International Journal of Mechanical and Electrical Engineering
ISSN: 3005-9615 (Print), ISSN: 3005-7132 (Online) | Volume 5, Number 2, Year 2025
DOI: https://doi.org/10.62051/ijmee.v5n2.12
Journal homepage: https://wepub.org/index.php/IJMEE/index

A Review of Modeling and Simulation Research on Steam Turbines of Supercritical Power Generation Units

Changlong Ma, Jing Chen, Geng Liang *

College of College of Control and Computer Engineering, North China Electric Power University, China

* Corresponding Author: Geng Liang

ABSTRACT

Under the background of the increasing energy demand and the tightening environmental protection requirements, steam turbines, as one of the key operating devices in power plants, hold significant importance for the modern power system. This paper conducts research by retrieving international literature journals and applying the literature analysis method, focusing on the simulation technology of steam turbines in supercritical power generation units. It summarizes three types of methods: mechanism modeling, system identification modeling, and composite modeling, aiming to provide references for subsequent related research.

KEYWORDS

Supercritical Power Generation Unit; Steam Turbine; Building Simulation Technology.

1. INTRODUCTION

Supercritical steam turbines, as core power equipment with high efficiency and flexibility, play an irreplaceable role in modern power systems. In recent years, researchers have made significant progress in the field of steam turbine modeling and simulation. These modeling methods can not only accurately predict the flow field distribution, thermodynamic performance and dynamic response of steam turbines, but also provide theoretical support for fault diagnosis and optimization control. However, existing research still faces some key challenges: Firstly, the model accuracy of steam turbine models under complex operating conditions is insufficient; Secondly, the use of empirical formulas in the thermal calculation of steam turbines is very common, which causes uncertainty in the research of steam turbine modeling and simulation. Therefore, systematically summarizing the research progress of current modeling and simulation technologies for supercritical steam turbines is of great significance for promoting the efficient operation and technological innovation of power systems. This paper classifies modeling and simulation methods into three categories, conducts a review and analysis, with the aim of providing references for subsequent related research.

2. STRUCTURAL CHARACTERISTICS OF STEAM TURBINE

The steam turbine has the characteristics of large power, high efficiency, high rotational speed and long service life, so it is widely used. In thermal power plants and nuclear power plants, steam turbine generator sets driven by steam turbines are adopted as the prime movers. As shown in Fig. 1, it is the structural schematic diagram of the steam turbine of a certain generator set in a thermal power plant.

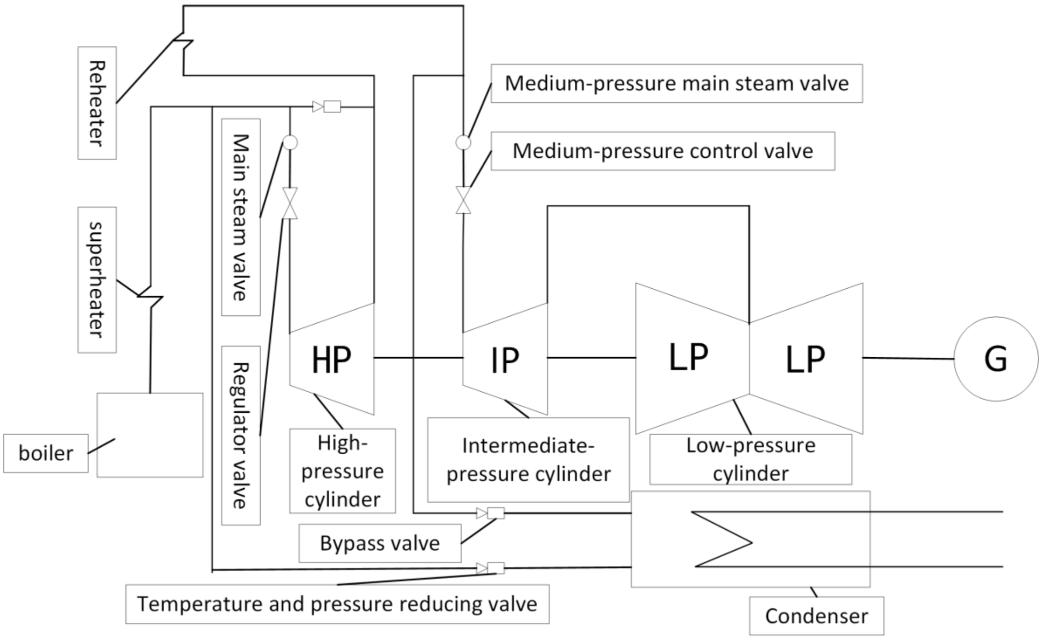

Figure 1. Steam turbine structure diagram

The steam turbine is the main component of the generator set. The steam turbine is connected to the generator through the coupling. The steam turbine is driven by the steam generated by the boiler. The steam turbine generator set is connected to the power grid through the power line. The steam turbine generator set is the main equipment of the thermal.

3. LMODELING METHOD OF STEAM TURBINE

3.1. Physical Modeling

The physical modeling method involves writing various equations related to the system by analyzing the changes it undergoes in actual production. By consulting relevant materials and based on the principles of mass conservation, energy conservation, momentum conservation, as well as some motion equations that reflect the fundamental laws of fluid flow, heat transfer, chemical reactions, and the characteristic equations of certain equipment, the required mathematical model is obtained. For the mechanism modeling of thermal power plant systems, there are usually two methods to construct thermodynamic models: lumped parameter and distributed parameter. The lumped parameter method treats the parameters of the system as a whole without considering the spatial distribution. The distributed parameter method is a modeling approach that takes into account individual or distributional differences and is suitable for problems with continuous variables, typically resulting in partial differential equations.

As early as the 1980s, Suzuki[1] introduced the idea of distributed parameters into the modeling process and established a nonlinear dynamic model of a supercritical once-through boiler.Astrom and Bell[2] conducted simulation studies on the nonlinear dynamic characteristics of drum boilers using the lumped parameter modeling method.Godbole[3] and other researchers used the MMS software tool for dynamic power plant modeling to establish a full-condition engineering application model for the Bellefonte nuclear power unit and its control system.Shirakawa[4] developed a model library capable of simulating the operation of actual thermal power plants based on object-oriented modeling technology. By modeling each component and equipment, a flexible power plant configuration was achieved. Users can build simulation models through the Matlab platform and conduct simulation studies on them.

Wu Jingsheng[5] proposed a power algorithm for steam turbines from the perspective of engineering application and real-time simulation. The comprehensive enthalpy drop efficiency was iteratively obtained offline and the power calculation module was automatically generated.Su Ming[6] established a simulation model of the volume link of a steam turbine based on the differential equations of pressure and enthalpy according to the conservation of mass and energy, and presented a simulation recursive formula derived from direct integration.Zhu Wei[7] proposed a segmented universal modular modeling method for the steam turbine body, which has high accuracy and strong practicability and can be applied to the simulation operation under various working conditions.Fang Weiming[8] established a simulation model of the basic thermodynamic characteristics of low-power steam turbine generator sets using Matlab software, providing an analytical tool for the quantitative design of thermodynamic systems. Han Zhongxu[9] placed the steam turbine generator set in the overall operating environment of the boiler and unit coordination control system and proposed an improved mathematical model for power system stability analysis.Nie Yu[10] took the high-pressure bypass system of the steam turbine as the object and proposed the idea of segmenting the bypass system into two stages: throttling and pressure reduction stage and water injection and cooling stage for modeling.Liu Junfeng[11] established a mathematical model of the steam turbine for high-temperature gas-cooled reactors based on Matlab/Simulink. The steady-state response results of key parameters of the steam turbine under various operating conditions of the unit were in good agreement with the thermal balance design values.Huang Yihan[12] conducted a mechanism analysis on the dynamic coupling characteristics of the steam turbine body, the return condensate pipeline and the return heat exchanger. Based on the structural data of the unit and the measured data from the distributed control system, a method for online determination of model parameters that follow the changes in operating conditions was proposed. The model can more accurately describe the dynamic response characteristics of the steam turbine under different primary frequency modulation schemes and different operating conditions.

3.2. System Identification Model

With the development and application of modern identification algorithms such as neural networks and genetic algorithms, in recent years many researchers have also introduced intelligent algorithms into the process of thermal system modeling. The core of the system identification model is to regard the system as a "black box" or a "grey box", without relying on a complete understanding of the internal structure and mechanism of the system. By using mathematical methods and algorithms, the features and laws of the system are extracted from the input and output data, and then a mathematical model that can describe the dynamic or static characteristics of the system is established.

Chaibakhsh[13] utilized genetic algorithms to conduct nonlinear modeling and solution for steam turbine units. For some special regions where the thermal load of the steam turbine changes drastically, independent nonlinear equations were established respectively. The genetic algorithm was also adopted to describe the parameters of the objective function for each section. This model has high accuracy and broad application prospects. Li Lirong, Shen Chunlin, et al.[14] constructed a BP neural network using Visual C++ language and proposed a method to convert the weights of the BP network into transfer functions. For common thermal processes in thermal power plants, without the need to artificially add special excitation signals, only the naturally existing disturbance signals in the on-site production were used for identification experiments, and the experimental results were accurate and reliable. Zhang Hongtao[15] applied the particle swarm algorithm to the identification of thermal process models in thermal power plants, considering the characteristics of the thermal process objects and the shortcomings of traditional model identification, and made improvements in implementation methods and parameter selection, thereby enhancing the accuracy and speed of identification. Zhang Chengming[16] introduced the idea of artificial immunity into the basic ant colony algorithm, making improvements in aspects such as the initial pheromone distribution, pheromone adjustment mechanism, and selection probability function in the algorithm, enabling the ant colony identification method to approach the output of the actual system more quickly and accurately. The simulation experiment results show that this method has higher optimization efficiency and identification accuracy than the basic ant colony algorithm. Su Zhipeng[17] modeled the boiler-turbine system based on the system identification algorithm of adaptive neuro-fuzzy inference. The traditional ANFIS was improved by using the Fletcher-Reeves update method, and the modeling effect before and after the improvement was compared to verify the effectiveness of the improvement. Hou Guolian[18] focused on the modeling of the coordinated control system of ultra-supercritical units based on a new type of fuzzy neural network. A new fuzzy neural network model was proposed for the modeling of the coordinated control system of ultra-supercritical units.

3.3. Composite Modeling

The main steps of the compound modeling method are to determine the model type and structure through mechanism analysis and expert experience, and then identify the model's dimension, order and other parameters by using system identification methods[19]. Chen Lijia, Wang Zicai, et al.[20, 21] established a compound model of the superheater by combining neural networks and mechanism models. The mechanism model was dominant, while the neural network was supplementary. After training the neural network, the parameters of the mechanism model were corrected online, which ultimately improved the accuracy of the simulation model. Qin Zhiming from North China Electric Power University[22] took a 1000MW ultra-supercritical unit as an example and established a simplified three-input and three-output nonlinear dynamic model of the once-through boiler unit. Some static parameters of the model were determined based on the steady-state operation data of the unit, and the dynamic parameters were identified using data with significant load changes. The model accuracy was verified by comparing it with the actual operation data. Iranian scholar Ali Chaibakhsh[23] modeled the main equipment of a thermal power plant, such as boilers and steam turbines, using mass and energy balance equations, and optimized the parameters of the established model using genetic algorithms, thereby improving the model's accuracy. American scholar Yasser A. Hussein[24] modeled a circuit board and optimized the model parameters using an adaptive genetic algorithm. Liu Junqiang[25] used a fuzzy neural network to model complex systems and determined the main parameters of the model online using the SPSA algorithm, and verified the effectiveness of the model. Ma Jin, Wang Bingshu, et al. from North China Electric Power University[26] established a mechanism model of the superheater, optimized the model parameters using genetic algorithms, and stored the parameters using neural networks. The established model met the expected accuracy requirements.

4. SUMMARY

In the field of thermal engineering system modeling, mechanism analysis and system identification are two typical modeling methods with distinct characteristics. The model parameters and structure of mechanism models have clear physical meanings. However, their description of the internal physical processes of the system relies on a large number of empirical formulas. These empirical formulas are often summarized under specific conditions and have certain limitations, making it difficult to precisely adapt to the complex and variable actual operating conditions of supercritical power generation unit steam turbines, thus limiting the model's accuracy. On the other hand, system identification modeling is constrained by experimental equipment, environmental conditions, measurement accuracy and other experimental conditions. Establishing a unified model that covers the entire operating range often faces many challenges and is difficult to achieve.

In contrast, when using composite modeling, the mechanism model provides a theoretical framework for the experimental model, helping to determine key variables and relationships; experimental data is used to correct and calibrate the parameters in the mechanism model, compensating for the errors caused by simplifying assumptions. The two complement each other, significantly improving the overall accuracy of the model. With the development of artificial intelligence algorithms, the prospects for composite modeling in the field of supercritical power generation unit steam turbines are increasingly broad. Artificial intelligence algorithms can more accurately calibrate the parameters of mechanism models through complex data fitting and pattern recognition. Composite modeling integrated with artificial intelligence algorithms, with its outstanding advantages in improving accuracy, adapting to complex operating conditions, reducing data requirements, and optimizing verification, will undoubtedly become the core direction for the subsequent development of supercritical power generation unit steam turbine modeling, effectively promoting the field to a higher level.

REFERENCES

[1] Suzuki Y, Sik P, Uchida Y. Simulation of a supercritical once-through boiler[J]. Simulation, 1979, 33(6): 181-193.

[2] K.J. Åström, R.D. Bell, Drum-boiler dynamics[J],Automatica, 36 (2000): 363-378.

[3] Yee N S, Godbole S S, Malan G F. Nuclear plant performance analysis using theModular Modeling System[J]. SYSTEMS ANALYSIS MODELLING SIMULATION,1995, 21: 279-292.

[4] Shirakawa M. Development of a thermal power plant simulation tool based on object orientation[J]. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 2006, 220(6): 569-579.

[5] Wu Jingsheng, Liu Qiaohong. A Preliminary Study on Steam Turbine Power Calculation in Real-time Simulation of Thermal Power Plants [J]. Journal of System Simulation, 1996, (04): 31-36.

[6] Su Ming, Weng Shili. A Simulation Model of Volume Linkage and Its Solution in Steam Turbine System Simulation [J]. Power Engineering, 1998, (02): 76-79+83+82.

[7] Zhu Wei, Jiang Zikang, Cheng Fangzhen, et al. Segmented Generalized Modular Modeling and Simulation of Steam Turbine Body [J]. Journal of Thermal Power Engineering, 2000, (03): 278-280+293-328.

[8] Fang Weiming, Xu Jian, Huang Guohua. Research on System Simulation of Low Power Steam Turbine Generator Set Based on Matlab/Simulink [J]. Chinese Journal of Ship Research, 2006, (Z1): 83-89.

[9] Han Zhongxu, Zhou Xiaoxin, Li Fang, Tian Xinshou. Analysis of Mathematical Model and Dynamic Characteristics Simulation of Unitized Reheat Condensing Steam Turbine [J]. Power System Technology, 2010, 34 (12): 180-186.

[10] Nie Yu, Zhang Yanping, Huang Shuhong, et al. Simulation Modeling of Steam Turbine Bypass System [J]. Journal of Thermal Power Engineering, 2013, 28 (04): 336-340+431-432.

[11] Liu Junfeng, Wang Chenglong. Simulation Modeling and Characteristic Analysis of Gas-cooled Reactor Steam Turbine Based on Matlab/Simulink [J]. Turbine Technology, 2022, 64 (06): 408-412.

[12] Huang Yihan, Hao Ling, Chen Lei, Xu Fei, Xu Darui, Sun Guohui, Jiang Nan, Cheng Renjing. Mathematical Model of Extraction Condensing Steam Turbine Applicable to Various Primary Frequency Regulation Technologies and Operating Conditions [J]. Proceedings of the CSEE, 2024, 44 (15): 6065-6078.

[13] Ali Chaibakhsh, Ali Ghaffari. Steam turbine model[J]. Simulation Modelling Practice and Theory, 2008, 16 : 1145-1162.

[14] Li Lirong, Shen Chunlin, Han Pu. Model Identification Method of Thermal Process Based on BP Network [J]. Journal of Nanjing University of Aeronautics and Astronautics, 2001, (05): 499-502.

[15] Zhang Hongtao, Hu Hongli, Xu Xinhang, et al. Model Identification of Thermal Process in Thermal Power Plant Based on Particle Swarm Optimization Algorithm [J]. Thermal Power Generation, 2010, 39(05): 59-61+81.

[16] Zhang Chengming, Zhang Yufei. Parameter Identification of Thermal Process Model Using Improved Ant Colony Algorithm [J]. Power Equipment, 2016, 30(02): 77-80+84.

[17] Su Zhipeng, Wang Dongfeng. Modeling of Boiler and Steam Turbine Based on Adaptive Neuro-Fuzzy System [J]. Instrument & Instrumentation User, 2019, 26(11): 99-102.

[18] Hou G, Xiong J, Zhou G, et al. Coordinated control system modeling of ultra-supercritical unit based on a new fuzzy neural network[J]. Energy, 2021, 234: 121231.

[19] M. Brown and C. J. Harris, Modelling capabilities of neurofuzzy networks for nonlinear control, IEE Colloquium on Non-Linear Control, London, UK, 1994, pp.6/1-6/3.

[20] Chen Xiaodong, Wang Zicai. Dynamic Simulation Model of Boiler Superheater System [J]. Thermal Power Engineering, 2000(03): 276-277 + 297-328.

[21] Chen Lijia, Shan Ye, Wang Zicai, Ma Kema. Mechanism and Neural Network Hybrid Modeling Method for Boiler Superheater System [J]. Proceedings of the CSEE, 2001(01): 74-77.

[22] Qin Zhiming. Research on Dynamic Model and Control of Ultra-supercritical Units [D]. Beijing: North China Electric Power University, 2014.

[23] Ali Chaibakhsh, Ali Ghaffari. Steam turbine model Simulation[C]. Modelling Practice and Theory, 2008: 1145-1162.

[24] Hussein YA, El-Ghazaly SM. Modeling and optimization of microwave devices and circuits using genetic algorithms[J]. IEEE Transactions on Microwave Theory and Techniques, 2004, 52(1): 329-360.

[25] Liu Junqiang, Shan Ye, Wang Zicai. Fuzzy Neural Network Method for Modeling Complex Large-scale Systems [J]. Journal of System Simulation, 2006, Vol. 13 No. 3: 304-307.

[26] Ma Jin, Wang Bingshu, Li Liping, Cui Ning. Research on Genetic Algorithm Parameter Optimization Method for Mechanism Model of Superheater [J]. Journal of System Simulation, 2008, 09: 2433-2436.