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To cite this article: Jun Li et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 242 032015

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PFC Performance Evaluation Based on Modeling and Identification of Unit’s Main Parameters

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Abstract. The rapid development of new energy brings great challenges to the frequency control of power grid, and the early adjustment of power grid frequency mainly depends on the PFC (primary frequency control) function of thermal power units. In view of the limitations of traditional PFC performance evaluation, combined with the grid's PFC technology standards, through the history of thermal power unit operation data, by selecting appropriate PFC data section, the mathematical model based on rotational speed, the main steam pressure and actual power was established. The performance index of PFC can be calculated from the model step response. The simulation and practical operation results show that the proposed method effectively represents the PFC performance of the unit and provides one reliable means for power grid to monitor the PFC performance.

1. Introduction

With the energy security, ecological environment, climate change and other issues becoming more and more prominent, the development of new energy has become a common consensus and concerted action of the international community in promoting energy transformation and addressing global climate change. At present, the installed capacity of new energy in China has reached 171.48GW, ranking first in the world. The output of wind and other new energy sources is random and fluctuating, and the large-scale absorption has always been a worldwide problem. Wind power and other new energy sources show strong uncertainty in the operation process, which has a great impact on the power system. At the same time, the active power output of wind power plant is mainly adjusted with the wind energy changes. In general, it does not participate in the frequency modulation of the system, and the PFC of the power grid must be shared by traditional thermal units [1-3]. In view of the large power gap caused by the power grid frequency fluctuations, on the one hand, the PFC of thermal units is required to act quickly, and at the same time, the unit is required to be able to increase the load at a faster adjustment rate, so that the frequency of power grid can quickly return to 50Hz and reduce the adverse impact on power equipment.

In steady state, the frequency of power system is one consistent operating parameter. When the total output and the total load are unbalanced in the power grid system, the frequency deviation will occur. Because the load is often changed, and the load change at any place will cause the power imbalance of the whole system, it will result in the fluctuation of the system frequency. Therefore, one of the important tasks in power system operation is frequency monitoring and evaluation. The traditional performance evaluation of PFC is mostly based on the unit step response test, but, according to the history data of daily operation performance evaluation of PFC, especially long
evaluation, the existing methods have three major drawbacks[4-7]: limited to step type PFC response, depending on specific data points which seriously disturbed by noise, the significant influence of main steam pressure on active power cannot be separated.

2. Performance Requirements of PFC
In case of frequency fluctuation of the power grid, it is required that the speed governing droop of thermal units should not be more than 5%, or the PFC integral power contribution index should not be less than the specified percentage value.

2.1. Definition of PFC Disturbance
As required in the Chinese national standard GB/T 30370 Guide of primary frequency control test and performance acceptance for thermal power generating units and other technical specification, the dead band of thermal unit’s PFC is 50±0.033Hz, the response delay time is no more than 3 seconds, the stabilization time is less than 1 minute.

![Figure 1. Frequency fluctuation curve](image)

As shown in Figure 1, the blue curve 1 is the grid’s frequency, the red curve 2 is the unit’s active power. When the grid’s frequency is more than dead band (50±0.033Hz) after point A, unit’s active power begin to act immediately according to frequency deviation. Point B is the active power change point after frequency more than dead band 3 seconds. At point C, frequency return to the dead band. It is an effective disturbance when the frequency exceeds the dead band (50±0.033Hz) and lasts for 6 seconds or more, and the maximum frequency deviation reaches 50±0.038Hz or other requirement.

2.2. Assessment method
The major mode of assessment of power grid PFC performance is speed governing droop method. According to the technical standard, the speed governing droop of the thermal power unit’s PFC should be 3%-5%[8-10]. If the speed governing droop is smaller, the greater contribution of unit contributes to the power grid. The calculation formula as follows

\[
L = \frac{\left| f_t - f_n \right| - 0.033}{P_t - P_0} 
\]

Among them, \( P_0 \) is the unit’s power value at power grid frequency beyond the dead band, \( P_t \) is the unit’s active power value at time \( t \), \( f_t \) is the frequency value corresponds to \( P_t \), \( f_n \) is the grid’s rated frequency 50Hz, \( P_n \) is the unit’s rated power.
3. Performance Evaluation Based on Modeling and Identification

Taking the PFC performance evaluation method identified by the system as the core, the historical operation data of thermal units are processed automatically through matlab program. The PFC data segment is selected to establish a mathematical model between the speed, main steam pressure and actual power. The PFC performance index is calculated from the model step response.

3.1. Data Segment Acquisition Means

First, based on the perturbation judgment of 6s lasting beyond the dead zone of frequency, and combined with the situation of power grid, the data segment suitable for the evaluation of PFC performance is obtained from the historical operation data of thermal power units throughout the month or the whole day. Considering the national standard and the operation experience of dispatch control centre, the unit can be exempted from assessment in the following situations, PFC exit, unit continuous rise or fall of output, the unit output less than the minimum stable combustion load.

According to the above constraints, the unit’s operation data is selected. The selected normal PFC data segment is shown in figure 2. It can be seen that the PFC response is obvious. During PFC operation, the direction of unit’s active power change is opposite to that of frequency change, and the direction of main steam pressure change is the same as that of frequency change.

3.2. Modeling

Model the selected data segment, the formula is

$$\hat{p} = \min \left\{ 1, \max \left\{ 0,1 - \frac{\sum_{t=1}^{N}(p(t) - \bar{p})}{\sum_{t=1}^{N}(\hat{p}(t) - \bar{p})} \right\} \right\}$$

Where, $\hat{p}$ is the model estimated value of the actual power, $p(t)$ is the unit’s actual active power, $\bar{p}$ is the average of the actual active power, and $fit$ is the fitting between the model and the actual active power.

According to the fitting degree of the model, the evaluation can be divided into A and B. Situation A is that the model has good quality and the rotation speed is the main reason for the change of actual active power. Then, the system modeling method is used to evaluate its performance and obtain more reliable performance indicators. Situation B is that the model has poor fitting degree, the speed is not the main reason for the change of real power, and the performance evaluation is of little significance.
3.3. Performance Evaluation
In case A, a step input is given to the model, then, the performance evaluation result is obtained from its step response. In order to facilitate observation and analysis, the amplitude of the step response should correspond to the actual speed change. After a series of tests, combined with the current PMU characteristics of the power grid, the weighted linear least squares and the local regression of the first polynomial model are used to filter the speed, and good results can be obtained.

Figure 3. Estimation of speed and actual power under step response of the model
As shown in figure 3, by comparing the original data in figure 2, it can be seen that the estimated value of the model is basically consistent with the actual power change observed by the eye, so the calculation result is relatively reliable.

4. Practical Application
According to the regulations for the grid-connected operation and management of power plants, the frequency step simulation experiment was carried out. The frequency is lower than the 50Hz, so the thermal unit needs to increase the active power to make the frequency return to the standard 50Hz.

The standard calculation basis is shown in figure 4. \( r_0 \) is the starting point of the step response corresponding to the dead zone of rotation speed. \( \Delta r \) is the variation amplitude of the step response corresponding to the change of rotation speed. \( t_1 \) is the moment when the rotation speed exceeds the dead zone, that is, the first non-zero point of the step response. \( p_0 \) is the starting point of the real power before the change corresponding to the model response. \( t_2 \) is the change time of the real power. \( t_3 \) is the stable time corresponding to the model response. \( \Delta p \) is the change amount of the real power.

The response time is \( \tau = t_2 - t_1 \). The stable time is \( T = t_3 - t_2 \). The speed governing droop equals to
\[
\delta = -\frac{\Delta r}{\Delta p / p_n}.
\]
Among them, \( r_n \) is the rated speed.
4th International Conference on Energy Equipment Science and Engineering  IOP Publishing
IOP Conf. Series: Earth and Environmental Science 242 (2019) 032015 doi:10.1088/1755-1315/242/3/032015

Figure 4. PFC performance index obtained from the step response

Figure 5. Load response speed indicators

Referring to the PFC experiment of the unit at the power plant site, the value of the dead band of the frequency deviation can be obtained from the speed curve, and the value of the speed governing droop of the power can be used to obtain the additional value of the actual power of the unit \( \Delta p \), then \( \Delta p \) is the unit's target load. Therefore, the load response speed can be discriminated on the original data actual power curve, and whether the thermal power unit can reach the target load within the specified time can be determined.

The red and black dots in figure 5 respectively represent the load change values reached in 15s and 30s during the operation of the PFC. It can be clearly seen from figure 5 that the load change value at 15s reaches 75% of the target change value, and the load change value at 30s reaches 90% of the target change value, which satisfies the national standard requirement. Comparing the actual data and curves of unit, the modeling simulation results are completely matched with the actual results, and the fitting degree exceeds 90%.

5. Conclusion

Because of the rapid development of new energy brings great challenges to the frequency control of power grid, at the same time, the early adjustment of power grid frequency mainly depends on the PFC of thermal power units, the PFC of thermal units is required to act quickly and accurately. In view of the limitations of traditional PFC performance evaluation, combined with the grid’s PFC technology standards, through the history of thermal power unit operation data, by selecting appropriate PFC data section, the mathematical model based on rotational speed, the main steam pressure and actual power were established. The performance index of PFC can be calculated from the model step response. The simulation and practical operation results show that the proposed method effectively represents the PFC performance of the unit and provide one reliable means to power grid to monitor the PFC performance. The modeling simulation results are completely matched with the actual results, and the fitting degree exceeds 90%.

References

[1] G. Nowak, A. Rusin. (2013) Shape and operation optimization of a supercritical steam turbine rotor. Energy Conversion and Management, 74:417-425.

[2] T. Liu, W.D. Zhang, F. Gao. (2007) Analytical decoupling control strategy using a unity feedback control structure for MIMO processes with time delays. J. Process Control, 17:2007.

[3] Li Duanchao, Chen Shi, Chen Zhongyuan. (2004) Real-time measurement and reward method of the efficiency of generator unit primary frequency regulation. Automation of Electric
Power Systems, 28(2):70-72.

[4] Huang, H.P. & Jeng, J.C. (2002) Monitoring and assessment of control performance for single loop systems. Ind. Eng. Chem. Res., 41:1297-1309.

[5] Fu Yuan, Wang Yi, Zhang Xiangyu, et al. (2014) Analysis and integrated control of inertia and primary frequency regulation for variable speed wind turbines. Proceedings of the CSEE, 34(27):4706-4716.

[6] F.Shinskey. (1996) Process Control Systems Application Design Adjustment. McGraw-Hill, New York.

[7] YIN Feng. (2005) Test and research on CCS-joined primary frequency regulation of thermal power units. Electric Power, 38(3):22-24.

[8] Zheng Tao, Gao Fuying. (2009) On-line monitoring and computing of unit PFR characteristic parameter based on PMU. Automation of Electric Power Systems, 33(11):57-61.

[9] K.H. Park, Z. Bien, D.H. Hwang. (1998) Design of an iterative learning controller for a class of linear dynamic systems with time delay. IEE Proc. Control Theory Appl., 145:1998.

[10] Yu Daren, Guo Yufeng, Xu Jiyu. (2000) The primary frequency regulation stability of parallel turbo-generators. Proceedings of the CSEE, 20(9):59-63.