Selection of steam turbine bypass system

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Abstract. This paper introduces the functions of steam turbine bypass system for the large coal-fired power units, the types of the steam turbine bypass system, the selections of the bypass system capacity and the current design situation of domestic units. About the functional design of the steam turbine bypass system, it is designed with the following functions: starting, protecting the reheater, tracking the main steam pressure, recovering working substance, quick opening when the steam turbine trips, relief valve and fast cut back etc. About the type of bypass system, this paper introduces the application of the bypass system for large capacity units, which can be divided into four types: the high pressure one-stage large capacity bypass system, the high and low pressure two-stage series bypass system, the tertiary bypass system and the triple-purpose valve bypass system, and the advantages and disadvantages of the design for all kinds of the bypass system. In terms of the capacity selection of the bypass system capacity, the capacity of the bypass system should be selected to match the peak-regulation capacity of the unit, while taking into account the investment and maintenance costs. In view of the current design situation of domestic units, this paper expounds the design patterns and the characteristics of the bypass system of several large thermal power units.

1. Introduction
The turbine bypass system has been widely used in large units at home and abroad, but the capacity and function of the bypass system are different in different countries \cite{1}. The steam turbine bypass system is a steam desuperheating and decompression system in parallel with the steam turbine. The steam is to bypass the steam turbine in whole or in part and it is discharged directly into the condenser after desuperheating and decompression. Steam turbine bypass system is a significant component of the thermal system of the unit, and it is composed of a temperature-reducing pressure-reducing valve, a temperature-reducing regulating valve, a pipeline and a control device.

2. Functions of turbine bypass system
The basic function of the turbine bypass system is to coordinate the unbalanced relationship between the steam production of the boiler and the steam consumption of the turbine \cite{2}, it is a means to adapt the difference of boiler and steam turbine characteristics under special operating conditions \cite{3}. The bypass system has the following functions: starting, protecting the reheater, tracking the main steam pressure, recovering working substance, quick opening when the steam turbine trips, relief valve and fast cut back etc.. At the same time, the bypass system provides “the bypass system is in operation”, “the bypass system is off” and other signals to the DEH system of the steam turbine to realize the startup of the intermediate pressure cylinder of the steam turbine.
3. Types of steam turbine bypass system

There are four main types of bypass systems used in large units: the high pressure one-stage large capacity bypass system, the high and low pressure two-stage series bypass system, the three-stage bypass system and the three-function valve bypass system.

3.1. The high pressure one-stage large capacity bypass system

A schematic diagram of the high pressure one-stage large capacity bypass system is shown in figure 1. When the bypass system is put into operation, the main steam is discharged directly into the condenser device after decompression and temperature reduction [4], that is, all steam of steam turbine is cut off by the bypass. There is no steam flow in the pipe of the reheat steam system before the unit starts. The reheater is usually made of stainless steel, can dry, don't need a cooling medium, and generally arranged in the flue gas temperature lower area. The material permissible temperature of the reheater is about 800°C. The bypass system is used to recover working substance when the unit starts up in cold or hot conditions. In the unit load rejection, because the bypass capacity is below the steam flow of the system, so the relief valve must be vented.

![Figure 1. Schematic diagram of the high pressure one-stage large capacity bypass system.](image)

The high pressure one-stage large capacity bypass system is simple, with less one-time investment. After the high pressure one-stage large capacity bypass system is adopted, the bypass system opens very fast. In the unit load rejection, the function of quick opening bypass system is interlocked [5]. The disadvantage is that the combustion rate of boiler must be strictly controlled during the unit start-up and load rejection. The heating pipes and heating up of the reheat pipeline is difficult, which is not conducive to the thermal start-up of the unit. The reheat steam temperature and the wall temperature of the intermediate pressure cylinder do not match, and the life of the intermediate pressure cylinder is lost. Therefore, this kind of bypass system is only suitable for units with the base load, and not suitable for units with frequent hot start.

3.2. The high and low pressure two-stage series bypass system

High pressure bypass can make the superfluous steam not enter the high pressure cylinder of the steam turbine but directly enter the reheater. The low pressure bypass can make the steam coming out of the reheater enter directly into the condenser rather than into the intermediate and low pressure cylinders of the steam turbine.

The schematic diagram of high and low pressure two-stage series bypass system is shown in figure 2. The steam flow of the bypass system is as follows: from main steam system to high pressure bypass system to reheater system to low pressure bypass system to condenser system. The general capacity of the two-stage series bypass system is 30%~40% BMCR. Units with the bypass system can be started under cold, warm, hot and extremely hot conditions, the steam temperature matches the metal
temperature, start-up time is shortened. The unit can effectively recycle working substance, and can protect the reheater arranged in the area with higher smoke temperature, and prevent reheater from dry burning, and the bypass system can be quickly opened.

![Schematic diagram of the high and low pressure two-stage series bypass system.](image)

This type of unit can be started jointly by high and intermediate pressure cylinders, can also be started by the intermediate pressure cylinder. The starting time of the intermediate pressure cylinder is less than that of the high pressure cylinder. In terms of the matching of the steam temperature with the rotor and the cylinder of the steam turbine, such as starting in the warm state, the hot state and the extremely hot state, the starting advantage of the intermediate pressure cylinder is outstanding.

Compared with the high pressure one-stage large capacity bypass system, the system is relatively complex and difficult to control, and the cost of short-term investment and long-term maintenance is relatively high.

3.3. The tertiary bypass system
The tertiary bypass is to connect the high pressure one-stage large capacity bypass system and the high and low pressure two-stage series bypass system in parallel. The high and low pressure two-stage series bypass system is mainly used to meet the requirements of the main steam in each stage of the turbine startup process, so that the boiler can maintain the stable operation of the unit under low load [6]. The three-stage bypass is easy to adapt to the unit load change, but the system is complex and the investment is large, so it is not used much.

3.4. The triple-purpose valve bypass system
The triple-purpose valve bypass system is developed from the high and low pressure two-stage series bypass system. In the three-purpose valve bypass system, the flow capacity of the high pressure bypass valve is 100% [7]. The system is equipped with reliable 100% capacity high pressure bypass system and 60%-70% capacity low pressure bypass system. The high pressure bypass system has the function of safety valve. The steam pipeline of the boiler outlet does not need to be equipped with other safety valves. The high pressure bypass system has three functions: regulation, overflow and safety valve [8].

The schematic diagram of the triple-purpose valve bypass system is shown in figure 3. The system is equipped with the high pressure bypass system, low pressure bypass system, intermediate pressure relief valve and condenser feeding device. The bypass system allows the low-temperature steam generated in boiler start-up period to bypass the turbine until the steam temperature matches the turbine temperature, and the turbine can speed up quickly. The bypass system enables the boiler and the turbine to operate independently during the unit start-up process, and enables the boiler to start...
with a large combustion rate and generates a large amount of steam in a short time. The bypass system takes in excess steam and carries it into the condenser. By adopting the bypass system, the start-up time can be shortened effectively, all working substance can be recovered, metal fatigue and crack can be avoided, and the service life of steam turbine can be improved.

![Schematic diagram of the triple-purpose valve bypass system.](image)

**Figure 3.** Schematic diagram of the triple-purpose valve bypass system.

When the unit fails, the unit needs to immediately reduce the load, and the boiler needs to burn down gradually, at this time the triple-purpose valve bypass system can accept the excess steam, and ensure the normal operation of the unit under the new load, and reduce the loss of steam. It can save time for unit maintenance, and helps to restore normal operation of the unit. It not only improves the unit availability, but also improves the stability of the power grid.

When the steam in the steam turbine is suddenly cut off, the high pressure bypass valve whose capacity is 100% BMCR, acts immediately in 1 to 5 seconds, and completely replaces the high pressure relief valve.

Disadvantages: the control system is relatively complex, must use electro-hydraulic regulation system.

4. **Capacity selection of bypass system**

The high pressure bypass capacity is equal to the steam flow through the full open high pressure bypass valve at the rated main steam pressure and temperature divided by the steam flow through the full open high pressure inlet valve at the rated main steam pressure and temperature. The low pressure bypass capacity is equal to the steam flow through the full open low pressure bypass valve at the rated reheat steam pressure and temperature divided by the steam flow through the full open intermediate pressure inlet valve at the rated reheat steam pressure and temperature. Bypass capacity shall be considered not less than 5% margin of bypass capacity.

When the capacity of the bypass system is selected, it should be decided according to the peak adjustment range of the unit, environmental noise requirements and working substance recovery requirements.

In the unit load rejection, boilers are required to operate at a minimum stable load, and steam turbines need to be run with auxiliary power, and large capacity bypass systems must be designed.

The larger the peak adjustment range of the unit is, and the higher the requirement of environmental noise and working substance recovery are, and the larger the bypass capacity is. However, the larger the bypass capacity is, the higher the corresponding equipment investment and operation and maintenance costs will be, therefore, the bypass should be reasonably equipped.
5. Design of bypass system for some units in China
In the 2×1000 MW ultra-supercritical unit of China Huadian Corporation Zouxian power plant, the steam turbine is produced by Dongfang steam turbine co., Ltd., and the unit starting mode is the high pressure cylinder starting, with a one-stage large capacity bypass whose capacity is 25% BMCR. The bypass system has the functions of starting, recovering working substance, quick opening when the steam turbine trips.

In the 2×1000 MW ultra-supercritical unit of China Huaneng Group Yuhuan power plant, the steam turbine is produced by Shanghai turbine co., Ltd., and the unit is can be started jointly by the high and intermediate pressure cylinders. The high and low pressure two-stage series bypass system is adopted, and the bypass capacity is 35% BMCR. The bypass system has following functions of starting, protecting the re heater, tracking the main steam pressure, recovering working substance, quick opening when the steam turbine trips.

In the 2×1000 MW ultra-supercritical unit of China Huaneng Group Yuhuan power plant, the steam turbine is produced by Harbin steam turbine co., Ltd., and the unit is can be started jointly by the high and intermediate pressure cylinders. The one-stage large bypass is adopted, and the bypass capacity is 30% BMCR. The bypass system has the functions of starting, recovering working substance, quick opening when the steam turbine trips.

In the 2×600 MW supercritical unit of the second plant of China Huaneng Group Shidongkou power plant, the steam turbine is produced by BBC Switzerland with four cylinders and four exhausts, and a three-use valve bypass system is adopted, and the high pressure bypass system capacity is 100% BMCR and the low pressure bypass system capacity is 60% BMCR. The bypass system has following functions of starting, protecting the reheater, tracking the main steam pressure, quick opening when the steam turbine trips, relief valve and fast cut back etc. [10].

In the 2×1000 MW ultra-supercritical unit of Phase iii project of Waigaoqiao power plant, the steam turbine is produced by Shanghai turbine co., Ltd., and the unit is can be started jointly by the high and intermediate pressure cylinders, and a three-use valve bypass system is adopted, and the high pressure bypass system capacity is 100% BMCR and the low pressure bypass system capacity is 65% BMCR. The bypass system has following functions of starting, protecting the reheater, tracking the main steam pressure, quick opening when the steam turbine trips, relief valve and fast cut back etc..

6. Conclusion
In the selection of turbine bypass system, it is necessary to intensify the research on the selection of turbine and boiler, and to take into account both technical factors and economic factors, as well as the unit operation mode, load characteristics and life loss. The selection of bypass system should take into account the safety, economy, reliability and flexibility of unit start-up, shutdown and operation [11].

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