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INDUSTRIAL DEVELOPMENT ORGANIZATION



Technical Guidelines for the Development of Small Hydropower Plants **DESIGN**

Part 6-2: Electrical System

SHP/TG 002-6-2: 2019



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Technical Guidelines for the
Development of Small Hydropower Plants
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Part 6-2: Electrical System

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Further recommendations and suggestions for application for the update would be highly welcome.

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Foreword

The United Nations Industrial Development Organization (UNIDO) is a specialized agency under the United Nations system to promote globally inclusive and sustainable industrial development (ISID). The relevance of ISID as an integrated approach to all three pillars of sustainable development is recognized by the 2030 Agenda for Sustainable Development and the related Sustainable Development Goals (SDGs), which will frame United Nations and country efforts towards sustainable development in the next fifteen years. UNIDO's mandate for ISID covers the need to support the creation of sustainable energy systems as energy is essential to economic and social development and to improving quality of life. International concern and debate over energy have grown increasingly over the past two decades, with the issues of poverty alleviation, environmental risks and climate change now taking centre stage.

INSHP (International Network on Small Hydro Power) is an international coordinating and promoting organization for the global development of small hydropower (SHP), which is established on the basis of voluntary participation of regional, subregional and national focal points, relevant institutions, utilities and companies, and has social benefit as its major objective. INSHP aims at the promotion of global SHP development through triangle technical and economic cooperation among developing countries, developed countries and international organizations, in order to supply rural areas in developing countries with environmentally sound, affordable and adequate energy, which will lead to the increase of employment opportunities, improvement of ecological environments, poverty alleviation, improvement of local living and cultural standards and economic development.

UNIDO and INSHP have been cooperating on the World Small Hydropower Development Report since year 2010. From the reports, SHP demand and development worldwide were not matched. One of the development barriers in most countries is lack of technologies. UNIDO, in cooperation with INSHP, through global expert cooperation, and based on successful development experiences, decided to develop the SHP TGs to meet demand from Member States.

These TGs were drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of these TGs may be subject to patent rights. UNIDO and INSHP shall not be held responsible for identifying any such patent rights.

Introduction

Small Hydropower (SHP) is increasingly recognized as an important renewable energy solution to the challenge of electrifying remote rural areas. However, while most countries in Europe, North and South America, and China have high degrees of installed capacity, the potential of SHP in many developing countries remains untapped and is hindered by a number of factors including the lack of globally agreed good practices or standards for SHP development.

These Technical Guidelines for the Development of Small Hydropower Plants (TGs) will address the current limitations of the regulations applied to technical guidelines for SHP Plants by applying the expertise and best practices that exist across the globe. It is intended for countries to utilize these agreed upon Guidelines to support their current policy, technology and ecosystems. Countries that have limited institutional and technical capacities, will be able to enhance their knowledge base in developing SHP plants, thereby attracting more investment in SHP projects, encouraging favourable policies and subsequently assisting in economic development at a national level. These TGs will be valuable for all countries, but especially allow for the sharing of experience and best practices between countries that have limited technical know-how.

The TGs can be used as the principles and basis for the planning, design, construction and management of SHP plants up to 30MW.

- The Terms and Definitions in the TGs specify the professional technical terms and definitions commonly used for SHP Plants.
- The Design Guidelines provide guidelines for basic requirements, methodology and procedure in terms of site selection, hydrology, geology, project layout, configurations, energy calculations, hydraulics, electromechanical equipment selection, construction, project cost estimates, economic appraisal, financing, social and environmental assessments—with the ultimate goal of achieving the best design solutions.
- The Units Guidelines specify the technical requirements on SHP turbines, generators, hydro turbine governing systems, excitation systems, main valves as well as monitoring, control, protection and DC power supply systems.
- The Construction Guidelines can be used as the guiding technical documents for the construction of SHP projects.
- The Management Guidelines provide technical guidance for the management, operation and maintenance, technical renovation and project acceptance of SHP projects.

Technical Guidelines for the Development of Small Hydropower Plants **DESIGN**

Part 6-2: Electrical System

1 Scope

This Part of the Design Guidelines sets forth the general requirements for the design of the electrical system of a small hydropower (SHP) station, and defines specific technical requirements for the selection and arrangement of connections to the power system, main electrical connection, grounding, lighting, relay protection, control system and other electrical equipment.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

SHP/TG 001, *Technical guidelines for the development of small hydropower plants —Terms and definitions.*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in SHP/TG 001 apply.

4 Connection of the hydropower station to the power system(grid)

4.1 General requirements for design

4.1.1 The output point, output voltage, number of circuits of outgoing line, transmission capacity (including traversing power), operating mode and mode of connection with the power grid shall be determined in light of the characteristics of the power station and the requirements of the electrical system.

4.1.2 The output voltage and the circuit number of the outgoing line of the power station shall be as simple as possible in light of the system and the on-site conditions.

4.1.3 The connection system shall be designed on the basis of both long-term and short-term perspectives, and several options shall be formulated for technical and economic comparison.

4.2 Design works to be submitted

4.2.1 As for the design for connection of the hydropower station to the electrical system, the following design works shall be submitted:

- a) Physical layout and single-line connection diagram of the power evacuation system and the connection with the grid;
- b) Transmission voltage, number of circuits of outgoing line with different voltage levels, directions and connecting points for every outgoing line, maximum/minimum transmission capacity, and annual maximum load utilization hours;
- c) Requirements of the system for the main electrical connection of the power station, including the role and standing of the power station in the system, and the operating mode of the power station;

- d) Requirements of the system for the main transformer of the power station, such as the type and voltage-regulating mode of the main transformer, the grounding mode of the neutral point, and the impedance;
- e) Whether the generator is used for phase-regulating operation;
- f) Requirements of the system for the generator parameters, excitation parameters and excitation modes, including the rated voltage and the allowable variation range, the rated power factor and the allowable variation range, temporary-state reactance, short circuit ratio, moment of inertia, maximum charging capacity and phase-regulating capacity, peak value multiple of the excitation voltage and overspeed;
- g) Requirements of the system for automatic operation, communication and relay protection of the power station.

4.2.2 When the power station is required to be equipped with parallel reactors, the type, voltage, capacity and connection mode of the reactors as well as the parameters and insulation level of the neutral reactor shall be determined.

5 Main electrical connection wiring

5.1 General requirements for design of main electrical connection

5.1.1 The main electrical connection shall meet the user's requirements or the requirement of the electrical system for reliability of the power supply and quality of the electrical energy.

5.1.2 The main electrical connection shall be simple and clear, easy to operate and maintain, and have a certain flexibility.

5.1.3 The main electrical connection shall meet the operational requirements of the power station at the early stage and in the final stage, and the transition by stages shall be taken into account.

5.1.4 The main electrical connection shall be designed on the basis of the following basic data:

- a) Installed capacity of the power station, the number of generator units, and the water energy data such as the regulating performance, utilization hours and firm capacity of the water reservoir;
- b) Importance of the power station in the grid system and its operating mode, the geological wiring map for connection with the power system, and the impedance diagram;
- c) Voltage level of the outgoing line, number of circuits and their input sequence, the requirements for trend distribution and traversing power under maximum/minimum operating mode, and the value of the power exchanged between two levels of boosted voltage;
- d) Quantity of the station-service power sources, their connection mode, and the demand on the near-zone power supply;
- e) Requirements for automatic operation and the dispatching mode of the power station;
- f) Requirements of the power system for the phase-regulating, voltage-regulating and leading phase operations of the power station.
- g) Requirements of the power system for voltage regulation and range of the transformer;
- h) Requirement for over-voltage for the connection of the power station within the stable and restricted scope of the system;

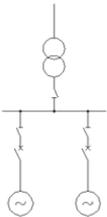
i) Project layout and transportation of the power station.

Under the precondition that the basic requirements are satisfied, the design of the connection shall meet the specific layout conditions.

5.2 Type, characteristics and applicability of the main electrical connection

The type, characteristic and applicability of the main electrical connection of the SHP station are detailed in Table 1 and Table 2.

Table 1 - Voltage connection of generator

Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Unit connection		<ol style="list-style-type: none"> 1. The capacity of the transformer is as the same as that of the generator, the scope of impact of the failure is the least, and the reliability is high; 2. The connection is simple and clear, and the operation is flexible; 3. There is the least voltage equipment for the generator, the layout is simple, and the maintenance workload is lighter; 4. The relay protection is simple; 5. The number of the transformer and the high-voltage electrical equipment is increased, and the area occupied by high-voltage equipment is increased. 	<p>This type of connection may be adopted for the power station which has a high requirement for reliability, or adopted for the power station which is constructed in phases. Generators can be connected to the grid one by one so as to have part generation from the power station.</p>
Expanded unit connection		<ol style="list-style-type: none"> 1. Two (or more than two) generator sets are connected with one transformer. The reliability in this system is lower than when the transformer fails or has to be inspected or repaired, as the output of two generators cannot possibly be sent to grid. 2. The connection is simple, clear, and easy to operate and maintain; 3. The number of outgoing lines from the high-voltage side of the transformer is reduced, and the high-voltage side connection arrangement is simplified, so that the investment is saved. 	<ol style="list-style-type: none"> 1. When the power station has important standing in the power grid, and there are no less than four generator sets, then two or more than two expanded units may be adopted; 2. For an ordinary power station with a relatively smaller near-zone load, an expanded unit may be composed of one transformer and several generator sets; 3. This connection may be adopted for a power station which is constructed in phases.

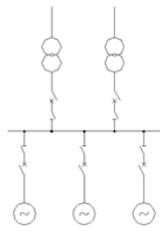
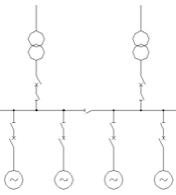
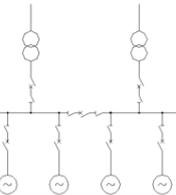
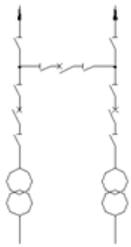
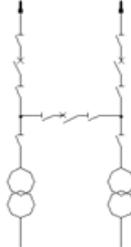
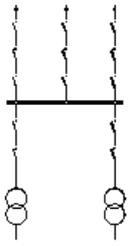
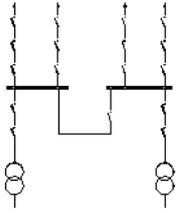
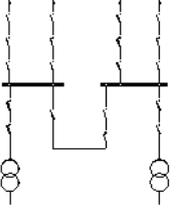
Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Single-bus connection		<ol style="list-style-type: none"> 1. There are fewer transformers, the investment is saved, and the loss of electrical energy is small; 2. The connection is simple, clear, and easy to operate; 3. There are more voltage distribution devices and components for generators, so that the inspection and repair workload is increased; 4. When the bus or the isolating switch connected to the bus fails or needs to be repaired, the whole station has to be shut off, so the reliability and flexibility are relatively lower. 	<p>This type of connection may be adopted for an SHP station which has relatively higher near-zone load.</p>
Single-bus isolating switch sectional connection		<ol style="list-style-type: none"> 1. When a section of the bus or the isolating switch connected to it is in trouble or has to be inspected or repaired, the station needs to be shut down for a short time, and after the section isolating switch is on, the generator set connected to another section of the bus can still be powered on; 2. When the section isolating switch is in trouble or has to be inspected or repaired, the entire station has to be shut down; 3. Other advantages and disadvantages are the same as those as detailed in Items 1 to 3 for a single-bus connection. 	<p>The use of the section isolating switch may lead to loaded misoperation, so it is rarely used.</p>
Single-bus circuit breaker sectional connection		<ol style="list-style-type: none"> 1. When any section of the bus and the isolating switch connected to it is in trouble or has to be inspected or repaired, the generator set on another section of the bus may continue to send electricity to the power grid, so the reliability and flexibility are higher than those of single-bus connection. 2. Other advantages and disadvantages are the same as those as detailed in Items 1 to 3 for a single-bus connection. 	<ol style="list-style-type: none"> 1. This connection may be adopted for the small power station which has more importance in the power grid 2. This connection may be adopted by the power station which has more generator sets and has near-zone load.

Table 2 - Boosted voltage side connection

Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Transformer-line group connection		<ol style="list-style-type: none"> 1. The connection is the simplest, there is the least equipment, and the investment is the least. 2. When the line fails or has to be inspected or repaired, the main transformer will stop working, and vice versa. 	<p>This connection may be adopted for the power station which has only one outgoing line.</p>
T-type connection		<p>The advantages and disadvantages are the same as those of the transformer-line group connection.</p>	<p>This connection may be adopted for the power station which is not important on the power grid and the transmission line is quiet near the generating station.</p>
Outer bridge connection		<ol style="list-style-type: none"> 1. The connection is simple, and the number of high-voltage circuit breakers is less (namely the number of incoming and outgoing lines minus one); 2. When the circuit of the transformer fails or has to be inspected or repaired, the operation of the line and another transformer will not be affected; 3. When an outgoing line fails or has to be inspected or repaired, half of the output of the power station has to be halted, and after the isolating switch is on, all of the power may be sent out by another circuit; 	<ol style="list-style-type: none"> 1. This connection maybe adopted when both incoming line and outgoing line have two circuits respectively and the power station has fewer annual utilization hours, of which the transformer is frequently switched on or switched off or the line is short; 2. When there is traversing power, the outer bridge connection should also be adopted.
Internal bridge connection		<ol style="list-style-type: none"> 1. The connection is simple, and the number of high-voltage circuit breakers is less (namely the number of incoming lines and outgoing lines minus one); 2. When an outgoing line fails or has to be inspected or repaired, the operation of the transformer will not be affected; 3. When a transformer fails or has to be inspected or repaired, an outgoing line has to be cut off temporarily, and after the transformer isolating switch is on, half of the power of the power station may be sent out by two outgoing lines. 	<p>This connection maybe adopted for the power station which has two circuits for the incoming line and the outgoing line respectively and has fewer annual utilization hours and for which the transformer is frequently switched on or switched off or the line is short;</p>
Single-bus connection		<ol style="list-style-type: none"> 1. Every circuit of the incoming or outgoing line is equipped with a circuit breaker, and the circuit breakers will not affect each other; 2. When the bus or the isolating switch connected to it fails or has to be inspected or repaired, the entire station will be powered off. 	<p>In general, this connection may be adopted for the hydropower station which is not important in the electrical system and has a lower requirement for continuity of power supply and for which the voltage of the outgoing line is not less than 35(33) kV and the number of circuits is not more than 3 to 5.</p>

Single-bus isolating switch sectional connection		When the bus or equipment connected is being inspected and repaired or fails, the entire station will be powered off; after the section isolating switch is on, another section of the bus may supply the power. However, when the section isolating switch is being inspected and repaired or fails, the entire station will still be power off.	Same as the single-bus connection.
Single-bus circuit breaker sectional connection		When the bus or equipment connected is being inspected and repaired or is faulted, only a section of the bus and the circuit connected will be powered off, so the reliability is higher than that of the single-bus connection and the single-bus isolating switch sectional connection.	As for the important load, in general, two lines are respectively connected with two sections of the bus for the power supply. The requirement for continuity of the power supply from the other outgoing line is not high. In general, the voltage of the outgoing line is not less than 35(33)kV, and the total number of circuits for the outgoing line is not more than 6.

5.3 Principle for configuration of the isolating switch

5.3.1 The isolating switch shall meet the requirements for inspection and repair of the equipment as well as the general requirements for the design of the main connection:

- In general, the bus of the generator shall be equipped with the isolating switch, and its location shall be as close to the outlet of the generator as possible;
- As for the expanded unit connection, when the outgoing line is relatively long, the circuit breaker is relatively far away from the generator set, and it is difficult to dismantle the bus connector, then a set of isolating switches may be installed at the outlet of the generator;
- As for the high-voltage isolating switch of no less than 35(33) kV, in order to facilitate the safe grounding for inspection and repair, the grounding switch shall be set up on one side or both sides of the isolating switch;
- As for the incoming/outgoing line, the voltage transformer, lightning arrester, and bypass bus circuit breaker side isolating switch, the grounding switch should be set up on both sides;
- In general, the isolating switch connected to both sides of the circuit breaker on the bus shall be equipped with the grounding switch on the side of the circuit breaker.

5.3.2 Principle for the configuration of the isolating switch for the voltage transformer, lightning arrester and circuit of the lightning arrester at the outlet of the transformer on the high-voltage side:

- In general, the voltage transformer and the lightning arrester connected to the bus for which the voltage is less than 110 kV may share the same set of isolating switches;
- In general, the lightning arrester at the high-voltage side outlet of the transformer is not provided with the isolating switch.
- When the voltage transformer is installed on the side of the outgoing line and may also be used for communication and protection (except for that specially installed for both purposes), the isolating switch shall be set up.

6 Calculation of the short circuit current

6.1 Purpose of the calculation

The calculation result for the short circuit current shall provide the basis for comparison and selection of the electrical connection scheme, for selection of the electrical equipment and current-carrying conductor, for selection of the relay protection, and for the design of the grounding system.

6.2 Basic principle for calculation

6.2.1 The short circuit current used to verify the dynamic stability and thermal stability of the conductor and the electrical equipment and to calculate the breaking current of the electrical equipment shall be determined in accordance with the design capacity of the project, and the long-term development plan for the power system (in general, 5 to 10 years after the project is completed) shall be considered.

6.2.2 When selecting the short circuit current for the conductor and the electrical equipment in the electrical connection grid, the impact imposed by the asynchronous motor which has the feedback effect and the impact imposed by the discharging current of the capacitance compensation device shall be considered.

6.2.3 When selecting the conductor and the electrical equipment, the selection of the calculation point for the short circuit shall follow the principle that the short circuit current under the normal connection mode is the maximum value.

6.2.4 In general, the dynamic stability and thermal stability of the conductor and the electrical equipment as well as the breaking current of the electrical equipment shall be calculated on the basis of the three-phase short circuit. If the two-phase short circuit at the outlet of the generator or the single-phase or two-phase grounding short circuit in the neutral point directly-grounded system and the auto transformer is more serious than the three-phase short circuit, then the calculation shall be based on more serious situations.

6.2.5 In general, only the reactance of the various elements (namely the generator, transformer, reactor and line) will be included in the calculation of the high-voltage short circuit current.

6.2.6 The per unit value shall be adopted for the calculation. In general, the reference capacity $S_j=100$ MVA or $S_j=1\ 000$ MVA shall be adopted; as for the reference voltage U_j , in general, the average voltage at every level shall be adopted.

6.2.7 The basic assumptions for the calculation shall meet the following requirements:

- a) During normal operation, the three-phase system operates symmetrically.
- b) The phase angles of the electromotive force of all power sources are the same.
- c) All the synchronous and asynchronous motors in the system are ideal motors, without considering the impact of magnetic saturation, magnetic lagging and vortex of the motor and the skin effect of the conductor; the structure of the rotor is fully symmetrical; the spatial position of the three-phase winding of the stator is staggered by a 120° electrical angle.
- d) The magnetic path of every element in the power system is unsaturated, which means that the reactance of the electrical equipment with the iron core will not change as the current changes.
- e) All power sources in the power system shall operate under the rated load.
- f) All the synchronous generators are equipped with the automatic excitation system (including forced excitation).

- g) The short circuit occurs at the moment when the short circuit current reaches the maximum value.
- h) The arc impedance of the short-circuit point and the excitation current of the transformer are not considered.

7 Selection of the main transformer

7.1 General requirements

7.1.1 The capacity of the main transformer shall be greater than the capacity of the connected generator.

7.1.2 When restricted by the transportation conditions, two three-phase transformers with lower capacity may be selected and used in parallel.

7.1.3 The energy-saving transformer shall be adopted.

7.1.4 The standard transformer should be adopted.

7.1.5 Under the circumstance that two kinds of transmission voltage are used to transmit electricity to the electrical grid, when selecting the transformer, if the transmission capacity of the medium-voltage side accounts for more than 20% of the capacity of a transformer, the three-coil transformer or auto transformer may be adopted. If one of the two kinds of voltage is used for the system of which the neutral point is not directly grounded, then the three-coil transformer shall be selected.

7.1.6 The type of main transformer shall be compatible with the external operational environment. A totally enclosed oil immersed transformer is not recommended in a situation with significant environment temperature changes.

7.1.7 The parallel operation shall meet the following requirements: The connection of the coils is same, the rated voltage of the primary coil and secondary coil is same (with same transmission ratio) and the impedance voltage is same.

7.2 Selection of parameters

7.2.1 The selection of the impedance voltage shall meet the following requirements:

- a) In general, the impedance voltage of ordinary two-coil transformers shall be selected in accordance with the value specified in the standard;
- b) The positional relationship between the maximum impedance voltage of the three-coil transformer and the auto transformer with the high/medium/low voltage shall be considered.

7.2.2 Selection of the current tap: The selection of the voltage regulation mode and the current tap for the main transformer shall be carried out in light of the design requirements of the power station connection system for the transformer:

- a) The low-voltage side voltage of the main transformer under the off load voltage regulation mode of the hydropower station shall be as same as the rated voltage of the generator, the voltage of the high/medium voltage coil of the transformer shall be 110% of the rated voltage of the current-bearing equipment, and normally equipped with a tap of +10% to - 10 % in increments of 2.5 %. On the load taps, if provided, they should have a tapping range of +10% to - 10 % in increments of 1.25%.

- b) The selection of the voltage regulation mode and the tap for the transformer shall be carried out in light of the design requirements of the power station connection system for the transformer.

7.2.3 As for the step-up transformer of which the voltage is 35(33) kV and above, the following modes should be selected:

- a) The three-phase two-coil power transformer is YNd11 or Yd11;
- b) The three-phase three-coil power transformer is YNYd-12-11.

7.3 Selection of the cooling mode

Under the circumstance that the limit of the temperature rise is satisfied, the oil-immersed air (ONAF) cooling mode should be selected.

8 Selection of high-voltage electrical equipment

8.1 General requirements

8.1.1 The selection of the high-voltage electrical equipment shall meet the following requirements:

- a) The requirements on normal operation, inspection, repair, short circuit and overvoltage shall be satisfied.
- b) The equipment shall meet the requirements of the local environmental conditions.
- c) The equipment shall be technically advanced and economically reasonable, and shall be easy to maintain.
- d) The types of similar equipment shall be minimized.

8.1.2 The general conditions for selection of the high-voltage electrical equipment are detailed as follows:

- a) The high-voltage electrical equipment may be selected in accordance with the items given in Table 3.

Table 3 - Items for selection of high-voltage electrical equipment

Serial No.	Item	Rated voltage (kV)	Rated current (A)	Rated capacity (kVA)	Rated breaking current (kA)	Stability of short circuit current	
						Thermal stability	Dynamic stability
1	Circuit breaker	√	√		√	√	√
2	Isolating switch	√	√			√	√
3	Current transformer	√	√			√	√
4	Voltage transformer	√					
5	Fuse	√	√		√		
6	Load switch	√	√			√	√
7	Current-limiting reactor	√	√			√	√
8	Arc suppression coil	√	√	√			
9	Post insulator	√					√
10	Wall-penetrating bushing	√	√			√	√

- b) The ambient temperature at the installation position of the electrical equipment may be selected in accordance with Table 4. When the ambient temperature at installation position is higher than +40°C (Max limit +60°C), the rated current shall be reduced by 1.8% for every 1°C that the temperature rises.

Table 4 - Ambient temperature for selection of electrical equipment

Installation place	Maximum ambient temperature (°C)	Minimum ambient temperature (°C)
Outdoor	Annual maximum temperature	Annual minimum temperature
Indoor reactor	Maximum ventilation temperature according to the ventilation design	
Indoor (others)	Temperature according to the ventilation design, or average maximum temperature in hottest month plus 5°C	

8.2 Selection of the high-voltage circuit breaker

8.2.1 The parameters of the circuit breaker shall be selected in accordance with the items given in Table 5.

Table 5 - Calculation formula for selection of the circuit breaker

Serial No.	Selection item	Calculation formula	Unit	Remarks
1	To be selected on the basis of the operating voltage	$U_{\max} \geq U_g$	V	U_{\max} : Maximum allowable operating voltage of the circuit breaker; U_g : Maximum operating voltage of the circuit
2	To be selected on the basis of the operating current	$I_n \geq I_g$	A	I_n : Long-term allowable operating current of the circuit breaker; I_g : Continuous operating current of the circuit
3	To be selected on the basis of the breaking current	$I_{dn} \geq I_{dt}$	kA	I_{dn} : Rated breaking current of the circuit breaker; I_{dt} : Short circuit current of the circuit at t second (in general, the t value shall be the actual breaking time of the circuit breakers, i.e. the sum of the action time of the relay protection and inherent breaking time of the circuit breaker)
4	To be selected on the basis of the rated closing current	$i_{Gn} \geq i_{ch}$	kA	i_{Gn} : Peak value of the rated closing current of the circuit breaker; i_{ch} : Peak value of the short circuit impact current of the circuit
5	To be verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$ $Q_t = I_t^2 \cdot t$	kA ² s	Q_t : Allowable thermal effect of the circuit breaker; Q_{dt} : Thermal effect of the short circuit current of the circuit at t second; I_t : Thermal stability current of the circuit breaker; t: Action time of the thermal stability current
6	To be verified on the basis of the dynamic stability	$i_{gr} \geq i_{ch}$	kA	i_{gr} : Peak value of the limit current of the circuit breaker;

8.2.2 The selection of the type of circuit breaker shall meet the following requirements:

- As for the circuit breaker in the SHP station of which the voltage 3 kV or more, the vacuum or SF₆ circuitbreaker may be selected
- When the vacuum circuit breaker is selected as the circuit breaker for the outlet circuit of the generator, it shall be equipped with the surge protection device or resistance-capacitance absorber.
- For voltage of 400 V, the air breaker may be adopted as the circuit breaker for the outlet circuit of the generator.

8.3 Selection of the isolating switch

8.3.1 The parameters of the isolating switch shall be selected in accordance with the items given in Table 6.

Table 6 - Calculation formulas for selection of the isolating switch

Serial No.	Selection item	Calculation formula	Unit	Remarks
1	To be selected on the basis of the operating voltage	$U_{\max} \geq U_g$	V	U_{\max} : Maximum allowable operating voltage of the isolating switch; U_g : Maximum operating voltage of the circuit
2	To be selected on the basis of the operating current	$I_n \geq I_g$	A	I_n : Long-term allowable operating current of the isolating switch; I_g : Continuous operating current of the circuit
3	To be verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$ $Q_t = I_t^2 \cdot t$	kA ² s	Q_t : Allowable thermal effect of the isolating switch; Q_{dt} : Thermal effect of the short circuit current of the circuit at t second; I_t : Thermal stability current of the isolating switch; t: Action time of the thermal stability current
4	To be verified on the basis of the dynamic stability	$i_{gr} \geq i_{ch}$	kA	i_{gr} : Peak value of the limit current of the isolating switch i_{ch} : Peak value of the short circuit impact current of the circuit

8.3.2 The selection of isolating switch type shall meet the following requirements:

- The type of isolating switch shall be determined in light of the installation place, environmental conditions, type of power distribution device and the requirements of the arrangement mode.
- As for the isolating switch for voltages of 35(33) kV and above which are to be controlled from the centralized control room shall have the electrical control mechanism as well as the manual control mechanism.

8.4 Selection of the current transformer and the voltage transformer

8.4.1 The items for selection and calculation for the current transformer shall comply with the requirements in Table 7.

Table 7 - Calculation formula for the selection of the current transformer

Serial No.	Selection item	Calculation formula	Unit	Remarks
1	To be selected on the basis of the operating voltage	$U_{\max} \geq U_g$	V	U_{\max} : Maximum allowable operating voltage of the current transformer; U_g : Maximum operating voltage of the circuit
2	To be selected on the basis of the operating current	$I_{n1} \geq I_g$	A	I_{n1} : Rated current of the primary coil of the current transformer; I_g : Continuous operating current of the circuit
3	To be verified on the basis of the thermal stability	$K_t \geq \frac{I_t}{I_{n1}}$ which may also be written as: $K_d \geq \frac{i_{ch}}{\sqrt{2}I_{n1}} \times 10^3$		K_t : Thermal stability current of the current transformer; I_t : Thermal stability current of the current transformer (normally expressed by 1 second); Q_{dt} : Thermal effect caused by the short circuit current (kA ² ·s)
4	To be verified on the basis of the dynamic stability	$i_{gr} \geq i_{ch}$ or $K_d \geq \frac{i_{ch}}{\sqrt{2}I_{n1}} \times 10^3$	kA	i_{gr} : Peak value of the limit current of the current transformer i_{ch} : Peak value of the short circuit impact current of the circuit; K_d : Multiple of the Dynamic current
5	The current transformer shall also be selected and verified in accordance with the different requirements for protection and measurement, and the secondary load, precision level and multiple of 10%.			

8.4.2 The selection of the voltage transformer shall comply with the following requirements:

a) Selection of the type of voltage transformer:

- 1) For voltages up to 1 kV, the electromagnetic voltage transformer with solid insulation or plastic casing may be selected;
- 2) For 35(33) kV indoor installation, the electromagnetic voltage transformer with solid insulation maybe selected.
For 35(33) kV outdoor installation, the electromagnetic voltage transformer with solid insulation or oil-immersed insulation which is suitable for the outdoor environment may be selected;
- 3) For 66 kV outdoor installation, the electromagnetic voltage transformer with oil-immersed insulation should be selected;
- 4) For 110(132) kV system, the capacitor or the electromagnetic voltage transformer may be selected;

b) Selection of the parameters of the voltage transformer:

- 1) The rated primary voltage of the voltage transformer shall be determined on the basis of the nominal voltage of the system used;
- 2) The rated secondary voltage of the voltage transformer shall be selected in accordance with the usage condition of the transformer: as for the single-phase transformer used for the connection of the lines of the three-phase system, its rated secondary voltage shall be the line voltage; as for the single-phase transformer used for connection between a phase of the three-phase system and the ground, its rated secondary voltage shall be the phase voltage; the rated secondary voltage of the residual voltage winding of the voltage transformer shall be the line voltage when the neutral point of the system is effectively grounded, and shall be the line voltage divided by 3 when the neutral point of the system is not effectively grounded;
- 3) The quantity, capacity and accuracy level of the secondary winding of the voltage transformer shall meet the requirements for measurement, protection and synchronous and automatic devices.

8.5 Selection of the high-voltage load switch and the high-voltage fuse

8.5.1 The high-voltage load switch shall be selected on the basis of the items given in Table 8.

Table 8 - Calculation formula for selection of the high-voltage load switch

Serial No.	Selection item	Calculation formula	Unit	Remarks
1	To be selected on the basis of the operating voltage	$U_n \geq U_g$	kV	U_n : Rated voltage of the load switch; U_g : Maximum operating voltage of the circuit
2	To be selected on the basis of the operating current	$I_n \geq I_g$	A	I_n : Rated current of the high-voltage load switch; I_g : Continuous operating current of the circuit
3	To be selected on the basis of the breaking current	$I_{dn} \geq I$	kA	I_{dn} : Maximum breaking current of the high-voltage load switch; I : Short-time maximum overload current of the circuit
4	To be verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$	$kA^2 \cdot s$	Q_t : Thermal effect caused by the short circuit current ($kA^2 \cdot s$) Q_{dt} : Allowable thermal effect of the load switch;
5	To be verified on the basis of the thermal stability	$i_{gr} \geq i_{ch}$	kA	i_{gr} : Peak value of the limit current of the load switch i_{ch} : Peak value of the short circuit impact current of the circuit

8.5.2 The high-voltage fuse shall be selected in accordance with the items given in Table 9.

Table 9 - Calculation formula for selection of the high-voltage fuse

Serial No.	Selection item	Calculation formula	Unit	Remarks
1	To be selected on the basis of the operating voltage	$U_{max} \geq U_g$	kV	U_{max} : Maximum allowable operating voltage of the equipment; U_g : circuit operating voltage
2	To be selected on the basis of the operating current	$I_n \geq I_{nj} \geq I_g$	A	I_n : Rated current of the fuse; I_{nj} : Rated fusing current; I_g : Continuous operating current of the circuit
3	To be selected on the basis of the breaking capacity	$S_{dn} \geq S_d$ or $I_{dn} \geq I_d$		S_{dn} : Rated breaking capacity of the fuse (MVA); S_d : Short circuit capacity of zero second(MVA); I_{dn} : Rated breaking current of the fuse (kA); I_d : Secondary transient current of the short circuit (kA)
4	To be selected on the basis of the protection characteristics	<p>1) For high-voltage fuse used to protect the power transformer, the rated current of melt may be selected by means of the following formula:</p> $I_{nj} = K_{st} I_n$ <p>(coefficient: When the automatic starting of the motor is not considered, the value shall be 1.1 to 1.3; when the automatic starting is considered, the value shall be 1.5 to 2.0; I_{nc} is the rated current on the high-voltage side of the transformer);</p> <p>2) For the fuse used to protect the power capacitor, the rated current of melt may be selected by means of the following formula:</p> $I_{nj} = K_r I_{nc}$ <p>(K_r coefficient: As for the drop-type high-voltage fuse, the value shall be 1.2 to 1.3; as for the current-limiting type high-voltage fuse, when there is one power capacitor, the value shall be set as 1.5 to 2.0; when there is a group of power capacitors, the value shall be set as 1.3 to 1.8; I_{nc} is the Rated current of the power capacitor circuit.)</p>		

8.6 Selection of the high-voltage complete switchgear

The high-voltage complete switchgear shall be selected on the basis of the parameters given in Table 10.

Table 10 - Performance parameters of the high-voltage complete switchgear

Serial No.	Name	Performance parameter	Remarks
1	Type	Movable type, fixed type	
2	Rated voltage	3.6, 7.2, 12, 40.5 kV	
3	Rated current	630, 1250, 1600, 2000, 2500, 3150, 4000 and 5000 A	
4	Rated frequency	60 Hz, 50 Hz	
5	Rated insulation level	To be determined in accordance with the relevant standards	
6	Rated short circuit breaking current	16, 20, 25, 31.5, 40, 50, 63 kA	
7	Rated short circuit closing current (peak value)	2.5 times the corresponding rated short circuit breaking current	
8	Rated short-time withstand current	16, 20, 25, 31.5, 40, 50, 63 kA	
9	Rated peak withstand current	2.5 times the corresponding rated short-time withstand current	
10	Rated short circuit duration	The rated short circuit duration is 4s. As for the high-voltage switch cabinet equipped with the load switch, the rated short circuit duration may be set as 2s or 4s as per the requirement of the user.	
11	Rated voltage of the breaking/closing coil and the auxiliary circuit	Standard voltage such as: DC: 110V, 220V; AC: 220V, 380V	

8.7 Selection and laying of the cable

8.7.1 The power cable should be flame-retardant cable. The high-voltage power cable should be flame-retardant cross-linked polyethylene insulated power cable. In the place where the cable may incur mechanical damage, the flame-retardant armoured cable should be selected.

The control cable should be copper-core plastic flame-retardant cable. If there is a requirement for anti-electromagnetic interference, the shielded flame-retardant cable shall be selected.

8.7.2 The power cable and the control cable should be laid separately. When they are laid on the same side or on the same cable tray (or bridge), the control cable shall be laid below the power cable.

8.7.3 The burying depth of buried cable should not be less than 700 mm. When the thickness of the frozen soil layer exceeds 700 mm, the measures to prevent the cable from being damaged shall be implemented.

8.7.4 The holes on the upper and lower ends of the cable shaft and on the wall, cabinet and floor where the cable traverses shall be sealed with non-flammable material.

9 Lightning overvoltage protection and grounding system

9.1 Lightning overvoltage protection

9.1.1 The direct-lightning overvoltage protection shall meet the following requirements:

a) The lightning rod or the lightning conductor of the direct-lightning overvoltage protection for the hydropower station shall meet the following requirements:

- 1) The protection scope shall include the switchyard, switching and other equipment, the main/auxiliary powerhouses and buildings adjacent to the main/auxiliary powerhouses;
- 2) In general, the main powerhouse, the main control room and the power distribution device room of the hydropower station will not be equipped with the direct-lightning protection device. The lightning rod for the purpose of protecting the other equipment should not be installed on the roof of the independent main control room and the switch room of which the voltage is less than 35 kV;
- 3) The main powerhouse, main control room and power distribution device room in the strong lightning area should be equipped with the direct-lightning protection device;
- 4) The lightning rod installed on the main powerhouse for protecting the other equipment, the lightning strip installed on the roof or the metal roof which may be used as the lightning arrester shunt measures shall be taken, or equipped with the centralized grounding mat, and the grounding point of the equipment shall be kept as far as possible away from the ground-entering point of the grounding wire of the lightning rods, and the grounding wire of the lightning rod shall be kept as far away from the electrical equipment as possible and other back-flashover protective measures shall be taken;
- 5) If any direct-lightning protection device is installed on the roof of the main control room or the roof of the power distribution system room of which the voltage is less than 35 kV, the metal roof, the metal structure on the roof, the metal casing of the equipment and the metal skin of the cable shall be grounded. The reinforcing bars in the reinforced concrete roof shall be welded to the grounding mat so as to be grounded.

The roof of the non-conductive structure shall be protected by lightning strips, the size of the grid composed of lightning strips shall be 8m to 10m, a grounding wire shall be set up every 10 m to 20 m, and such grounding wires shall be connected with the main grounding mat.

- 6) The hydropower station or switchyard located in a valley should be protected by the lightning conductor;
- 7) The metal casing of the equipment, the metal skin of the cable and the metal member of the building on the roof shall be grounded;
- 8) As for the casing of the outdoor-installed GIS equipment, the direct-lightning protection device may be omitted;

b) The lightning rod installed on the structure or roof shall comply with the following requirements:

- 1) As for systems of which the voltage is 110 kV or more, in general, the lightning rod shall be installed on the framework or roof; however, in the area where the soil resistivity is more than 1 000 $\Omega \cdot m$, the independent lightning rod should be installed; and measures to reduce the grounding resistance or improve the insulation shall be taken after checking the calculation;

- 2) As for 66 kV power distribution device, the lightning rod may be installed on the framework or roof; however, in the area where the soil resistivity is more than $500 \Omega \cdot \text{m}$, the independent lightning rod should be installed;
 - 3) The framework or roof of the high-voltage system of which the voltage is 35 kV or less should not be equipped with the lightning rod;
 - 4) The lightning rod installed on the framework shall be connected with the grounding mat, and the centralized grounding device shall be set up near it. On the framework where there is a lightning rod installed, the air distance between the grounded portion and the live portion may not be less than the length of the insulator string; however, in the area where the air is polluted, if there is difficulty, the air distance may be determined on the basis of the standard length of the insulator string in the area where the air is not polluted.
- c) The independent lightning rod (conductor) shall comply with the following requirements:
- 1) The independent grounding device should be set up. In the area where the soil resistivity is not high, the grounding resistance should not exceed 10Ω . If there is difficulty, the grounding device may be connected with the main grounding mat, but the length of the underground connection point between the lightning rod and the main grounding mat along the grounding body should not be less than 15m.
 - 2) The independent lightning rod shall not be set up in a place that pedestrians frequently walk through, and the distance of the lightning rod and its grounding device from the road or the main entrance should not be less than 3m; otherwise the voltage equalizing measures shall be taken.

9.1.2 The lightning-invasion-wave overvoltage protection shall meet the following requirements:

- a) The 35(33) kV to 110(132) kV overhead transmission line which is not equipped with the lightning conductor throughout its entire length shall be equipped with the lightning conductor on the incoming line which is 1 km to 2 km away from the outgoing bay of the switchyard.
- b) A group of lightning arresters shall be set up on the side of the isolating switch or the circuit breaker of the 35(33) kV to 110(132) kV incoming/ outgoing transmission line.
- c) As for the cable-type incoming line of which the voltage is 35(33) kV or more, the connection between the cable and the overhead line shall be provided with the lightning arrester, its grounded end shall be connected with the metal skin of the cable.
- d) Configuration of the lightning arrester in the open-type high-voltage power distribution device of the 35(33) kV and above hydropower station which has the overhead incoming/outgoing line:
 - 1) Every group of the bus shall be equipped with the lightning arrester. All lightning arresters shall be connected to the main grounding mat of the power plant via the shortest grounding wire, and the centralized grounding device shall be set up near it;
 - 2) Since the overhead incoming/outgoing line may have the double-circuit tower, there is the possibility that both of them incur lightning at the same time. When determining the maximum electrical distance between the lightning arrester and the transformer, the lines shall be deemed to be one circuit; and in the thunder season, none of the circuits should be disconnected.
- e) As for the transformer in the effective grounding system for which the neutral point is not grounded, if the neutral point has hierarchical insulation and is not provided with the protection clearance, then the metal oxide lightning arrester shall be installed on the neutral point. As for the transformer in the grounding system which has high resistance and for which the neutral point is not grounded and the arc suppression coil is grounded, its neutral point should be equipped with the metal oxide lightning arrester.

- f) As for the three-winding auto transformer connected with the overhead line, if the low-voltage winding of the transformer (including the three-winding transformer connected with two motors) may operate in the opened-circuit state and the two-winding transformer of the hydropower station will send the station-service electricity in reversed direction by the high-voltage side when the generator is cut off, then the lightning arrester shall be set up on the outgoing line of the low-voltage winding of the transformer, so as to prevent the insulation of the low-voltage winding from being damaged by the induced voltage arising from the lightning wave of the high-voltage winding; however, if such winding is connected with the metal skin cable whose length is not less than 25 m, then the lightning arrester may be omitted.
- g) The lightning-invasion-wave overvoltage protection for the gas-insulated switchgears (GIS) transformer substation shall meet the following requirements:
 - 1) As for the GIS step-up substation for which the incoming line contains no cable, the connection between the GIS pipe and the overhead line shall be equipped with the metal oxide lightning arrester, and its grounded end shall be connected with the metal casing of the pipe;
 - 2) As for the GIS step-up substation for which the incoming line contains the cable, the connection between the cable and the overhead line shall be equipped with the metal oxide lightning arrester, and its grounded end shall be connected with the metal skin of the cable. As for the three-core cable, the metal skin on its end shall be connected with the metal casing of the GIS pipe and grounded; as for the single-core cable, the grounding shall be realized via the metal oxide cable protector;
 - 3) Whether the GIS step-up substation for which the overall length of the incoming line is a cable shall be equipped with the metal oxide lightning arrester shall be determined after verification in light of the possibility that the lightning overvoltage wave may invade from another end of the cable.

9.2 Grounding system

9.2.1 The grounding resistance and the grounding resistance reducing measures shall meet the following requirements:

- a) The grounding resistance of the effective grounding system shall meet the following requirements:

$$R \leq 2000 / I \dots\dots\dots (1)$$

where

R is the maximum grounding resistance in consideration of seasonal change, in Ω;

I is the maximum ground-entering current passing through the grounding device used for the calculation, in A (effective value).

- b) The grounding resistance of the grounding system which is not directly grounded shall meet the following requirements:

$$R \leq 120 / I \dots\dots\dots (2)$$

The grounding resistance *R* should not exceed 4Ω.

- c) The hydropower station may be equipped with underwater manual grounding devices so as to reduce the grounding resistance. For example: to be set up in the water reservoir, upstream cofferdam, construction diversion tunnel, tailwater channel, downstream river or nearby low-resistivity water source, and in areas below the minimum water level in the water reservoir or the diversion system.

- d) When there is a low-soil-resistivity area or water source available near the hydropower station, the external grounding measures may be adopted to reduce the grounding resistance.
- e) When the soil resistivity is relatively lower or there is groundwater that is deeply underground in the area of the hydropower station and its nearby area, but the soil resistivity in the surface layer is relatively higher, then the deep well grounding mode may be adopted.
- f) In a place where the deep-well grounding mode and the external grounding mode cannot be used, when the area of the grounding mat is not large, the manual resistance reducing measures may be adopted in light of on-site situations and technical and economic comparison, so as to reduce the grounding resistance. The manual resistance reducing measures include the use of the resistance-reducing agent, use of the electrolysis pole and replacement with low-resistivity material.

9.2.2 The design for the voltage equalization shall meet the following requirements:

- a) The high-voltage power distribution device shall be equipped with the voltage equalizing mat. The outer edge of the voltage equalizing mat shall be closed, every corner on the outer edge shall be arc shaped, and the radius of such an arc should not be less than half of the interval between the voltage equalizing straps. In the voltage equalizing mat, there shall be the horizontal voltage equalizing strap, and the burying depth shall be 0.6 m to 0.8 m;
- b) The design of the voltage equalizing mat shall employ the internal contact potential difference and the external step potential difference as the safety standard. The allowable values of the contact potential difference and the step potential difference are specified as follows:
 - 1) In the effectively-grounded short circuit current system, when any single-phase grounding fault or same-point two-phase grounding fault occurs to the electrical grid, the contact potential difference and the step potential difference generated shall not exceed the following values:

$$E_j = \frac{174 + 0.17 \rho_b}{\sqrt{t}} \dots\dots\dots (3)$$

$$E_k = \frac{174 + 0.17 \rho_b}{\sqrt{t}} \dots\dots\dots (4)$$

where

E_j is the allowable value for the contact potential difference in V;

E_k is the allowable value for the step potential difference, in V;

ρ_b is the soil resistivity of the surface where the person stands, in Ω m;

t is the auration of the grounding short circuit fault, which shall be as same as the duration of the grounding fault used in the thermal stability verification of the grounding device, in s.

- 2) In the short circuit current system which is not directly grounded, when any single-phase grounding fault occurs, the contact potential difference and the step potential difference of the grounding device of the power equipment shall not exceed the following values:

$$E_j = 50 + 0.05\rho_b \dots\dots\dots(5)$$

$$E_k = 50 + 0.2\rho_b \dots\dots\dots(6)$$

9.2.3 The provisions on grounding device are detailed as follows:

- a) The grounding mat shall be connected by at least two main grounding lines, and shall constitute the grounding system for the entire project. The distance between the main grounding lines should be relatively large, and the main grounding lines should be the flat steel for which the cross section is not less than 50mm × 6mm or the round steel for which the diameter is not less than 20mm.
- b) The natural grounding bodies which may be used for grounding include:
 - 1) Reinforcing bar in the surface layer of the reinforced concrete of the hydraulic structure in contact with water or damp soil;
 - 2) Metal lining of the penstock, tailwater canal and tailwater pipe;
 - 3) Hydro-mechanical structures of various gates or trash racks;
 - 4) Metal post or reinforcing cage of the building;
 - 5) Water-supply steel pipe buried underground;
 - 6) Metal well pipe.
- c) The horizontally-laid grounding body may be round steel or flat steel; the vertically-laid grounding body may be angle steel, round steel or steel pipe. The length of the vertical grounding body should be 2.5 m to 3.0 m, and the burying depth should be 0.6 m to 0.8 m.
- d) The connection between the grounding line and the grounding body should be realized by welding; the connection between the grounding line and the electrical equipment may be realized by bolt or welding.
- e) When the neutral point of the transformer or generator which is grounded directly or via arc suppression coil is to be connected with the grounding body or the main grounding line, the separate grounding wire shall be used. When the neutral point of the transformer is grounded, there shall be two grounding wires connected with the different main lines of the main grounding mat.
- f) Every grounded portion of the electrical equipment shall be connected with the main grounding line via a separate grounding wire, and it is prohibited to connect several portions to the same grounding line.
- g) The connection of the reinforcing bars in concrete used as grounding body shall be realized by welding, and the reinforcing bars shall be welded at the separated point.
- h) The sectional area of the steel grounding line shall meet the requirements for current carrying capacity, thermal stability during the short-circuit automatic cut-off period and the voltage equalization, and shall not be less than the specifications as specified in Table 11.

Table 11 - Minimum specifications for the steel grounding body and the grounding line

Type	Specification	Aboveground		Underground
		Indoor	Outdoor	
Round steel	Diameter(mm)	8	10	12
Flat steel	Cross section (mm ²)	75	100	120
	Thickness (mm)	3	4	4
Angle steel	Thickness (mm)	2.5	3	4
Steel pipe	Wall thickness (mm)	2.5	3	4

10 Lighting system

10.1 The power-supply network for the working lighting and emergency lighting of the power station shall be set up separately. The power supply for the working lighting shall come from the AC station-service power system. Emergency lighting may obtain its power supply from the storage battery or other DC power sources.

10.2 The premises where work must be continued after the working lighting is interrupted by trouble and the main passages shall be equipped with emergency lighting. For the outdoor area of the plant, provision of the emergency lighting is not required.

11 Arrangement of the main electrical equipment inside and outside of the power station

11.1 The step-up transformer and the switchyard should be close to the powerhouse. When the switchyard and the transformer are required to be installed at separate places, the transformer shall be installed nearest to the generating units.

11.2 For generating voltages between 6 kV to 35 kV, the indoor arrangement for the complete switchgear or the outdoor arrangement should be adopted. For voltage systems of 66 kV or more the outdoor arrangements should be adopted. However, in the polluted area or if restricted by the terrain conditions, the enclosed-type assembled switchgear may also be adopted after technical and economic evaluation.

11.3 The central control room shall be set up in accordance with the automatic control mode of the power station. The central control room area shall be determined in light of the quantity, arrangement requirements and arrangement mode of the control screens (panels).

12 Automatic devices for relay protection and system safety

12.1 General requirements

12.1.1 The relay protection device shall meet the requirements for reliability, selectivity, sensitivity and quick action.

12.1.2 The type selection and configuration of the relay protection shall meet the requirements of the main electrical connection of the power station, and in consideration of the operational flexibility of the electrical grid and the power station.

12.1.3 The relay protection device shall be put into operation together with the equipment of the power station which is to be protected.

12.1.4 The electrical equipment and lines shall be equipped with the main protection and the backup protection devices.

12.1.5 The minimum sensitivity coefficient of the relay protection shall meet the provisions in Table 12.

Table 12 - Minimum sensitivity coefficient of the relay protection

Category of protection	Type of protection	Component	Sensitivity coefficient	Remarks
Main protection	Overall differential protection for the generator and the transformer	Starting current of the differential current element	1.5	—
	Current quick-break protection for the generator, transformer and lines	Current element	1.5	To be calculated on the basis of the short circuit at the installation position of the protection
	Complete current differential protection for the bus	Starting current of the differential current element	1.5	—
	Incomplete current differential protection for the bus	Differential current element	1.5	—
Backup protection	Remote backup protection	Current, voltage and impedance elements	1.2	To be calculated on the basis of short circuit at the adjacent electrical equipment and the end of line (The short circuit current shall be more than 1.5 times the accurate operating current of the impedance element), while the relay action may be taken into account.
		Zero-sequence or negative-sequence direction element	1.5	
	Near backup protection	Current, voltage and impedance elements	1.3	To be calculated on the basis of short circuit at the end of line
		Negative-sequence or zero-sequence direction element	2	
Auxiliary protection	Current quick-break protection		1.2	To be calculated on the basis of short circuit at the installation position of the protection under normal operating mode

12.1.6 The current transformer equipped with the various protection devices shall meet the requirements to eliminate the blind zone of protection and to reduce the impact caused by the faults of the current transformer.

12.1.7 If the breaking of the secondary circuit of the voltage transformer may lead to malfunction of the protection device, the broken-line locking device shall be installed so as to give the warning signal. If the breaking of the secondary circuit will not lead to malfunction of the protection device, only the voltage circuit breaking signal device shall be installed.

12.1.8 The line which is equipped with the circuit breaker and for which the voltage is not less than 10 kV should be equipped with the automatic reclosing device; when there is a power source on the opposite side, the line should be equipped with the synchronization-check or no-voltage-check automatic reclosing device.

12.1.9 The power station which has two or more station-service transformers shall be equipped with the automatic input device for the backup station-service power source.

12.2 Protection of the generator

12.2.1 General requirements

- a) The generator shall be equipped with corresponding protection against the following troubles and abnormal operations in accordance with the provisions of this Section:
- 1) Inter-phase short circuit of the stator winding;
 - 2) Grounding of the stator winding;
 - 3) External inter-phase short circuit of the generator;
 - 4) Overload of the stator winding;
 - 5) Overload of the stator winding;
 - 6) Overload of the excitation winding;
 - 7) One-point grounding of the excitation circuit;
 - 8) Abnormal reduction or loss of the excitation current;
 - 9) Disconnection from the system during phase-regulating operation;
 - 10) Reverse power of the generator;
 - 11) Abnormal frequency;
 - 12) Other trouble and abnormal operations.

- b) The protection should, in light of the nature of the trouble or the abnormal operating mode and in accordance with the provisions in this Section, respectively act on:
- 1) Shutdown: cut-off the circuit breaker for the generator, discharge the field, and close the guide vane;
 - 2) Disconnection and de-excitation: cut-off the circuit breaker for the generator, discharge the field and close the guide vane to the unloaded position;
 - 3) Disconnection: cut-off the circuit breaker for the generator and close the guide vane to the unloaded position;
 - 4) Reduction of the output force: reduce the output force of the turbine to a specified value;
 - 5) Reduction of the impact scope of the trouble: for example, cut-off the other pre-determined circuit breaker;
 - 6) Tripping: first close the guide vane to the unloaded position, and then cut-off the circuit breaker for the generator and carry out de-excitation;
 - 7) Signal: send the sound and optical signals.

12.2.2 The inter-phase short circuit protection for the stator winding of the generator and its outgoing connecting leads shall meet the following requirements:

- a) The generator whose capacity is not less than 1MW shall be equipped with differential protection, as the main protection for the inter-phase short circuit of the stator winding and its connecting leads. The protection shall immediately lead to shutdown. The generator whose capacity is less than 1MW shall be equipped with the current quick-break protection, as the main protection for the inter-phase short circuit of the stator winding and its connecting leads. The protection shall immediately lead to shutdown.
- b) In the generator transformer bank connection mode, when there is a circuit breaker between the generator and the transformer, the generator should be equipped with separate main protection.
- c) Differential protection shall be used in the three-phase connection scheme.

12.2.3 The single-phase grounding fault protection for the stator winding of the generator shall meet the following requirements:

- a) Different grounding protection shall be set up in light of the grounding mode of the neutral point of the generator and the allowable value of the grounding current of the generator. The allowable value of the single-phase grounding fault current of the stator winding of the generator shall be the value specified by the manufacturer. If there is no specified value, the data listed in Table 13 may be used.

Table 13 - Allowable value for the single-phase grounding fault current of the stator winding of the turbine generator

Rated voltage of the generator (kV)	Allowable value of the grounding current (A)
6.3	≤4
10.5	≤3

- b) When the single-phase grounding fault current (without considering the compensation role of arc suppression coil) is more than the allowable value, the single-phase grounding protection device which has selectivity shall be set up. The protection shall act on the signal with a time limit. However, when the arc suppression coil quits operation or the residual current is more than the allowable value of the grounding current for any other reason, the protection shall lead to shutdown. When the single-phase grounding fault current is less than the allowable value, the single-phase grounding monitoring device may act on the signal, and will lead to shutdown, if necessary. In order to inspect whether there is a grounding fault before the generator is connected in parallel with the system, the protection device shall be able to monitor the value of the zero-sequence voltage at the terminal of the generator.
- c) The different single-phase grounding protection device or the single-phase grounding monitoring device may be set up in light of the different grounding mode of the neutral point of the generator.

12.2.4 The near backup protection for the external inter-phase short circuit trouble of the generator and the far backup protection for the inter-phase short circuit trouble of the adjacent element shall meet the following requirements:

- a) As for the generator other than the self-shunt generator, the over-current protection initiated by the combined voltage (including the negative-sequence voltage and line voltage) should be set up. The current should come from the current transformer on the neutral point side of the generator. In case the sensitivity fails to meet the requirements, the negative-sequence over-current protection may be added.
- b) As for the self-shunt generator, the low-voltage over-current protection with current memory should be adopted, and the current should come from current transformer on the neutral point side of generator.
- c) When the protection services for remote backup protection for adjacent element (transformer), the protection sensitivity shall be verified in accordance with the inter-phase short circuit at the end of protected area, and the protected area should not go beyond the scope of first section of protection for adjacent lines.
- d) The protection devices specified in articles in this Section should have two time limits. Within the shorter time limit, the protection will reduce the scope of impact of trouble, or act for disconnection and de-excitation. Within the longer time limit, and the protection will lead to shut down.
- e) The backup protection for the generator and transformer bank operated in parallel and the protection for the inter-phase short circuit trouble of the connection bus shall have the necessary sensitivity coefficient, which should not be lower than the value specified in Table 15.

12.2.5 The generator shall be equipped with overvoltage protection, and its set value shall be determined in light of the insulation of the stator winding. The overvoltage protection shall lead to disconnection and de-excitation or shutdown.

12.2.6 The overload protection shall be equipped for the stator winding of the generator. The protection will act on the signal with a time limit.

12.2.7 The generator shall be equipped with the special protection device for one-point grounding of the excitation circuit. The protection device shall be able to effectively eliminate the impact of the DC and AC component in the excitation circuit. The protection will act on the signal with a time limit, which should reduce the load for smooth shutdown, and may lead to tripping, if permissible.

12.2.8 The de-excitation protection shall be equipped for the generator. The protection will act on the disconnection from the system with a time limit.

12.2.9 As for the turbine generator unit which has the phase-regulating operating condition, under the

phase-regulating operating condition, the protection for loss of the power source upon disconnection from the system shall be set up. The protection device may employ the low-frequency protection, and will lead to shutdown with a time limit.

12.2.10 As for the generator which has the abnormal operating mode under which the generator may operate as a motor, the reverse power protection should be provided. The protection will lead to disconnection with a time limit.

12.2.11 In order to prevent the occurrence of a breakdown of the electrical grid due to abnormal frequency (over or under frequency), the generator shall be equipped with abnormal frequency protection. Under normal operating conditions, the abnormal frequency protection for the generator shall act as per the set value of thunder-frequency load-reducing device of the electrical grid. The action of this protection shall lead to de-excitation or tripping.

12.3 Protection of the main transformer

12.3.1 General requirements for protection of the transformer:

- a) Inter-phase short circuit of the winding and its outgoing leads, and single-phase grounding short circuit on the directly grounded side or the small-reactance grounded side of the neutral point;
- b) Over-current caused by external inter-phase short circuit;
- c) Over-current and neutral-point overvoltage caused by external grounding short circuit in the electrical grid of which the neutral point is grounded directly or via a small reactor;
- d) Single-phase grounding fault on the side of the neutral point which is not effectively grounded;
- e) Turn to turn short circuit of the winding;
- f) Overload;
- g) Drop of oil level;
- h) High oil temperature, high winding temperature of the transformer, high oil tank pressure and fault of the cooling system.

12.3.2 The provisions on gas protection are detailed as follows:

- a) The oil-immersed transformer, loaded voltage regulation device and high-voltage cable terminal box embedded in the transformer oil tank shall be equipped with gas protection, as the main protection for the transformer winding inter-phase, inter-turn, inter-layer short circuit, single-phase grounding short circuit at the directly-grounded side of the neutral point, and internal short circuit of the voltage-regulating device and the high-voltage cable terminal box.
- b) Light gas protection: If slight gas is generated or the oil level drops owing to any fault in the oil-immersed transformer, loaded voltage regulation device or high-voltage cable terminal box, the protection shall immediately act and initiate the alarm and indication on the annunciation window.
- c) Heavy gas protection: If a lot of gas is generated owing to any fault in oil-immersed transformer, loaded voltage regulation device or high-voltage cable terminal box, the protection shall immediately trip the circuit breakers on both sides of the transformer.
- d) As for gas protection, appropriate measures shall be taken to prevent the false operation of the gas protection caused by a fault or vibration of the leading wires of the gas relay.

12.3.3 The provisions on the main protection for the short circuit trouble of the outgoing line, bushing and interior of the transformer are detailed as follows:

- a) As for the generator transformer bank connection mode, when there is a circuit breaker between the generator and the transformer, the transformer should be equipped with separate main protection.
- b) The transformer for which the capacity is not less than 2MVA shall be equipped with differential protection.
- c) The differential protection shall immediately trip the circuit breakers on both sides of the transformer.

12.3.4 The provisions on backup protection for inter-phase short-circuit are detailed as follows:

- a) The backup protection for inter-phase short-circuit of the transformer shall serve as the backup for the main protection for the generator and for the protection for the adjacent elements (transformer). The protection shall be sufficiently sensitive for inter-phase bus short circuit on both sides of the transformer. In order to simplify the protection, when the protection serves as the remote backup for the adjacent connection, the requirement for the protection sensibility may be appropriately reduced.
- b) The backup protection for inter-phase short-circuit of the transformer should be the overcurrent protection. If the overcurrent protection cannot meet the sensibility requirements, the overcurrent protection initiated by the combined voltage (negative-sequence voltage and line-to-line voltage) or the combined current protection (negative-sequence current and overcurrent protection initiated by the single-phase voltage) should be adopted. The protection will trip the corresponding circuit breaker in a delayed manner.
- c) In light of the different system and power source for the connection on either side, different backup protection for inter-phase short-circuit for the generator shall be set up. The protection should be able to reflect the trouble between the current transformer and the circuit breaker, and the requirements are detailed as follows:
 - 1) As for the two-winding transformer and the three-winding transformer with the single-side power source, the backup protection for inter-phase short-circuit should be set up on both sides. The non-power-source-side protection has two or three time limits. With the first time limit, the protection will cut off the bus-connected or section circuit breaker on this side, so as to reduce the scope of impact of the trouble; within the second time limit, the protection will cut off the circuit breaker on this side; within the third time limit, the protection will cut off the circuit breakers on both sides of the transformer. The protection on the power source side has a time limit, and will cut off the circuit breakers on both sides of the transformer.
 - 2) As for any two-winding transformer or three-winding transformer which has power sources on two or three sides, the backup protection for inter-phase short-circuit on every side may have two or three time limits. In order to meet the selectivity requirement or reduce the action time of the backup protection, the backup protection for inter-phase short-circuit may be equipped with the direction element, and the direction should point at the bus on either side, but the backup protection which will cut off the circuit breakers on both sides of the transformer shall not be equipped with the direction element.
 - 3) If there is no special bus protection on the low-voltage side of the transformer, or the backup protection for inter-phase short-circuit on the high-voltage side of the transformer is not sufficiently sensitive for the low-voltage side bus inter-phase short circuit, in order to improve the reliability of cutting off the low-voltage side bus trouble, two sets of backup protection for inter-phase short-circuit shall be set up on the low-voltage side of the transformer. These two sets of backup protection are connected to different current transformers.

- 4) As for the generator transformer bank, no backup protection for inter-phase short-circuit will be set up on the low-voltage side of the transformer, but the backup protection for inter-phase short-circuit installed on the neutral point side of generator shall be used as backup protection for inter-phase short-circuit of the transformer and the branch line and outside the high-voltage side.

12.3.5 The provisions on single-phase grounding overcurrent and overvoltage backup protection are detailed as follows:

- a) In the electrical grid for which the neutral point is grounded, if the neutral point of the transformer is directly grounded, then, as for the overcurrent caused by external single-phase grounding, the zero-sequence current protection shall be set up and the requirements are detailed as follows:
 - 1) The booster transformer for which the neutral point is directly grounded may be provided with the two-section-type delayed zero-sequence overcurrent protection, with two time limits for each section. The protection will reduce the impact scope of trouble within the shorter time limit, or lead to tripping of the circuit breaker on its side; the protection will lead to tripping of the circuit breakers on both sides of the transformer within the longer time limit.
 - 2) As for any auto transformer or any three-winding transformer for which the high/ medium-voltage-side neutral points are directly grounded, when there is a selectivity requirement, the direction element shall be set up, and the direction shall point at the bus on either side.
 - 3) The zero-sequence current protection for the ordinary transformer shall be connected to the secondary winding of the current transformer on the outgoing line from the transformer neutral point, and the zero-sequence current direction protection may also be connected to the zero-sequence circuit the three-phase current transformer on the high/medium voltage side.
 - 4) The zero-sequence current protection for the auto transformer shall be connected to the zero-sequence circuit of the three-phase current transformer on the high/medium voltage side.
 - 5) As for the auto transformer, in order to improve the reliability in cutting off the single-phase grounding short circuit, the zero-sequence overcurrent protection may be added in the neutral point circuit of the transformer.
- b) In the electrical grid for which the neutral point is directly grounded, if the neutral point of the transformer with power source on the low-voltage side may operate with or without grounding, then as for the overcurrent caused by external single-phase grounding, and the voltage rise owing to loss of the grounded neutral point, the protection shall be provided in accordance with the following provisions:
 - 1) The zero-sequence current protection shall be set up, so as to meet the requirement for the direct grounding of the neutral point of the transformer. In addition, the zero-sequence overvoltage protection shall be set up. When the grounded neutral point of the electrical grid connected with the transformer is lost, the zero-sequence overvoltage protection will lead to tripping of the circuit breakers on both sides of the transformer within the time limit of 0.3s to 0.5s.
 - 2) In order to limit the overvoltage of the neutral point which may occur when such transformer operates with the neutral point not grounded, the discharging gap shall be set up at the neutral point of the transformer. In such case, the zero-sequence current protection shall be set up, and the zero-sequence current protection for the reactive zero-sequence voltage and the gas discharging current shall be provided. When the electrical grid is grounded in single phase and the grounded neutral point is lost, the gap zero-sequence current voltage protection will trip off the circuit breakers on both sides of the transformer within 0.3s to 0.5s.

- c) In the electrical grid where the neutral point is not effectively grounded, as for the overvoltage caused by a single-phase grounding fault inside the transformer or on its outgoing line, the zero-sequence overvoltage protection shall be provided, and the zero-sequence voltage may come from the residual winding of the voltage transformer on such side or the neutral-point voltage transformer (arc suppression coil). The protection will act on the signal with the time limit.

12.3.6 In light of the situation where the transformer may get overloaded, the overload protection shall be equipped. The protection shall act on the signal.

12.3.7 The protection for the temperature, oil tank pressure, oil level and cooling system shall meet the following provisions:

- a) In order to indicate the rise of the transformer oil temperature and the winding temperature, the temperature protection shall be set up. The temperature protection may be divided into two levels, namely high temperature and excessively high temperature. As for high temperature, the action will be carried out on the signal; as for excessively high temperature, the action will lead to tripping of the circuit breakers on both sides of the transformer.
- b) The high/low transformer oil level protection shall be provided. All the high/low oil level protection shall immediately act on the signal, and may also lead to tripping of the circuit breakers on both sides of the transformer, if necessary.
- c) The forced oil-circulation air cooling or the forced oil-circulation water cooling transformer shall be equipped with the cooling system fault protection.
- d) As for increased pressure in the transformer oil tank, the pressure releasing protection shall be provided. The protection will immediately act on the signal, and if necessary, the action may also lead to tripping of the circuit breakers on both sides of the transformer.

12.3.8 The low-voltage station service transformer shall be equipped with the protection in accordance with the following provisions

- a) The current quick-break protection shall be set up, as the main protection for inter-phase short circuit trouble of the winding and the high-voltage side outgoing line of the transformer. The protection will immediately lead to tripping of the circuit breakers on both sides of the low-voltage station service transformer. The capacity of the low-voltage station service transformer shall be not less than 2MVA. When the sensibility of the current quick-break protection fails to meet the requirements, the differential protection may also be provided.
- b) The overcurrent protection shall be provided, serving as the backup protection for the inter-phase short circuit trouble of the transformer and the adjacent elements.
- c) The high-voltage side may share the single-phase grounding protection with the connected bus, rather than be equipped with the separate single-phase grounding protection.
- d) When the low-voltage side neutral point of the transformer is directly grounded, the zero-sequence overcurrent protection shall be provided, as the backup protection for single-phase grounding short circuit trouble on the low-voltage side of the transformer.
- e) The oil-immersed transformer shall be equipped with the gas protection. When slight gas is generated owing to fault inside the transformer tank or the oil level drops, the protection will act on signal; when a lot of gas is generated, the protection shall immediately lead to tripping of the circuit breakers on both sides of the transformer.

- f) In order to indicate the rise of the oil temperature and winding temperature of the transformer, the temperature protection shall be provided. The temperature protection may be divided into two levels, namely high temperature and excessively high temperature. The protection will give an alarm for high temperature, and the protection will lead to tripping of the circuit breakers on both sides of the transformer for excessively high temperature.

12.4 Bus protection

The bus protection shall meet the following provisions:

- a) As for the 3kV to 10kV segmented bus and double bus in parallel operation, the protection for the bus may be achieved by the backup protection for the generator and the transformer. Under any of the following circumstances, the special bus protection shall be provided:
- 1) The trouble on a segment of the bus or on a set of bus must be eliminated in a quick and selective manner, so as to ensure the safe operation of the power station and the power grid as well as the reliable power supply for significant loads;
 - 2) The line circuit breaker is not to be set to cut off the short circuit in front of the line reactor.
- b) As for the 35(33) kV to 110(132) kV bus of the power station, under any of the following situations, the special bus protection shall be provided:
- When the trouble on the 110(132) kV single bus or the 35(33) kV to 66 kV bus is significant, the power station must be quickly cut off.
- c) The special bus protection shall meet the following requirements:
- 1) When the AC circuit is abnormal or broken, the bus differential protection shall be initiated and the alarm shall be given.
 - 2) When a set of healthy bus or a section of the bus is connected to a faulted bus, the bus protection should be able to disconnect the faulted bus in a quick and selective manner.
 - 3) The bus protection should be capable of disconnecting the faulty portion during all the operating modes of the main connection.
 - 4) The bus protection may use the current transformer with the different transformation ratio.
 - 5) As for various external faults, the bus protection shall not act incorrectly owing to temporary saturation of the current transformer caused by the non-periodic component of the short circuit current.
 - 6) The bus protection shall be connected with a set of special secondary coils of the current transformer.
 - 7) After the bus protection acts, as for the line without the bypass and with the longitudinal protection, the appropriate measures shall be taken to ensure that the opposite circuit breaker can quickly carry out the tripping operation.
 - 8) The bus protection only realizes the three-phase tripping exit, and the failure protection for circuit breaker connected to the bus may share its tripping exit circuit.
- f) The bypass circuit breaker, the bus-connected circuit breaker used as the bypass or the section circuit breaker shall be equipped with the protection device which can substitute the line protection. During the period when the bypass circuit breaker is used as a substitute for the in-line circuit breaker, if it is necessary to maintain the longitudinal protection operation of the line, a set of longitudinal protection of such line may be switched to the bypass circuit breaker, or other measures may be taken, so as to ensure

that the bypass circuit breaker will continue to operate with longitudinal protection.

- g) The bus-connected or section circuit breaker should be equipped with the phase-current or zero-sequence current protection, as the charging protection for the bus.

12.5 Matching and interface between the protection and other systems

The protection device shall be able to communicate with the computer monitoring system of the power station, and the specific requirements are detailed as follows:

- a) The protection device and its outlet circuit shall be able to operate independently without the computer monitoring system.
- b) Various inputs required by the circuits based on the logic judgment of the protection device shall be directly connected to the protection device, and shall not pass through the computer monitoring system and its communication network.
- c) The protection device shall be able to communicate with the protection information sub-station of the power station, and upload and download the following types of information:
 - 1) Identification information and installation position information for the device;
 - 2) On-off input (such as the position of the circuit breaker, and the pressing plate for protection);
 - 3) Abnormal signal (including abnormal situation of the device and the abnormal situation of the external circuit);
 - 4) Fault information (record of faults, and record of the sequence of incidents relating to the internal logic quantity);
 - 5) Measured value of the analogue quantity;
 - 6) Specified value and range number of the device;
 - 7) Control information about the computer monitoring system, circuit breaker tripping and the closing command.
- d) The protection device shall be able to receive the clock synchronization signal from the satellite clock system.
- e) The communication protocol between the protection device and the computer monitoring system/ protection information substation shall comply with the provisions of the standard.

13 Excitation system

13.1 Main basis for selection of the excitation system

13.1.1 The control mode and main circuits of the excitation system shall be selected on the basis of the excitation mode and the operating mode of the generator. The parameters of the excitation transformer, power unit and de-excitation device shall be calculated and the excitation system shall be selected on the basis of the set parameters of the generator.

13.1.2 Basic data for selection of the excitation system:

- a) Excitation mode and forced excitation multiples of the generator;
- b) Rated power of the generator;
- c) Rated voltage of the generator;
- d) Rated current of the generator;
- e) Rated power factor of the generator;
- f) Rated frequency of the generator;
- g) Rated excitation voltage of the generator (or exciter);
- h) Rated excitation current of the generator (or exciter);
- i) Unloaded excitation voltage of the generator (or exciter);
- j) Unloaded excitation current of the generator (or exciter);
- k) DC resistance (75 °C) of the excitation winding.

13.2 Selection of the excitation mode

13.2.1 The rotating excitation mode shall employ the brushless excitation.

13.2.2 The static excitation mode shall employ the self-shunt excitation.

13.3 Self-shunt static silicon-controlled excitation system

13.3.1 The excitation regulator shall meet the following requirements:

- a) The microcomputer should be adopted to complete the calculation for regulation and control (P, PI, PID);
- b) The measurement signals that the excitation regulator must acquire shall include the terminal voltage of the generator, stator current of the generator, active power of the generator, reactive power of the generator, frequency of the generator, the excitation voltage and the excitation current;
- c) The PID control algorithm should be adopted as the regulation algorithm of the excitation regulator;
- d) When the power system is in trouble and thus the output voltage of the generator decreases sharply, the excitation regulator shall carry out the forced excitation;
- e) When the overvoltage is caused as the speed of turbine generator increases, the excitation regulator shall carry out forced de-excitation;
- f) The generator set which meets all the following conditions shall be equipped with the power system stabilizer (PSS):
 - 1) Main generator set in the system;
 - 2) Generator set which is in long-distance and weak contact with the system;
 - 3) Generator set which operates at the high power factor for a long time.

13.3.2 The excitation system shall employ the residual voltage excitation mode, while supported by the separate excitation. The excitation current of the excitation system shall not be more than 10% to 20% of the unloaded excitation current of the generator.

13.3.3 The provisions on the de-excitation unit are detailed as follows:

- a) During the de-excitation, the reverse voltage of the excitation winding shall be controlled within 30% to 50% of the voltage used in the winding withstand test to ground in the delivery test.
- b) The selection of the de-excitation mode and the calculation of the parameters shall meet the following requirements:
 - 1) As for the three-phase full-control bridge rectification circuit, the inverter de-excitation mode shall be adopted for normal shutdown. Under fault conditions, the linear or non-linear de-excitation mode may be adopted.
 - 2) The linear de-excitation mode is suitable for the generator whose excitation capacity is small and the excitation voltage is low. Its resistance shall be selected as 4 to 5 times the resistance of the excitation winding in the generator at 75 °C; the capacity shall be determined as 10% of the energy stored in the rotor under rated operating conditions.
 - 3) The non-linear de-excitation mode is suitable for the generator whose excitation capacity is high and the excitation voltage is high.
- c) The selection of the de-excitation switch shall consider:
 - 1) The rated current value is more than 110% of the rated excitation current;
 - 2) The rated voltage value is more than 110% of the rated excitation voltage;
 - 3) The rated insulation voltage is more than 200% of rated excitation voltage;
 - 4) The maximum breaking current is more than 300% of the rated excitation current;
 - 5) The accumulated peak value of the arc voltage at the broken position is more than the sum of the peak value of the forced excitation voltage and the maximum residual voltage on both ends of the non-linear resistance, or is more than the sum of the peak value of the maximum excitation voltage and the maximum excitation current multiplied by the linear resistance;
 - 6) The AC circuit breaker shall not be used as the DC de-excitation switch.

13.3.4 Excitation transformer:

- a) Technical requirements for the excitation transformer
 - 1) Connection mode: The connection mode should be Y/ Δ -11; as for the secondary terminal voltage of the transformer, the multi-tap output mode should be adopted;
 - 2) The short circuit impedance of the excitation transformer shall be within 4% to 8%;
 - 3) The high-voltage side of the excitation transformer should not be equipped with the automatic switch or the quick fuse;
 - 4) As required for the protection, the current transformer may be equipped on the secondary side of the transformer;

- 5) The asymmetrical degree of the three-phase voltage on the low-voltage side of the excitation transformer shall be no more than 5%.
- b) Selection of the type of the excitation transformer
- 1) There are two types of the excitation transformers, namely dry type and oil-immersed type:
 - 1) Ordinary dry type: Suitable for the low-voltage generator set. The insulation material with high flame retardance and a high insulation level shall be adopted;
 - 2) Epoxy-resin dry type: Suitable for the high-voltage generator set;
 - 3) Oil-immersed type: Suitable for outdoor installation. This type should not be adopted in an environment which has a relatively higher requirement for fire protection.
 - 2) The parameters of the excitation transformer include the secondary line voltage, the secondary line current, capacity and turns ratio of the primary coil and secondary coil.
- c) The current transformer and voltage transformer used for the excitation should be installed in the switch cabinet for measurement. The secondary side of the voltage transformer is 100 V or 110 V, and the precision is at the 0.5 level. The secondary side of current transformer is 5 A or 1 A, and the precision is at the 0.5 level.

13.4 Local indication and external interface of the excitation system

13.4.1 The excitation system shall be equipped with: the terminal voltage meter, the excitation voltage meter and the excitation current meter, and the generator set whose capacity is relatively higher may also be equipped with the reactive power meter;

13.4.2 The excitation system shall be equipped with the communication interface.

14 Automatic monitoring system

14.1 General requirements for selection of the computer monitoring system

14.1.1 The computer monitoring system shall be selected through comprehensive analysis on the technical, economic and operational safety and reliability in light of the installed capacity of the power station, the capacity of the single generator set and the voltage level of the power station.

14.1.2 The control of the computer monitoring system may employ the mode of few persons on duty or the unattended (or barely attended) mode in light of the characteristics and operating mode of the power station as well as the dispatching requirements of the power system.

14.1.3 The computer monitoring system for the entire station should be used to realize the integrated automation function of the entire station, so as to improve the automation level of the power station.

14.1.4 The computer monitoring system shall be able to accept the command information from the dispatchers at any time, and shall be able to automatically dispatch for remote measurement, remote signalling, remote regulation and remote control of the hydropower station from the centralized control room as well as from the offsite control station.

14.1.5 The monitoring of the safe operation of the entire station as well as the acquiring and processing of the data as per the requirement of the system.

14.1.6 The start-up, grid connection and shutdown of the generator set can be completed with a command.

14.1.7 The active power and reactive power of the generator set can be automatically adjusted.

14.1.8 The automatic and economical operation of the entire station can be possible.

14.1.9 The remote monitoring command can be received.

14.2 Basic requirements for the computer monitoring system

14.2.1 As for the hydropower station whose total installed capacity is not less than 5 MW, the full-open and hierarchically distributed computer monitoring system should be adopted.

14.2.2 As for the hydropower station whose total installed capacity is less than 5 MW, the integrated plant monitoring system should be adopted.

14.2.3 As for the hydropower station whose generator voltage is 0.4 kV or less, the compact-type monitoring system wherein the control protection system and the low-voltage primary equipment are integrated into a cabinet should be adopted.

14.2.4 The computer monitoring system shall meet the requirements for real-time control of the hydropower station.

14.2.5 The communication function of the computer monitoring system should be realized with the communication controller, and the operating system of the communication controller shall meet the requirements for safe and stable operation of the hydropower station.

14.2.6 The automatic control of the generator unit should be realized with the programmable logic controller (PLC).

14.2.7 The automatic control of the unit auxiliary equipment of the generator set and the station auxiliaries shall be realized by using the PLC.

14.2.8 The control of the unit auxiliary equipment of the generator set of whose installed capacity is less than 5 MW and public station auxiliaries may be realized by using the PLC distributed in various local control cabinets for the generator sets.

14.2.9 As for the PLC which realizes the communication with the computer monitoring system via the bus connection mode, its communication interface should be equipped with the surge protection device (SPD).

14.2.10 The input point of the analogue quantity should be equipped with the SPD.

14.2.11 The computer monitoring system shall be able to correctly receive the clock check information, and realize the synchronization of the clocks in various points in the system.

14.2.12 The station-level control of the computer monitoring system shall be equipped with the inverter power source or the uninterruptible power source (UPS), and the inverter power source shall be preferred.

14.2.13 The inverter power source or the UPS should be equipped with the SPD.

14.3 Selection of the measurement and control instruments

14.3.1 The selection of the measurement and control instruments shall comply with the following requirements:

- a) As for the measurement and control instruments, the electronic intelligent instruments shall be preferred. Instruments shall have digital indication, and shall have the communication interface, so as to meet the

requirements for communication with the computer monitoring system;

- b) The electrical quantity measuring instruments and the electrical energy meter shall comply with the provisions of the national standards;
- c) The single-channel temperature measuring instrument shall have the temperature indication, alerting and temperature control function;
- d) The multi-channel temperature measuring instrument should be used for the temperature indication and alerting, but should not be used for temperature control;
- e) The over speed protection for the generator set shall be equipped with the electrical speed signal device; the electrical speed signal device may employ the residual voltage frequency measurement or the tooth-disc speed measurement mode;
- f) As for the remote water level measurement for which the wired communication cannot be adopted, the remote wireless measurement instruments should be adopted. The instruments shall have the analogue quantity output interface and the communication interface.

14.3.2 The selection of the synchronizing device shall comply with the following requirements:

- a) As for the manual synchronizing device, the digital synchroscope with the phase angle compensation function should preferably be adopted, and then the combined type synchroscope may be selected;
- b) A set of manual synchronizing device/automatic quasi-synchronizing devices may be shared by the entire station, or a set may be allocated to every generator set;
- c) The automatic quasi-synchronizing device shall have the function to automatically regulate the frequency and voltage.

15 Plant service power supply and dam region power supply

15.1 Power source of the plant service power supply

15.1.1 The power supply shall meet the following requirements:

- a) Plant power load under various operating modes;
- b) Relatively independent power supply;
- c) When one power supply fails, the other power supply can operate automatically.

15.1.2 The plant power supply can be obtained using the following methods:

- a) Connected through the generator voltage bus or the unit lead;
- b) When a coupling transformer is equipped at the high-voltage side of the hydropower plant, the power supply is connected through the tertiary winding of the transformer.
- c) The power supply is connected from the local power grid;
- d) The diesel generator is used as the backup power supply.

15.1.3 No less than two plant supplies are required.

15.1.4 A hybrid power supply is recommended for the unit service power and common power demand of the plant.

15.1.5 The plant supply system is powered by a one-level voltage, or by a two-level voltage (high and low), and needs to be determined according to the plant supply load and the distribution, layout of plant, and local power grid.

15.2 Selection of the plant service transformer capacity

15.2.1 The transformer satisfies the maximum load that may occur under various operating modes.

15.2.2 When one plant service transformer will be overhauled or fails, the other plant service transformers should be able to bear significant plant supply load or the maximum plant supply load over a short term.

15.2.3 It shall be ensured that the plant supply bus voltage of a motor is not less than 65% of the rated voltage when the motor starts automatically after a fault is resolved.

15.3 Dam region power supply

15.3.1 The dam region's production power shall be supplied by a special dam region transformer or a public plant service transformer. Two independent power supplies for significant loads in the dam region are required. For particularly important flood discharge facilities, a third power supply or special generator can be added after discussion. Some insignificant loads in the plant and dam region can also be supplied by the local power grid.

15.3.2 The voltage for the supply network in the dam region should be determined according to the supply scope, the plant high-voltage power supply and the local power grid voltage.

15.4 Power supply in the living Area

15.4.1 Local network step-down transformer is preferentially used for the power supply in the hydropower plant living area. If no local network step-down transformer is configured, a special transformer can be configured for the plant supply.

16 DC operational power source

16.1 The operational power source of the power station shall be the DC power source device with the storage battery. There shall be only one storage battery, which shall work in the float charging mode. When the power station is controlled in an expanded plant station mode, two sets of storage batteries shall be provided.

16.2 The voltage of the DC operational power source should be the standard voltage such as DC 220 V or 110 V.

16.3 The capacity of the storage battery shall meet the needs for capacity when the entire station is powered off owing to an accident and for the capacity of the maximum impact load. The accidental power-off time may be set as 1h, and may be set as 2 h for the power station operated in the expanded plant station mode.

16.4 The storage battery should be the valve-controlled battery. As for the charging and float charging of the battery, one set of rectification devices shall be set up for every set of batteries. The charging power circuit for the storage battery shall have the corresponding power source indication.

16.5 The DC device shall have the function to automatically complete the charging/discharging control, the function to measure the capacity and voltage of the battery, the function to monitor the insulation, and the function to give the trouble alert signal.

17 Video monitoring system

17.1 The power station should be equipped with the video monitoring system. The monitoring points shall be determined in light of the needs of production, operation, fire-protection monitoring and the necessary safeguard.

17.2 The video monitoring system equipment shall meet the requirements of the working environment.

18 Communication

18.1 The power station shall be equipped with the in-station communication facilities. The production dispatching communication and administrative communication may share a programmed dispatching communication exchanger. As for the cascade hydropower stations, a dispatching communication exchanger may be set up in the cascade control centre, and a remote subscriber module may be set up on the power station side, so as to realize the voice communication.

18.2 For the communication links with the remote offsite control, the following methods are available for implementing the control from a remote location:

- a) Hardwired communication circuits (telephone type line, optical cables);
- b) Leased telephone lines;
- c) Power line carries the communication system;
- d) Microwave communication system.

18.3 The power source for the communication equipment shall be the special 24 V or 48 V communication power source, and the capacity of the storage battery shall be able to meet the needs for power supply for 8 hours.

19 Electrical repair and electrical testing

19.1 The power station may have a special electrical repair workshop, and may, in accordance with its scale and the requirements for centralized management, be equipped with the electrical repair tools and equipment.

19.2 The power station whose installed capacity is 10 MW or more may have an electrical test room; the power station whose installed capacity is less than 10 MW may have a simplified electrical test room.

19.3 The cascade hydropower stations and the hydropower station group under centralized management should have a centralized electrical test room.

As for the configuration standards for the instrument and the equipment in the electrical test room, the current classification standards shall apply.



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