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# Research on Automatic Generation Control System (AGC) for Small and Medium Sized Hydropower Plants

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***Abstract***

*Automatic generation control of hydropower plants is an important content of the safe and economic operation of hydropower plants. The main task of hydropower plant AGC is: In order to meet the requirements of the system, the active power of the hydropower plant is automatically controlled by the fast and economical way according to the predetermined conditions and requirements. Considering the operating limits of power plant and unit and ensuring the safe operation of the power plant, and according to the requirements of the amount of water or system on the tour, in economic operation principle, determine the number of power plant unit operation units and unit operation combination and unit load distribution. So that the unit runs in the optimal conditions, with the least water consumption of the largest electricity, to create the largest economic benefits for the power plant.*

***Keywords***: *hydropower plant, automatic generation control, operation mode, group control, load distribution*

## 1. Introduction

Automatic generation control of hydropower plant (AGC) is the technology to meet the needs of the system in order to meet the requirements of the system. It is a kind of automatic control system based on the automatic control of the turbine generator set in the hydraulic turbine generating unit.

According to the target value of the total active given value or system frequency, AGC calculate and distribute active power for the factory, The principle of distribution can be according to the water consumption rate allocation, such as when the mild increase unit rate characteristics are the same ,then they can be simplified as the unit capacity allocation proportion, *etc*. In order to make the unit value of load distribution reasonably, the limiting condition for operation will checkout the rationality of the load distribution value. Operating conditions can be the not runnable area of unit (such as Cavitation area, Vibration area), the limit value of current under water head *etc*. Determining the number of operating units in power plant, operating unit combination, to make the unit running in optimized conditions, and make reasonable arrangement of the unit, to run AGC in the principle of economy under the condition of ensuring the safe operation of power plant and power system. So as to realize to the active power and the system frequency change quickly, meet the requirements of power system.

## 2. Hydropower Electricity Control (AGC) Principle

### 2.1. The Basic of AGC

Generally ,the basic of automatic generation control includes: ① The upstream inflow. It is suitable for regulating reservoir runoff power plant to make the most of the upstream

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inflow, based on principles of don't abandon water or less abandoned water, try to keep the power plant running at a high water head. ② A given power load curve or real-time given total active power of power plant. This is under the unified dispatching in power system power plants to participate in the regulation of the active power and frequency of the power system, accomplish planning scheduling order or random generating tasks. ③ Maintaining the power system frequency run under a certain level. According to the frequency of power system transient deviation or the integral value of frequency deviation, we can determine the total output of power plants, and participate in the FM task of power system directly. ④ Composite reason. Such as according to a given power and power system frequency deviation, according to the requirement of the power system of power and the downstream water demands, *etc*.

### 2.2. The Visual Explanation of AGC

The final purpose of hydropower plant is making the biggest electricity with the least amount of water consumption. Each pump unit in power plant, under the condition of the same water and with the same power generation, the amount of water consumed is different, because each unit has different capacity and running characteristic. Therefore, we should consider the water areas, unit capacity, the not runnable area of unit (cavitation, vibration), unit consumption of characteristics, operating conditions and other factors, for hydropower station of automatic generation control, in order to achieve the goal of economic operation.

After the system scheduling personnel or power plant operation personnel have given the output of the power plant according to system load, AGC need to consider the problem that how to allocate the value into the AGC units.

Actually, with the increasing output of hydroelectric generating set, there will be an increasing consumption of water, this is the water consumption characteristics of hydroelectric generating set, as shown in Figure 1

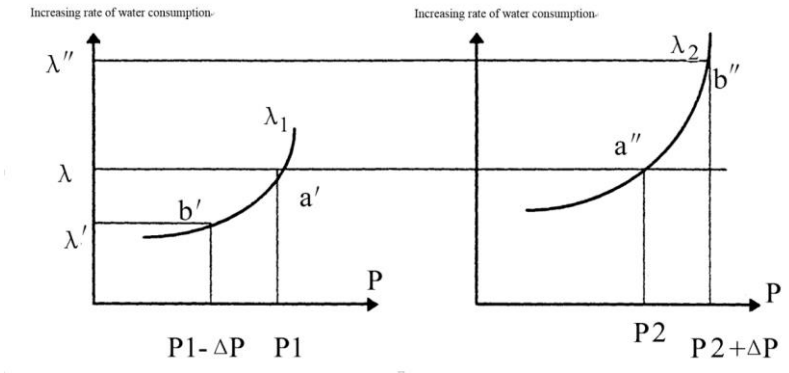


**Figure 1. Water Consumption Characteristics of Hydropower Generating Unit**

The S point in the figure said that when the turbines output get to Ps, the water consumption will get to Qs, While the tangent slope of point S said that the turbine at the output of Ps, when the unit power increase or decrease the increase of water consumption, that is to say $\lambda = \frac{\Delta Q_s}{\Delta P_s}$ , $\lambda$ is called a mild increase water consumption rate.

In practice, the consumption of turbine units is a concave upward curve, so each point of the tangent slope is an incremental curve, shown in Figure 2 below.

 

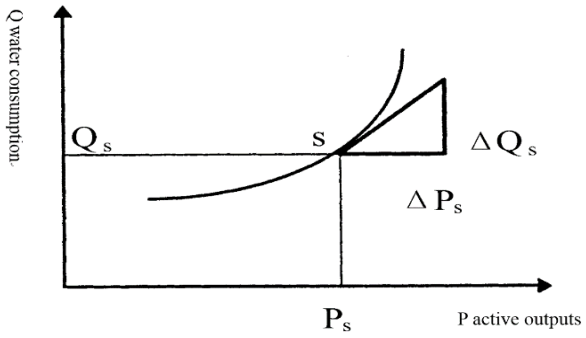


**Figure 2.The Actual Water Consumption Characteristics of Hydropower Generating Unit**

Suppose there are two units in a hydropower station, the water consumption of micro rate curve is shown in Figure 3.

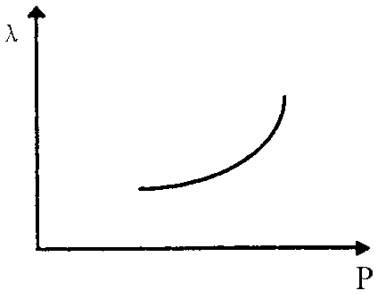


**Figure 3.Two Units of Mild Increase of Water Consumption Rate Curve**

When the given the output of the whole power plant is $P_s$, and $P_s=P_1+P_2$;

When two micro turbine water consumption rate $\lambda_1=\lambda_2=\lambda$, the water consumption is the least.

If $P_1$ reduce output $\triangle P$ (very small), and $P_2$ increase output $\triangle P$.

Though the entire output still is $P=P_1-\triangle P \pm P_2+\triangle P=P_1+P_2$.

The water consumption of water turbine 1 will reduce to the area of the trapezoid a′ b′ $(P_1-\triangle P)P_1$:

$$S_{dec}=\frac{1}{2}\Delta P(a'P_1+b'(P_1-\Delta P))=\frac{1}{2}\Delta P(\lambda+\lambda') \quad (1)$$

The water consumption of water turbine 2, because of increased output, will increase to the area of the trapezoid a″ b″ $(P_2+\triangle P)P_2$:

$$S_{dec}=\frac{1}{2}\Delta P(a''P_2+b''(P_2-\Delta P))=\frac{1}{2}\Delta P(\lambda+\lambda'') \quad (2)$$

Because $\lambda' > \lambda''$ (obviously) to be sure $S_{inc}>S_{dec}$, that is to say water consumption would increase due to the change of water turbine operation mode. But when $P_1+P_2=P$, in other words, when all units of a mild increase consumption rate as equal, the water consumption is the least.

## 3. The Implementation of Hydroelectric Power Station Automatic Generation Control

Hydroelectric power station automatic generation control should be compatible with the structure of computer monitoring system. At present, the latest automatic generation control system adopts hierarchical control mode. Automatic generation control of small and medium-sized hydropower plants generally can be divided into two levels, namely the power plant control level and units control level, as shown in Figure 4.

The computer in the power plant control level figure out the unit number and power of each operational unit should be sent to meet the higher level of power plant to power under the current head, then send these results to the unit to perform by local control unit. The latter will do the rationality of the necessary checking to power plant level information (command), In order to improve the security, then the governor and a key device will control the power and the on-off of the unit. At the same time, the unit control level send the real-time information of each units such as the unit running state and net power of power plant back to control level computer.

Under normal circumstances, the power plant undertake the task of power system frequency modulation and peak shaving, for the power plant have good regulation performance and high speed adjustment. In power system, diffident hydropower has diffident task, most of the small hydropower station undertake the task of electricity generation only; Large and medium-sized hydropower and small and medium-sized hydropower that as the main power plant in small power grid, they need to have the function of the frequency peak shaving.

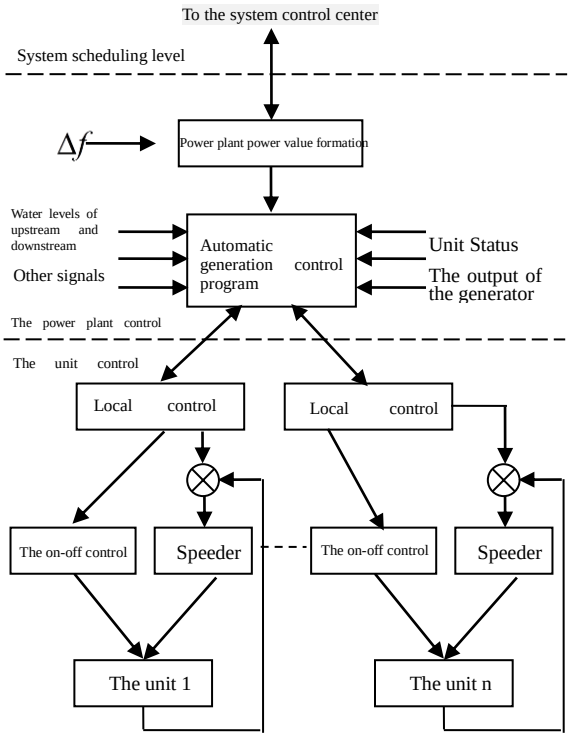


**Figure 4. Hydropower Electricity Control Implementation Schematic Diagram**

When automatic generation control is realized, we need to consider many constraints in addition to the conditions of the power system load balance, the requirement of water level, such as, upstream or downstream water restrictions, shipping restrictions on water

 

flow rate, sparing parts storage before flood and storing water to normal level after flood and so on. Therefore hydropower station need to, generate as much as power to improve the economic benefit of power plant under the given head water, have the ability of generating electricity according to the given water.

## 4. Hydroelectric Power Station of Automatic Generation Control Function

Based on the analysis of all kinds of actual control requirements of small and medium-sized hydropower plants, we can find that there are four parts in hydroelectric power station automatic power control function, including frequency adjustment, power control, generate electricity according to the given water level and power distribution of units.

### 4.1 Frequency Regulation Function

If hydropower station is the main power plants in the grid, hydropower station need to perform power grid frequency modulation. In the non-frequency modulation mode, when the instantaneous frequency deviation or the integral frequency offset exceed the permitted value, automatic electricity generation control program would automatically switch to the FM mode, and directly involved in the power system frequency modulation. Automatic electricity generation control program is allowed to enter other function model, if the system frequency back to normal. In the frequency modulation mode, if the load of the units participate in the automatic generation control has met the current head load upper and lower limit, then we should to keep the output of the hydropower station in the upper and lower limit, the principle called the priority principle of frequency adjustment.

It is necessary to adopt a constant frequency control mode, if hydropower plant is the FM factory in the isolated grid, and the calculation of ACE (Area Control Error, referred to as ACE) is relied on the hydropower plant itself. The automatic generation control program of hydropower plant sets should be assigned AGC active power PAGC according to the deviation value of system bus frequency, as shown in the formula:

$$P_{AGC} = P_A + K_f \Delta f - P_{NAGC} \tag{3}$$

The $P_A$ in the formula is the actual active power system; $K_f$ is FM coefficient; $\triangle f$ is system bus frequency deviation; $P_{NAGC}$ does not participate in the AGC unit and the actual active power. The frequency offset of the large system is generally 0.1Hz, and the error of the small system is slightly larger.

### 4.2 Power Control Function

Automatic generation control is the problem of the regulation and distribution of active power. Therefore, the power control function is the most fundamental and important function of automatic generation control. According to different control requirements of power grid and power plant, the power control function can be divided into three kinds of operating modes, such as the instantaneous load of the power network, the daily load curve and the load of the hydropower plant.

The basic principles of these three modes of operation are the same. According to the 2-15 automatic generation control program can calculate the whole plant should be allocated AGC active power $P_{AGC}$:

$$P_{AGC} = P_S + P_{NAGC} \tag{4}$$

The Ps in formula is the whole plant active setting value. The difference between these three modes is that the active setting value of the whole plant is different and can be applied to different practical conditions.

(1) Grid instantaneous load given value method: The hydroelectric power plant is directly controlled by the energy management system (EMS), That is, according to the power grid AGC calculated from the given value, immediately issued to hydropower plant.
(2) Daily load curve method: Power grid dispatch center give a power plant a whole day load given value curve in advance, when reach zero, the computer supervisory control system automatically put this pre given daily load curve in the daily load curve of storage area, so that the power plant AGC can implement. In general, the daily load curve of each 30min is a stage to divide, PC every 30min make a call to AGC calculation, and then send the results to the local control unit of each unit (LCU), and control unit operation, adjust unit output.
(3) Method of load value of hydropower plant: The whole plant for daily load curve is not send to the computer monitoring system of hydropower plant directly by the Power grid dispatching center, but by the operation staff of hydropower plant according to the scheduling requirements, through the monitoring software interface input. Operator can also according to the actual need to determine the power of a given value, sent to the LCU, thereby controlling the unit output.

### 4.3 According to the Given Head Power Generation Function

Power generation by a given head (or water level), *i.e.*, the requirements of the integrated power system, irrigation and shipping and so on, the operation of the hydropower station sets the water head value of the power plant, and adjusts the output of the whole hydropower station, to make the hydropower plant running under the setting of the hydropower station. At the same time, considering the given head, as far as possible to improve the power of the power plant, and improve the economic benefits of the power plant.

The given the water head values are input by the power plant operator, when the actual water level runs in the error allowable range of the given water head values, the unit operates at constant load in a certain period of time; when the actual water level deviates from allowable range of the given water head values, according to the given water level power generation program to adjust the output power of the generator, first, the actual water level is adjusted to the water level near the given level, and then the output value of the unit output is adjusted to maintain the balance of the water level, in a certain period of time to maintain the value of the unit output unchanged, so as to maintain the balance of the water level.

### 4.4 Power Allocation Function between Units

According to the requirements of the total power and standby capacity and the actual condition of the equipment, automatically calculate the optimal unit commitment and the most economical load distribution scheme of the power station under the current head. In the calculation, the safety condition of each unit and its auxiliary equipment should be considered, and the optimization objective is to satisfy the given total power and the limiting conditions, so that the water consumption of generator unit is the lowest, while avoiding the cavitation vibration zone, and avoiding frequent starting and frequent power adjustment operation.

In large and medium sized hydropower plants, the power distribution of the units is generally divided into the optimal combination program of units and the economic distribution program. The control requirements and input of the medium and small hydropower plants are much lower than those of large and medium hydropower plants, so the power distribution function of the units need to be simplified, practical and easy to implement.

 

## 5 .The Overall Design Idea and Program Structure

According to the division of automatic generation control function in small and medium hydropower plant, the automatic generation control program is set up with three power generation mode, they are FM power generation program, given power generation program and by a given water hair electronic program. The three sub procedures respectively calculate the allocated requirements of automatic generation control active power $P_{AGC}$ of the whole plant, then, send the requirements into the subroutine of power allocation between units, calculate the active power value that each unit of the automatic generation control operation should bear, and send to the local control unit to perform. In addition, in the total program also includes a number of important auxiliary subroutine, such as head measurement subroutine, head alarm processing procedures, *etc*...

When the automatic power generation program was first launched, the first input unit characteristics, including hydropower plant number of hydraulic turbine units, each turbine output range, each turbine cavitation zone, vibration area, head range and automatic generation control program timing operation time and so on.

In every cycle running of the automatic generation control program, the SCADA system is required to read all kinds of information required for the current power plant from the AGC system, such as the operating condition of the turbine units, the current output of the turbine units, the current water head, and the current set of power generation mode, *etc*.

The general flow diagram of the automatic generation control program of hydropower station is shown in Figure 5.

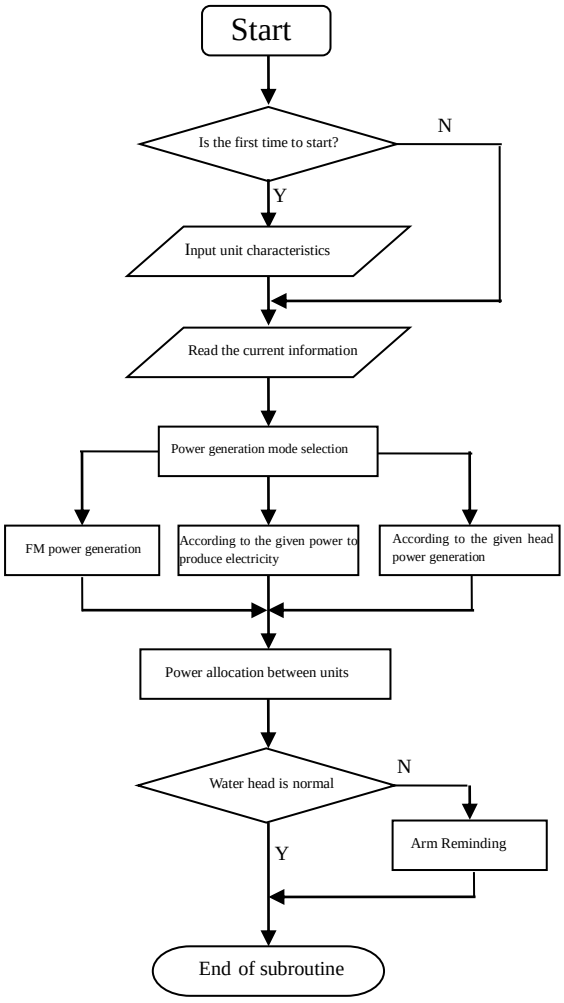


**Figure 5. Auto Power Control Program Flow Chart**

## 6. Concluding Remarks

With the continuous improvement of the power grid scheduling real-time control system, the implementation of the power market open and competitive bidding, the power plant units with the function of automatic generation control (AGC) are becoming more and more important in the power system. The automatic generation control technology has become an indispensable tool in the modern power system. It will play an important role in maintaining the stable operation of the power system and the safe operation of power plant. System also need power plant with large regulating capacity, high speed and high precision to make a contribution to the stability of the system. As power grid scheduling, as long as grasping the operation of power plant units, controlling the whole plant output, and sending the AGC command to the monitoring system. As per unit load distribution is controlled by the power plant AGC software, we can use of reasonable optimization strategy to distribute the load of the unit according to the equipment and the economic performance. At the same time, the load of all the units are sent to the power grid dispatching system as feedback , so as to realize the economic operation of hydropower plant.

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