



UNITED NATIONS  
INDUSTRIAL DEVELOPMENT ORGANIZATION



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

## **Part 6-2: Electrical System**

**SHP/TG 002-6-2: 2019**



## **DISCLAIMER**

This document has been produced without formal United Nations editing. The designations and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as “developed”, “industrialized” and “developing” are intended for statistical convenience and do not necessarily express a judgement about the stage reached by a particular country or area in the development process. Mention of company names or commercial products does not constitute an endorsement by UNIDO. Although great care has been taken to maintain the accuracy of information herein, neither UNIDO nor its Member States assume any responsibility for consequences which may arise from the use of the material. This document may be freely quoted or reprinted but acknowledgement is requested.

© 2019 UNIDO / INSHP- All rights reserved

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

**Part 6-2: Electrical System**

**SHP/TG 002-6-2: 2019**

## ACKNOWLEDGEMENTS

The technical guidelines (TGs) are the result of a collaborative effort between the United Nations Industrial Development Organization (UNIDO) and the International Network on Small Hydro Power (INSHP). About 80 international experts and 40 international agencies were involved in the document's preparation and peer review, and they provided concrete comments and suggestions to make the TGs professional and applicable.

UNIDO and the INSHP highly appreciate the contributions provided during the development of these guidelines and in particular those delivered by the following international organizations:

- The Common Market for Eastern and Southern Africa (COMESA)
- The Global Network of Regional Sustainable Energy Centres (GN-SEC), particularly the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), the East African Centre for Renewable Energy and Energy Efficiency (EACREEE), the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) and the Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE).

The Chinese government has facilitated the finalization of these guidelines and was of great importance to its completion.

The development of these guidelines benefited greatly from the valuable inputs, review and constructive comments as well as contributions received from Mr. Adnan Ahmed Shawky Atwa, Mr. Adoyi John Ochigbo, Mr. Arun Kumar, Mr. Atul Sarthak, Mr. Bassey Edet Nkposong, Mr. Bernardo Calzadilla-Sarmiento, Ms. Chang Fangyuan, Mr. Chen Changjun, Ms. Chen Hongying, Mr. Chen Xiaodong, Ms. Chen Yan, Ms. Chen Yueqing, Ms. Cheng Xialei, Ms. Chileshe Kapaya Matantilo, Ms. Chileshe Mpundu Kapwepwe, Mr. Deogratias Kamweya, Mr. Dolwin Khan, Mr. Dong Guofeng, Mr. Ejaz Hussain Butt, Ms. Eva Kremere, Ms. Fang Lin, Mr. Fu Liangliang, Mr. Garaio Donald Gafiye, Mr. Guei Guillaume Fulbert Kouhie, Mr. Guo Chenguang, Mr. Guo Hongyou, Mr. Harold John Annegam, Ms. Hou ling, Mr. Hu Jianwei, Ms. Hu Xiaobo, Mr. Hu Yunchu, Mr. Huang Haiyang, Mr. Huang Zhengmin, Ms. Januka Gyawali, Mr. Jiang Songkun, Mr. K. M. Dhareesan Unnithan, Mr. Kipyego Cheluget, Mr. Kolade Esan, Mr. Lamyser Castellanos Rigoberto, Mr. Li Zhiwu, Ms. Li Hui, Mr. Li Xiaoyong, Ms. Li Jingjing, Ms. Li Sa, Mr. Li Zhenggui, Ms. Liang Hong, Mr. Liang Yong, Mr. Lin Xuxin, Mr. Liu Deyou, Mr. Liu Heng, Mr. Louis Philippe Jacques Tavernier, Ms. Lu Xiaoyan, Mr. Lv Jianping, Mr. Manuel Mattiat, Mr. Martin Lugmayr, Mr. Mohamedain SeifElnasr, Mr. Mundia Simainga, Mr. Mukayi Musarurwa, Mr. Olumide TaiwoAlade, Mr. Ou Chuanqi, Ms. Pan Meiting, Mr. Pan Weiping, Mr. Ralf Steffen Kaeser, Mr. Rudolf Hüpfel, Mr. Rui Jun, Mr. Rao Dayi, Mr. Sandeep Kher, Mr. Sergio Armando Trelles Jasso, Mr. Sindiso Ngwenga, Mr. Sidney Kilmete, Ms. Sitraka Zarasoa Rakotomahefa, Mr. Shang Zhihong, Mr. Shen Cunke, Mr. Shi Rongqing, Ms. Sanja Komadina, Mr. Tareqemtairah, Mr. Tokihiko Fujimoto, Mr. Tovoniaina Ramanantsoa Andriampaniry, Mr. Tan Xiangqing, Mr. Tong Leyi, Mr. Wang Xinliang, Mr. Wang Fuyun, Mr. Wang Baolu, Mr. Wei Jianghui, Mr. Wu Cong, Ms. Xie Lihua, Mr. Xiong Jie, Ms. Xu Jie, Ms. Xu Xiaoyan, Mr. Xu Wei, Mr. Yohane Mukabe, Mr. Yan Wenjiao, Mr. Yang Weijun, Ms. Yan Li, Mr. Yao Shenghong, Mr. Zeng Jingnian, Mr. Zhao Guojun, Mr. Zhang Min, Mr. Zhang Liansheng, Mr. Zhang Zhenzhong, Mr. Zhang Xiaowen, Ms. Zhang Yingnan, Mr. Zheng Liang, Mr. Mr. Zheng Yu, Mr. Zhou Shuhua, Ms. Zhu Mingjuan.

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

## Table of Contents

Foreword .....	III
Introduction .....	VI
1 Scope .....	1
2 Normative references .....	1
3 Terms and definitions .....	1
4 Connection of the hydropower station to the power system(grid) .....	1
4.1 General requirements .....	1
4.2 Deliverables .....	1
5 Main electrical wiring design .....	2
5.1 General requirements .....	2
5.2 Type, characteristics and applicability of the main electrical connection .....	3
5.3 Configuration principles of the isolating switch .....	7
6 Calculation of the short circuit current .....	7
6.1 Purpose of the calculation .....	7
6.2 Basic principles for calculation .....	8
7 Selection of the main transformer .....	9
7.1 General requirements .....	9
7.2 Selection of parameters .....	10
7.3 Selection of the cooling mode .....	10
8 Selection of high-voltage electrical equipment .....	10
8.1 General requirements .....	10
8.2 Selection of the high-voltage circuit breaker .....	12
8.3 Selection of the isolating switch .....	13
8.4 Selection of the current transformer and the voltage transformer .....	13
8.5 Selection of the high-voltage load switch and the high-voltage fuse .....	15
8.6 Selection of the high-voltage complete switchgear .....	16
8.7 Selection and laying of the cable .....	17
9 Overvoltage protection and grounding .....	17
9.1 Overvoltage protection .....	17
9.2 Grounding .....	21
10 Lighting system .....	24
11 Layout of main electrical equipment inside and outside the power station .....	24
12 Relaying protection and security automatic equipment .....	25
12.1 General requirements .....	25
12.2 Generator protection .....	27
12.3 Main transformer protection .....	30
12.4 Bus protection .....	35
12.5 Coordination and interface between the protection and other systems .....	36

13	Excitation system	37
13.1	Selection of the excitation system	37
13.2	Selection of the excitation mode	38
13.3	Self-shunt static silicon-controlled excitation system	38
13.4	Field indication and external interface of the excitation system	41
14	Automatic monitoring system	41
14.1	General requirements for selection of the computer monitoring system	41
14.2	Technical requirements for the computer monitoring system	42
14.3	Selection of the measurement and control instruments	42
15	Plant service power supply and dam area power supply	43
15.1	Power source of the plant service power supply	43
15.2	Selection of the plant service transformer capacity	44
15.3	Dam area power supply	44
15.4	Power supply in the living Area	45
16	DC operating power supply	45
17	Video monitoring system	45
18	Communication	45
19	Electrical repair and electrical testing	46

## 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](http://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 30 MW.

- 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 an 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

4.1.1 The power delivery point, transmission voltage, number of outlet transmission lines, transmission capacity, operation mode and the format of connection to the grid shall be determined in light of the characteristics of the hydropower station and the requirements of the power system.

4.1.2 The output voltage and the circuit number of the outlet line of the power station shall be simplified as far as possible in light of the system and the site conditions.

4.1.3 The connection 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 Deliverables

4.2.1 The following design results shall be submitted for the design of the connection of the hydro-power station to the electrical system:

- a) Geographic system connection diagram and single-line wiring diagram;
- b) Transmission voltage, number of circuits of outlet line with different voltage levels, directions and connecting points for every outlet 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 operates as phase modulation;
- f) Requirements of the system for the generator parameters, excitation parameters and excitation modes, including the rated voltage and allowable variation range, the rated power factors and 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 wiring design

### 5.1 General requirements

The main electrical wiring shall meet the following requirements:

- a) It shall meet the requirements of power supply reliability and power quality of users or power systems.
- b) It shall be simple and clear, easy to operate and maintain, with certain flexibility.
- c) It 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.
- d) It shall be designed on the basis of the following basic data:
  - 1) Installed capacity of the power station, the number of turbine-generator units, and the water energy data such as the regulating performance, utilization hours and firm capacity of the water reservoir;
  - 2) Importance of the power station in the power system and its operating mode, the geographical wiring diagram impedance diagram connected to the power system;
  - 3) Voltage level of the outlet 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;
  - 4) Quantity of the station-service power sources, their connection modes, and the demand on the near-zone power supply;
  - 5) Requirements for automatic operation and the dispatching mode of the power station;
  - 6) Requirements of the power system for the phase-regulating, voltage-regulating and leading phase operations of the power station;
  - 7) Requirements of the power system for voltage regulation and range of the transformer;
  - 8) Requirements of over-voltage for the connection of the power station within the stable and restricted range of the system;
  - 9) Project layout and transportation.
- e) On the premise of meeting the basic requirements, 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 recommended in Table 1 and Table 2.

Table 1 Voltage connection of generator


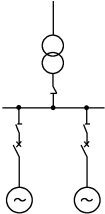
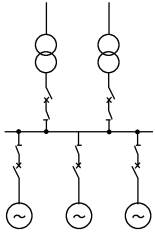
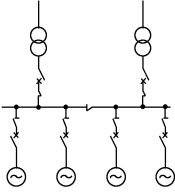
Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Unit connection		<ol style="list-style-type: none"> <li>1. The capacity of the main transformer is as the same as that of the generator, and the range of the fault is minimal;</li> <li>2. The connection is simple, clear and flexible;</li> <li>3. Minimum generator voltage equipment is required, and the layout is simple;</li> <li>4. The relaying protection is simple;</li> <li>5. The number of the main transformers and high-voltage electrical equipment is increased.</li> </ol>	<p>Applicable to the power stations with high reliability requirements, or applicable to the power stations constructed in phases.</p>
Expanded unit connection		<ol style="list-style-type: none"> <li>1. Two (or more than two) units connected to one main transformer, and the range of the fault is relatively large;</li> <li>2. The connection is simple, clear, and easy to operate and maintain;</li> <li>3. The number of outlet circuits from the high-voltage side of the main transformer is reduced.</li> </ol>	<ol style="list-style-type: none"> <li>1. Applicable to the power stations that play important roles in the grid, with 4 or more units;</li> <li>2. Applicable to the ordinary power stations with a relatively small near-zone load.</li> </ol>
Single-bus connection		<ol style="list-style-type: none"> <li>1. There is a small number of main transformers;</li> <li>2. There are more components for generator switchgear installation;</li> <li>3. When the bus or the isolating switch connected to the bus fails or is repaired, the power of entire station will be cut off.</li> </ol>	<p>Applicable to the ordinary SHP stations with a relatively large near-zone load.</p>
Sectional single-bus connection with isolating switch		<ol style="list-style-type: none"> <li>1. When any section of the bus and the isolating switch connected to it fails or is repaired, the station only needs to power off for a short time, and after the sectional isolating switch is opened, the unit connected to another section of the bus may resume to send electricity to the grid;</li> <li>2. When the sectional isolating switch fails or is repaired, the entire station will be cut off.</li> </ol>	<p>The use of the section isolating switch may lead to loaded misoperation, so it is rarely used.</p>

Table 1 (continued)

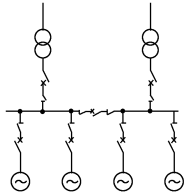
Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Sectional single-bus connection with circuit breaker		When any section of the bus and the isolating switch connected to it fails or is repaired, the unit connected to another section of the bus may continue to send electricity to the grid.	<ol style="list-style-type: none"> <li>1. Applicable to the SHP stations that play important roles in the grid;</li> <li>2. Applicable to the power stations which have many units and near-zone load.</li> </ol>

Table 2 Boosted voltage side connection


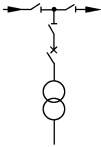
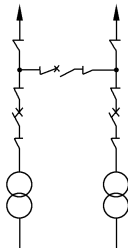
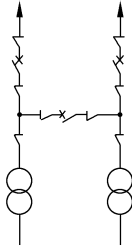
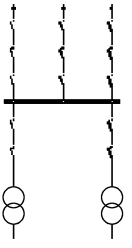
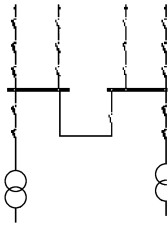
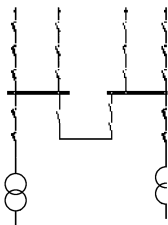
Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Transformer-line unit connection		<ol style="list-style-type: none"> <li>1. The connection is the simplest, and the least equipment is needed;</li> <li>2. When the line fails or is repaired, the main transformer will stop working, and vice versa.</li> </ol>	Applicable to the power station with one single outlet circuit.
T-type connection		The advantages and disadvantages are the same as those of the transformer-line unit connection.	Applicable to the power station which is not important on the power grid and there is a nearby transmission line.
Outer bridge connection		<ol style="list-style-type: none"> <li>1. The connection is simple, and the number of high-voltage circuit breakers is less (namely the number of inlet and outlet circuits minus one);</li> <li>2. When the one of the main transformer fails or is inspected or repaired, the operation of the line and another main transformer will not be affected;</li> <li>3. When the one of the outlet circuit fails or is inspected or repaired, the output of half the power of the station will be suspended, and after the isolating switch is opened, all the power may be sent out by another outlet circuit.</li> </ol>	<ol style="list-style-type: none"> <li>1. Applicable to the power stations with two inlet and outlet circuits respectively, and the main transformer switching on and off frequently;</li> <li>2. When there is crossing power, the outer bridge connection should also be adopted.</li> </ol>

Table 2 (continued)

Name of the connection	Schematic diagram	Advantages and disadvantages	Applicability
Inner bridge connection		<ol style="list-style-type: none"> <li>1. The connection is simple, and the number of high-voltage circuit breakers is less (namely the number of inlet and outlet circuits minus one);</li> <li>2. When the outlet circuit fails or is inspected or repaired, the operation of the main transformer will not be affected;</li> <li>3. When the one of the main transformer fails or is inspected or repaired, an outlet circuit will be cut off temporarily, and after the main transformer isolating switch is opened, half the power of the power station may be sent out by the two outlet circuits.</li> </ol>	<p>Applicable to the power stations with two inlet and outlet circuits respectively, fewer annual utilization hours, and the main transformer frequently switching on or off or the outlet line is long.</p>
Single-bus connection		<ol style="list-style-type: none"> <li>1. Each circuit of the inlet or outlet is equipped with an independent circuit breaker;</li> <li>2. When the bus or the isolating switch connected to it fails or is inspected or repaired, the entire station will be powered off.</li> </ol>	<p>Applicable to the hydropower stations that are not important in the power system and have less requirement for the continuity of power supply. The voltage of the outlet circuit is 35 (33) kV and above, and the total number of outlet circuits is not more than 3 to 5.</p>
Sectional single-bus connection with isolating switch		<p>When the bus or the connected equipment is being inspected and repaired or fails, the entire station will be powered off; after the sectional isolating switch is opened, another section of the bus may supply the power. However, when the sectional isolating switch is being inspected and repaired or fails, the entire station will be power off.</p>	<p>Same as the single-bus connection.</p>
Sectional single-bus connection with circuit breaker		<p>When the bus or connected equipment is being inspected and repaired or is faulted, only one section of the bus and the circuit connected will be powered off.</p>	<p>Applicable to the power stations that the voltage of the outlet circuit is 35 (33) kV and above, and the total number of outlet circuits is not more than 6.</p>

### 5.3 Configuration principles of the isolating switch

5.3.1 The isolating switch shall meet the following requirements for main connection design in equipment inspection and repair:

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

5.3.2 The configuration of the isolating switch for the voltage transformer, lightning arrester and circuit of the lightning arrester at the outlet of the high-voltage side of the main transformer shall meet the following principles:

- a) 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;
- b) In general, the lightning arrester at the high-voltage side outlet of the main transformer may not be equipped with the isolating switch.
- c) When the voltage transformer is installed on the side of the outlet line and may also be used for communication and protection (except for that specially installed for both purposes), the isolating switch should 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 the comparison and selection of electrical connection scheme, the selection of electrical equipment and current-carrying conductor, the selection of and setting of relay protection, and the design of grounding system.

## 6.2 Basic principles 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 the breaking current of the electrical equipment shall be calculated by the design capacity of the project, and the long-term development plan for the power system (generally 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 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 electrical equipment, the short-circuit calculation point shall be selected in accordance with the principle of the maximum short-circuit current in normal connection mode.

6.2.4 In general, the dynamic stability and thermal stability of the conductor and electrical equipment as well as the breaking current of the electrical equipment may 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, the calculation shall be based on more serious situations.

6.2.5 Only the reactance of each component (i.e., generator, transformer, reactor, circuit, etc.) may be included in the calculation of 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 all levels shall be adopted.

6.2.7 The basic assumptions for 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) Both synchronous and asynchronous motors in the system are ideal, without considering the impact of magnetic saturation, magnetic lagging and vortex of the motor and 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  $120^\circ$  electrical angle.
- d) The magnetic circuit of each element in the power system is unsaturated, that is, the reactance value of the electrical equipment with the iron core will not change as the current.



- e) All power sources in the power system shall operate under the rated load.
- f) 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 higher than the generating capacity of the connected generator. When restricted by the transportation conditions, two three-phase transformers with small capacity may be selected and used in parallel.

7.1.2 The energy-saving transformer shall be adopted.

7.1.3 The standard transformer should be adopted.

7.1.4 Under the circumstance that two types of high voltage are used to transmit electricity to the grid, if the transmission capacity of the medium-voltage side accounts for more than 20% of the capacity of the main transformer, a three-coil transformer or an auto transformer may be adopted; if one of the two types of the voltage is neutral and not directly grounded, a three-coil transformer shall be selected.

7.1.5 The type of main transformer shall be compatible with the external operational environment. The fully enclosed oil-immersed transformer should not be recommended if the environment temperature changes greatly.

7.1.6 Parallel operation of transformers shall meet the following requirements:

- a) The coil connection is the same;
- b) The rated voltage of the primary and secondary coils are the same (with the same transformation ratio);
- c) The impedance voltage is the 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 may 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 high/medium/low voltage shall be considered comprehensively.

7.2.2 The selection of the voltage regulation mode and the voltage tap of the main transformer shall be based on the design requirements of the power station connection system for the transformer. The low-voltage side voltage of the main transformer under the off-load voltage regulation mode of the hydropower station shall be the 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 shall be equipped with  $\pm 4 \times 2.5\%$  taps. On-load voltage regulation shall be provided with  $\pm 8 \times 1.25\%$  taps.

7.2.3 The connection group of booster transformer of 35(33) kV and above should be selected as follows:

- 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 natural air 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 met.
- 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 selection of the high-voltage electrical equipment shall be made according to the following requirements:

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**

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 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	
Others (Indoor)	Ventilation design temperature, 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 formulas for selection of the circuit breaker**

No.	Selection basis	Calculation formula	Unit	Key
1	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	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	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	Making 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	Verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$ $Q_t = I_t^2 \cdot t$	$\text{kA}^2 \cdot \text{s}$	$Q_t$ : 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	Verified on the basis of the dynamic stability	$i_{gf} \geq i_{ch}$	kA	$i_{gf}$ : 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:

- a) The vacuum or Sulfur Hexa-Fluoride ( $\text{SF}_6$ ) circuit breaker may be selected for the circuit of 3 kV or above.
- b) When the vacuum circuit breaker is selected as the generator circuit breaker, it shall be equipped with the surge protection device or resistance-capacitance absorber.
- c) When the output voltage of the generator is 400 V, the air circuit breaker may be adopted as the generator circuit breaker.

### 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**

No.	Selection basis	Calculation formula	Unit	Key
1	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	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	Verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$ $Q_t = I_t^2 \cdot t$	$\text{kA}^2 \cdot \text{s}$	$Q_t$ : 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	Verified on the basis of the dynamic stability	$i_{gf} \geq i_{ch}$	kA	$i_{gf}$ : 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:

- a) The type of isolating switch shall be determined by comprehensive comparison in light of the installation location, environmental conditions, type of power distribution device and requirements of layout.
- b) As for the isolating switch for voltages of 35(33) kV and above required for remote operation shall be operated by electrical control mechanism and shall be equipped with manual control mechanism.

### 8.4 Selection of the current transformer and the voltage transformer

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

**Table 7 Calculation formulas for the selection of the current transformer**

No.	Selection basis	Calculation formula	Unit	Key
1	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	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	Verified on the basis of the thermal stability	$K_t \geq \frac{I_t}{I_{n1}}$ which may also be written as: $K_t \geq \sqrt{\frac{Q_{dt}}{I_{n1}^2}} \times 10^3$		$K_t$ : 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 ( $\text{kA}^2 \cdot \text{s}$ ).
4	Verified on the basis of the dynamic stability	$i_{gf} \geq i_{ch}$ or $K_d \geq \frac{i_{ch}}{\sqrt{2} I_{n1}} \times 10^3$	kA	$i_{gf}$ : 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 voltage transformer type:

- 1) Electromagnetic voltage transformer with solid insulation or plastic shell should be selected for indoor distribution devices at or below 1 kV;
- 2) For 35(33) kV indoor distribution devices, the electromagnetic voltage transformer with solid insulation should be selected. For 35(33) kV outdoor distribution devices, the electromagnetic voltage transformer with solid insulation or oil-immersed insulation which is suitable for the outdoor environment should be selected;
- 3) For 66 kV outdoor distribution devices, 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 voltage transformer parameters:

- 1) The rated primary voltage of the voltage transformer shall be determined by the nominal voltage of the system used;
- 2) The rated secondary voltage of the voltage transformer shall be selected in accordance with the application 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 windings of the voltage transformer shall meet the requirements of 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 formulas for selection of the high-voltage load switch

No.	Selection basis	Calculation formula	Unit	Key
1	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	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	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	Verified on the basis of the thermal stability	$Q_t \geq Q_{dt}$	$\text{kA}^2 \cdot \text{s}$	$Q_{dt}$ : Thermal effect caused by the short circuit current ( $\text{kA}^2 \cdot \text{s}$ ); $Q_t$ : Allowable thermal effect of the load switch.
5	Verified on the basis of the thermal stability	$i_{gf} \geq i_{ch}$	kA	$i_{gf}$ : 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 formulas for selection of the high-voltage fuse**

No.	Selection basis	Calculation formula	Unit	Key
1	Operating voltage	$U_{max} \geq U_g$	kV	$U_{max}$ : Maximum allowable operating voltage of the equipment; $U_g$ : Circuit operating voltage.
2	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	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	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>(<math>K_{st}</math> 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; <math>I_n</math> 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>(<math>K_r</math> 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; <math>I_{nc}</math> 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**

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, 1 250, 1 600, 2 000, 2 500, 3 150, 4 000 and 5 000 A	
4	Rated frequency	60 Hz, 50 Hz	



Table 10 (continued)

No.	Name	Performance parameter	Remarks
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 4 s. As for the high-voltage switch cabinet equipped with the load switch, the rated short circuit duration may be set as 2 s or 4 s as per the requirement of the user.	
11	Rated voltage of the breaking/closing coil and the auxiliary circuit	Standard voltage such as: DC: 110 V, 220 V; AC: 220 V, 380 V	

## 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 insulated with flame-retardant cross-linked polyethylene. Flame-retardant armoured cable should be used in places vulnerable to mechanical damage. The control cable should be made of copper-core plastic flame-retardant cable. If there is the requirement of 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 depth of buried cable should not be less than 700 mm. When the thickness of the frozen soil layer exceeds 700 mm, measures shall be taken to prevent the cable damage.

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 Overvoltage protection and grounding

### 9.1 Overvoltage protection

9.1.1 The direct-lightning overvoltage protection of hydropower stations shall meet the following

requirements:

- a) Lightning rod or lightning conductor of the direct-lightning overvoltage protection for the hydro-power station shall meet the following requirements:
  - 1) The protection range 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, main control room and power distribution device room of the hydropower station is not equipped with the direct-lightning protection devices. The main powerhouse, main control room and power distribution device room in the strong lightning area should be equipped with the direct-lightning protection devices. The lightning rod installed for the protection of other equipment should not be installed on the roof of the separate main control room and switch room up to 35 kV;
  - 3) 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;
  - 4) The main control room with direct-lightning protection device on the roof, the metal roof of the power distribution device room up to 35 kV or the metal structure on the roof, the metal casing of the equipment and the metal skin of the cable shall be all grounded. The reinforcing bars in the reinforced concrete roof shall be welded into a net and grounded. Non-conductive roof shall be protected by lightning strips, the grid of lightning strips shall be 8 m to 10 m, and grounding wires shall be set up every 10 m to 20 m, and such grounding wires shall be connected with the main grounding grid, and a centralized grounding device shall be installed at the connection point.
  - 5) The metal casing of the equipment, the metal skin of the cable and the metal components of the building on the roof shall be grounded;
  - 6) The shell of GIS equipment installed outdoor may not be equipped with direct-lightning protection device;
  - 7) Lightning protection should be used for hydropower stations and substations in the valley.
- b) The lightning rod installed on the structure or on the roof shall comply with the following requirements:

- 1) Lightning rod should be installed on the structure roof of distribution device with 110 kV and above. In the area with soil resistivity greater than  $1\ 000\ \Omega \cdot \text{m}$ , the independent lightning rod should be installed; otherwise, measures to reduce the grounding resistance or improve the insulation shall be taken through calculation;
  - 2) As for a 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) Lightning rods should not be installed on the framework or roof of the high-voltage distribution devices with 35 kV of voltage or less;
  - 4) The lightning rod installed on the framework shall be connected to the grounding mat, and shall be provided with a centralized grounding device nearby. On the framework equipped with lightning rods, the air distance between the grounded portion and the live portion shall not be less than the length of the insulator string; however, in the area where the air is polluted, if there is any 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 earth resistance should not exceed  $10\ \Omega$ . If there is any difficulty, the grounding device may be connected to 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 shall not be less than 15 m.
  - 2) The independent lightning rod shall not be set up in a place that pedestrians frequently walk through, and the distance between the lightning rod and its grounding device and the road or the main entrance should not be less than 3 m; 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 without lightning conductor in the whole line, lightning conductor shall be installed in the inlet section of 1 km to 2 km of the substation.
- 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/outlet transmission line.
- c) As for the cable-type incoming line of which the voltage is 35(33) kV or more, lightning arrester shall be installed at the connection between the cable with 35 (33) kV and above cable inlet sec-

tion and the overhead line, and its grounded end shall be connected with the metal skin of the cable.

- d) Configurations of the lightning arrester in the open high-voltage power distribution device of 35(33) kV and above hydropower stations with overhead incoming/outlet lines shall meet the following requirements:
  - 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 with the shortest grounding wire, and the centralized grounding device shall be set up nearby;
  - 2) Double circuit poles and towers are used for the overhead incoming/outlet line, which may be struck by 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 it is advisable to avoid disconnecting one circuit in the thunderstorm.
- e) As for the transformer with ungrounded neutral points in the effective grounding system, if the neutral point are classified insulated and no protection clearance is installed, a neutral metal oxide lightning arrester shall be installed at 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 to 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 outlet line of the low-voltage winding of the transformer; however, if such winding is connected to the metal skin cable whose length is not less than 25 m, the lightning arrester may be omitted.
- g) The lightning-invasion-wave overvoltage protection for the gas-insulated switchgears (GIS) substation shall meet the following requirements:
  - 1) As for the GIS substation without cable segment on the incoming line, metal oxide lightning arrester shall be installed at the connection point between GIS pipe and overhead line, and its grounded end shall be connected with the metal casing of the pipe;
  - 2) As for the GIS substation with cable segments on the incoming line, metal oxide lightning arrester shall be installed at the connection point between the cable segments and the overhead line, 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; single core cable shall be grounded by metal oxide cable protector;

- 3) Whether the metal oxide lightning arrester shall be installed in the GIS substation of the cable with the whole length of the incoming line shall be determined by checking according to the possibility of lightning overvoltage wave invading the other end of the cable.

## 9.2 Grounding

9.2.1 The earth resistance shall meet the following requirements:

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

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

where

*R* is the maximum earth 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 earth resistance of the grounding which is not directly grounded shall meet the following requirements:

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

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

9.2.2 Measures to reduce the earth resistance shall meet the following requirements:

- a) The hydropower station may be equipped with underwater manual grounding devices so as to reduce the earth 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. Such device shall be installed in the areas below the minimum water level in the water reservoir or the diversion system.
- b) 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 earth resistance.
- c) When the underground soil resistivity of the hydropower station and its nearby areas is low or there is underground water, while the surface soil resistivity is high, deep-well grounding may be adopted.
- d) 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 too large, the manual resistance reduction

measures may be adopted in light of on-site conditions and technical and economic comparison, so as to reduce the earth resistance. The manual resistance reduction measures include the use of the resistance reduction agent, electrolysis pole and replacement with low-resistivity materials.

9.2.3 The high-voltage power distribution device shall be equipped with the voltage equalizing mat. The design for the voltage equalization shall meet the following requirements:

- a) The outer edge of the voltage equalizing mat shall be closed, each angle of the outer edge shall be arc shaped, and the radius of such arc should not be less than half of the interval between the voltage equalizing straps. Horizontal equalizing strap shall be laid in the voltage equalizing mat, and the burying depth should be 0.6 m to 0.8 m;
- b) The internal contact potential difference and the external step potential difference shall be taken as the safety standard in the design of the voltage equalizing mat. 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 in 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;

$\rho_b$  is the soil resistivity of the surface where the person stands, in  $\Omega \cdot m$ ;

$t$  is the duration 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 non-direct grounding short circuit current system, 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:

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

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

9.2.4 The grounding device shall meet the following requirements:

- a) The grounding mat shall be connected by at least two main grounding lines to form the grounding system for the entire project. The main grounding lines should be far apart from each other, and the main grounding lines should be the flat steel with a cross section of no less than 50 mm × 6 mm or the round steel with a diameter of no less than 20 mm.
- b) The natural grounding conductors 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 horizontal grounding body may be made of round steel or flat steel; the vertical 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 buried depth should be 0.6 m to 0.8 m.
- d) The connection between the grounding line and the grounding body should be welded; the connection between the grounding line and the electrical equipment may be bolted or welded.
- e) The neutral point of the main transformer or generator directly grounded or grounded by arc suppression coil shall be connected with the grounding body or the main grounding line, and 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 welded and welded into one at the section 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 <sup>2</sup> )	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 for working lighting and emergency lighting of the power station shall be set up separately. Working lighting shall be supplied by the station-service power system. Emergency lighting may be powered by a battery bank when all AC power is gone.

10.2 The premises and main passages where work must be continued after the working lighting is interrupted shall be equipped with independent emergency lighting. For the outdoor switchgear installation, the emergency lighting is not required.

## 11 Layout of main electrical equipment inside and outside the power station

11.1 The main transformer and switchyard should be close to the powerhouse. When the switchyard and the main transformer are arranged separately, the main transformer shall be installed near the generator switchgear installation room.

11.2 The switchgear installation with 6 kV to 35 kV may be arranged indoor with a complete switchgear, or outdoor. The switchgear installation with 66 kV or more preferably be arranged outdoor. However, in the polluted area or if terrain conditions are restricted, enclosed assembled switchgear may also be adopted.



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 panels.

## 12 Relaying protection and security automatic equipment

### 12.1 General requirements

12.1.1 The relay protection device shall meet the requirements of reliability, selectivity, sensitivity and quick action. The minimum sensitivity coefficient of relaying protection shall meet the provisions in Table 12.

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

12.1.3 The relay protection device shall be put into operation synchronously with the protected equipment of the power station.

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

**Table 12 Minimum sensitivity coefficient of the relay protection**

Category of protection	Type of protection	Component	Sensitivity coefficient	Remarks
Main protection	Longitudinal differential protection for generator and transformer	Starting current of the differential current element	1.5	—
	Current quick-break protection for generator, transformer and lines	Current element	1.5	Calculated as short circuit at the installation position of the protection
	Complete current differential protection for bus	Starting current of the differential current element	1.5	—
	Incomplete current differential protection for bus	Differential current element	1.5	—

Table 12 (continued)

Category of protection	Type of protection	Component	Sensitivity coefficient	Remarks
Backup protection	Remote backup protection	Current, voltage and impedance elements	1.2	Calculated as 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 relaying action may be taken into account.
		Zero-sequence or negative-sequence directional element	1.5	
	Near backup protection	Current, voltage and impedance elements	1.3	Calculated on the basis of short circuit at the end of line
		Negative-sequence or zero-sequence directional element	2	
Auxiliary protection	Current quick-break protection		1.2	Calculated on the basis of short circuit at the installation position of the protection under normal operating mode

12.1.5 The current transformer equipped with various protection devices shall meet the requirements of eliminating protective dead zones and reducing the impact caused by the faults of the current transformer.

12.1.6 If the breaking of the secondary circuit of the voltage transformer leads 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 may be installed.

12.1.7 Automatic reclosing device should be installed on 10 kV and above voltage circuits equipped with circuit breakers; when there is a power supply on the opposite side, the line should be equipped with the synchronization-check or no-voltage-check automatic reclosing device.

12.1.8 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 Generator protection

### 12.2.1 Generator protection shall meet the following requirements:

- a) The generator shall be equipped with corresponding protection for the following faults and abnormal operations:
  - 1) Internal phase to phase short circuit of the stator winding;
  - 2) Grounding of the stator winding;
  - 3) External phase to phase short circuit of the generator;
  - 4) Overvoltage of the stator winding;
  - 5) Overload of the stator winding;
  - 6) Overload of the field winding;
  - 7) One-point grounding of 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 faults and abnormal operations.
- b) Generator protection should, in light of the nature of the trouble or the abnormal operating mode, 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: reduce the output of the turbine to a specified value;
- 5) Reduction of the impact range 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 phase to phase short circuit protection for the stator winding of the generator and its outlet connecting leads shall meet the following requirements:

- a) The generator of 1 MW or above shall be equipped with longitudinal differential protection which shall serve as the main protection for the Internal phase to phase short circuit of the stator winding and its connecting leads. The protection shall immediately lead to shutdown. The generator less than 1 MW shall be equipped with the current quick-break protection which shall serve as the main protection for the internal phase to phase short circuit of the stator winding and its connecting leads. The protection shall immediately lead to shutdown.
- b) When there is a circuit breaker between the generator and the transformer, the generator should be equipped with a separate main protection.
- c) The three-phase connection scheme shall be adopted for longitudinal differential protection.

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 generator neutral grounding mode and generator grounding current allowable value. The allowable current 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	$\leq 4$
10.5	$\leq 3$

- 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 generator neutral point.

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

- a) Non-self-shunt generator should be equipped with over-current protection initiated by the combined voltage (including the negative-sequence voltage and line voltage). The current should be suitable for the neutral side current transformer of the generator. In case the sensitivity fails to meet the requirements, the negative-sequence over-current protection may be added.
- b) Self-shunt generator should be equipped with the low-voltage over-current protection with current memory. The current should come from the neutral point side current transformer 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 phase to phase short circuit at the end of protection zone, and the protection zone should not exceed the range of first section of protection for adjacent lines.
- d) The protection devices specified in articles of this Section should be equipped with two time limits. The shorter time limit should be used to reduce the range of fault impact, or act for disconnection and de-excitation. The longer time limit should be used to stop the machine.
- e) The backup protection for the generator and generator-transformer unit operated in parallel and the protection for the phase to 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, whose setting value shall be determined by insulation of the stator winding. The overvoltage protection shall lead to disconnection and de-excitation or shutdown.

**12.2.6** The generator shall be equipped with overload protection of stator winding with time-limit

action on signal.

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 generator shall be equipped with de-excitation protection, which shall act on the disconnection from the system with a time limit.

12.2.9 As for the turbine-generator unit under phase-regulating operation condition, the protection of power system disconnection i.e. loss of power shall be provided. The protection device may be protected with low-frequency protection, and will lead to shutdown with a time limit.

12.2.10 As for the abnormal operation mode in which the generator is likely to operate as a motor, the reverse power protection should be provided. The protection will lead to disconnection with a time limit.

12.2.11 The generator shall be equipped with abnormal frequency protection. Under normal operation conditions, the abnormal frequency protection for the generator shall act as per the setting value of abnormal frequency load-reducing device of the electrical grid. The action of this protection shall lead to de-excitation or tripping.

### 12.3 Main transformer protection

12.3.1 The main transformer protection shall meet the following basic requirements:

- a) Phase to phase short circuit of the winding and its outlet leads, and single-phase grounding short circuit at neutral point directly or through the small-reactance grounded side;
- b) Over-current caused by external phase to phase short circuit;
- c) Over-current and neutral-point overvoltage caused by external grounding short circuit in the neutral point directly grounding or small reactance grounding power grid;
- d) Single-phase grounding fault on the non-effective grounding side at neutral point;
- e) Inter turn short circuit;
- f) Overload;
- g) Drop of oil level;

- h) High transformer oil and winding temperature, high tank pressure and cooling system failure.

12.3.2 The gas protection shall meet the following requirements:

- 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, serving 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 oil-immersed transformer, loaded voltage regulation device and high-voltage cable terminal box fail to produce slight gas or oil level drop, it shall immediately act on the signal instantaneously.
- c) Heavy gas protection: if a large amount of gas is generated in oil-immersed transformer, loaded voltage regulation device or high-voltage cable terminal box, the circuit breaker on each side of the transformer shall be disconnected instantaneously.
- d) Appropriate measures shall be taken for gas protection to prevent the false operation of the gas protection caused by a fault or vibration of the gas relay.

12.3.3 The main protection for the short circuit fault of the outlet line, bushing and interior of the transformer shall meet the following requirements:

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

12.3.4 The backup protection for phase to phase short-circuit shall meet the following requirements:

- a) The backup protection for phase to phase short-circuit of the transformer shall serve as the backup for the main protection of the generator and the adjacent elements (transformer). The protection shall be sufficiently sensitive for phase to phase bus short circuit on both sides of the transformer. 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 phase to 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 supply for the connection on each side, different backup protection for phase to phase short-circuit of the generator shall be set up. The protection should be able to reflect the fault between the current transformer and the circuit breaker, and the requirements should be met as follows:
  - 1) As for the two-winding transformer and the three-winding transformer with the single-side power supply, the backup protection for phase to phase short-circuit should be set up on both sides. The non-power-supply-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, to reduce the range of fault impact; 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 supply 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 supply on two or three sides, the backup protection for phase to phase short-circuit on every side may have two or three time limits. The backup protection for phase to phase short-circuit may be equipped with the direction element, and the direction should point at the bus on each 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 phase to phase short-circuit on the high-voltage side of the transformer is not sufficiently sensitive for the low-voltage side bus phase to phase short circuit, two backup protection for phase to phase short-circuit shall be set up on the low-voltage side of the transformer. These two backup protection are connected to different current transformers.
  - 4) As for the generator transformer unit connection, no backup protection for phase to phase short-circuit will be set up on the low-voltage side of the transformer, but the backup protection for phase to phase short-circuit installed on the generator neutral point side shall be used as backup protection for phase to phase short-circuit of the transformer and the branch line and outside the high-voltage side.

**12.3.5** The single-phase grounding overcurrent and overvoltage backup protection shall meet the



following requirements:

- a) In the power grid where neutral point is directly grounded, such as a transformer operated by neutral point directly grounded, zero sequence current protection shall be set up for the over-current caused by external single-phase grounding, and the following requirements shall be met:
  - 1) The booster transformer with neutral point directly grounded may be provided with the two-section-type delayed zero-sequence overcurrent protection, and two time limits may be set for each section to reduce the impact range of fault within the shorter time limit, or to switch the circuit breaker on its side; the protection will lead to tripping of the circuit breakers on both sides of the transformer for a long time.
  - 2) For auto transformer and three-winding transformer whose neutral point on high/medium-voltage-side are directly grounded, direction element shall be set up when there is selective requirements, and the direction shall point to the bus on each side.
  - 3) The zero-sequence current protection for the ordinary transformer shall be connected to the secondary winding of the current transformer on the outlet 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 sides.
  - 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 sides.
  - 5) The zero-sequence overcurrent protection may be added to the neutral point circuit of the auto transformer.
  
- b) In the power grid where neutral point is directly grounded, if the neutral point of the transformer with power supply on the low-voltage side may operate with or without grounding, the overcurrent caused by external single-phase grounding and the voltage rise caused by the loss of the grounded neutral point shall be protected in accordance with the following provisions:
  - 1) The zero-sequence current protection shall be set up to meet the requirements for the direct grounding of the neutral point of the transformer. In addition, the zero-sequence overvoltage protection shall be set up. When the power grid connected to the transformer loses the grounded neutral point, the zero-sequence overvoltage protection will lead to tripping of the circuit breakers on both sides of the transformer within the time limit of 0.3 s to 0.5 s.
  - 2) The discharging gap shall be set up at the neutral point of the transformer. The zero-se-

quence current protection shall be set up, and the zero-sequence current protection shall be provided to reflect zero-sequence voltage and gap discharging current. When the power 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 0.3 s to 0.5 s time limit.

- c) In the power grid with non-effective neutral point grounding, for the zero-sequence overvoltage protection shall be installed for the overvoltage caused by single-phase grounding fault inside the transformer and its outlet line.

**12.3.6** Overload protection shall be installed according to the actual potential overload of the transformer.

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

- a) The temperature protection shall be set up. The temperature protection may be divided into two levels: temperature rise and high temperature. The temperature rise shall be acted on the signal while the high temperature shall be acted on the circuit breaker on each side 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 shall 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 phase to phase short circuit trouble of the winding and the high-voltage side outlet line of the transformer. The protection shall 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 2 MVA. 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 phase to phase short circuit fault 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 fault 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 caused by fault inside the transformer tank or the oil level drops, the protection will act on signal; when a large amount of gas is generated, the protection shall immediately lead to tripping of the circuit breakers on both sides of the transformer.
- f) Temperature protection shall be provided when the oil temperature of the reaction transformer and winding temperature rise. The temperature protection may be divided into two levels: temperature rise and high temperature. The temperature rise shall act on the signal, while the high temperature shall act on the circuit breaker on each side of the transformer.

## 12.4 Bus protection

### 12.4.1 The usage of bus protection shall meet the following provisions:

- a) As for the 3 kV to 10 kV segmented bus and double bus in parallel, backup protection of the generator and the transformer may be used to realize the bus protection. Special bus protection shall be installed under the following circumstances:
  - 1) When it is necessary to quickly and selectively remove a section or a group of bus fault, in order to insure the safe operation of power station and power grid and reliable power supply of important loads;
  - 2) When the line circuit breaker is not allowed to cut off the short circuit in front of the line reactor,
- b) Special bus protection shall be installed for the 35 (33) kV to 110 (132) kV bus of the power station, and when the trouble on the 110 (132) kV single bus or the 35 (33) kV to 66 kV bus in significant, the power station must be quickly cut off, the special bus protection shall be provided.

### 12.4.2 The special bus protection shall meet the following requirements:

- a) When the AC circuit is abnormal or broken, the bus differential protection shall be initiated and the alarm shall be given.
- b) When a set of charged bus or a section of the bus is connected to a fault bus, the bus protection shall be able to disconnect the fault bus in a quick and selective manner.

- c) The bus protection shall be able to disconnect the faulty portion during all the operating modes of the main connection.
- d) The bus protection shall use the current transformer with the different transformation ratio.
- e) 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.
- f) The bus protection shall be connected with a set of special secondary coils of the current transformer.
- g) After the bus protection operation, appropriate measures shall be taken for the circuit without branches and with longitudinal protection to enable the contralateral circuit breaker to trip rapidly.
- h) The bus protection only realizes the three-phase tripping exit, and the circuit breaker connected to the bus shall be allowed to share its tripping exit circuit for failure protection.

**12.4.3** 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.

**12.4.4** 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 Coordination and interface between the protection and other systems**

The protection devices shall be able to communicate with the computer monitoring system of the power station, and the following specific requirements shall be met:

- 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 of the device;
  - 2) On-off input (such as the position of the circuit breaker, and the pressing plate for protection);
  - 3) Abnormal signals (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 relevant standards.

## 13 Excitation system

### 13.1 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 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

The rotating excitation mode shall employ the brushless excitation. 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 to be collected by the excitation regulator shall include the generator end voltage, generator active power, generator reactive power, generator frequency, excitation voltage and excitation current;
- c) The PID control algorithm should be adopted as the regulation algorithm of the excitation regulator;
- d) When the power system fails and the generator output voltage decreases sharply, the excitation regulator shall carry out the forced excitation;
- e) When the excitation regulator causes the overvoltage due to the increasing speed of turbine-generator unit, it shall carry out forced de-excitation;

f) The turbine-generator unit which meets all the following conditions shall be equipped with the power system stabilizer (PSS):

- 1) Main turbine-generator unit in the system;
- 2) Turbine-generator unit which is in long-distance and weak contact with the system;
- 3) Turbine-generator unit 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 de-excitation unit shall meet the following requirements:

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) 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. The selection of the de-excitation mode and the calculation of the parameters shall meet the following requirements:

- 1) The linear de-excitation mode is suitable for the generator with small excitation capacity and low excitation voltage. Its resistance value shall be selected as 4 to 5 times of the resistance of the excitation winding in the generator at 75 °C ; the capacity shall be considered at 10% of the rotor energy storage under rated operating conditions.
- 2) The non-linear de-excitation mode is suitable for the generator with high excitation capacity and high excitation voltage.

c) The following considerations shall be considered in the selection of the de-excitation switch:

- 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 shall meet the following requirements:

- a) Technical requirements for the excitation transformer:
  - 1) Connection mode: the connection mode should be Y/ $\Delta$ -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) Type selection of the excitation transformer:
  - 1) There are two types of the excitation transformers: dry type and oil-immersed type. The conditions of application shall meet the following requirements:
    - ① Ordinary dry type: suitable for the low-voltage turbine-generator unit. 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 turbine-generator unit;
    - 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 Field indication and external interface of the excitation system

13.4.1 The excitation system shall be equipped with the terminal voltage meter, excitation voltage meter and excitation current meter, and the reactive power meter may also be configured with larger capacity units.

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 according to the installed capacity, unit capacity and voltage level of power station, from comprehensive analysis on technical, economic and operational safety and reliability.

- a) As for the hydropower station with a total installed capacity of 5 MW or above, the full-open and hierarchically distributed computer monitoring system should be adopted.
- b) As for the hydropower station with a total installed capacity of less than 5 MW, the integrated plant monitoring system should be adopted.
- c) 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.

14.1.2 According to the characteristics of the power station, the operating mode and the dispatching requirements of the power system, the control mode with fewer people on duty or unattended mode shall be selected.

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

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

- a) 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.
- b) The unit start-up, grid connection and shutdown can be completed with one command.

- c) The active power and reactive power of the unit can be automatically adjusted.
- d) The automatic and economical operation of the entire station can be realized.
- e) The command information of dispatching can be accepted at any time, which can meet the functions of the dispatching automation system for telemetry, remote signal, remote adjustment and remote control of the hydropower station.

## 14.2 Technical requirements for the computer monitoring system

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

14.2.2 The automatic control shall meet the following requirements:

- a) The automatic control of the turbine-generator unit should be realized with the programmable logic controller (PLC).
- b) The automatic control of the unit auxiliary equipment of the turbine-generator unit and the station auxiliaries shall be realized by the PLC.
- c) The control of the unit auxiliary equipment of the turbine-generator unit with installed capacity of less than 5 MW and public station auxiliaries may be realized by the PLC distributed in various local control cabinets.

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

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

14.2.5 The computer monitoring system shall be able to receive correct clock check information, and realize clock synchronization of all nodes in the system.

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

14.2.7 The inverter power supply 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 with digital indication shall have the communication interface, 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 turbine-generator unit 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 that cannot adopt wired communication, 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 synchronous device shall comply with the following requirements:

- a) As for the manual synchronizing device, the digital synchronous meter with the phase angle compensation function should preferably be adopted, followed by the combined synchronous meter.
- b) One manual synchronous device/automatic quasi-synchronous devices may be shared by the entire station, or one set may be allocated to each unit.
- c) The automatic quasi-synchronous device shall have the function to automatically regulate the frequency and voltage.

## **15 Plant service power supply and dam area power supply**

### **15.1 Power source of the plant service power supply**

**15.1.1** The plant service power supply shall meet the following requirements:

- a) Meet the needs of power load under various operating modes;
- b) Relatively independent power supply;

- c) No less than two plant service power supplies are required. When one power supply fails, another power supply can operate automatically.

**15.1.2** The plant service power supply may be obtained by the following methods:

- a) Connected by the generator voltage bus or the unit lead;
- b) When a coupling transformer is equipped on the high-voltage side of the hydropower station, the power supply is connected by 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** A hybrid power supply is recommended for the unit service power and common power demand of the plant.

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

## **15.2 Selection of the plant service transformer capacity**

**15.2.1** The capacity of the power transformer in the plant shall meet the maximum load that may occur under various operating modes.

**15.2.2** When one plant service transformer is scheduled for maintenance or failure, the other power transformers of the plant shall 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 area power supply**

**15.3.1** Power for dam area shall be supplied by a special dam area transformer or a public station service transformer. There shall be two independent power supplies for significant loads in the dam area. For particularly important flood discharge facilities, a third power supply or special diesel generator of suitable capacity may be added. Some insignificant loads in the plant and dam area can also be supplied by the local power grid.

**15.3.2** The voltage for the power supply in the dam area should be determined according to the supply range, the plant high-voltage power supply and the local power grid voltage.

#### 15.4 Power supply in the living Area

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

### 16 DC operating power supply

16.1 The operating power supply of the power station shall be the DC power supply device with the storage battery and suitable battery chargers. 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 operating power supply should be the standard voltage of 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 preferably as 1 hour, and may be set preferably as 2 hours for the power station operated in the expanded plant station mode.

16.4 The storage battery should be the valve-controlled battery. The charging and float charging of the battery shall be equipped with a set of rectification devices. The charging power circuit for the storage battery shall be equipped with corresponding power indication.

16.5 The DC device shall have the function such as automatic charge and discharge control, battery capacity and voltage detection, insulation monitoring and fault alarm.

### 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 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 power

dispatching communication and in-station communication may share a program-controlled dispatching switchboard. As for the cascade hydropower stations, a dispatching switchboard may be set up in the cascade control centre, and a remote subscriber module may be set up on the power station side to realize voice communication.

**18.2** External communication of power station may be conducted in the following ways:

- 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 supply for the communication equipment shall be the special 24 V or 48 V communication power supply, and the capacity of the storage battery with suitable battery charger shall meet the power supply preferably for 8 hours.

## **19 Electrical repair and electrical testing**

**19.1** Special electrical repair workshop may be set up for the power station, and electrical repair tools and equipment shall be equipped in accordance with the requirements of its scale and centralized management.

**19.2** Electrical test room may be set up for the power station with installed capacity of 10 MW or above; the power station with installed capacity less than 10 MW may be equipped with a simple electrical test room.

**19.3** Centralized electrical test room should be set up for cascade hydropower stations and hydro-power station groups under centralized management. The configuration standards of the instrument and the equipment in the electrical test room may be implemented according to the current classification standards.