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Feasibility analysis of changing turbine load in power plants using continuous condenser pressure adjustment

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A B S T R A C T

A variety of power generation complementary can reduce the large power fluctuation in the electrical power system caused by large-scale new energy power connected into grid. The quick power generation such as hydropower, gas power, and fuel power are the most suitable complementary power. However, they are very short in China; meanwhile the coal-fired power with slow rate of power change is dominant. Consequently, the coal-fired power has to increase its load change range and speed so as to undertake the job of power complementation in the electric power system. This paper proposes a method to improve the load change capacity for the water cooled power plants through controlling the cooling water flow. Then the CCWCS (condenser cooling water control system) is put forward to execute this method on the premise of unit safety. CCWCS can also reduce the coal consumption in steady turbine load conditions. Based on the modeling of condenser, variable speed pump for the condenser cooling water and the characteristics of turbine power output to condenser pressure, the paper presents the relationship between the cooling water flow and turbine power output. Finally, a case study on a 600,000 kW unit proves the feasibility of our idea.

1. Introduction

With the great development of such fluctuant renewable energies as wind and solar power, more and more thermal power plants have been forced to compensate the loss of generation as the power source reserves for the grid stability [1]. Also, the reserves must be adequate and operated swiftly, or the grid frequency will fall [2]. Consequently, lots of power associations all over the world have made stringent requirements for the speed and range of load changes in thermal power plants. The Deutsche Verbund Gesellschaft, which is a German association concerned with the interconnection of power systems, requires that participating plants must be able to increase their power output by 5% within 30 s, where half of that, i.e. 2.5%, must be delivered after only 5 s [3]. And in China, if the load-change speed were not reach 5% of their power output per minute, the thermal power plants will be impose a heavy fine. Consequently, it is crucial to develop steam turbine power control technique so as to improve the load-change rate of thermal power units.

Aiming at utilizing the stored energy of boiler to the largest extent, CCS (coordinated control system) is commonly used in power plants for turbine power control [4]. And lots of control algorithms, such as predictive control, adaptive control, and fuzzy control and so on, were developed for better power load response. However, their control effect was very limited due to the large delay and inertia of boiler [5]. Gerhard K. Lausterer [3] once proposed a method called condensate throttling, which has an excellent result in thermal power plants on account of its swift speed. However, it has not been generalized on account of its complicated transformation on the extraction steam system and condensate system. Fei Wang [6] put forward a new method for the boiler control system based on radiation intensity to improve the load-following capacity of the coal-fired power plant. It is very essential to further improve the load change ability of coal-fired power plants so as to provide conditions for more and more intermittent energy connected into grid.

This paper puts forward to set up the CCWCS (condenser cooling water control system) to improve the load change capacity of wet cooled power plants through continuous cooling water flow adjustment. This is because, on the one hand, the condenser pressure has a great influence on the turbine power output, shown in Fig. 1. On the other hand, under certain steam load and environmental conditions, the condenser pressure mainly depends on

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Nomenclature

B_r	total coal consumption
C_p	specific heat of water at constant pressure
D_c	flow of exhaust steam
D_w	flow of condenser cooling water
H	pump head
H_0	net head
P	generator active power
P_e	rated turbine power
P_p	pump power consumption
P_T	active turbine power output
Q	pump flow
W	total electricity generation output
b_{bg}	coal consumption rate
b_r	coal consumption in per unit time
e	auxiliary power consumption rate of units
g	acceleration due to gravity
h_c	enthalpy of exhausted steam
n	an indeterminate constant
p_k	condenser pressure
p_{k0}	rated condenser pressure
t_s	temperature of saturated vapor
t_{w1}	inlet temperature of cooling water
t_{w2}	outlet temperature of cooling water
Δh	enthalpy difference between the exhausted steam and saturated vapor
ΔP	variation sum of unit power output and CCWP consumption
ΔP_T	influencing deviation rate of turbine power output
Δt	temperature rise of cooling water
β	ratio between the current power and rated power
η	pump efficiency
δ_t	terminal temperature difference
ρ	density of cooling water
$\omega_{pk,max}$	upper limit of speed ratio
$\omega_{pk,min}$	lower limit of speed ratio
ω	ratio between the operating speed and the rated speed

Abbreviations

CCWCS	condenser cooling water control system
CCWP	condenser cooling water pump
CCS	coordinated control system
DCS	distributed control system
EMS	energy management system
LCS	load change system
MES	most efficient system
PSO	particle swarm optimization
SPS	safety protection system

the cooling water flow for wet cooled power plants. Therefore, it is feasible to control turbine power output through cooling water flow provided that the condenser pressure adjustment brought about no unsafe threat.

Maybe someone would ask why this idea has never appeared in the past. There were two factors which limited the idea to come into being. First of all, inappropriate adjustment on condenser pressure will do great harm to the unit safety, so great care is taken when thinking of changing the condenser pressure. Secondly, the constant speed CCWP (condenser cooling water pump) made it impossible to change condenser pressure as well as steam turbine load continuously. This is because condenser pressure is only determined by the condenser cooling water flow when the unit working conditions have no indifference, and the constant speed CCWP could only provide few constant cooling water flow points, not continuous flow points. To date, the variable speed CCWP has being popularized in the power plants for its energy saving [7]. Furthermore, it has the ability to provide continuous flow of condenser cooling water, which makes it feasible to carry out controllable adjustment on the condenser pressure and turbine power. So this paper establishes the CCWCS (condenser cooling water control system) to execute this method on the basis of unit safety. Furthermore, the coal consumption variation CCWCS causes is also analyzed in this paper.

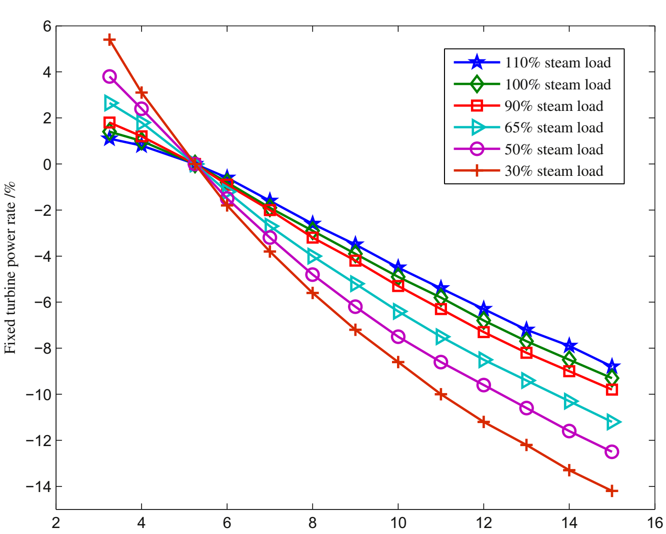

Fig. 1. The power output characteristics to the condenser pressure.

This paper is organized as follows: Section 2 builds the models for condenser and CCWP, and gives the characteristics of turbine power output to condenser pressure. The CCWCS is set up in Section 3 for better load-following capacity with overall consideration of unit safety and energy-saving. Section 4 presents a case study on a 600,000 kW unit to calculate the load-change range and the coal consumption variation after taking use of CCWCS. Finally, conclusions are given in Section 5.

2. Modeling

If you want to control the turbine power output through continuous condenser pressure variation in wet cooled power plants, it is necessary to firstly set up the relationship between the turbine power output and the motor speed of variable speed CCWP. As shown in Fig. 2, the CCWP (condenser cooling water pump) is the vehicle of condenser cooling water, and it determines the flow of water [8]. So far, the constant-speed CCWP, providing only one constant flow of cooling water, has been commonly used in China. However, more and more power plants have been replacing it with the variable-speed pump for lower auxiliary power consumption [9], which also supplies us the opportunity to carry out our load change plan through continuous condenser pressure variation. So, the CCWP we discuss here is the variable speed pump. The modeling on condenser is to gain the relationship between the condenser pressure and the cooling water flow under conditions of