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Theoretical Studies of Automatic Generation Control Technology

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ABSTRACT: This paper presents new techniques of Automatic Generation Control (AGC) technology which are employed to increase the certain demand of power system stability and control. Today, power system control operation is fully automated with an Automatic Generation Control (AGC) technology and improves the reliability, productivity and efficiency of power industry. The power generating equipment can be controlled by maintaining the power system frequency at constant value. And power system frequency control is achieved by Automatic Generation Control (AGC) and governing systems of individual turbine-generators. This achieves the automation of whole power plant based on automatic control of water-turbine generator. Therefore the mechanism of Automatic Generation Control (AGC) makes operation limitation condition units that ensure the safe operation of power plant with the principle of Energy Management System and primary functions. At the time of carrying out these functions, it is necessary to avoid the frequent start/stop of units caused by short-term load fluctuation of power system and detail problems are discussed in the paper. At the end study is also focused in engineering problems and target function of Automatic Generation Control (AGC) in hydropower plant.

KEYWORDS: AGC, Power System, Hydropower Plant, load distribution, active power control engineering problems.

1 INTRODUCTION

Automatic Generation Control (AGC) is an integral part of Energy Management System and primary function of the Automatic Generation Control (AGC) is to balance the total power system generation versus system load and losses [1]. In 1989 the Automatic Generation Control (AGC) technology was first introduced which had an operation in continuously and successfully. In this account power plant operation security was significantly improved and it raised the plant automation control and operation function level [2]. Therefore huge demand of Automatic Generation Control (AGC), eventually reasonable economic benefits were obtained. In short way, this paper initially presents the Control technical levels of Automatic Generation Control (AGC) in the manner of theoretical study and focus on mode of operation of AGC, Frequency adjustment of power system, engineering problems and as well as load and no load disturbance. This paper also examined the Automatic Generation Control (AGC) method in power system of hydropower plant [3].

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1.1 FREQUENCY ADJUSTMENT OF POWER SYSTEM

The frequent load change of each power station results to imbalance power of whole power grid, thus leading to frequency fluctuation of power grid. Function of frequency adjustment of power system, When the system frequency fluctuates, adjust generator output to reach new balance, so as to keep the frequency deviation be within allowable range [3].

Variation of three kinds of load:

- Random load component: variation period is less than 10s, small amplitude and short period.
- Impactive load change: variation period is 10s to 2~3 minutes, large amplitude.
- Long period component: the period is about 2~3 minutes to 10~20 minutes; it is load change caused by production, daily life and meteorology and so on, has its regularity and can be forecasted.

1.2 PRIMARY FREQUENCY ADJUSTMENT

The primary frequency adjustment is for first kind of load change component. It is finished under the combined action of generator prime mover and load regulation effect. Therefore, it has the highest response speed.

The primary adjustment refers to differential regulation. The more load changes, the more frequency deviates. Therefore, it is impossible to meet requirement of frequency quality only by means of primary adjustment.

1.3 SECOND ADJUSTMENT OF FREQUENCY

The secondary frequency adjustment is for the second kind of load change component. This kind of adjustment has to be realized through automatically or manually changing the synchronizer (also called as frequency modulator) of FM generator. The change of synchronizer position will translate the static characteristic of speed governing system and change generator output, so as to modulate frequency.

Un-differential regulation can be achieved if the capacity of FM unit is large enough. As for the secondary adjustment, in addition to requirement for reserve capacity of system, it is still required that the regulation speed can adapt to load change and the regulation course must be stable.

1.4 THIRD ADJUSTMENT OF FREQUENCY

The third adjustment is for the third kind of load change component. It regulates unit output as per time to execute power generation plan or redistributes output every once in a while (e.g. 1 minute) in accordance with principle of economical dispatching.

Forecast the short-term load of system correctly and arrange power generation program (including unit start/stop) reasonably to ensure the economical operation of whole system and achieve AGC control requirement in advance, thus avoiding frequent regulation of unit by AGC. At present, a large number of units still cannot take part in AGC. If these units can be strictly operate on schedule, they actually also take part in generation control, but in form of manual generation control (MGC). The output can be redistributed to AGC controllable units in accordance with result of online economical dispatching, so as to achieve economical operation.

2 AUTOMATIC GENERATION CONTROL (AGC) LOAD DISTRIBUTION PRINCIPLE

In proportion to capacity, as a simple load distribution principle, this kind of principle is usually used when some characteristic curves of water turbine set are incomplete or not precise enough

$$P_i = P_{AGC} \times \frac{P_{i\max}}{\sum_{i=1}^{n} P_{i\max}} \qquad (i = 1, 2 \cdots, n) \tag{1}$$

n : n set of units which take part in AGC

$P_{i\max}$: the unit number i taking part in AGC with maximum output under current head

$\sum_{i=1}^{n} P_{i\max}$: Sum of maximum outputs of all units taking part in AGC under current head

P_i : Active power distributed by AGC to unit number i taking part in AGC

2.1 DISTRIBUTION ACCORDING TO EQUAL INCREMENT

The total water consumption of hydropower plant is minimized on the premise that AGC target function has meet related restrictions. When the active power undertaken by hydropower plant is fixed (PL), it is necessary to distribute load among all generator sets according to equal consumption increment, so as to make the total water consumption be minimum.

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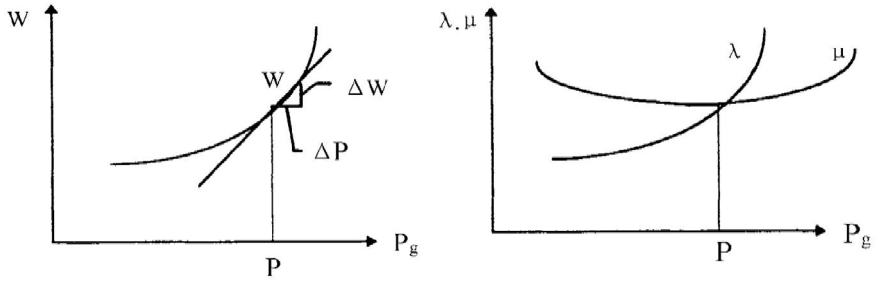

(a) (b)

Fig. 1. (a) Consumption Characteristics & (b) Variation of Specific Consumption and Consumption Increment

On the consumption characteristic curve, the specific valve of vertical coordinate and horizontal coordinate of some point is just the ratio of input energy and output power in unit time, which is called as specific consumption μ.

$$\mu = \frac{W}{P} \tag{2}$$

The tangent slop of some point on consumption characteristic curve is called as consumption increment λ, which refers to the specific value of input energy increment and output power increment in unit time, i.e.

$$\lambda = \frac{\Delta W}{\Delta P} = \frac{dW}{dP} \tag{3}$$

2.2 PRINCIPLE OF MULTI-OBJECTIVE PROGRAMMING

The in-plant AGC has to meet following objectives in order:

(1) Make provincial water generate more power;

(2) Make AGC distributed value close to set value as far as possible;

(3) Prevent units from frequently passing through the vibration area;

(4) The load fluctuation of units caused by two adjacent load regulations is minimized.

2.2.1 INTUITIONAL INTERPRETATION OF AGC

The ultimate purpose of hydropower plant AGC is to generate maximum electric energy with minimum water consumption on the premise of ensuring the safe and reliable operation of units. In power plant, each unit consumes different water amount even if with the same water regimen and same generation power due to its specific capacity and operation characteristics. Therefore, it is necessary to comprehensively consider multiple factors as water regimen, unit capacity, area where units cannot operate (cavitation area and vibration area), unit consumption characteristics, and operating conditions and so on for Automatic Generation Control, so as to achieve economical operation. Strategy of unit startup/shutdown

- Unit startup algorithm:

1. Theoretical startup condition: PAGC+Pb＞∑PT In the formula, Pb standards for rotation reserve capacity of whole plant; ∑PT is adjustable capacity of whole plant units which take part in AGC and is generating.
2. Theoretical number of operating units: Nk = (PAGC+Pb - ∑PT)/Pm + 1, In the formula: Nk is theoretical number of operating units; Pm is maximum capacity of single generator.

- Unit shutdown algorithm:

1. Theoretical shutdown condition: ∑PT －（PAGC+Pb）＞ Pm
2. Theoretical number of stopped units: Nt = (∑PT －(PAGC+Pb))/Pm

In the formula: Nt is theoretical number of stopped units

2.2.2 MEASURES TO AVOID FREQUENT STARTUP/SHUTDOWN OF UNITS

Set coverage area at both sides of adjusting range corresponding to theoretical number of operating/stopped units. In consideration of load change tendency of power plant, try best to avoid stopping unit which has operated only for a moment or immediately starting unit after it is shut down. Calculate the optimal number of operating units of each kind of unit in the next time interval according to forecasted load curve; then, compare number of units which has been in operation, optimal number of operating units required to operate in this time interval and optimal number of units to be operated in next time interval. If it is found that some units have to be shut down in current time interval and also some units have to start in next time interval, the optimal number of operating units in current time interval equals to that of next interval

2.2.3 PRINCIPLE OF UNIT STARTUP/SHUTDOWN SEQUENCE

- Priority set manually;
- Time of unit startup/shutdown and total cumulative time of startup/shutdown;
- Limit for shortest time of startup or shutdown;
- Requirement of plant service power and grounding requirement of main transformer neutral point;
- Priority of units with failed startup or shutdown automatically descends.
- The startup/shutdown priority of units is obtained through comprehensive calculation as per above principles. If you want to start or shut down units according to the manually set priority, please increase the priority coefficient manually set and make it be far more than priority coefficient of other factors, i.e. the startup/shutdown sequence of units is only related to manually set priority

3 AUTOMATIC GENERATION CONTROL OPERATION MODE

The establishment of automatic generation control operation mode is becoming increasingly significant element in view of increased load demand & reducing generating resources [4]. Therefor increasing load demands are seriously threats to reliable operation of power systems and due to control strategies are chiefly realized in power plant to maintain the generating unit [4].

3.1 SWITCH ON/OFF

Unit AGC switch-on means that the unit takes part in AGC and AGC program will carry out load distribution and startup/shutdown guidance. Unit AGC switch-off means that the unit doesn't take part in AGC and AGC program treats the

unit as unit with fixed load and will not carry out load distribution and startup/shutdown guidance for it. AGC function of whole plant can be manually switched on/off and will switch off automatically when there is no unit taking part in AGC. Whole plant AGC switch-on refers to start the function of unit load distribution and startup/shutdown guidance. Whole plant AGC switch-off refers to not start the function of unit load distribution and startup/shutdown guidance.

3.2 BLOCKING CONDITIONS OF AGC FUNCTION

When AGC function is switched on, if one of following blocking conditions is destroyed, switch off whole plant AGC, alarm and log in. No unit takes part in AGC; System frequency is more than upper limit of failure frequency or less than lower limit of failure frequency; Accident happens in power plant; When AGC control right is remote, there is communication failure between host and communication unit or between communication unit and provincial dispatching; The quality of system frequency measuring point is bad; When AGC control right is remote, the quality of remote setting value is bad.

3.2.1 POWER/FREQUENCY REGULATION MODE

AGC regulation mode can be divided into power regulation mode and frequency regulation mode. In case of AGC power regulation mode, the setting of whole plant given value includes two modes, i.e. curve and constant value. Curve mode: When the value setting mode is set to curve, the given load of whole plant tracks and sets the current value of curve. Constant value mode: Sometimes, the daily load curve cannot be provided due to difficulty to forecast future load. The general method is to receive the load dispatching command of cascade dispatching and adjust total load. Therefore, AGC provides whole plant active adjustment of given whole plant load.

3.2.2 FREQUENCY REGULATION MODE

Set function of frequency regulation for some FM power plants. This function can monitor bus frequency at all times, but cannot ensure the total active power of whole plant. When the frequency is out of normal FM section, AGC increases or decreases the load of units taking part in AGC according to KfEΔf until system frequency returns to normal FM section, or until load of units taking part in AGC reaches to upper and lower limit values of load with current head. When frequency (f) is within normal FM section:

$$P_{AGC} = P_{ACT} + K_{fN}\Delta f - \overline{P_{AGC}} \tag{4}$$

When frequency (f) is out of normal FM section:

$$P_{AGC} = P_{ACT} + K_{fE}\Delta f - \overline{P_{AGC}} \tag{5}$$

Adjustment open-loop/closed-loop: In case of open loop, AGC program only provides load distribution guidance for units taking part in AGC. In case of closed loop, AGC program provides active setting value of units taking part in AGC, which is transmitted to units for execution through LCU. In this case, the setting value of units traces AGC setting value. Control open-loop/closed-loop: In case of open loop, AGC program only provides startup/shutdown guidance for units taking part in AGC. In case of closed loop, A GC program provides startup/shutdown guidance for units taking part in AGC, automatically start unit startup/shutdown sequence control flow and automatically executes the flow. The flow cannot be interrupted manually. In this case, operators have no need to operate unit startup/shutdown.

3.2.3 REMOTE/LOCAL CONTROL RIGHT

When the control right is set to “Remote”, both remote startup/shutdown command and remote whole-plant active setting value are valid; while the local manual startup/shutdown and whole-plant active setting value of power station are invalid. When the control right is set to “Local”, both remote startup/shutdown command and remote whole-plant active setting value are invalid; while the local startup/shutdown and whole-plant active setting value of power station are valid.

4 ENGINEERING PROBLEM OF TARGET FUNCTION

The minimum total water consumption of hydropower plant is just a general guideline. For various actual conditions, there are still various variations or rectifications. For example, in flood season, the actual target function can be that make the total generation of hydropower plant be maximum in case that amount of available water is present. As for system with joint dispatching of water, fire and electricity, it is necessary to meet the generation task defined by joint dispatching and make the total coal consumption of system be minimum in case that there is some accessible water. With regard to hydropower plants for peak regulation, frequency regulation and undertaking reserve and impact load in case of emergency accident, it is necessary to sacrifice partial economic benefit of the power plant to ensure the economic and safe benefits of whole power system, e.g. the power generation of whole power system is maximum and outage time and range minimum. Besides, we still have to consider line loss of long transmission line and difference of working head of different units for multi-unit power station, e.g.: the maximum difference between water heads of left and right banks can reach to 1~2 m.

4.1 LOAD REGULATION AND AVOIDANCE OF VIBRATION AREA

When hydropower plant AGC is carrying out optimal distribution of unit load, it is necessary to pay special attention to load transfer and distribution at the time of unit startup or shutdown and avoiding frequent adjustment of unit load caused by small fluctuation of setting value. In other words, AGC shall try best to ensure that the whole plant load stably closes to setting value of system at full speed. Furthermore, in actual project, different units have different power regulation characteristics and regulation time. Therefore, it is necessary to especially consider units with long regulation time, transfer of unit load under condition of balance load and fluctuation and response time of whole plant total power at the time of rapid load regulation. In distribution of small load when the setting value of two adjacent grid dispatching is small, we can select one unit for adjustment of small load. If one unit cannot meet requirement of small load adjustment, we can increase another unit to take part in the adjustment. In case of No disturbance of load there are functions are involved such as switching of host and slave, Machine reboot (host and communication unit), AGC switch-on/off, Local/remote switching

4.2 LIMITING CONDITIONS AND OTHER PROBLEMS

At the time of realizing AGC of hydropower plant, in addition to meet the load balance conditions of power system, it is still necessary to consider many other limiting conditions, such as water consumption limit for downstream industry and agriculture, limit for water-flow change rate required by shipping, limit for water consumption during reserving partial reservoir capacity before flood season and storing water to normal water level after flood season, limit for operation mode of hydropower plant with grouping (regional) power transmission and without electrical connection among groups and preferential startup requirement of units with plant service power or reactor grounding, i.e. units with plant service power which starts firstly and then shuts down, etc. Meanwhile, we still have to pay attention to the load change tendency of power system after some time intervals, so as to avoid unnecessary startup or shutdown caused by rise or fall of power system load in short term, which may result to waste of no load flow.

5 CONCLUSION

In conclusion, the study was focused at the issue of the main characteristics of the Automatic Generation Control System adopted for hydropower plant and theoretical puts a step forward in the technology of the automatic control configuration for the power system of hydropower plant [5]. Therefore this paper also realizes the frequency adjustment of power system along with load disturbance principle of Automatic Generation Control (AGC). The short description of operation mode of AGC and engineering problems are discuss and realizing the limitation conditions AGC of hydropower plant as well.

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