Simulation study on the start-up process of heat recovery steam generator in F-class peak shaving combined cycle power plant

Hongtao Liu*

SEPCO Electric Power Construction Corporation, Jinan 250001, China

Abstract. Peak shaving of power systems and the improvement of balance adjustment capabilities are important issues that need to be resolved in the energy sector to carbon neutrality. Moderately constructing some gas-steam combined cycle power stations is one feasible way to alleviate this issue. Heat recovery steam generator plays a vital role in the safe and reliable operation of gas-steam combined cycle power plant. Start-up process of heat recovery steam generator in a typical F-class peak shaving combined cycle plant under cold, warm and hot modes was researched in this paper. Parameters of heat recovery steam generator increase with the increase of gas turbine load. The shortest cold, warm and hot start-up time are 60 minutes, 50 minutes and 35 minutes, respectively. Temperature and pressure rise rate of heat recovery steam generator should be strictly controlled during start-up process. It is recommended to start-up the heat recovery steam generator in hot or warm mode.

1 Introduction

The low-carbon transition of the energy structure is an important condition for China to achieve its carbon neutral goal [1]. New energy sources represented by wind power and solar power will usher in large-scale growth [2]. By 2030, the total installed capacity of wind power and solar power will reach 1.2 billion kilowatts, which is more than twice that of 2020. However, under the current energy power system, due to the intermittent and instability of wind power and solar power generation, the power system must be equipped with a corresponding scale of flexible power reserve capacity. Otherwise, balance of power supply will be broken when wind power and solar power cannot provide output due to the constraints of wind and solar power resources [3]. The serious shortage of system peak shaving capacity is the core problem that affects China's renewable energy consumption. Therefore, the peak shaving of power systems and the improvement of balance adjustment capabilities are important issues that need to be resolved in the energy sector to carbon neutrality. Gas-steam combined cycle power stations have many advantages, e.g., high-efficiency, rapid start-stop, strong adaptability. Hence, moderately constructing some gas-steam combined cycle power stations in areas where electricity load is concentrated, is one of the means to solve above problems [4].

* Corresponding author: lhtsepco@163.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

Gas turbine power generation has characteristics of high energy conversion efficiency, low pollutant emissions, rapid start and stop, and flexible operation [5]. By installing a Heat Recovery Steam Generator (HRSG) at the tail of gas turbine, waste heat of exhaust gas can be further recovered to generate steam for power generation and steam export. As a critical equipment for heat recovery and steam generation, HRSG plays a vital role in the safe and reliable operation of gas-steam combined cycle power plant [6]. However, both structure and operation of HRSG are significantly different with that of conventional coal-fired boiler. In this paper, start-up process of HRSG in F-class peak shaving combined cycle power plant was simulated. Results obtained can provide reference for related work.

2 Configuration

The simulation study takes a typical F-class plant as the research object. The HRSG is a dual-pressure, reheat, horizontal boiler, the circulation mode is natural circulation, and the steam pressure is operated at sliding pressure according to the steam turbine load. Schematic of the thermal system is shown in Fig. 1. The heating surface arranged in sequence along the flue gas flow direction is superheater, reheater, high-pressure evaporator, intermediate-pressure evaporator and economizer, respectively. Two steam drums, namely High Pressure (HP) and Intermediate Pressure (IP) steam drums, are equipped. Initial conditions of HP and IP drums under different start-up modes are shown in Table 1.

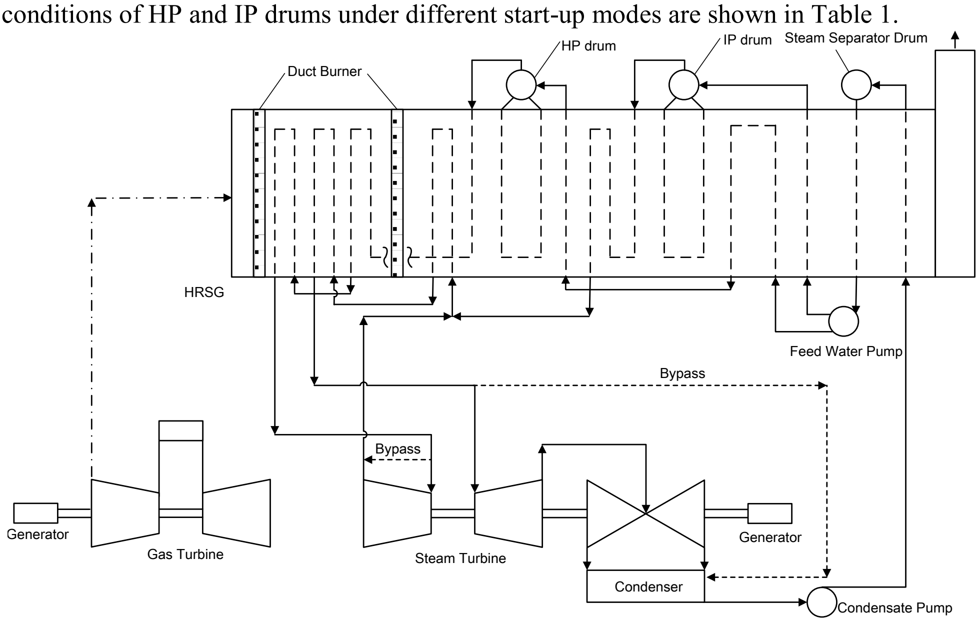

Fig. 1. Schematic of the thermal system.

Table 1. Initial conditions of HP and IP drums.

start-up mode	HP drum		IP drum	
	pressure/bar	temperature/℃	pressure/bar	temperature/℃
cold	1	30	1	30
warm	1	100	1	100
hot	18	207	4.8	150

3 Results and analysis

The proposed start-up sequence is as follows:

The Gas Turbine (GT), HRSG and associated duct work are purged with the GT on cranking speed at ambient temperature for at least 10 minutes.

GT is ignited and start-up following the normal start-up procedure, Including ignition at starting speed, acceleration to full speed without load, synchronization, grid connection.

GT is synchronised and set to a load, at which the exhaust temperature is 340 ℃. The GT is held at this load for several minutes to soak the HRSG until the temperature of the last superheater reaches 250 ℃.

HRSG starts to warm up and with that, the pressure rises.

GT is loaded and when the steam conditions are suitable for Steam Turbine (ST), steam is allowed to pass and the ST starts to roll. After starting the ST, the control valves are closed in a controlled way. The GT is set into the standard loading rate.

GT load ramp is continued according to allowable transients of the ST to maximum load. HRSG is at maximum sliding pressure and maximum temperature, feeding steam to the ST.

The start-up curves of high-pressure steam, reheat steam, intermediate-pressure steam were simulated in this paper. Parameters change regularity of above steam is similar with that of HP&IP drums. Hence, parameters change of HP&IP drums are adopted to judge the start-up status of HRSG. Simulation results of GT, HRSG HP & IP drums start-up curves under different modes are shown in Figure 2 to 4. In Figure 2, Q stands for exhaust gas mass flow, and T stands for exhaust gas temperature. In Figure 2, Q stands for exhaust gas mass flow, and T stands for exhaust gas temperature. In Figure 3 and 4, P stands for steam drum pressure, and T stands for steam drum temperature.

The GT start-up curves show that parameters of both GT exhaust and HRSG drums increase with the increase of GT load. However, there is a certain hysteresis. It takes about 20 minutes from purge command issued to steam generation.

When GT exhaust temperature reaches 340℃, keep GT load stable until the temperature of the last superheater reaches 250 ℃. Time required to keep GT load stable is different under different start-up modes. In cold, warm and hot start-up modes, the duration is about 21 minutes, 12 minutes and 2 minutes, respectively. During normal operation, front tube bundle (superheater, reheater, etc.) can withstand exhaust gas temperature due to the cooling effect of steam. However, no steam flow is generated at the early stage of HRSG start-up. Front tube bundle may be overheated if GT load is not controlled. Once temperature of the tube bundle exceeds limitation of the material working temperature, HRSG heating surface will be damaged. Guarantee of HRSG safe and reliable operation will therefore be threatened [7].

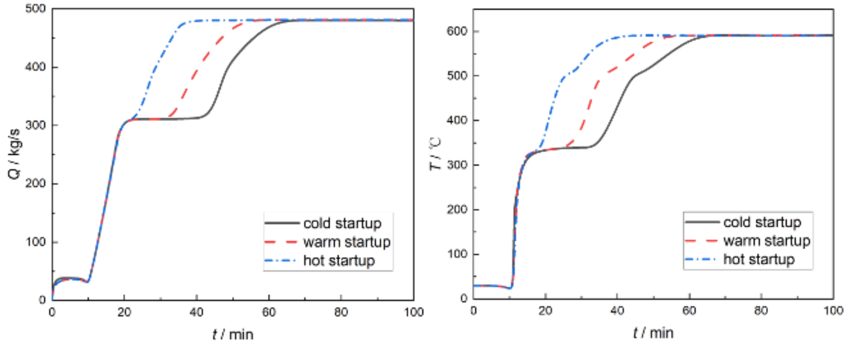

Fig. 2. GT start-up curves.

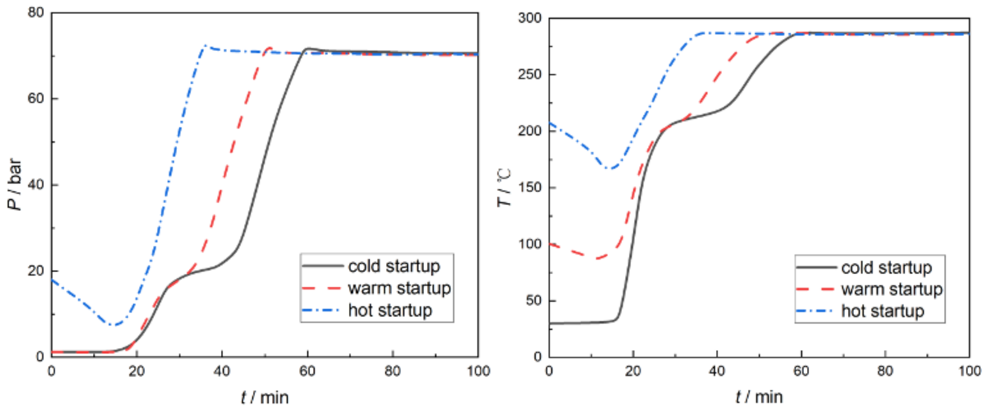

Fig. 3. HP drum start-up curves.

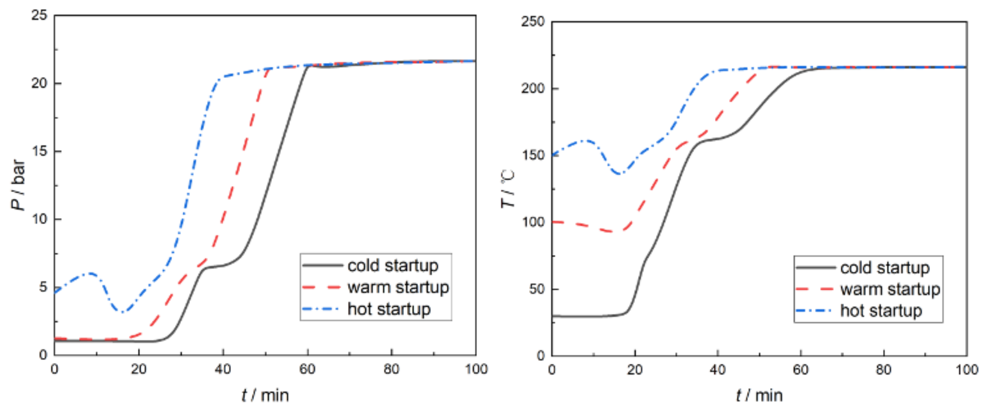

Fig. 4. IP drum start-up curves.

Gas turbine can continue to increase load when stable steam is generated. Due to the restriction of thermal stress on the heating surface, the temperature and pressure rise rate should be strictly controlled [8]. Steam parameters and pressure rise rate of HRSG are directly affected by the exhaust temperature and exhaust flow of GT, and the exhaust parameters are directly controlled by GT load. Therefore, to meet the needs of HRSG and ST for boosting pressure, heating pipes, and warming up, GT load rise rate must be controlled and slowed down under gas-steam combined cycle mode. This is significantly different with gas turbine simple cycle mode.

Time required to complete the start-up process is different under different start-up modes. In this paper, approaching stability of the parameters of steam drum is used as the basis for judging the completion of the start-up. In cold, warm and hot start-up modes, start-up time is 60 minutes, 50 minutes and 35 minutes, respectively. Correspondingly, time required for GT to reach full load is approximately 65 minutes, 55 minutes, and 38 minutes, respectively. Within a certain time range, the shorter time plant shutdown, the shorter time required for restart-up. Pressure rise rate of cold mode is much higher than that of other modes. However, if plant starts frequently in cold mode, the drums will inevitably be damaged. Therefore, frequency of cold start-up should be minimized. It is better to start-up the HRSG in hot or warm mode as much as possible.

4 Conclusion

Moderately constructing some gas-steam combined cycle power stations in areas where electricity load is concentrated, is one of the means to solve the system peak shaving challenge caused by renewable energy consumption. Heat recovery steam generator plays a vital role in the safe and reliable operation of gas-steam combined cycle power plant. Start-up process of HRSG in F-class peak shaving combined cycle power plant was simulated in this paper. Parameters of HRSG increase with the increase of GT load. About 20 minutes hysteresis exists from purge command issued to steam generation. In cold, warm and hot start-up modes, start-up time is 60 minutes, 50 minutes and 35 minutes, respectively. In order to ensure the safe and reliable operation of HRSG, temperature and pressure rise rate should be strictly controlled. Frequency of cold start-up should be minimized, and it is recommended to start-up the HRSG in hot or warm mode.

References

1. Y.S. Zhang, D. Dong, Y. Xiao, T. Wang, J.W. Wang, Chinese Science Bulletin, **66**, doi: 10.1360/TB-2021-0797 (2021)
2. C.N. Zou, B. Xiong, H.Q. Xue, D.W. Zheng, Z.X. Ge, Y. Wang, Petroleum Exploration and Development, **48**, 411-420 (2021)
3. H. Li, D. Liu, D.Y. Yao, Proceedings of the CSEE, **18**, 6245-6258 (2021)
4. Z.T. Liu, Y.G. Li, G.J. Yang, W.F. Wang, Natural Gas Industry, **6**, 152-161 (2021)
5. P. Yan, S.Y. Liang, Energy Conservation, **9**, 76-80 (2019)
6. C. Guo, H. Dong, R. Wu, F.Z. Qian, X.H. Kan, W.D. Ge, Industrial Furnace, **5**, 1-5 (2019)
7. C.W. Zhang, W.Q. Yao, Y.M. Cai, F. Yuan, Y.H. Li, Gas Turbine Technology, **2**, 55-58 (2012)
8. W.T. Liu, Zhejiang Electric Power, **2**, 38-39 (2002)