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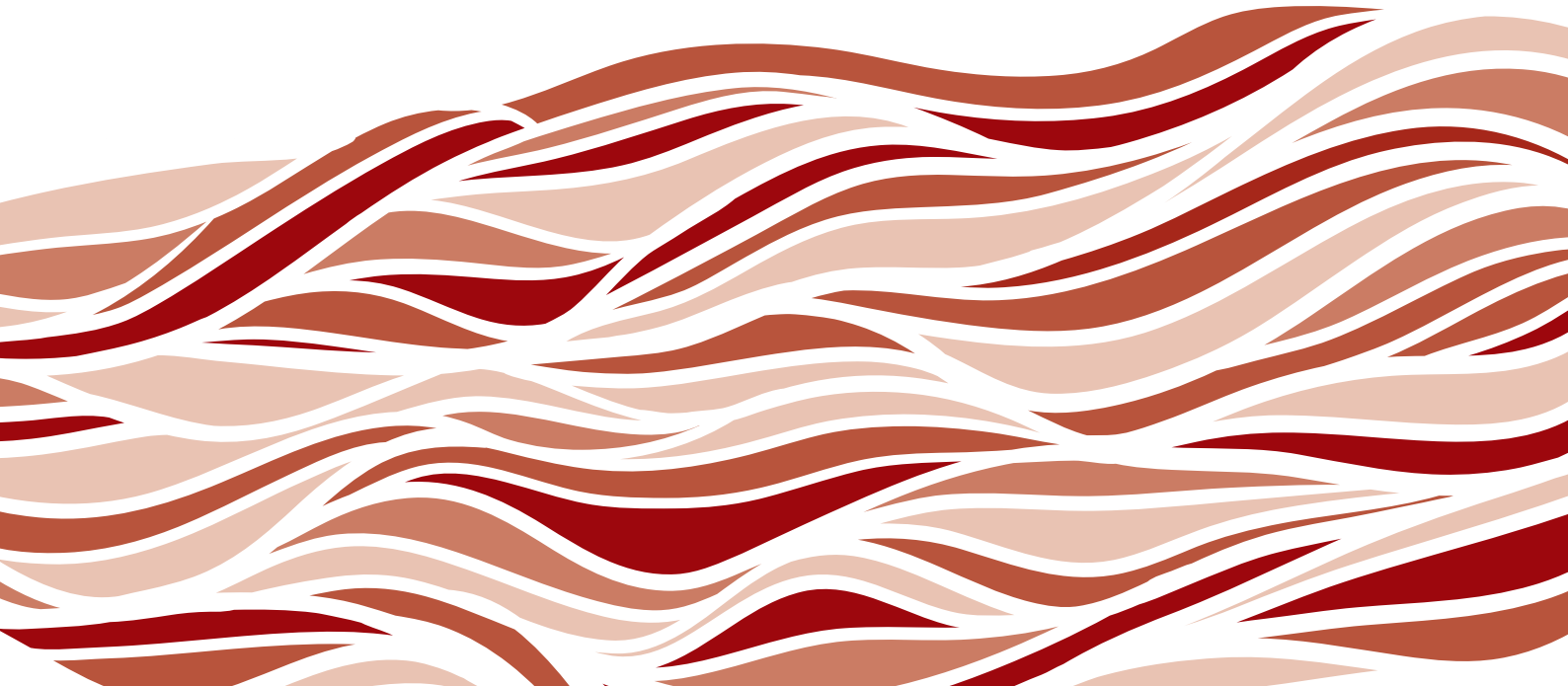
INDUSTRIAL DEVELOPMENT ORGANIZATION

Technical Guidelines for the
Development of Small Hydropower Plants

UNITS

Part 2: Hydro Turbine Generator

SHP/TG 003-2: 2019



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Part 2: Hydro Turbine Generator

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

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Foreword

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

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

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

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

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

Introduction

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

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

The TGs can be used as the principles and basis for the planning, design, construction and management of SHP plants up to 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-Units
Part 2: Hydro Turbine Generator

1 Scope

This Part of the Units Guidelines specifies the technical requirements as well as the basic requirements for the supply scope, spare parts, technical documents, inspection and acceptance, packing, transportation, storage, installation, operation and maintenance for the small hydropower (SHP) three-phase 50 Hz or 60 Hz salient pole synchronous hydro turbine generator with rated capacity up to 12.5 MWA connected to a hydro turbine.

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.

ISO 1680, *Acoustics—Test Code for the Measurement of Airborne Noise Emitted by Rotating Electrical Machines*

IEC 60034-1, *Rotating Electrical Machines—Rating and Performance*

IEC 60034-2-1, *Determining Losses and Efficiency from Tests*

IEC 60034-2A, *Measurement of Losses by the Calorimetric Method*

IEC 60038, *IEC Standard Voltages*

IEC 60050-411, *Electro technical Vocabulary—Part* 411: *Rotating Machinery*

IEC-60085, *Classification of the materials for the insulation of the electrical machines*

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 IEC 60034-1, IEC 60050-411 and SHP/TG 001 apply.

4 Service conditions

The generator shall be installed in the sheltered plant and shall be able to operate continuously under the following service conditions:

a) The altitude is not more than 1 000 m. When the generator is used in the place with an altitude exceeding 1 000 m, the reduction of the dielectric properties and the decrease of the air cooling effect shall be considered, and the user shall negotiate with the supplier;

b) The cooling air temperature is not more than 40 ℃; the water inlet temperature of the heat exchangers of the generator, such as the air cooler and oil cooler, is not higher than 28 ℃ nor lower than 5 ℃;

c) The relative humidity in the plant is not more than 85%;

d) The design acceleration values corresponding to the seismic intensities of the service site are as shown in Table 1.

Table 1 Design acceleration values under different seismic intensities

Design acceleration value	Seismic intensities		
	7	8	9
Horizontal direction	0.2g	0.25g	0.4g
Vertical direction	0.1g	0.125g	0.2g
NOTE g is the gravitational acceleration of the site where the generator is used.			

5 Technical requirements

5.1 Basic technical requirements

5.1.1 Rated capacity output

Under the following conditions, the generator shall be able to output rated capacity:

a) The deviation between the voltage and its rated value shall not exceed ±5% at the rated rotation

speed and the rated power factor;

b) The deviation between the frequency and its rated value shall not exceed ±1% at the rated voltage and the rated power factor;

c) At the rated power factor, when the voltage and the frequency deviate simultaneously (the deviations do not exceed ±5% and ±1% respectively) and both deviations are positive, the sum of the deviations shall not exceed 6%; if both deviations are negative or one deviation is positive while another deviation is negative, the sum of the absolute values of the percentages of both deviations shall not exceed 5% (the generator shall be able to operate continuously when the deviations of voltage and frequency exceed the aforesaid values; at this moment, the output capacity shall ensure that the exciting current does not exceed the rated value and the stator current does not exceed the rated value by more than 105%).

5.1.2 Rated power factor

The rated power factor of the generator should not be lower than 0.8 (lagged).

NOTE If the user has special requirements, the rated power factor may be determined by the supplier and the user through negotiation.

5.1.3 Rated voltage

The rated voltage of the generator shall be determined by the user and the supplier through negotiation, and shall comply with the provisions of IEC 60038. The following voltage grades (kV) shall preferably be selected: 0.4, 0.48, 0.69, 3.15, 3.3, 4.16, 6.3, 10.5 and 11.

5.1.4 Rated rotation speed

The rated rotation speed of the generator shall preferably be selected from Table 2:

Table 2 The rated rotation speed of the hydro turbine generator Unit: r/min

50 Hz	60 Hz
1 500, 1 000, 750, 600, 500, 428.6, 375, 333.3, 300, 250, 214.3, 200, 187.5, 166.7, 150, 142.9, 136.4, 125, 115.4, 107.1, 100, 93.8, 88.2, 83.3, 75	1 200, 900, 720, 600, 514.3, 450, 400, 360, 300, 257.2, 240, 225, 200, 180, 171.5, 163.7, 150, 138.5, 128.5, 120, 112.6, 105.8, 100, 90

5.2 Electrical characteristics

5.2.1 Capacity

5.2.1.1 It is allowed to increase the active power value of the generator to the rated capacity (ap-

parent power) value by improving the power factor. If required by the user, the maximum capacity may be set for the generator; at this moment, the power factor, electrical parameter value, allowable temperature rise and the performance of the generator related to continuous operation shall be determined by the supplier and the user through negotiation.

5.2.1.2 The generator shall have the long-term continuous leading phase and lag phase operation performance. The allowable leading phase and lag phase capacity and operation scope as well as the allowable charging capacity of the no-load line shall be determined by the supplier and the user through negotiation.

5.2.2 Efficiency and loss

5.2.2.1 Rated efficiency

The guaranteed value for the rated efficiency of the generator operating at rated capacity, rated voltage, rated power factor and rated rotation speed shall be specified in the order contract signed by and between the supplier and the user.

The rated efficiency of the generator shall be as follows:

a) The generator with a rated capacity of 0.6 MVA to 1.25 MVA, with an efficiency of 90% to 95%;

b) The generator with a rated capacity greater than 1.25 MVA to 2.5 MVA, with an efficiency of 90% to 96%;

c) The generator with a rated capacity greater than 2.5 MVA to 6.25 MVA, with an efficiency of 92% to 96.5%;

d) The generator with a rated capacity greater than 6.25 MVA to 12.5 MVA, with an efficiency of 93% to 97%.

5.2.2.2 Weighted average efficiency

The weighted average efficiency is the weighted average value corresponding to the generator efficiency at rated voltage, rated rotation speed and specified power factor and under different capacity conditions. The guaranteed value of the weighted average efficiency shall be specified in the order contract signed by and between the supplier and the user.

The weighted average efficiency of the generator may be calculated by means of the Formula(1). The weighting coefficient shall be provided by the user.

$$\eta = A\eta_1 + B\eta_2 + C\eta_3 \quad \cdots\cdots(1)$$

where

A, B and C…… are the corresponding to the weighting coefficient at the specified power factor and under capacity conditions, and $A + B + C + \cdots\cdots = 1$;

η_1、η_2 and η_3…… are corresponding to the efficiency values at the specified power factor, capacity and weighting coefficient.

5.2.2.3 Loss

5.2.2.3.1 The loss and efficiency of the generator shall be measured with the direct method, indirect method or calorimetric method. The losses include:

a) Copper loss of the stator winding;

b) Copper loss of the rotor winding;

c) Core loss;

d) Loss from wind and friction;

e) Loss of the guide bearing;

f) Loss of the thrust bearing (only the loss apportioned to the rotating part of the generator is considered);

g) Stray loss;

h) Loss from the excitation system;

i) Electrical and friction losses of the brushes;

j) Other losses.

5.2.2.3.2 For determining the loss value I^2R of the windings, the DC resistance of the windings shall be converted into the values at the reference working temperature corresponding to insulation class marked on the generator nameplate. If the temperature rise or the rated temperature is specified to be lower than the thermal classification of the structure, its reference working temperature shall be specified as per the lower thermal classification, as shown in Table 3.

Table 3 Reference working temperature specified as per the thermal classification of the hydro turbine generator insulation

Thermal classification of the insulation structure	Reference working temperature ℃
130(B)	95
155(F)	115
180(H)	130

5.2.3 Electrical parameters and time constant

The electrical parameters such as the synchronous reactance, transient reactance, ultra-transient reactance, short circuit ratio and time constant of the generator shall meet the operational requirements of the electric power system and shall be specified in the order contract signed by and between the supplier and the user.

5.2.4 Total harmonic distortion factor

When the stator winding of the generator is connected with the normal functioning connection method, the total harmonic distortion (THD) factor of the line voltage should not exceed 5% at the no-load rated voltage and rated rotation speed.

5.2.5 Temperature rise of components like the windings and stator core

The generator shall be able to operate continuously for a long-term under the service conditions and the rated working conditions specified in Section 4, and the temperature rise limit value of its stator winding, rotor winding and stator core shall comply with the provisions of Table 4. Stator and rotor shall be provided with insulating material with temperature classification of 130 (B) or higher.

Table 4 Allowable temperature rise limit value of the stator winding, rotor winding and stator core of the hydro turbine generator

Components of the hydro turbine generator	Maximum allowable temperature rise limit value for insulating materials of different levels(K)					
	130(B)			155(F)		
	Thermometer method Th	Resistance method R	Embedded temperature detector method ETD	Thermometer method Th	Resistance method R	Embedded temperature detector method ETD
Stator winding	—	80	85	—	100	105
Stator core	—	—	85	—	—	105
Rotor winding of two layers or more	—	80	—	—	100	—
Single-layer rotor winding with exposed surface	—	90	—	—	110	—
Collecting ring	75	—	—	85	—	—

5.2.6 Correction of the temperature rise limit value under non-reference operating conditions and ratings

5.2.6.1 When the generator is used in places at an altitude of 1 000 m to 4 000 m, and the maximum environment air temperature is not more than 40 ℃, its temperature rise limit value may not be corrected. When the altitude is higher than 4 000 m, it shall be determined by the supplier and the user through negotiation.

5.2.6.2 When the generator is used in places at an altitude no higher than 1 000 m, and the maximum temperature of the ambient air or cooling air at the air cooler outlet of the generator is different than 40 ℃, the temperature rise limit value specified in Table 4 may be corrected as follows (which only applies to the measurement with the embedded temperature detector method):

a) When the cooling air temperature is below 40 ℃, the temperature rise limit value shall increase by the difference value of the cooling air temperature below 40 ℃;

b) When the cooling air temperature is higher than 40 ℃ but lower than 60 ℃, the temperature rise limit value shall decrease by the difference of the cooling air temperature above 40 ℃;

c) When the cooling air temperature is higher than 60 ℃, the decrease in the temperature rise limit value may be determined by the supplier and the user through negotiation.

5.2.6.3 As for the generator which is started and stopped three or more times every day, the temperature rise limit value in Table 4 may be considered to decrease by 5 K to 10 K.

5.2.7 Bearing temperature

Under normal operating conditions of the generator, the maximum temperature of its bearing shall be measured with the embedded temperature detector method and shall not exceed the provision in Table 5.

Table 5 Allowable temperature rise values for the hydro turbine generator bearings

Components of the hydro turbine generator	Maximum allowable temperature rise value ℃
Babbitt bearing bush of the thrust bearing	75
Babbitt bearing bush of the guide bearing	70
Plastic bearing bush body of the thrust bearing	55
Plastic bearing bush body of the guide bearing	55
Babbitt bearing bush of cradle-type sleeve bearing	80
Rolling bearing	95 (thermometer method)

5.2.8 Special operating requirements

5.2.8.1 The generator allows short-time overcurrent under accident conditions. The multiples of the overcurrent of the stator winding and corresponding allowable duration shall be determined as per Table 6. However, the occurrence of overcurrent reaching the allowable duration in Table 6 shall not exceed 2 times on average every year.

Table 6 Relationship between allowable multiples of the overcurrent of the stator winding and the allowable duration of the hydro turbine generator

Allowable multiples of the overcurrent of the stator (stator current/ stator rated current)	Allowable duration min.
1.10	60
1.15	15
1.20	6
1.25	5
1.30	4
1.40	3
1.50	2
NOTE As for the generator with overload operation requirements (see 5.2.1.1), the allowable multiples of the overcurrent and the duration of its stator winding shall be determined by the supplier and the user through negotiation.	

5.2.8.2 The rotor winding of the generator shall be able to withstand 2 times the rated exciting current for no less than 50 s.

5.2.8.3 When the generator is operating in the unsymmetrical power system, if the current of any phase does not exceed rated current I_N, and the ratio (per-unit value) of the negative sequence current component (I_2) to the rated current is not more than 12%, the generator shall be able to operate for a long period.

5.2.8.4 When the generator operates unsymmetrically for a short time due to failure, the allowable product of the squared ratio (per-unit value) of the negative-sequence current component to the rated current and the allowable unsymmetrical operation duration t (s) is 40 s, i.e. $(I_2/I_N)^2 \times t = 40$ s.

5.2.9 Connecting to the system by synchronization

The generator shall be connected to the system by quasi-synchronization.

5.2.10 Main outgoing line, neutral outgoing line and phase sequence

5.2.10.1 Main outgoing line and neutral outgoing line

The number of main outgoing lines of the stator winding of the generator should be 3 or 6. The direc-

tion and layout of the outgoing lines of the stator winding as well as the outgoing mode of the neutral outgoing lines shall be determined by the supplier and the user through negotiation.

5.2.10.2 Phase sequence

The phase sequence arrangement of the outgoing terminal of the generator should be: Viewed from the outgoing terminal of the generator, the sequence is U, V and W horizontally from left to right. If another phase sequence arrangement is to be used, it shall be determined by the supplier and the user through negotiation.

5.2.11 Insulating property and withstand voltage test

5.2.11.1 Insulating property

5.2.11.1.1 The insulation resistance value between the stator winding of the generator and the enclosure or between the windings shall not be lower than the value calculated by the Formula(2) when it is converted to 100 ℃:

$$R = \frac{U_N}{1\,000 + 0.01 S_N} \qquad \cdots\cdots (2)$$

where

R is the calculated value of the hot insulation resistance of the winding corresponding to a temperature of 100 ℃, in MΩ;

U_N is the rated line voltage of the generator, in V;

S_N is the rated capacity of the generator, in kVA.

As for the dry and clean generator, the insulation resistance value R_t(MΩ) of the stator winding at room temperature t (℃) may be corrected by the Formula(3):

$$R_t = R \times 1.6^{(100-t)/10} \qquad \cdots\cdots (3)$$

5.2.11.1.2 When the rotor is megger tested with a 500 V or 1 000 V tramegger at room temperature 10 ℃ to 40 ℃ before and after the single magnetic pole is hung, its insulation resistance value shall not be less than 5 MΩ. After hanging, the insulation resistance value of the complete winding of the rotor shall not be less than 0.5 MΩ.

5.2.11.1.3 When the stator winding of the generator is in the actual cold state, the difference in the DC resistance of the various branches between the maximum phase and minimum phase shall not exceed 2% of the minimum value after the error arising from the different length of the lead wire is

corrected.

5.2.11.1.4 The polarization coefficient R_{10}/R_1 of the stator winding of the generator shall not be less than 2.0, it will not be evaluated when the rated voltage is 2.5 kV or lower.

NOTE R_{10} and R_1 are the measured insulation resistance values in 10 minutes and 1 minute when the temperature is lower than 40 ℃

5.2.11.1.5 Dielectric loss angle tangent of the normal-state medium of the stator winding of the generator and the limit value of its increment shall comply with the provisions of Table 7 (it will not be evaluated when the rated voltage is 2.5 kV or lower).

Table 7 Dielectric loss angle tangent of the normal-state medium of the hydro turbine generator and the limit value of its increment

Test voltage	$0.2U_N$	$0.2U_N$—$0.6U_N$
Dielectric loss angle tangent of the medium and its increment	$\tan\delta$	$\Delta\tan\delta = \tan\delta_{0.6U_N} - \tan\delta_{0.2U_N}$
Index value (%)	⩽3	⩽1
NOTE U_N refers to the rated line voltage of the generator, in kV. For each generator, a casual inspection shall be carried out by 3%. The frequency of casual inspections shall be doubled if failure of the inspection.		

5.2.11.1.6 When the insulation resistance values of the thrust bearing, guide bearing, cradle-type sleeve bearing and embedded temperature detector of the generator with ground insulation requirements are measured at 10 ℃ to 30 ℃, they shall comply with the provisions of Table 8.

Table 8 Insulation resistance values of the various components of the hydro turbine generator

Bearing components	Insulation resistance MΩ	Voltage of the tramegger V	Remark
Thrust bearing	1	1 000	Install the thermometer into the thrust bearing and guide bearing and measure before injecting the lubricating oil.
Split-type guide bearing bush	5		
Cradle-type sleeve bearing	1		Measure the ground insulation resistance of the bearing pedestal.
Embedded temperature detector	5	250	

5.2.11.2 Withstand voltage test

5.2.11.2.1 Before the AC withstand voltage test is carried out on the generator with rated voltage of 6.3 kV or higher, the DC withstand voltage and leakage shall be measured for the stator winding with 3 times the rated voltage. The test voltage shall increase in a stable manner in stages; each stage shall be 0.5 times the rated voltage and it will last 1 minute. The leakage current shall not in-

crease over time. The difference in the leakage current for the various phases shall not be greater than 50% of the minimum value.

5.2.11.2.2 Power frequency breakdown voltage value of the stator winding insulation should be 5.5 to 6 times the rated voltage, and shall be verified through the sampling test.

5.2.11.2.3 The stator winding and the rotor winding of the generator shall be able to sustain the AC withstand voltage test at the power frequency specified in Table 9 (the waveform is the actual sinusoidal waveform) for 1 minute without puncturing the insulation.

Table 9 Standard for the winding dielectric withstand voltage test of the hydro turbine generator

Coil or winding test		Test voltage, kV		Remark
		$U_N<6.3$	$6.3\leqslant U_N\leqslant 13.8$	
Stator winding	a) Finished coil product	$2.75U_N+4.5$	$2.75U_N+6.5$	
	b) After slot wedge assembling off line	$2.5U_N+2.5$	$2.5U_N+2.5$	
	c) At completion of stator assembly	$2.25U_N+2.0$	$2.25U_N+2.0$	
	d) Stator after the immersion paint is cured	$2.0U_N+2.0$	$2.0U_N+2.0$	Total immersion
	e) At completion of final assembling of the generator	$2.0U_N+1.0$	$2.0U_N+1.0$	
Rotor winding	a) At completion of rotor assembling	10 times rated the exciting voltage + 0.5 (minimum is 2.0 kV)		
	b) At completion of final assembling of the generator	10 times rated the exciting voltage + 0.5 (minimum is 1.5 kV)		

NOTE 1 U_N refers to the rated voltage of the generator (kV);

NOTE 2 Stator winding which is not treated by total immersion will not be subjected to item d); dielectric strength test of the stator winding treated by total immersion will be carried out from item d);

NOTE 3 For the stator and rotor to be accepted on site, the AC dielectric strength test value of its winding is 0.8 times the test voltage value upon completion of the generator final assembly.

5.2.11.2.4 As for the generator with rated voltage of 6.3 kV and above, the single coil of its stator shall not incept corona at 1.5 times the rated voltage when the altitude of the service location is 1 000 m or lower; during the dielectric strength test of a complete machine, the terminals shall be free from any obvious golden bright spots and continuous corona strips at 1.05 times the rated voltage. When the altitude is higher than 1 000 m, the test value of the corona inception voltage shall be as follows:

a) Corona inception voltage value of the stator winding shall not be lower than the values obtained by the Formula(4):

$$U_{BS} = 1.5U_N \frac{1 - KH_S}{1 - KH_A} \quad \text{……(4)}$$

where

U_{BS} is the corona inception voltage of the stator winding, in kV;

U_N is the rated line voltage of the generator, in kV;

K is the declining rate of corona inception voltage along with the increase in altitude, K takes 0.1, in km^{-1};

H_S is the altitude of the test location for the motor, in km;

H_A is the altitude of the installation location for the motor, in km.

b) Corona inception voltage value of the complete generator shall not be lower than the values obtained by the Formula(5):

$$U_{JS} = 1.3U_\phi \frac{1 - KH_S}{1 - KH_A} \quad \text{……(5)}$$

where

U_{JS} is the corona inception voltage of the generator, in kV;

U_ϕ is the rated phase voltage of the generator, in kV.

5.3 Mechanical characteristics

5.3.1 The rotation direction specified for the generator shall be seen clockwise from the non-driving terminal. If there is any special requirement, it shall be specified in the order contract signed by and between the supplier and the user.

5.3.2 The moment of inertia(GD^2) value of the generator shall satisfy the requirements for the regulation guarantee calculation and the technical and economic reasonability of the hydropower station. If the GD^2 value of the generator could not satisfy the requirement of the regulation guarantee calculation of the hydropower station, it shall be determined by the supplier and the user through negotiation.

5.3.3 The generator and the auxiliary machine directly connected to it shall be able to operate for 5 minutes at maximum runaway speed and shall not become adversely deformed and damaged.

5.3.4 The structural strength of the various components of the generator shall be able to sustain the 3 s three-phase sudden short-circuit test at the rated rotation speed and no-load voltage that is equal to 105% of the rated voltage and shall not be adversely deformed. Meanwhile, it shall be able to undertake a 20 s short-circuit failure at the rated capacity, rated power factor and 105% of the rated voltage and stable exciting conditions and shall not be adversely deformed or damaged.

5.3.5 The structural strength of the generator shall be able to undertake the action of the unbalanced magnetic pull produced by the short circuit of half of the magnetic poles of the rotor, and shall not be adversely deformed or damaged.

5.3.6 After the stator and rotor of the generator are assembled, the difference between the maximum or minimum value of the stator in-radius and rotor ex-radius and its design radius shall not be more than ±4% of the design air gap value. The difference between the maximum value or minimum value of the air gap between the stator and the rotor and its average value shall not be more than ±8% of its average value.

5.3.7 The allowable double amplitude vibration of the generator shall comply with the provisions in Table 10.

Table 10 Allowable vibration limit value of the various components of the hydro turbine generator

Unit: mm

Hydro turbine generator unit type	Items	Rated rotation speed n_N/(r/min)				
		$n_N<100$	$100\leqslant n_N<250$	$250\leqslant n_N<375$	$375\leqslant n_N\leqslant 750$	$750<n_N$
Vertical type	Vertical vibration of the bracket with thrust bearing	0.08	0.07	0.05	0.04	0.03
Vertical type	Horizontal vibration of the bracket with guide bearing	0.11	0.09	0.07	0.05	0.04
Horizontal type	Vertical vibration of the bearings at various positions	0.11	0.09	0.07	0.05	0.04
NOTE The vibration value refers to the double amplitude value of the hydro turbine generator unit under all kinds of stable operating conditions except for over-speed operation.						

5.3.8 The noise level of the hydro turbine generator shall not be greater than that specified in Table 11.

Table 11 Noise level of the hydro turbine generator

Unit mode	Position of measurement	Rated speed n_N/(r/min)		
		$n_N\leqslant 250$	$250<n_N<750$	$n_N\geqslant 750$
Vertical unit	Vertical distance 1 m above the outer edge of the upper cover	80 dB(A)	85 dB(A)	90 dB(A)
Horizontal unit	1 m away from the unit at the non-transmission end	80 dB(A)	85 dB(A)	90 dB(A)

5.3.9 After the generator and the turbine are assembled, the first-stage critical speed of rotation of the rotating part of the hydro turbine generator unit shall not be less than 120% of maximum runaway speed.

5.3.10 The vertical deflection value of the load-bearing frame of the generator shall not be more than 1.5 mm under the action of maximum axial load.

5.4 Basic requirements of the structure

5.4.1 The structural style of the generator shall be determined after technical and economic analysis and comparison in accordance with type of the turbine, rotation speed of the hydro turbine generator unit, rated capacity, powerhouse type and operating stability of the hydro turbine generator unit.

5.4.2 The connection between the generator and the drive end should employ the rigid or flexible coaxial drive structure but should not employ the belt drive structure. When it is necessary to employ the belt drive structure, it shall be determined by the supplier and the user through negotiation.

5.4.3 The generator with the rolling bearing structure should not bear the axial thrust; as for the generator required to bear the axial thrust, the load value shall be determined by the supplier and the user through negotiation.

5.4.4 The generator with the sliding bearing structure should employ the self-circulation bearing, and the horizontal turbine generator unit (excluding the shaft-extension tabular turbine generator unit) should preferably have the structure with two supporting points.

5.4.5 The rotor for the generator with a rated capacity above 1 MVA shall be fitted with the damping winding (or structure with the damping function). The rotor for the generator with a rated capacity of 1 MVA or less will not be fitted with the damping winding; where necessary to fit, it shall be determined by the supplier and the user through negotiation.

5.4.6 The structure of the vertical hydro turbine generator shall be convenient for maintenance and overhaul. If the structure permits, the generator should be designed so that its lower rack and the removable components of the hydraulic turbine could pass through the inner diameter of the stator core without the need to remove the stator when installing and overhauling.

5.4.7 The hydro turbine generator unit could be started when the oil temperature of the oil groove is no lower than 10 ℃ for the thrust bearing and the guide bearing with the bearing alloy bush, and the generator could be started immediately after it stops. The hydro turbine generator unit could be started when the oil temperature of the oil groove is no lower than 5 ℃ for the thrust bearing and the guide bearing with the elastic metal plastic bearing bush, and the generator could be started immediately after it stops.

5.4.8 If the generator needs to be fitted with the electric heating dehumidification system, it shall

be determined by the supplier and the user through negotiation.

5.5 Ventilation and cooling system

5.5.1 The generator may employ the following ventilation and cooling system:

a) Open-type self-ventilation and cooling system: Usually applies to the generator with a rated capacity of 1 MVA or less;

b) Duct-based ventilation and cooling system: Usually applies to the generator with a rated capacity above 1 MVA but less than 4 MVA;

c) Closed circulation ventilation and cooling system: Usually applies to the generator with a rated capacity above 4 MVA.

5.5.2 Cooling water pressure of the air cooler may usually be designed as per 0.15 MPa to 0.3 MPa, or the working pressure may be determined according to the actual situation and confirmed by the supplier and the user through negotiation. The test water pressure of the cooler shall be 1.5 times of the working water pressure (minimum pressure shall not be lower than 0.4 MPa). The test shall last 60 minutes.

5.6 Braking system

5.6.1 The generator with the rolling bearing structure will not be fitted with the braking device.

5.6.2 The vertical hydro turbine generator with the sliding bearing structure shall be fitted with the braking device. The vertical hydro turbine generator with a rated capacity above 1 MVA should be fitted with a set of mechanical braking devices operated with compressed air or pressure oil. The braking system shall be able to jack up the rotating part of the hydro turbine generator unit with the hydraulic oil and be reliably locked.

5.6.3 When the horizontal hydro turbine generator with the sliding bearing structure needs to be fitted with the braking device, it shall be determined by the supplier and the user through negotiation.

5.6.4 When the generator is provided with the mechanical brake, the compressed air with a pressure of 0.5 MPa to 0.7 MPa may be used, or pressure oil may be used as the braking medium. The mechanical braking system shall be able to continuously apply braking and to stop the rotating part of the hydro turbine generator unit from 20% to 30% rated rotation speed (10% to 20% for the generator with plastic bearing bush) within the specified time. When the rotation torque produced by the hydro turbine generator unit due to the water leakage of the turbine guide vane is not greater than 1% of the rated rotation torque of the turbine, the mechanical braking system shall apply braking and stop the hydro turbine generator unit.

5.7 Fire extinguishing system

The setting of the fire extinguishing system shall meet the following requirement:

a) For the generator with a rated capacity of 12.5 MVA, the stator winding head may be fitted with water fire extinguishing apparatus.

b) The generator with a rated capacity less than 12.5 MVA may not be fitted with fire extinguishing apparatus;

c) The setting of the fire extinguishing system of the generator shall be selected according to the firefighting standard of the country.

5.8 Detecting system

5.8.1 Residual pressure velocity measuring device shall be set for the generator. If other methods of speed measurement are adopted, they shall be agreed by both supplier and buyer.

5.8.2 For measuring the temperature of the stator winding and stator core, it is necessary to embed electric resistance thermometers, in the quantities as follows, in the stator groove of the generator:

a) Zero for the generator with a rated capacity of 1 MVA or less;

b) Six for the generator with a rated capacity above 1 MVA but less than 12.5 MVA.

5.8.3 For measuring the temperature of the thrust bearing and the guide bearing, it is necessary to embed the electric resistance thermometers (signal thermometers) in at least the following quantities:

a) Four are to be embedded in the thrust bearing bush on the generator with a rated capacity above 1 MVA, two are embedded in the guide bearing bush, one is embedded in the thrust bearing oil groove and one in the guide bearing oil groove;

b) One to be embedded in the thrust bearing oil groove and one in the guide bearing oil groove of the generator with a rated capacity of 1 MVA or less for measuring the temperature of the hot oil in the oil groove. If electric resistance thermometers (signal thermometers) need to be embedded in the thrust bearing and the guide bearing, it shall be determined by the supplier and the user through negotiation;

c) At least one is to be embedded in the cradle sleeve bearing of the horizontal hydro turbine generator; if the cradle sleeve bearing is fitted with the thrust bearing, at least one thermometer is embedded in the thrust bearing bush.

5.8.4 One electrical resistance thermometer for measuring the cool air temperature shall be embedded on each air cooler; each of the two air coolers of every hydro turbine generator shall be equipped with one thermometer for measuring the hot air temperature; one thermometer for measuring the hot air temperature shall be embedded if there are two or fewer air coolers; the thermometers shall be convenient for replacement.

5.8.5 The automatic detection system used on the generator shall be configured according to the decision of the supplier and the user through negotiation, such as the liquid level detector, cooling water flow indicator, water-in-oil detector, pressure detector, heating and drying and dehumidification detector.

The type and performance requirements of each automatic detection system and device as well as the configuration of the computer monitoring system interface shall be determined by the supplier and the user through negotiation, and the communication interface shall be provided with RS-485.

5.9 Excitation System

The generator shall be provided with the self-shunt excitation thyristor rectification excitation system. If other excitation methods are adopted, they shall be agreed by both the supplier and the buyer.

6 Supply scope and spare parts

6.1 Supply scope

6.1.1 The generator body and its accessories.

6.1.2 The supply of the complete package of the excitation system shall be determined by the supplier and the user through negotiation.

6.1.3 Dedicated tools and special tools for installation and overhaul.

6.2 Spare parts

6.2.1 The items and the quantity of the main spare parts for the generator should be subject to the provisions of Appendix A.

6.2.2 Other spare parts should be determined by the supplier and the user through negotiation.

7 Technical Documents

The supplier shall submit the necessary technical documents to the user, mainly including:

a) Arrangement plan, foundation drawing and embedded parts diagram of the generator;

b) General assembly drawing of the generator, assembly drawing of the various components of the generator, overall dimensions and layout plan of the air cooler, schematic diagram for lifting of the rotor, schematic diagram for installing/removing of the thrust block and the schematic diagram of the unit's barring;

c) Main electrical parameters of the generator, and the dimensions and weight of the main components;

d) No-load, short-circuit characteristic curve and efficiency characteristic curve of the generator;

e) Schematic diagram and layout plan of the braking system, oil, water and air pipeline layout drawing of the generator and detailed diagram for the auxiliary connection of the generator;

f) Installation, use and maintenance instructions, delivery inspection report, and delivery details of the generator.

8 Inspection and acceptance

8.1 Each product shall pass the inspection before being delivered, and shall be accompanied by the product quality inspection certificate.

8.2 The generator which could be subjected to general assembly and start-up and trial run at the supplier's premise shall be inspected and accepted according to the delivery tests and commissioning test items in Table B.1.

8.3 The generator which could not be subjected to general assembly and start-up and trial run at the supplier's premises shall be inspected and accepted according to the hand-over test items in Table B.1.

8.4 The supplier shall provide the conformity certificates, material chemical components and mechanical property reports for the key components of the generator including:

a) Material chemical components, mechanical properties and non-destructive testing of the spindle forgings;

b) Material chemical components and mechanical properties of the rotor spider (magnet yoke);

c) Material chemical components and mechanical properties of the runner plate forgings;

d) Magnetization characteristic and loss of the silicon steel sheet;

e) Wire size, electric conductivity and dielectric strength of the winding.

8.5 For the equipment to be assembled on the site of the hydropower station, the work-piece dimensions and assembling dimensions of the components shall be checked before delivery, and the components (stator split frame, disc rotor spider, assembling and cover plates of guide bearing and thrust bearing as well as the assembling of the wind screen) shall be pre-assembled, as appropriate, by the supplier.

8.6 Site acceptance including:

a) The start-up and trial run items for acceptance shall be carried out according to the start-up and trial run items in Table B.1;

b) The performance test items for acceptance shall be carried out according to the performance test items in Table B.1.

9 Nameplate, packing, transportation and storage

9.1 Nameplate

The materials and engraving method of the nameplates shall ensure that its text is not to be obliterated during the entire service period, and the following information shall be marked:

Name and model; rated capacity (MVA, kVA), rated voltage (V), rated current (A), rated frequency (Hz) and rated power factor ($\cos\varphi$); rated rotation speed (r/min.) and runaway speed (r/min.); rated exciting voltage (V) and rated exciting current (A); number of phases, connection method for the stator winding and insulation grade; country name, manufacturer name, delivery date and the products number.

9.2 Packing, transportation and storage

9.2.1 The packing shall be determined by the supplier and the user through negotiation and shall comply with relevant provisions of the importing country of the equipment. Special requirements for the equipment, if any, shall be marked on the packing container.

9.2.2 The packing container shall be manufactured according to the encasing drawing. The following information shall be marked on the outside of the container:

a) User name and address;

b) Supplier name and address;

c) Name, model and serial number;

d) Net weight, gross weight, centre of the gravity line of the packing container, position of the slings and the overall dimensions of the packing container;

e) Wordings and marks like "Handle with Care", "Keep Away from Moisture" and "Do not Put Upside Down".

9.2.3 Before packing, the following preparations shall be made:

a) Inspect whether the equipment appearance gets damaged;

b) Take the necessary rust-prevention and anti-deformation measures for the external machining surface of the equipment;

c) Remove the fragile and vibration-sensitive components and meters, and pack them separately;

d) Fix the movable parts in the equipment with the generator body;

e) Ensure that the spare parts, compliance certificate and relevant technical documents that accompany the equipment are complete, wrap them properly and affix them in proper position.

9.2.4 After the packing container of the equipment has been opened after being delivered to the site of the hydropower station, the equipment shall be stored in the sheltered warehouse, the storage temperature shall not be lower than 5 ℃, shall be protected from dampness and moisture, shall be properly stored and shall not be stacked at will.

10 Installation, use and maintenance

10.1 Installation

It shall be installed in accordance with the provisions of the product installation, use and maintenance instructions provided by the supplier.

10.2 Operation and maintenance

The operation and maintenance shall comply with the provisions of the normative references, the installation, use and maintenance instructions provided by the supplier as well as the relevant operation specifications for the hydropower station.

The supplier shall provide technical support for solving the problems occurring during the installation, use and maintenance process of the equipment, and train the user's personnel in the as-

pects of the equipment's installation, use and maintenance.

11 Quality guarantee period

Under the premise that the product is properly stored, installed and used, the quality guarantee period shall be one year after the date on which the 72-hour trial operation is completed, or two years after the delivery date of the last batch of goods, whichever comes earlier. If the equipment gets damaged or is unable to function properly due to the manufacturing quality during the quality guarantee period, the supplier shall repair or replace it free of charge.

Appendix A
（Informative）
Main spare parts for the hydro turbine generator

Table A.1 Main spare parts for the hydro turbine generator

No.	Name	Unit	Quantity			Remarks
			1—2 units	3—4 units	5 units or more	
1	Brake block, seal ring and spring	Unit/set	1	1	1	Mandatory spare parts
2	Carbon brush	Unit/set	One set for each unit or 2 pieces for each unit			
3	Rotation silicon	piece	2 pieces for each unit			
4	Brush holder	Unit/set	1/4	2/4	3/4	
5	Insulating plate and insulating sleeve for the bearing	Unit/set	1	1	1	
6	Temperature measuring component	Piece	One of each type for each unit			
7	Stator winding	Unit/set	1/15	2/15	3/15	Optional spare parts
8	Stator slot wedge		1/3 reserve level of coils multiplying the number of branches per slot			
9	Thrust bearing bush	Unit/set	1	1	1	
10	Guide bearing bush	Unit/set	1	1	1	
11	Sleeve bearing bush (horizontal bearing)	Unit/set	1	1	1	
NOTE “Unit/set” refers to the sets (or quantity) for each unit.						

Appendix B
（Informative）
Acceptance inspection items of the hydro turbine generator

Table B.1 Acceptance inspection items of the hydro turbine generator

No.	Test items	Delivery tests	Hand-over tests	Start-up and trial run	Performance test	Remarks
1	Inspection of the chemical components and mechanical properties of the key components and materials		√			According to the agreement between the supplier and the buyer
2	Test of the stator core magnetization（iron loss）		√			According to the agreement between the supplier and the buyer
3	Dielectric strength inspection of the formed coil of the stator		√			Apply to the split stator assembling completed on the construction site of the hydropower station
4	Measurement of the insulation resistance of the winding to the enclosure and between windings	√	√			
5	Measurement of insulation resistance of temperature measuring component	√	√			
6	Measurement of the DC resistance of the winding in the actual cold state	√	√			
7	DC withstand voltage test of the stator winding to the enclosure and between windings, as well as the leakage current measurement	√	√			$U_N \geqslant 6.3$ kV
8	Power frequency AC withstand voltage test of the winding to the enclosure and between windings	√	√			
9	Measurement of the AC impedance of the single magnetic pole of the rotor	√	√			According to the agreement between the supplier and the buyer
10	Rotor balance test	√	√			
11	Measurement of the bearing insulation resistance	√	√			The resistance does not need to be tested if the rolling bearing is not fitted with insulation

Table B.1（*continued*）

No.	Test items	Delivery tests	Hand-over tests	Start-up and trial run	Performance test	Remarks
12	Withstand voltage test of the cooler	√	√			
13	Withstand voltage test of the brake	√	√			
14	Test of the oil-air-water system			√		
15	Measurement of the bearing temperature	√		√		If the bearing is fitted with the temperature measuring device
16	Dynamic balance calibration			√		If necessary
17	Inspection of the braking function			√		
18	Overspeed test	√		√		
19	Measurement of the phase sequence	√		√		
20	Measurement of the shaft voltage			√		The resistance does not need to be tested if the rolling bearing is not fitted with insulation
21	Test of the no-load characteristics	√		√		
22	Over-voltage test	√		√		
23	Three-phase stable-state short-circuit test	√		√		
24	Overcurrent test	√		√		
25	Measurement of the vibration and throw			√		
26	Measurement of the rated exciting current and the voltage change ratio				√	
27	Measurement of the winding impedance and the time constant				√	
28	Measurement of the total harmonic distortion（THD）factor of the voltage waveform				√	
29	Measurement of the noise level				√	
30	Temperature rise test				√	
31	Measurement of efficiency and loss				√	According to the agreement between the supplier and the buyer
32	Over-excitation phase modulation and under-excitation leading phase operation test				√	According to the agreement between the supplier and the buyer

Table B.1（*continued*）

No.	Test items	Delivery tests	Hand-over tests	Start-up and trial run	Performance test	Remarks
33	Load throw-off test				√	To be carried out under 25%，50%，75% and 100% of rated loads.
34	Three-phase sudden short-circuit test				√	According to the agreement between the supplier and the buyer
35	Runaway speed test				√	According to the agreement between the supplier and the buyer

NOTE 1 The items marked with "√" in the table shall be completed.

NOTE 2 If the tested equipment does not have the structure and function relevant to a certain test item，such item does not need to be tested.

NOTE 3 The functions and purchased parts not listed in Table 12 may be tested according to the supplier's provisions；

NOTE 4 Some test items among the delivery tests which could not be done at the supplier's premises may be carried out on the site of the hydropower station after the hydro turbine generator is installed.