Analysis of Postprint on AVC Control Strategy for Hydropower Plants

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Abstract

Voltage is a critical indicator of power quality. Automatic Voltage Control (AVC) is a regulation process that conducts reactive power-voltage optimization subject to the constraint of qualified bus voltages throughout the system, and dispatches control commands to equipment. Hydropower plant AVC automatically controls the plant bus voltage or the total plant reactive power according to predetermined strategies, stabilizing the bus voltage within a reliable range by regulating the plant' s reactive power. This paper analyzes the control strategies of hydropower plant AVC, including setpoint methods, control modes, reactive power allocation, safety considerations, and precautions, taking into account system conditions, transformer operation modes, generator vibration zones, etc. It proposes optimization strategies for AVC in terms of regulation lag, regulation capacity, and setpoint ranges. The rational formulation of AVC control strategies not only satisfies system requirements but also ensures the safe and reliable operation of hydropower plant equipment.

Full Text

Analysis of Control Strategy for AVC in Hydropower Plants

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Abstract

Voltage is a critical indicator of power quality. Automatic Voltage Control (AVC) is a regulation process that optimizes reactive power and voltage while maintaining qualified bus voltages throughout the system as constraints, and issues control commands to equipment. Hydropower plant AVC automatically controls plant bus voltage or total plant reactive power according to predetermined strategies. By adjusting the plant’ s reactive power, it maintains bus voltage within a reliable range. This paper analyzes AVC control strategies for hydropower plants, including setting methods, control modes, reactive power distribution, safety measures, and precautions, while also considering system conditions, transformer operation modes, and unit vibration zones. Optimization strategies are proposed for AVC regulation lag, regulation capacity, and setting intervals. Proper formulation of AVC control strategies satisfies system requirements while ensuring safe and reliable operation of hydropower plant equipment.

Keywords: hydropower plant, automatic voltage control (AVC), control strategy

1 Introduction

Voltage represents a crucial indicator of power quality, and significant voltage deviations can cause substantial damage to electrical equipment and even compromise grid security. As power grids expand and voltage requirements become increasingly stringent, traditional voltage control methods no longer satisfy the demands for grid safety and reliability. Automatic Voltage Control (AVC) is a regulation process that uses qualified bus voltages throughout the system as constraint conditions, aims to minimize grid power losses, performs reactive power-voltage optimization, and issues control commands to equipment.

Hydropower plant AVC automatically controls plant bus voltage or total plant reactive power according to predetermined conditions and requirements. By regulating the plant’ s reactive power, it stabilizes bus voltage within a reliable range. Based on the deviation between bus voltage setpoints and actual values, or reactive power deviations, AVC calculates the required reactive power adjustment according to voltage regulation coefficients. Under safe conditions for both the plant and individual units, AVC adjusts unit reactive power using predetermined control strategies to ensure plant bus voltage meets grid requirements and enhances power system stability. Hydropower plant AVC control strategies encompass setting methods, control modes, reactive power distribution strategies, safety strategies, and precautions, while also incorporating considerations such as system status, transformer operation modes, and unit vibration zones. This paper concludes by proposing optimization strategies for AVC regulation lag, regulation capacity, and setting intervals.

2.1 Hydropower Plant AVC System Structure

[Figure 1: see original paper] illustrates the structure of a hydropower plant AVC system, which comprises the dispatch master station, plant-level sub-station monitoring systems, unit local control units, unit excitation systems, and generating units. The dispatch master station exchanges four remote data types (telemetry, teleindication, remote control, and remote adjustment) with the plant-level sub-station monitoring system through telecontrol communication. The plant-level sub-station monitoring system uploads telemetry data including unit active power, reactive power, and bus voltage, as well as teleindication signals such as unit outlet breaker status, unit and plant AVC status, and unit disconnector states. The dispatch master station issues remote adjustment commands including bus voltage setpoints and total plant active power setpoints, along with remote control commands for unit start-up, shutdown, excitation increase, and excitation decrease.

2.2 AVC Setting Methods

Generator reactive power and terminal voltage are related to excitation current. When excitation current changes, the generator’ s reactive power and terminal voltage change accordingly, thereby affecting bus voltage. Through the excitation regulator, excitation current can be increased or decreased to ultimately regulate and change bus voltage. Consequently, AVC can select either plant bus voltage or reactive power as the control setpoint. The setting methods include reactive power setting and bus voltage setting.

(1) Reactive Power Mode. The AVC dispatch master station or plant monitoring system can directly set reactive power in the plant AVC system. The setpoint value equals the total plant reactive power minus the reactive power of units not participating in AVC, with the remainder distributed among participating units:

$$Q_{AVC} = Q_{SET}!Q_{AVC}$$

where Q_{AVC} is the plant reactive power distribution value, Q_{SET} is the plant reactive power setpoint, and Q_{AVC} is the reactive power of units not participating in AVC.

(2) Bus Voltage Mode. The AVC master station or plant monitoring system can directly set bus voltage in the AVC system. The setpoint represents the plant bus voltage. Based on the deviation between the set voltage value and the actual bus voltage, and according to the voltage regulation coefficient (the relationship between voltage and reactive power), this deviation is converted into a required reactive power change value. This reactive power value is then calculated and distributed among participating units together with the current actual reactive power and the reactive power of non-participating units. Bus voltage setting represents the most common method for AVC plants and can be further divided into curve mode and fixed value mode. In curve mode, AVC operating intervals are configured, namely the upper and lower limits of bus voltage. AVC continuously monitors whether bus voltage remains within the set range and initiates regulation control when bus voltage exceeds these limits.

In fixed value mode, AVC performs distribution according to the setpoint. AVC deadbands are configured based on different grids or unit capacities. When the actual plant bus voltage exceeds the deadband, AVC distributes according to the deviation between setpoint and actual value. When the actual plant bus voltage remains within the deadband of the setpoint, AVC performs no distribution. The voltage regulation coefficient calculation is:

$$Q_{AVC} = Q_{ACT} + !VKVNOR"Q_{AVC}$$

where Q_{AVC} is the plant reactive power distribution value, Q_{ACT} is the current actual reactive power, ΔV is the deviation between actual bus voltage and set voltage, $KVNOR$ is the voltage regulation coefficient, and Q_{AVC} is the reactive power of units not participating in AVC.

2.3 Control Modes

(1) Dispatch Master Station Mode. The plant AVC dispatch master station control mode includes two types: plant control mode and single-unit control mode. In plant control mode, the plant AVC sub-station receives the bus voltage setpoint issued by the AVC dispatch master station, calculates the required reactive power for the plant, distributes reactive power reasonably among participating units, and sends excitation increase/decrease signals to generator excitation systems through local control units to regulate generator reactive power, thereby achieving plant-level AVC and bringing bus voltage to the control setpoint. In single-unit control mode, the plant AVC sub-station directly receives reactive power setpoints for each unit from the AVC dispatch master station and adjusts generator reactive power through local control units. Hydropower plant AVC master station control modes generally adopt plant control mode.

(2) Control End Mode. AVC control end modes typically include local and remote options. In remote mode, the master station calculates AVC setpoints and distributes them to participating units according to predetermined strategies. In local mode, the plant monitoring system calculates AVC setpoints and distributes them to participating units according to predetermined strategies.

3 AVC Load Distribution Strategy

AVC controls bus voltage by adjusting unit reactive power. AVC reactive power distribution strategies primarily include proportional reactive power distribution, equal power factor distribution, and similar adjustment margin distribution. Reactive power adjustments are first undertaken by units operating in phase modulation mode, with the remaining portion shared by units participating in reactive power regulation.

3.1 Proportional Reactive Power Strategy

The proportional reactive power distribution strategy calculation is:

$$Qi_{AVC} = Q_{SET}!\frac{Qi_{Max}}{\sum Qi_{Max}}$$

where n is the number of units participating in AVC, Q_{SET} is the AVC reactive power setpoint, Qi_{Max} is the maximum reactive power capacity of the i-th participating unit, $\sum Qi_{Max}$ is the sum of maximum reactive power capacities of all participating units, and Qi_{AVC} is the reactive power allocated by AVC to the i-th participating unit.

3.2 Equal Power Factor Strategy

The equal power factor distribution strategy calculation is:

$$Qi_{AVC} = Q_{SET}!\frac{Qi}{\sum Qi}$$

where n is the number of units participating in AVC, Q_{SET} is the AVC reactive power setpoint, Pi is the current active power output of the i-th participating unit, $\sum Pi$ is the sum of current active power outputs of all participating units, and Qi_{AVC} is the reactive power allocated by AVC to the i-th participating unit.

3.3 Similar Adjustment Margin Strategy

The similar adjustment margin distribution strategy calculation is:

$$Qi_{AVC} = Q_{SET}!\frac{(Qi_{Max} - Qi)}{\sum(Qi_{Max} - Qi)}$$

where n is the number of units participating in AVC, Q_{SET} is the AVC reactive power setpoint, $Qi_{Max} - Qi$ is the reactive power adjustment margin of the i-th participating unit, $\sum(Qi_{Max} - Qi)$ is the sum of current reactive power adjustment margins of all participating units, and Qi_{AVC} is the reactive power allocated by AVC to the i-th participating unit.

4 AVC Safety Control Strategy

Plant AVC must employ reliable safety control strategies during operation to ensure the safety of generating units and the system. The primary AVC safety control strategies include the following:

(1) Bus voltage faults, including voltage measurement channel failures and voltage limit violations, trigger plant AVC exit.

(2) Unit reactive power measurement faults. When faults occur, the accuracy of reactive power measurements cannot be determined. To prevent impact on the plant reactive power setpoint, plant AVC exits.

(3) Unit LCU faults during generating state. Since unit LCU faults during generating state may upload zero reactive power values or prevent AVC from determining the number of operating units, plant AVC exits to avoid distribution errors caused by zero reactive power or incorrect AVC data.

(4) If a unit suddenly changes from generating state to another state and the unit reactive power exceeds 10% of the unit' s maximum reactive power value, data error is assumed and plant AVC exits.

(5) Plant water level signal faults. Depending on hydropower plant conditions, plants with high heads and large flow variations exit plant AVC, while plants with low heads and small flow variations may continue AVC operation.

(6) Unit strong excitation limit action triggers plant AVC exit.

(7) System oscillations caused by synchronous or asynchronous equipment faults, or relay protection actions, trigger plant AVC exit.

4.2 Excitation Increase Blocking Strategy

When increasing reactive power, if unit conditions meet any excitation increase blocking criteria, reactive power increase stops. Blocking conditions include maximum bus voltage, maximum stator current, maximum excitation current, upper terminal voltage limit, and upper auxiliary bus voltage limit. The excitation increase blocking signal is sent to the master station AVC, which no longer performs AVC increase settings. The plant AVC blocks increase actions and can only operate in the decrease direction until the blocking signal clears.

4.3 Excitation Decrease Blocking Strategy

When decreasing reactive power, if unit conditions meet any excitation decrease blocking criteria, reactive power decrease stops. Blocking conditions include minimum bus voltage, minimum stator current, minimum excitation current, lower terminal voltage limit, and lower auxiliary bus voltage limit. The excitation decrease blocking signal is sent to the master station AVC, which no longer performs AVC decrease settings. The plant AVC blocks decrease actions and can only operate in the increase direction until the blocking signal clears.

5 AVC Precautions

(1) **Accuracy of voltage regulation coefficient.** The voltage regulation coefficient is a critical AVC parameter representing the relationship between reactive power and bus voltage, ensuring accurate AVC control. It can be obtained from excitation parameters and verified through multiple tests.

(2) **AVC safety control strategy.** Generally, when auxiliary bus voltage reaches its limit, it blocks excitation increase/decrease and affects AVC

operation. Since some plant asynchronous motors have large capacity and their starting may cause auxiliary bus voltage variations, the impact of large motors must be considered in AVC strategies when blocking auxiliary bus voltage.

(3) **Coordination with transformer tap changers.** When the plant step-up transformer includes on-load tap changers, unit reactive power adjustment must coordinate with tap changer regulation. Generally, generator voltage adjustment should be maximally utilized before adjusting transformer taps.

(4) **Unit vibration zones.** Hydraulic turbine generators crossing vibration zones cause reactive power fluctuations. When fluctuations exceed AVC deadband values, units should minimize crossing vibration zones or temporarily exit AVC during zone crossing.

(5) **Bus voltage selection strategy.** Plant AVC selects bus sections according to numbered priority sequence. Under normal conditions, Bus I serves as the controlled bus for receiving and judgment. If Bus I faults or undergoes maintenance outage, Bus II becomes the controlled bus. During parallel bus operation, the voltage difference between Bus I and Bus II should not be excessive.

6 Other Control Strategies

(1) **Data processing.** Hydropower plant AVC must provide real-time data processing with digital filtering functions for all data to ensure accuracy of control data sources such as reactive power and bus voltage, prevent misoperation caused by data 突变, and identify erroneous measurement sources and switch statuses.

(2) **Protection handling.** Hydropower plant AVC must support protection handling strategies for various protection signals including instantaneous, self-holding, and automatic reset types, such as main transformer differential protection, main transformer heavy gas protection, high-voltage side breaker non-full-phase protection, and high-voltage side backup protection, forming the basis for AVC analysis, judgment, blocking, and exit.

(3) **Events and alarms.** Hydropower plant AVC must provide event alarm functions under various abnormal conditions, enabling definition, recording, monitoring, confirmation, and querying of all events and alarms generated during AVC operation.

(4) **Recording, statistics, and querying.** Hydropower plant AVC must include recording, statistics, and querying capabilities to log all control schemes, commands, and equipment actions, enabling statistical analysis of equipment-related control information. It must record equipment control counts, action counts, correct action counts, and refusal counts with time-period statistical queries. AVC must also log equipment operating

status, evaluate AVC performance indicators, and provide querying, curve plotting, and report generation for all AVC data.

7 AVC Optimization Strategies

Various issues arise during actual AVC operation in hydropower plants, including regulation lag and insufficient grid regulation capacity. AVC optimization should address the following aspects:

(1) **Regulation lag optimization.** Hydropower plants obtain AVC setpoints from dispatch master stations through communication as illustrated above, typically issued at intervals, causing regulation lag. AVC setpoints are based on voltages of important central buses within the system. Since numerous telecontrol data points exist between hydropower plants and dispatch, while setpoints are issued at intervals, incorporating central bus voltage data into telecontrol communication enables hydropower plants to obtain central bus voltage data in real time. By incorporating central bus voltage conditions into hydropower plant AVC algorithms, AVC can regulate based on system central bus voltages, achieving real-time regulation and response.

(2) **Regulation capacity optimization.** Hydropower plant AVC has defined regulation capacity, generally based on generator reactive power capability. When excitation current becomes too high or too low, the excitation system triggers over-excitation or under-excitation limit actions, blocking reactive power and AVC regulation. Over-excitation and under-excitation limit settings are typically conservative, often based on empirical values or unit capacity. Generators frequently have significant remaining potential when these limits act, preventing full utilization of generating units. Therefore, reliable data for over-excitation and under-excitation limit actions should be obtained through testing to ensure both generator safety and full utilization of generating units and AVC capabilities.

(3) **Setting interval optimization.** Hydropower plant bus voltage generally operates according to grid-required intervals, with interval operating times varying by grid. This requires periodic modification of bus voltage intervals, while most AVC parameters remain unchanged. In actual operation, bus voltage operating intervals change, and AVC may fail to meet grid regulation requirements. AVC operating intervals can be optimized by implementing real-time interval setting, performed by qualified operators to satisfy grid requirements for hydropower plant AVC.

8 Conclusion

Implementing hydropower plant AVC facilitates streamlined dispatch control objects and simplified plant operation, while improving power quality. Hydropower plant AVC control strategies must consider numerous factors including setting methods, control modes, reactive power distribution strategies, safety controls, system conditions, transformer operation modes, and unit vibration zones. Proper formulation and optimization of AVC control strategies satisfy system requirements while ensuring safe and reliable operation of hydropower plant equipment.

References

[1] Li Changsheng, Liu Guangming, Jiang Chungang. Application of optimal power generation and pumping combined control in a pumped storage power plant[J]. Technology and Life, 2010(17): 114-115.

[2] Yu Ting, Pu Tianjiao, Liu Guangyi, et al. Coordinated control method of AGC and AVC in power grid[J]. Power System Protection and Control, 2015, 43(15): 42-47.

[3] China Electricity Council. DL/T 5065—2009 Design code for computer monitoring system of hydropower plants[S]. Beijing: China Electric Power Press, 2009.

[4] China Electricity Council. DL/T 578—2008 Basic technical requirements for computer monitoring system of hydropower plants[S]. Beijing: China Electric Power Press, 2008.

[5] China Southern Power Grid Company. Q/CSG 110008—2012 Technical specification for automatic voltage control (AVC) of China Southern Power Grid[S]. 2012.

Note: Figure translations are in progress. See original paper for figures.

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