Influence of Boiler Thermal Storage Coefficient on Stable Operation of Shipboard Power Station

Yongxin Zhua, Xiaofeng Zhangb and Jing Huangc

School of Electrical Engineering, Naval University of Engineering, Wuhan 430033, China

agagaga92@163.com, b1546659454@qq.com, chuangjing99421@126.com

Abstract. Stable operation of shipboard turbine generator is a key factor affecting the safety of power grid, and heat storage system influences the stability of turbine main pressure significantly. On the basis of boiler-turbine integral model, prohibition effect of thermal storage system on cyclical disturbance is studied. In order to compare the influences of varied heat storage coefficient on turbine unit stable operation after sudden load, PSCAD simulation software is applied. Result of experimental test based on megawatt turbo-generator has confirmed the conclusion, and this paper may provide reference for further research on shipboard power station design and control.

1. Introduction

With the increasing demand for shipboard power grid capacity, turbine generator is becoming an important part of shipboard power station. Although the structure of shipboard turbine unit is similar to that of land turbine, output power of shipboard turbine is smaller due to limited space and load, and it’s working conditions as well as regulation characteristics differs from land turbine too. If turbine unit is not properly regulated, shipboard power grid stability level will be reduced.

At present, the research on land turbo-generator is comprehensive, and achievements of turbine structure and control are gained [1]. Low-frequency oscillation is one of the main destabilizing situations in land power grid. As the accidents frequently occur and influence widely, scholars have made in-depth analysis and designed some improved methods [2]. Considering the actual situation, shipboard power grid may need to adjust frequently owing to the complex sea conditions, and boiler thermal storage system will play an important role in the regulation process. Starting from the relationship between the working mechanism of heat storage system and actual regulation process, the influence of heat storage coefficient on stability of shipboard turbo-generator operation is studied. This work may provide reference for further research on shipboard power station design and control.

2. Turbine Unit Model And Control Method

2.1. Shipboard Turbine Model

Digital electro-hydraulic (DEH) speed control system is widely adopted in turbo-generator unit. Prime mover system includes boiler, hydraulic actuator, steam turbine and control system, generator is coaxially connected with steam turbine, which is shown in Fig.1.
IEEE working group has built boiler transient model as Fig.2, revealed the connection between characteristics of main pressure (throttle pressure in Fig.2) regulation and valve control. The model has considered the influence of boiler heat storage system, and its accuracy can meet the practical requirements [3].

Steam turbine may contain several control valves, its generic model is shown in Fig.3. Shipboard turbine unit is usually single-cylinder designed, so the steam spread characteristic can be simply described by volume time constant $T_{SM}$. As DEH signal $u_{in}$ is given by the controller, $C_v$ changes with inertia effect in (1). Eventually, $C_v$ and $T_{SM}$ are consistent at steady state.

$$T_{SM} \frac{dC_v}{dt} = -C_v + u_{in} \tag{1}$$

Steam turbine may contain several control valves, its generic model is shown in Fig.3. Shipboard turbine unit is usually single-cylinder designed, so the steam spread characteristic can be simply described by volume time constant $T_s$, which directly affects the real-time output power of steam turbine.
By adjusting the mechanical structure, lift-flow characteristics of turbine valves can achieve linearity [4], and per-unit values of output power and valve opening can be the same.

2.2. Coordinated Control Method
For the operation of steam turbine, throttle pressure is mainly controlled by boiler combustion, also influenced by valve control and steam flow rate. Because of time delay along the steam circulation process, it is difficult for boiler to control the main pressure to meet real-time power requirements. Real-time output torque of turbine unit is related to steam flow rate, main steam conditions and cylinder efficiency. Therefore, valve control and boiler control are equally important for power regulation of turbine unit [5], coupled control method is shown in Fig.4.

![Figure 4. Coordination control signal model.](image)

3. Influence Of Thermal Storage System On Unit Regulation
As an inherent property of steam boiler, thermal storage ability is commonly characterized by storage coefficient, which is dominant by $C_\theta$ in Fig.2. Part of energy produced by fuel combustion is stored in water and boiler wall, and the energy will release when boiler pressure reduces, which can maintain the newly generated steam conditions to some extent. In the regulation process of turbo-generator unit, fluctuation of output power is partly inhibited due to thermal storage of boiler, this effect will be described in steady state oscillation analysis and sudden load transient analysis next.

3.1. Influence on Low Frequency Oscillation
Low-frequency oscillation is a common threat for land power grid. Unstable operation of steam turbine may cause local fault, then spread along the grid and cause damage widely. When boiler combusts unsteadily, new steam conditions may fluctuate and lead to oscillation of output power [6, 7]. While main pressure $P_T$ changes, steam flow rate $G$ will be changed by thermal storage effect as (2) and maintain the output power. $C_\theta$ is the storage coefficient.

$$C_{\theta} \Delta P_T = \Delta G$$

(2)

3.2. Influence on Transient Process
Turbine generator is usually clustered in land electric power plant, load change speed is relatively low. By contrast, shipboard power station need to cope with sudden load change. At the beginning of regulation transient, power balance is dominant by turbine valve control, while the boiler response is delayed. According to the research, main pressure will decrease as turbine valve opens fast, which will reduce the expected power output. Meanwhile, thermal storage system can partly compensate the power loss like (2), assist turbine generator to restore stability.
4. Simulation And Experiment

4.1. Simulation Test
Simulation model is established according to Fig.1, Fig.2 and Fig.3. Waveforms of fuel signal, drum pressure and throttle pressure are shown in Fig.5, where \( C_D \) equals 60s, turbine load rate is 0.5, and cyclical disturbance with amplitude of 0.5p.u. and frequency of \( \frac{1}{2\pi} \) is added from the 80th second.

![Figure 5. Pressure disturbance test waveforms.](image)

(1) fuel signal disturbance  (2) drum pressure disturbance

As is shown above, heat storage blocks signal disturbance well. Without this barrier effect, fluctuation with amplitude of 0.3p.u. is observed in the waveform of main pressure \( P_T \) (the green line in Fig.5(2)). Then, as turbine unit load rate suddenly increased from 0.3 to 0.8 at the 80th second, main pressure transient waveforms with different \( C_D \) are recorded in Fig.6.

![Figure 6. Pressure waveforms after sudden load.](image)

(1) pressure waveform as \( C_D \) equals 60s  (2) pressure waveform as \( C_D \) equals 150s

According to the result, main pressure’s recovery time is extended by about 10 second as \( C_D \) increased from 60s to 150s, but the latter transient reciprocates less, which is advantageous for unit safe operation. Therefore, on the premise of well-designed unit condition, larger thermal storage coefficient can help stabilize the main pressure of turbine unit.

4.2. Experimental Result
By using megawatt turbine generator, actual speed waveforms of disturbance test are recorded. The result of drum disturbance test is shown in Fig.7 (1), and Fig.7 (2) shows the result of fuel signal disturbance test.
Experimental result, which is consistent with the analysis above, shows that drum blocks disturbance well.

5. Conclusion
The main pressure significantly influences output power of turbo-generator. Based on boiler-turbine integral model, response of unit dynamic to boiler fluctuation and sudden load change is studied, inhibition effect of boiler heat storage system on generator power fluctuation is revealed. The result indicates that, heat storage system can effectively reduce influence of disturbance on boiler main pressure, and increased thermal storage coefficient may be helpful for stable operation of turbo-generator. The output waveforms of simulation test as well as megawatt turbine generator experiment have proved the conclusion, and this paper may provide reference for further research on turbine generator.

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