The Design of Parameter Modeling Software Applicable for Turbine Control Systems of Power Units Operated at Deep Shaving States

Longfei Zhu\textsuperscript{a*}, Paiyou Si\textsuperscript{1}, Shuangbai Liu\textsuperscript{1}, ChangYa Xie\textsuperscript{1}, Teng Zhang\textsuperscript{1}, Yuou Hu\textsuperscript{2} and Xiaozhi Qiu\textsuperscript{3}

\textsuperscript{1}State Grid Jibei Electric Power Co. Ltd. Research Institute, North China Electric Power Research Institute Co. Ltd., Beijing 100045, China
\textsuperscript{2}North China Branch of State Grid Co. of China, Beijing 100053, China
\textsuperscript{3}Beijing Jingneng Power Co. Ltd., Beijing 100025, China
\textsuperscript{a*}zlf03110221@126.com

Abstract: Against the backdrop of achieving the “dual carbon” reduction goals, the proportion of renewable energy consumption in China is gradually increasing, and more and more thermal power units are gradually being operated at the deep peak shaving states, which puts forward higher requirements for stable operation of the power grid system. In view of the current situation, this paper designs a new type of Python-based parameter modeling software for turbine control systems, including the load selection module, data pre-processing module, parameter identification module, and result output module. To solve the problem that the primary frequency regulation parameters of the units operated at the deep peak shaving states change with the load, the software is designed to set key model parameters of different load segments of the units. The actual measurement results of a unit operated at the deep peak shaving state show that this developed software is convenient and friendly to operate, creates accurate parameter identification results, and has a wider range of applicability.

1. Introduction

At the United Nations General Assembly in September, 2020, President Xi made a solemn commitment that China would peak carbon emissions by 2030 and aim to achieve carbon neutrality by 2060 (hereinafter referred to as dual carbon reduction goals)\textsuperscript{[1]}. Since then, the “dual carbon” goals have become solemn commitments made by China to the world. Because the electricity sector is the largest source of carbon emissions, President Xi Jinping also pointed out that China's electricity sector is moving into a new direction to “build a new electricity system mainly driven by new energy”. Therefore, coal-fired power generation in China is facing unprecedented challenges. One of the most important aspects is how to realize the “deep peak shaving” of coal-fired power units. With the gradual increase of the proportion of renewable energy consumption in China, it is becoming extremely important to ensure the stability of the power grid system. More and more thermal power units are gradually being operated at the deep peak shaving states. Improving the operation flexibility of thermal power units has become an important issue for coal-fired power units. Thermal power units need to continue to ensure the reliability of frequency regulation and peak-shaving when they are being operated at the deep peak shaving states.
Carrying out the parameter measurement and identification and establishing a required mathematical model for turbine control systems can help systematically analyze the frequency response and load response of the power grid system under various disturbance conditions, which is of significant and practical value for the analysis of the stability of the grid\cite{2-3}. The model of turbine control systems is one of the four major component models of the power grid system. The model accuracy directly affects the simulation precision of the power grid system\cite{4-7}. Therefore, the accuracy of the model parameter identification method and the reliability of the simulation and validation method are increasingly valued. Reference [8] DL/T 1235-2019 Guide for modeling and testing of generator prime mover and governing system (short for “Guidelines”) puts forward the simulation quality parameters and stipulates the allowable deviation of each quality parameter in comparison between simulation and actual measurement.

In recent years, some scholars have developed parameter modeling software for turbine control systems. Reference [9] designed software based on the Matlab/GUI platform, implemented graphical interception of raw data, and performed wavelet denoising, data standardization (per unit), and normalization, which provides a basis for accurate parameter identification. Reference [10] realized the intelligent pre-processing of raw test data, the intelligent identification of model parameters and the result selection, and the automatic calculation of deviation values of simulation quality parameters by using the software developed based on the Matlab/Simulink platform. Based on the Matlab/GUI platform, reference [11] adopted modular and localized software design principles and designed visualized software with reasonable functional models. It can be easily mastered, thus effectively improve work efficiency.

The above-mentioned software has certain limitations when thermal power units are being operated at the deep peak shaving states. Based on the wxPython graphics library, this paper designs a new type of parameter modeling software for turbine control systems and adds a load selection module to realize parameter identification and modeling under different operating conditions. The actual measurement results show that the developed software is convenient to operate, creates accurate parameter identification results, and has a wider range of applicability.

2. Parameter Measurement Status Quo and Software Architecture Design of Power Units Operated at Deep Shaving States

In accordance with the spirit of the Guiding Opinions on Improving the Regulation Capability of Power Systems (Energy of Development and Reform Department [2018] No. 364), the Beijing-Tianjin-Tangshan Power Grid proposed the Incentive Measures for the Improvement of Thermal Power Unit Regulation Capability (hereinafter referred to as the Measures). The “Measures” gives guidance on the primary frequency regulation capability of speed governing systems when units are being operated at the deep shaving states: when a unit is being operated at the lower limit of the load (less than 40% of the rated load), the response index for the output of a generator in response to a primary frequency regulation within 15 seconds is no less than 37.5%, the response index of the output of a generator in response to a primary frequency regulation within 30 seconds is no less than 45%, and the power contribution index is no less than 37.5%. It can be seen that the frequency regulation capability of the unit is reduced at low load segments. The existing modeling software cannot meet the modeling requirements of low load segments, and the software architecture needs to be redesigned.

2.1 Parameter Measurement Status Quo of Power Units Operated at Deep Shaving States

According to the Measures and combining the actual operation of power units operated at the deep shaving states, in the process of transforming the unit flexibility, we modified the logic of the primary frequency regulation and set the primary frequency regulation function of different load sections and the upper and lower load limits. The relationship between the load amount per slip for frequency regulation and rate between the speed droop and the rated speed is shown in Formula (1).

\[
k = \frac{Pe}{\delta \cdot n}
\]

Where \(k\) is the load amount per slip for frequency regulation (MW/rpm); \(Pe\) is the rated load (MW);
\( \delta \) is the rate between the speed droop and the rated speed; \( n \) is the rated speed (rpm).

For a 600 MW unit, the rate between the speed droop and the rated speed is set to 4.5% and the rated speed is set to 3000rpm. According to Formula (1), the load amount per slip for frequency regulation of the unit can be calculated as 4.44MW/rpm. After the flexibility transformation of the unit, to prevent the impact of the drastic fluctuation of the network frequency on the safety of the unit during operation at a low load, under the prerequisites of meeting the requirements of Measures, the \( k \) is set in segments and multiplied by a coefficient \( m \). Table 1 shows \( m \) and the upper and lower load limits for primary frequency regulation.

| Load Segment (MW) | Regulated frequency coefficient \( m \) | Upper and lower load limit for primary frequency regulation (MW) |
|------------------|---------------------------------------|---------------------------------------------------------------|
| 119~120          | 0.6                                   | 0~15                                                          |
| 120~180          | 0.7                                   | -15~15                                                       |
| 180~240          | 1                                     | -20~20                                                       |
| 240~300          | 1                                     | -36~36                                                       |

### 2.2 Software Requirement and Software Architecture

#### 2.2.1 Traditional Parameter Modeling Method

At present, the efficiency of using the traditional parameter modeling data processing method is low, manual operations are complex, and many repetitive tasks are involved. The data processing flow is shown in Fig. 1.

#### 2.2.2 Limitations of Existing Software

The existing parameter modeling software has simplified the steps of data pre-processing, parameter identification, and result output, and is equipped with human-computer interaction functions to improve the convenience of use. However, it is not possible to simulate the data of different load segments when units are being operated at the deep peak shaving states. Improvements have been made to address the limitations of this type of software. The new one includes data pre-processing module, load selection module, parameter identification module and result output module. The architecture is shown in Fig. 2.
3. Software Function Implementation

When designing and developing a Python-based visualized programming environment, Python programming language and wxPython graphics library are used.

3.1 Overview of Python-based Visualized Design

Visualized programming, also known as visualized program design, aims at visualizing the programming based on the principle of “what you see is what you get”, that is, to see the final result at any time, and to synchronize the programming with the result.

The visualized programming environment for Python is designed using the wxPython graphics library. wxPython is a GUI toolkit for Python. It makes it easy for Python programmers to create programs with robust and powerful GUIs.

3.2 Data Preprocessing Module

The raw data pre-processing module imports the raw data obtained from the wave recorder into the corresponding model of the prime mover and its speed governing system, and then performs data pre-processing such as standardization (per unit) and normalization on the raw data, so as to make the comparison and analysis of the characteristics and parameters of the subsequent module components easier and simplify the calculation. The interfaces are shown in Fig.3.

3.3 Load Selection Module

This module marks one of the important parts of this software, which improves the adaptability and accuracy of the model by setting the function of the rate between the speed droop and rated speed and the upper limit of primary frequency regulation in the primary frequency regulation logic for different
load segments. Its interface is shown in Fig.4.

3.4 Parameter Identification Module
This is the core part of the software, including actuator parameter identification, prime mover parameter identification and speed governing system parameter identification.

3.4.1 Actuator Parameter Identification
Actuator parameter identification is to use standardized raw data and model simulation tests to identify PID parameters to provide accurate parameters for parameter identification of speed governing systems. The relevant actuator parameters are obtained through control logic check and data collection, and the parameter identification process requires human intervention. The specific process is as follows: firstly, give the initial values of the parameters to be measured, use the simulation model for simulation calculation, and compare the output waveforms to continuously reduce the deviation between the simulated and measured values; secondly, simulate the system parameters on the basis of meeting the identification error criteria, and finally select the simulation value with the highest fit as the identification result of the parameters to be measured [12-13]. The software interface is shown in Fig.5. The simulation results and errors are shown in Fig.6 and Table 2. It can be seen that the simulation results of actuator parameters have high accuracy, and the simulation errors meet the requirements of the Standard.

![Fig.6 Actuator parameter simulation results (upwards and downwards)](image)

Table 2 Actuator parameter simulation error

|                      | Rise Time | Drop Time | Rise Settling Time | Drop Settling Time |
|----------------------|-----------|-----------|--------------------|--------------------|
| Curve of Measured    | 0.89      | 0.75      | 1.63               | 0.97               |
| Results              |           |           |                    |                    |
| Curve of Simulation  | 0.87      | 0.73      | 1.73               | 0.86               |
| Results              | 0.02      | 0.02      | -0.10              | 0.11               |
| Deviation            | ±0.20     | ±0.20     | ±1.00              | ±1.00              |

3.4.2 Prime Mover Parameter Identification
The identification of prime mover parameters is to use standardized raw data and the model simulation test to identify system parameters of the prime mover model and to provide accurate parameters for parameter identification of the speed governing system. The relevant prime mover parameters are mainly measured and identified by using the field data, and the parameters to be identified do not require initial value assignment and manual adjustment. The interface is shown in Fig.7.
3.4.3 Parameter Identification of Speed Governing Systems

The function of the parameter identification module of speed governing systems is to use normalized raw data, PID parameter identification results of the actuator and parameter identification results of the prime mover to identify PID parameters of the speed governing system model, which is the final part of the system parameter processing. The interface is shown in Fig.8. The standard model of the turbine and its speed governing system is shown in Fig.9.

4. Software Application Example

A supercritical unit with a rated power of 600MW was tested to measure the parameters of the turbine and its speed governing system when the unit was operated at the deep shaving state. During the test, ±6rpm disturbance data at 40%, 30% and 20% of the rated load was used, and this software was used for simulated identification. The simulation results were shown in Fig.10~Fig.12. The simulation result obtained when the load is 40% of the rated load was used as an example to calculate the simulation error, and the results are shown in Table 3. It can be seen that the simulation results obtained by using this software for turbine control system parameter identification have a good fit and the simulation errors meet the requirements of the Standard.
The software application process and results also show that by simplifying all complex programming operations and calculation processes into a small number of key parameter inputs and adjustments, the technical threshold for engaging in the simulation and identification work and the impacts of personnel skills and experience can be reduced while the accuracy of identification results can also be ensured. The development and application of the following visualized functions can effectively reduce the parameter modeling workload of turbine control systems: raw data collection, extraction, and processing, synchronized adjustment of input parameters and identification images, and effective extraction of the curve of the comparison between simulated result and measured result.

5. Conclusions
In this paper, we designed a new type of Python-based parameter modeling software for turbine control systems. It consists of the load selection module, data pre-processing module, parameter identification module and result output module. This software simplifies all the complex programming operations and calculation processes into a small number of key parameter inputs and adjustments, which reduces the technical threshold for engaging in the simulation and identification work and the impacts of personnel skills and experience. Moreover, the software can set the key model parameters for different load segments of the unit to address the problem that the primary frequency regulation parameters of a unit operated at the deep shaving state change with the load. The measured results of a unit operated at the deep shaving state show that the developed software is easy to operate and friendly and can create accurate parameter identification results and has wider applicability.

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