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Suggestion on load regulation reserve capacity criterion of china power system

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Abstract. This paper firstly explains the mechanism of frequency deviation caused by load fluctuation and their mapping relationship. Based on the systematic survey and analysis on the load regulation reserve criteria of China, Europe, and United States, suggestions on load regulation reserve capacity are proposed. The results contribute to improving load regulation reserve criteria in auxiliary service markets and power grid planning of regional and provincial grids.

1. Introduction

System load reserve is set to cope with system load fluctuations in a short period of time and unplanned increases and decreases.

China's current load reserve capacity is selected by experiences, which does not have a definite principle. Although the definition and function of load reserve capacity are clear and the implementation form is unified, with the continuous expansion of power system scale and the deepening of power market reform, the rough evaluation method based on the percentage of power generation load cannot meet the needs of large-scale power system analysis. During the implementation process, there are three problems[1]: ① Missing selection basis. There is no reasonable basis and method for the industry standards and enterprises. Except for the method determined by the load percentage, there is no detailed method for evaluating the reserve capacity of the load. ②Not considering the actual characteristics of the grid. Power system scales and structures and load levels and characteristics vary respectively, making the grid have its own actual characteristics. ③ Not correctly guiding the design of load backup auxiliary markets. In the electricity market environment, it is necessary to weigh the auxiliary services of frequency regulation and economics in case of safety.

In recent years, systematic research on load reserve capacity has rarely been seen domestically and abroad. Literature [2] considered the dynamic load standby model under the time-sharing electricity price scenario, and selected less reference to the load reserve capacity of the spot market that was to be implemented. In literature [3], the load frequency characteristics of the British power grid were analyzed in depth, and reasonable load frequency sensitivity factors were proposed. The frequency load sensitivity coefficient of 2% MW/Hz was proposed, which did not make much sense for the characteristic grid reference.

This paper firstly explains the relationship between power system load fluctuation and frequency regulation. Then, the paper systematically discusses the load reserve standards of power grids in China, Europe, North America and other regional power grids. The system and values of load reserve capacity selection in China power grid are suggested, which is of great reference significance for regional and provincial grids for load reserve capacity reservation in renewable energy [4-9] and electricity markets [2].

2. Load fluctuation and frequency adjustment of power system

In steady state, the frequency of the power system is a consistent operating parameter of the whole system. Figure 1 shows that when the total output and the total load are unbalanced, active power exists deviation, and a frequency deviation occurs. The grid frequency reflects the current system power balance state. Through the system frequency offset data, the current system power deviation value can be obtained and the load fluctuation value can be evaluated.

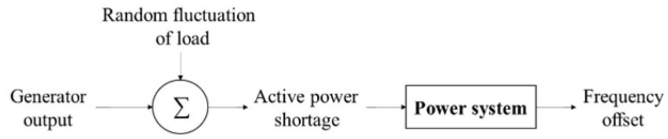

Figure 1. Diagram of active power deviation and frequency deviation.

2.1. Load fluctuation of power systems

In actual operation, the load fluctuation of power systems has certain rules, which can be divided into two types: under normal conditions and under abnormal conditions. The load fluctuation under normal conditions shows a certain periodicity in terms of time, and the load change under abnormal conditions varies with the type of fault and the development process.

Load fluctuations under normal conditions are usually composed of load components of three different variations.

(a) A load component with a variation period of less than 10s and a small variation range. The variation law of this kind of load is: the amplitude of the load change is small, and the variation amplitude is generally lower than 1% of the load peak; the load change rate is large, and the change rate can change the load peak value by more than 5% per minute; the load change changes direction. Changing directions are the most frequent changes, which happens hundreds of times per hour.

(b) The load component with a period of change between 10s and several minutes. The main types of such loads are electric furnaces, rolling machines, electric locomotives, etc. The variation law of this kind of load is: the magnitude of the load change is small, and the average change amplitude is about 2.5% of the load peak; the load change rate is large, and the average change rate is about 1%~2.5% of the peak load per minute; changing directions are relatively frequent, which happens 20-30 times per hour.

(c) A continuously changing load changes slowly. The causes of such load changes are mainly the work and rest of various industries, the lifestyle of residents, and the changes in weather. The variation law of this kind of load is: the magnitude of the load change is large, and the amplitude of the day-night load change (that is the peak-to-valley difference of the power system) tends to be above 40% of the load peak; the load change rate is small, and the average change rate is every minute. The peak value of the load is about 0.5%; the number of changing direction times is small, which is from ten to several dozen times.

(2) Load fluctuation under abnormal conditions

The abnormal change of the load refers to the imbalance between the sudden prime mover power and the generator electromagnetic power caused by the fault of generator tripping, loss of exchange power with the adjacent power systems, loss of large power load, etc. The most common event is a sudden trip of the generator sets, which is uncoupled from the power system. In the abnormal situation of power systems, the law of load change is as follows:

(a) The magnitude of the load change is large, and the maximum change amplitude is the largest single power supply capacity considering only a single fault condition;

(b) The load change rate is large, and the whole change process is completed in an instant;

(c) The load change is unidirectional and does not change direction by itself.

2.2. Frequency regulation of power system

Since the load is constantly changing, any change in load can cause a power imbalance across the system, which can cause fluctuations in the system frequency. The frequency fluctuation of the power system will adversely affect the users, the power plant and the power system itself. Thus, the frequency must be kept above and below the rated 50 Hz, and the offset cannot exceed a certain range, which requires the frequency regulation of power systems[10-14].

Power system frequency regulation can be divided into three levels, primary [15-16], secondary and tertiary regulation. The functions of each level complement each other. The primary frequency regulation is the automatic response of the load and the generator to the grid frequency change; the secondary frequency regulation is mainly to control the active processing of the generator by the Automatic Generation Control (AGC) [17-18] software of the power grid dispatching center, thereby quickly recovering the frequency offset; the tertiary frequency regulation distributes the power output of the power plants through the economic dispatch optimization.

3. Load reserve capacity criteria of China

This section introduces China's accident reserve capacity selection criteria in two levels: industry standards and national standards. In terms of industry standards, there are "Technical Guidelines for Power Systems (Trial) SD131-84 "[19]. The specified load standby is 2% to 5% of the maximum power generation. The low value is suitable for large systems and the high value is suitable for small systems. In terms of national standards, there is "Grid Operating Guidelines (GB/T 31464-2015)"[20], which stipulates that during normal operation, the grid dispatching agency should arrange appropriate reserve capacity and organize the allocation of capacity.

State Grid Corporation of China follows the industry standard, and the load reserve capacity is 2% to 5% of the maximum power generation; China Southern Power Grid Corporation stipulates that the load reserve is not less than 2% of the maximum load of the whole network.

4. Load reserve capacity criteria abroad

4.1. Load reserve capacity criteria of Europe

ENTSO-E (European Network of Transmission System Operators for Electricity), covering most of European area, divides the reserve into three types, namely frequency containment reserve, frequency recovery reserve, and replacement reserve [21-23].

(1) Frequency containment reserve

The frequency suppression preparation is used to maintain the operational reliability of the system, and to maintain the stability of the system frequency after an accident or fluctuation occurs. However, the frequency suppression preparation is differentially regulated, and the power exchange between the frequency and the area of the system is not restored to normal value.

(2) Frequency recovery reserve

The frequency recovery reserve controls the load fluctuation under normal conditions and the fluctuation of the system frequency and the power exchange between the areas after the accident occurs, and maintains the balance between the power generation and the load in the control area, so that the frequency of the system returns to the normal value.

(3) Replacement reserve

The replacement reserve is manually controlled by the TSO to release the frequency recovery backup if the frequency is restored to normal, or as a supplement to the frequency recovery backup in the event of a large accident to restore the system frequency to normal value.

Five power organizations of ENTSO-E (ATSOI, BALTSO, NORDEL, UCTE, and NGET) have no separate provision for load reserve, disperse it in three types above[24-28].

This paper analyzes the three major areas such as UCTE, NORDEL, and NGET, which are with larger scale grid. The reserve system and reserve capacity are selected as shown in Table 1.

UCTE is the largest synchronous grid in Europe. The three reserves are defined as primary, secondary, and tertiary control reserve. The primary control reserve is mainly determined according to the fault; the secondary control reserve maintains the balance between power generation and load in the control area, which is mainly determined according to the load, and considers the primary control, also for a partial replacement. The tertiary control reserve releases primary control and secondary control reserve, which serves as an alternative. UCTE belongs to a large-scale power grid, and the normal fluctuation of the load does not trigger a control reserve. Therefore, the UCTE load reserve belongs to the secondary control reserve (frequency recovery reserve) range.

NORDEL reserve system mainly includes frequency control normal operation reserve, frequency control disturbance reserve, fast disturbance reserve and slow disturbance reserve. Frequency control normal operation reserve is used to balance the normal fluctuation of power generation and load; frequency control disturbance reserve is used to stabilize the frequency offset after an accident; fast disturbance reserve is used to release frequency control normal operation reserve and frequency control disturbance reserve; slow disturbance reserve is after 15 minutes. Load reserve is used to balance the load fluctuation under normal operating conditions, and the frequency is controlled at 49.9~50.1Hz, which is a range for frequency containment reserve.

Table 1. Reserve system and load reserve capacity of three main regions in ENTSO-E.

	UCTE	NORDEL		NGET	
		reserve system			
frequency containment reserve	primary control reserve	frequency control normal operation reserve	frequency control disturbance reserve	dynamic frequency response	non-dynamic frequency response
frequency recovery reserve	secondary control reserve	fast disturbance reserve		none	
replacement reserve	triple control reserve	slow disturbance reserve		fast reserve	short-running reserve
		load reserve capacity			
reserve subjection	frequency recovery reserve	frequency containment reserve		frequency containment reserve and replacement reserve	
calculation method	$R=\sqrt{a\cdot L_{\max}+b^2}$	none		none	
reserve rate	0.47%of peak load	0.94% of peak load		1%～1.15% of peak load	
response speed of generation	none	none		25MW/min	
reserve response time	30s-15min	2-3min		dynamic frequency response in real-time, fast reserve within 2min, at least 15min	

[a] R is minimum load reserve, $L_{\max}$ is peak load in some time in control region, a and b is determined by operating experience, a=10MW, b=150MW.

NGET divides the reserve into frequency response reserve, fast reserve, short-running reserve, and balancing mechanism start. The frequency response reserve is divided into dynamic and non-dynamic, the dynamic response is mainly for load fluctuation, and the non-dynamic is mainly for faults, which is used for frequency containment reserve. NGET is an island country. There is no frequency recovery reserve. The fast reserve is mainly used to cope with possible load fluctuations in the future. It must be started within 2 minutes, which is a replacement reserve. The short-term operation reserve is related to the electricity market, and the unit should be unavailable. It is an alternative reserve; the balance mechanism is activated, mainly because the British National Grid signs a contract with the power producer to ensure the supply of electricity. Associated with load fluctuations is dynamic frequency response and fast reserve in NGET.

4.2. Load reserve capacity criteria of North America

North American load standby reserve concludes North American Electric Reliability Corporation (NERC), Regional Reliability Organization (RRO), and Independent System Operator (ISO/RTO). Reserve system of nine power operators in the North American independent system operators and the regional power transmission organization committees all have regulation reserve and spinning reserve [29-39].

In North American reserve classification, the regulation reserve is generally defined as: reserve in the case of non-fault conditions, which should be set to maintain rapid and frequent load fluctuations and power imbalance caused by generator output changes. The main function is ① correct load or generator output deviation; ②correct load forecast deviation; ③ maintain system frequency at rated value. From the definition and function of the regulation reserve, China's load reserve definition is basically the same.

In the North American power system, due to its large scale, the load regulation effect is strong, and the load fluctuation under non-fault conditions cannot trigger the primary frequency regulation of the unit. The regulation reserve of the North American power system is provided by the AGC controlled unit. In actual operation, the balance area control center sends an AGC control signal, and the unit adjusts the output according to the control signal to balance the power system load and power generation in real time.

4.2.1. Regulation reserve of NERC Regulation reserve is a certain number of rotation reserve in NERC, which can quickly respond to the AGC signal and provide enough normal adjustment range. The regulation reserve is suitable for non-fault situations, dealt with the power deviation caused by the difference between the load and the generator output. It is stipulated that each balance area should maintain a certain number of adjustment standbys controlled by AGC, so that Area Control Error (ACE) meets the Control Performance Standard (CPS). Units that provide regulations must be able to respond quickly to AGC signals, increase or decrease output, track minute-level load changes, and correct output changes of generator.

The CPS is based on a rigorous mathematical statistical method, due to control the frequency deviation and the exchange power of tie-lines in control area. The standard is based on the ACE evaluation of the contribution to the entire grid frequency, so that the control target becomes the safe and stable control of the entire grid, which fully meets the control needs of the grid and ensures the economic benefits of most regions.

4.2.2. Regulation reserve of ISC Reserve criterion of nine power operators in ISC as shown in Table 2. The paper summarizes and presents in terms of load reserve function, the unit governor participation in the control, the AGC control signal, the load reserve determination principle, etc.

In comparison with domestic criterion, the ISO/RTO load reserve capacity percentage of the 2015 system peak load is shown in Figure 2.

As can be seen from Figure 2, the scale of AESO grid is minimum. The regulation reserve capacity has a large proportion of peak. Since ISO-NE has successively put the generations with strong adjustment capability into operation, and with the improvement of the communication control device, the regulation reserve requirements have gradually decreased, and the regulation reserve capacity has the smallest proportion of peak among the ISC subordinate power operators. The scale of CAISO and

SPP grid is similar, and the ratio of regulation reserve to peak load is also the same. A large scale of wind power is installed in ERCOT, and the uncertainty and volatility of wind power output require the system to reserve more regulation reserve. Therefore, the regulation reserve capacity of ERCOT has the largest proportion of peak load. The PJM system scale is the largest. When the load fluctuates, the system's own regulation ability is strong and the required reserve capacity is small. Thus, the regulation reserve has a lower proportion of peak load.

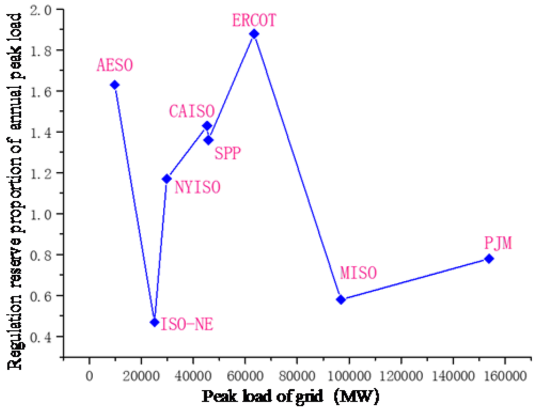

Figure 2. Regulation reserve to annual peak load ratio of 9 ISO in North America.

There are several factors that affect the regulation reserve capacity by power operators in various regions:

(1) The strength of the generation's regulation capability

The generation's regulation capability includes the unit's response speed, the generation's minimum regulation capacity, the generation's ramping rate, etc., and the system with strong regulation capability can adjust the reserve capacity to a slightly lower value. The system with more water motor assembly machines considers the fast response characteristics of the hydropower unit, and its regulation capability is strong. If the proportion of the standby water turbine unit is increased, the adjustment of the reserve total amount can be correspondingly reduced. At the same time, if the system communication control device is improved and the unit control capability is strengthened, the total amount of regulation reserve can also be appropriately lower, which is the case in the ISO-NE grid.

(2) Structure of load type

Load types include loads that are independent of frequency (e.g. incandescent lamps), loads that are proportional to frequency (e.g. ball mills), proportional to quadratic frequencies (e.g. eddy current losses in transformers), and proportional to cubic frequencies (e.g. ventilators) and types that are proportional to the higher orders of the frequency (e.g. circulating water pumps with large hydrostatic head resistance). Different power grids have different types of load, and their sensitivity to frequency is also different. Therefore, to meet the qualified CPS assessment standards, there are also differences in the regulated reserve capacity settings in each region.

(3) Renewable energy sources

The access of renewable energy sources such as wind power and solar energy has changed the characteristics of the power generation in previous system, which makes the generation output uncertain and volatile. They bring difficulties and challenges to keep balance between output and load and the settings of regulation reserve capacity. Renewable energy sources, especially grids with more wind power installed capacity, often need to reserve more regulation reserve capacity, which is the case in ERCOT.

(4) Load forecasting

During operation, the system operators formulate power generation and reserve plans based on the load forecasting. The accuracy of the load forecast will affect the formulation of the above plan. If the load prediction accuracy is high, the power generation plan based on this can better balance the system output and load, which can reduce the reserve capacity correspondingly.

Table 2. Regulation reserve criterion of nine power operators in ISC.

	NPCC				WECC		ERCOT	MISO	SPP
independent operator	ISO-NE	NYISO	PJM	IESO	CAISO	AESO	ERCOT	MISO	SPP
function	respond to load fluctuation,balance generation output and load in real time	track changing load, balance load and output, maintain frequency at 60Hz	correct the power deviation caused by load fluctuations, maintain frequency at 60Hz	respond to load fluctuations, balance system output and load (including power loss)	balance generation output and load	respond to load fluctuation, balance generation output and load in real time	respond to load fluctuations, maintain frequency within reasonable range	respond to load fluctuations and load prediction error, balance generation output and load	respond to load fluctuations, fast response power deviation
generation governor participates in control or not	no	yes	no	no	no	no	yes	no	no
AGC control signals need or not	yes	yes	yes	yes	yes	yes	yes	yes	yes
divide into up/down adjustment or not	no	no	no	no	yes	no	yes	no	yes
regulation reserve principle	base on CPS assessment standards								
peak load(MW)	25081	29781	153782	25815	45809	9806	63400	96790	45373
proportion of peak to load	0.47%	1.17%	peak load 0.78% valley load 0.70%	no	up1.36%, down1.36 %	peak load1.63 % valley load 1.22%	up 1.88%, down1.88 %	0.58%	up 1.43%, down 1.25%
trigger time of regulation reserve	several seconds	several seconds	fast response	several seconds	several seconds	several seconds	4-6s	4s	fast response
the longest time required to fully invest (min)	5	5	5	no	10-30	15	10	5	60
generation minimum ramping rate (MW/min)	60	no	no	50	no	no	no	1	no

5. Suggestions on load reserve capacity in China

5.1. Experiences from foreign load reserve capacity criterion

European ENTSO-e and North American power system reserve capacity criterions are different in terms of system and value. The principle of reserve determination is basically the same. The following can be used for reference.

(1) System

The system divided into two layers in five regions of ENTSO-E, the system divided into three layers (NERC, RRO, and ISO) in North America. Their criterions present from coarse to fine, considering universality and difference.

(2) Value

Grids of different scales, characteristics, load properties, etc., do not require the same value and type of operational reserves.

The value of ENTSO-E load reserve rate is based on the standard of large regional with high reserve ratio and small regional with low reserve ratio. The ISO in North America is further refined to peak/valley load or up/down values.

5.2. Suggestions on load reserve capacity criterion in China

At present, China's power system has many characteristics: ① with the rapid development of UHV AC and DC, the scale of power exchange capacity between inter-regional and inter-provincial levels has been increasing. Due to the elimination of renewable energy, hydropower and other clean energy policies, it has increased the difficulty of regional or provincial generations to cope with load fluctuations; ② with the continuous deepening of the power market reform, the load reserve capacity under frequency regulation has a greater impact on the design of the auxiliary power market, and it is also a game of reliable abundance and economy; ③ the utilization hours of coal-fired power plants have decreased drastically year by year, and in order to further respond to policies such as increasing the proportion of non-fossil energy consumption, the installed capacity and proportion of nuclear power, wind power and cogeneration will also increase. Under such conditions, their access will cause the system to peak the difficulty to a certain extent, especially the small way, thus increasing the difficulty of the generation to cope with the fluctuation of the valley load.

The current criterion generally causes the load reserve capacity redundancy, which determined by the percentage of the maximum power generation. It also reduces the power system operation efficiency to a certain extent. Considering the vastness of China and the differences in the characteristics of various grid systems, this paper proposes the following recommendations from the system and the two levels of load reserve capacity standards:

(1) System

① Establish industry-level, regional power grid-level, and provincial-level load reserve criterions from top to bottom. The industry criterion mainly involves the AGC control and ACE assessment standards, and does not specify the content of the localization design such as the primary frequency regulation, secondary frequency regulation, and the response time.

② The load reserve criterion should be formulated to meet the load changes, and can be continuously developed and improved according to the grid characteristics, load characteristics, and market environment.

(2) Value

① It is based on the principle that the large-scale grid reserve rate is lower and the small-scale grid reserve rate is higher. The specified percentage value is not specified. It is recommended to roll the plan or plan the load reserve value according to the system scale and characteristics year by year.

② The probability distribution of the active power deviation is obtained by sampling the frequency offset value of the actual system for a period of time with high frequency, and combining the integrated frequency characteristics to obtain the probability distribution of the load reserve.

③ Distinguish reserve capacity value of peak load/valley load time, which can improve equipment utilization rate in grids

6. Conclusions

With the increasing of regional network scales, system scale, renewable energy scales, the deepening of power market reform, from the perspective of satisfying marketization and improving equipment efficiency on the premise of ensuring system security, this paper firstly explains the mechanism of frequency deviation caused by load fluctuations and the mapping relationship between the two. Then, it systematically investigates and sorts out the load reserve criterions of China, Europe, North America and other countries or regions. This paper presents the preliminary suggestions on load reserve criterions for China, regional and provincial levels. The results provide references of load regulation reserve auxiliary service market and power grid planning for China's regional and provincial power grids.

References

[1] Zheng Xiubo, Lin Yong, Bie Chaohong, et al 2012 Study on Selection of Reserve Capacity of Guangdong Power System [R] *Guangzhou: Power Grid Planning Center of Guangdong Power Grid Company*
[2] CHANG Xiangwei, ZHANG Youbing, CAO Yijia, etc 2011 Influence of time-of-use strategy on optimal load reserve capacity in market environment [J] *Power System Technology* **35(11)** 206-211
[3] James W Taylor ,Matthew B 2016 robertForecasting frequency-corrected electricity demand to support frequency control[J] *IEEE Transactions on Power System* **31** 1924-1932
[4] Zhang Nan, Huang Yuehui, Liu Dewei, etc 2016 Reserve capacity calculation of power system considering wind power integration[J] *Proceedings of the CSU-EPSA* **28(3)** 6-10
[5] Gao Feng, Ma Shuo, Zhang Shuang et al 2014 Research and determination of reserve requirements in power system with significant wind power penetration[J] *ELECRIC POWER* **47(8)** 72-78
[6] Su Peng, Liu Tianqi, Li Xingyuan 2012 Determination of optimal spinning reserve of power grid containing wind [J] *Power System Technology* **12(34)** 158-162
[7] KIM Y J,DEL-ROSARIO-CALAF G,NORFORD L K 2017 Analysis and experimental implementation of grid frequency regulation using behind-the-meter batteries compensating for fast load demand variations [J] *IEEE Trans on Power System* **32(1)** 484-498
[8] LAM A Y,LEUNG K C,LI V O 2016 Capacity estimation for vehicle-to-grid frequency regulation services with smart charging mechannism [J] *IEEE Trans on Smart Grid* **7(1)** 156-166
[9] CHANG G W, CHUANG C S, LU T K, et al Frequency-regulating reserve constrained unit commitment for an isolated power system[J] *IEEE Transactions on Power System* 2013 **28(2)** 578-586
[10] Wu Jiekang,Shi Meijuan,Chen Guotong,et al 2009 Immune genetic algorithms for modeling optimal reserve capacity of interconnected regional power systems[J] *Proceedings of the CSEE* **29(1)** 14-20
[11] R Pearmine, Y,H, Song, TG Williams, et al 2006 Identification of a load-frequency characteristic for allocation of spinning reserves on the British electricity[J] *IEE Proc-Gener TransmDistrib***153(6)** 633-638
[12] SKPandey, SRMohanty, NKishor 2013 A literature survey on load-frequency control for conventional and distribution generation power system[J] *Renewable and Sustainable Energy Reviews* **25** 318-334
[13] Yang Mi, Xuezhi Hao, Yongjuan Liu, et al 2017 Sliding mode load frequency control for multi-area time-delay power system with wind power integration [J]*IET Generation Transmission & Distribution* **11(18)** 4644-4653
[14] Innocent Kamwa, Annissa Heniche,Martin De Montigny, et al 2014 Long Term Statistical Assessment of Frequency Regulation Reserves Policies in the Quebec Interconnection [J] *IEEE Trans on Sustainable Energy* **3(4)** 868-879
[15] Liu Mingsong, Sun Huangdong, He Jian 2011 An optimization method for spinning reserve in primary frequency control considering transient frequency deviation[J] *Power System Technology* **35(11)** 206-211

[16] Jin Na, Liu Wenying, Cao Yinli, et al 2012 Influence on the grid frequency characteristic by the parameters of primary frequency modulation of large capacity generator units [J] *Power System Protection and Control* **40(1)** 91-95
[17] "Power system frequency modulation and automatic power generation control"Editorial committee Power system frequency modulation and automatic power generation control [M]*Beijing: China Electric Power Press* 2006
[18] Xu Rui, Teng Xianliang, Ding Qia, et al 2016 Study of AGC control mode changing technology for complex condition of power grid[J] *Power System Technology* **40(6)** 1785-1791
[19] Ministry of Water Resources and Electric Power Power System Technical Guidelines(SD131-84) [S]*Beijing: Water Power Press* 1984
[20] China National Standardization AdministrationGrid operation guidelines(GB/T 31464-2015)[S] *China Standard Press* 2015
[21] ENTSO-EAgreement regarding operation of the interconnected Nordic power system[S]2016
[22] ENTSO-EAppendix of system operation agreement[S]2016
[23] ENTSO-ESupporting Document for the Network Code on Load-Frequency Control and Reserves[S] *European Network Code on Load-Frequency Control and Reserves* 2013
[24] Frequency control in the Nordic Power System experiences and requirements [C]IEEE Power Engineering Society: 1999 Winter Meeting, 31 Jan-4 Feb,1999
[25] UCTE(Union for the Coordination of Transmission of Electricity)UCTE operation handbook policy 1: load-frequency control and performance[S]2009
[26] UCTEUCTE operation handbook appendix 1: load-frequency control[S]2004
[27] NORDIC(Organ for Nordiskt Elsamarbete)Nordic Grid Code 2007（Nordic collection of rules）[S]2007
[28] NGETBalancing principles statement[R]2009
[29] NPCC(Northeast Power Coordinating Council)NPCC regional reliability reference directory #5 reserve[S]2015
[30] ISO-NE(Independent System Operator New England) IncISO New England operating procedure No8 operating reserve and regulation[S]2015
[31] NYISO(New York Independent System Operator) NYISO locational reserve requirements [S]2015
[32] PJM Interconnection LLCPJM manual 13:emergency operation [S]2016
[33] IESO(Independent Electricity System Operator)Daily market summary(Wednesday, Nov15, 2017)[R]2017
[34] WECC(Western Electricity Coordinating Council)WECC standard BAL-STD-002-03 Purpose: Regional Reliability Standard to address the Operating Reserve [S]2014
[35] CAISO(California ISO)Day-ahead daily market watch for operating day of 06/26/18 [R]2018
[36] AESO(Alberta Electric System Operator)Alberta Reliability Standards [R]2018
[37] ERCOT(Electric Reliability Council of Texas) ERCOT methodologies for determining ancillary service requirement [S]2016
[38] MISO(Midcontinent Independent System Operator) IncMISO FERC Electric Tariff SCHEDULES: Demand Curves for Operating Reserve, Regulating and spinning[S]2017
[39] SPP(Southwest Power Pool) IncSPP operating criteria revision 15[S]2015