the efficiency, which is 10% to 20% higher than the former two types, the highest efficiency exceed to 60%. Therefore, it's an efficient and viable way to improve overall system efficiency and resource utilization.

4. Summary

For the purpose of achieving efficiency of the gas turbine generator set and to establish a more environmentally friendly use method, this paper proposes three improvement methods of compressor interstage waste heat utilization for the power generation, auxiliary catalytic technology, and gas-steam combined cycle generator technology, and investigates their working principles and places to pour attention to in the course of operation. This paper draws the following conclusions:

(1) Based on the Organic Rankine Cycle, the use of compressor interstage waste heat for the power generation can not only reduce the power consumption in the process of consumption, which contribute to the energy savings, but also can use the waste heat to generate electricity again, thus achieving the improvement of resource utilization and the optimization of the generator set.

(2) Auxiliary catalytic technology, as a key technology in waste heat utilization, accelerates the chemical reaction through catalysts, which can utilize the waste heat more efficiently. The composition and structure of the catalyst can be optimized to convert the harmful gas in the exhaust gas to achieve the requirements of green development.

(3) Gas-steam combined cycle connects gas-cycling and vapour-cycling, which can greatly improve the efficiency of the generator set and is friendly to the environment.

In summary, this paper provides three innovative ideas for the optimization of gas turbine generator sets.

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