भारत सरकार
Government of India
विद्युत मंत्रालय
Ministry of Power
केंद्रीय विद्युत प्राधिकरण
Central Electricity Authority
जल विद्युत अभियांत्रिकी और प्रौद्योगिकी विकास प्रभाग
Hydro Engineering and Technology Development Division

जलविद्युत संयंत्रों की क्षेत्र दक्षता परीक्षण के लिए दिशानिर्देश (पंप भंडारण परियोजनाओं सहित)

Guidelines for Field Efficiency Test in Hydropower Plants (including Pumped Storage Projects)

नई दिल्ली
New Delhi
जून, 2023

1. Introduction

1.1. This CEA Guideline "Guidelines for Field Efficiency Test in Hydropower Plants (including Pumped Storage Projects)" for field efficiency acceptance tests of Generating/ Pumped Storage Unit(s) comprising Generator/ Motor and Hydraulic Turbine/ Pump in Hydro Power Plants/ Pumped Storage Projects has been prepared with the objective to guide Hydropower Generating Utilities in the Country, to provide a uniform approach for carrying out said tests, its acceptance and to minimize dispute between Project Authority & the Supplier of the units in the project. This Guideline mainly focuses on defining the terms and quantities to be used in the process, validity, the period for acceptance of test, agency to perform the test, to specify methods & ways of measuring quantities involved to ascertain the Hydraulic/ Electrical Efficiency of the unit(s) and determination of fulfilment of contract guarantees and penalization in case of failure of its fulfilment.

1.2. The decision to perform field acceptance tests including the definition of their scope shall be subject to the agreement between the Purchaser and the Supplier of the unit(s), and therefore the same should be clearly spelt out in the Contract Agreement/ Technical Specification for the project between the parties. Accordingly, it may be examined in each case as to whether the measuring conditions recommended in this Guideline has been fulfilled before carrying out such field tests. Further, the influence on the measuring uncertainties due to hydraulic and civil conditions, testing instruments etc. has to be taken into account in said testing. These specifications shall be the part of the agreement between the two parties.

1.3. This Guideline will be applicable to any size and type of unit comprising generator –motor and impulse/ reaction turbine, and pump-turbine above unit size of 5 MW.

1.4. Field Efficiency Test may be conducted, however, not limiting under the following conditions:

a) After Power House/ unit has been commissioned and running in steady state condition.
b) After Renovation, Modernization, Life Extension and Uprating of units.
c) After capital overhauling (5-10 years). The project authority may use the test values to compare the present operational efficiency viz-a-viz Model/ Factory/ Field Acceptance Test values (i.e. originally supplied one) as applicable to the equipment, and as reference & records.
d) After replacement/ refurbishment of major equipment like Generator/ Motor (Stator/ Rotor), Turbine/ Pumps (Runner, Guide Vane etc.)
e) Under condition of short fall in power (running at derated capacity) or increase in Discharge/ Flow in Water Conductor System.
f) For deciding/analyzing the requirement of RM&U (Renovation, Modernization & Uprating) of unit.

2. Standards

2.1. The list of applicable Standards shall be as described below:

Standard	**Description**
IEC 60034/ IS 15999	Rotating Electrical Machines
IEC 60034-2-1 IS 15999-2-1	Rotating electrical machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles
IEC 60034-2-2 IS 15999-2-2	Rotating electrical machines – Part 2-2: Specific methods for determining separate losses of large machines from tests – Supplement to IEC 60034-2-1
IEC 60193	Hydraulic Turbines, Storage Pumps and Pump Turbines – Model Acceptance Tests.
IEC/ IS 60041	Field Acceptance Tests to determine the Hydraulic Performance of Hydraulic Turbines, Storage Pumps and Pump Turbines.
IEEE 115	Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis
IEC 60308	Hydraulic turbines - Testing of control systems
IEC 62006	Hydraulic Machines-Acceptance tests of small hydroelectric installation
ISO 3354	Measurement of Clean Water Flow in Closed Conduits.

3. Terms, Definitions, Symbols and Units

S.no.	Term	Definition	**Symbol**
1.	Discharge	Volume of water per unit time flowing through any section in the system.	Q
2.	No-load turbine discharge	Turbine discharge at no-load, at specified speed and specified specific hydraulic energy and generator not excited.	
3.	No-load turbine Speed	The steady state turbine speed at no load with governor connected and generator not excited.	

4.	Regulated machine	A regulated machine is a machine in which the flow is controlled by a flow-controlling device such as guide vanes, needle(s), and/or runner/impeller blades.	
5.	Non-regulated machine	A non-regulated machine is a machine in which no flow-controlling device is provided.	
6.	Specific hydraulic energy of the plant	Specific hydraulic energy available between head water level of the reservoir and tail water level of the plant.	
7.	Specific hydraulic energy of Machine	Specific energy of water available between the high and low pressure reference sections of the machine, taking into account the influence of the compressibility.	E
8.	Specific hydraulic energy loss	The specific hydraulic energy dissipated between any two sections	
9.	Hydraulic power	The hydraulic power available for producing power (turbine) or imparted to the water (pump)	P_h
10.	Mechanical power of the machine (Power)	The mechanical power delivered by the turbine shaft or to the pump shaft, assigning to the hydraulic machine the mechanical losses of the relevant bearings.	P
11.	Hydraulic Power Correction	Correction term to be evaluated after a relevant analysis according to contractual definitions and local conditions	ΔP_h
12.	Hydraulic efficiency	For Turbine: It is defined as the ratio of Mechanical power of the runner to the Hydraulic power. For Pump: It is defined as the ratio of Hydraulic power to the Mechanical power of the impeller.	η_h

13.	Efficiency	Ratio of output power to input power expressed in the same units and usually given as a percentage	η
14.	Cycle Efficiency	Ratio of Generation units in Generation mode of operation (kWh) to Consumption units in Pump-Motor mode of Operation (kWh), for an operation cycle comprising pumping-to-generation for same storage volume of water in a Pumped Storage Project.	η_c
15.	Total Losses	Difference between the input power and the output power, equivalent to the sum of the constant losses, the load losses, additional load losses (stray load losses) and the excitation circuit losses	P_T
16.	Constant losses	Sum of the iron losses and the friction and windage losses	P_k
17.	Friction and windage losses	Friction losses Losses due to friction (bearings and brushes), Windage losses Total losses due to aerodynamic friction in all parts of the machine, including power absorbed in shaft mounted fans, and in auxiliary machines forming an integral part of the machine	P_{fw}
18.	Excitation circuit losses	The excitation (field) winding losses are equal to the product of the exciting current Ie and the excitation voltage Ue (for synchronous machine)	P_e
19.	Load losses	The sum of the winding (I2R) losses and the electrical brush losses, If any	P_L
20.	Additional load losses (stray-load losses)	Losses produced by the load current in active iron and other metal parts other than conductors; Eddy current losses in winding conductors caused by load current-	P_{LL}

		dependent flux pulsations and additional brush losses caused by commutation	
21.	Terminal voltage	For polyphase a.c. Machines the arithmetic average of line voltages	U
22.	Line current	For polyphase a.c. Machines the arithmetic average of line currents	I
23.	Weighting factor for turbine	Weighting factor at different operating conditions (load) for turbine weighted average efficiency	w_{t1}, w_{t2} .....
24.	Weighting factor for generator	Weighting factor at different operating conditions (load) for generator weighted average efficiency	w_{g1}, w_{g2} ....

4. Testing- Conditions and Guarantees

4.1. The field efficiency acceptance tests of Generator/ Motor and Hydraulic Turbine/ Pump in Hydro Power Plants/ Pumped Storage Projects shall be in strict accordance with applicable IEC/ IS Standards.

4.2. The Purchaser shall be responsible for specifying the values of all the parameters on which field efficiency guarantees are based including water quality and temperature, specific hydraulic energies of the plant and specific hydraulic energy losses, the correct inlet and outlet conditions of the machine and all parts and equipment relating thereto, all the driven or driving machinery whether electric or not and the revolving parts thereof, and all governors, valves, gates and allied mechanisms. A format for Power Station Data to be supplied by the Owner/ Purchaser is given at Appendix-I.

4.3. The electric generator or motor and its auxiliaries to be used for measuring turbine or pump power shall be given appropriate tests. It should be a condition of the contract that the supplier of the hydraulic unit as well as that of generator/motor unit or his representative shall have the right to be present at such tests. A certified copy of the generator or motor test calculations and results shall be given to the supplier of the hydraulic machine before performance of field efficiency test of the turbine/ pump.

4.4. A contract agreement for a regulated or non-regulated machine should contain guarantees covering at least power i.e. P_{rated} (at rated head & corresponding discharge) and efficiencies besides other parameters. Conversion and correction of test results to specified conditions available at the plant during testing should also be mentioned as per relevant IS/ IEC.

4.5. It is suggested that the contractual agreements avoid fixing more than one guarantee for correlated quantities; for example, in the case of a regulated turbine, efficiency shall be guaranteed versus discharge or power, but not versus discharge and power.

4.6. The field acceptance test shall be conducted on any one of the randomly selected turbine/generating unit to determine the actual rated output and efficiency at various points of operation. The contract shall specify whether several or only one of a group-of identical machines are to be tested with regard to efficiency. If only one of a group-of identical machines is to be tested, the Purchaser shall identify the machine for performing the efficiency test.

4.7. The provisions for testing specifically for discharge measurements (i.e. before the turbine inlet) and pressure/ temperature measurements at inlet, outlet and differential (if provided) shall be made at the design stage, and construction/ erection stage as per IS/ IEC standards so that testing can be performed . Provisions required to be made later in this regard not only expensive and challenging but may also lead to non-conducting/ non-compliance of IS/ IEC standard.

4.8. During the design stage of the plant and the machines to be tested, provision shall be made for more than one method of measuring discharge and pressure (or free water level). The methods of measurement should be fully covered in the specifications and the contracts. During construction stage, if the machine settings have to be changed due to unforeseen circumstances then the changes may be analyzed and determined whether the field efficiency is going to be affected or not due to these changes. If there is any impact/ variation in field efficiency then both the parties have to agree on the impact of said changes and perform Field Efficiency Test as indicated in the document. In case of lack of agreement, the matter shall be referred to an independent arbitrator acceptable to all parties.

4.9. It may be even impracticable/ difficult to make arrangements for field acceptance test for the power house already commissioned or at the final stage of construction. However, feasibility of carrying out field acceptance test may be thoroughly analyzed in such cases.

4.10. After completion of the test, the readings and recordings shall be examined by both parties and representative results shall be provisionally computed on-site using the pre-test calibrations. All errors or inconsistencies thereby discovered shall be eliminated or taken into account. Only on this basis, the test shall be concluded terminated and the test instruments removed.

5. Agency to Perform the Test

5.1. The Test shall be carried out/ witnessed preferably by experienced Third Party agencies and in cases where such agencies are not available, the Test may be carried out either by OEM (Original Equipment Manufacturer) or the Purchaser himself.

5.2. The Purchaser may predefine third party agencies (i.e. from the empaneled/ preferred list mutually agreed between Purchaser and Supplier as per contract) from whom an agency can be selected by the Purchaser to conduct the field efficiency acceptance tests of Generator/ Motor and Hydraulic Turbine/ Pump in Hydro Power Plants/ Pumped Storage Projects. This shall be clearly indicated in the contract agreement for the project work.

5.3. Purchaser shall seek separate price quote for the Field Efficiency Test in the work tender to ensure that payment is made only in the case of test having been actually conducted on work completion.

6. Period to Perform Field Efficiency Test

6.1. The Field Efficiency Test shall not take place until the commissioning test, including speed and pressure variation trials have been conducted.

6.2. It is for the Purchaser to decide the date of efficiency while considering the plant operation and flow condition. This test shall be conducted within the contract guarantee period and within 6 months after the trouble free running of the machine, unless otherwise agreed by both the parties in writing.

7. Types of Efficiency

The efficiency for the unit(s) shall be defined as follows:

7.1. For Generating Unit mode

a) For Turbine

The efficiency calculated from the formula:

$$\eta_{wt} = \frac{w_1\eta_{\mathrm{t1}}+w_2\eta_{\mathrm{t2}}+w_3\eta_{\mathrm{t3}} + \cdots}{w_1+w_2+w_3 + \cdots}$$

Where $\eta_{\mathrm{t1}}, \eta_{\mathrm{t2}}, \eta_{\mathrm{t3}}$ are the values of efficiency at specified operating conditions and w_1, w_2, w_3, … are their agreed weighting factors respectively.

b) For Generator

The efficiency calculated from the formula:

$$\eta_{wg} = \frac{w_1\eta_{\mathrm{g1}}+w_2\eta_{\mathrm{g2}}+w_3\eta_{\mathrm{g3}} + \cdots}{w_1+w_2+w_3 + \cdots}$$

Where $\eta_{\mathrm{g1}}, \eta_{\mathrm{g2}}, \eta_{\mathrm{g3}}$ …. are the values of efficiency at specified operating conditions and w_1, w_2, w_3, … are their agreed weighting factors respectively.

c) Combined Efficiency (Turbine-Generator)

$$\eta_{tg} = \eta_{wt} * \eta_{wg}$$

7.2. For Pumped Storage Unit

A) Generating Mode: The efficiencies are as per clause 7.1 above.

B) Pumping Mode:

a) For Pump

The efficiency calculated from the formula:

$$\eta_{wp} = \frac{w_1\eta_{\mathrm{p1}} + w_2\eta_{\mathrm{p2}} + w_3\eta_{\mathrm{p3}} + \cdots}{w_1 + w_2 + w_3 + \cdots}$$

Where $\eta_{\mathrm{p1}}, \eta_{\mathrm{p2}}, \eta_{\mathrm{p3}}$ …. are the values of efficiency at specified operating conditions and w_1, w_2, w_3, … are their agreed weighting factors respectively.

For Motor

The efficiency calculated from the formula:

$$\eta_{wm} = \frac{w_1\eta_{\mathrm{m1}} + w_2\eta_{\mathrm{m2}} + w_3\eta_{\mathrm{m3}} + \cdots}{w_1 + w_2 + w_3 + \cdots}$$

Where $\eta_{\mathrm{m1}}, \eta_{\mathrm{m2}}, \eta_{\mathrm{m3}}$ …. are the values of efficiency at specified operating conditions and w_1, w_2, w_3, … are their agreed weighting factors respectively.

b) Cycle Efficiency: The cycle efficiency is the ratio of Generation units in Generation mode of operation (kWh_g) to Consumption units in Pump-motor mode of operation (kWh_m) for an operation cycle comprising pumping-to-generation for same storage volume of water in a Pump Storage Project.

$$\eta_c = kWh_g \,/\, kWh_m$$

kWh_g = Units generated in Generating mode
kWh_m = Units consumed by motor in Pumping mode

NOTE: Units are measured at Generator/ Motor terminal.

8. Test Methods for Determination of Efficiency

8.1. Generator/ Motor Field Efficiency Measurement test

8.1.1. This procedure covers the efficiency test to verify the specified requirement for the efficiency of synchronous generator/ induction machine at site. A conventional efficiency is determined by means of giving the segregated losses of the generator in accordance with the applied standard of IEC 60034-2. The segregated loss which should be included in efficiency are the friction and windage, core loss, stray-load loss, resistance loss of armature and field windings, brush loss and exciter loss.

8.1.2. The electric power output is measured using preferably an integrating-type high-accuracy digital wattmeter connected to the generator terminals through high-accuracy-class current and voltage transformers. The benefit of using a three-element watt transducer over a two-element transducer is that the effect of a phase angle error between the current and voltage for each element is much smaller. These outputs are accessible at the Unit Control Board.

8.1.3. Generator losses typically are measured when the units are commissioned and are assumed to remain stable over time.

8.1.4. Standard Test method

8.1.4.1. Indirect method by which the determination of efficiency is made by measuring the input power or the output power of a machine under particular condition and determining the total losses. Those losses are added to the output power, thus giving the input power, or subtracted from the input power, thus giving the output power. The choice of test to be made depends on the information required, the accuracy required, the type and size of the machine involved and the available field test equipment etc.

8.1.4.2. Calorimetric method

The calorimetric method for full-load conditions is recognized and hence, this method is described in detail here. It is a test method in which the losses in a machine are deduced from the measurements of the heat generated/ produced by them. The losses are determined from the product of the amount of coolant and its temperature rise, and the heat dissipated in the surrounding media.

The calorimetric method may be used to determine the efficiency of large electrical rotating machinery:

i) Either by the determination of the total loss on load, or
ii) By the determination of the segregated losses.

8.1.5. Test procedure

The tests shall be conducted on an assembled machine with the essential components in place to obtain test conditions equal or very similar to normal operating conditions.

During testing, the test machine temperature and the coolant temperature shall be kept as close to normal operating conditions as possible.

Following assembly of the machine, determine the area of the reference surface. Divide the surface into 10 to 15 approximately equal area segments and attach thermal detectors to each segment. Install sufficient thermal detectors in the ambient air to determine the most accurate average temperature rise.

8.1.6. Efficiency determination

The efficiency is:

$$\eta = \frac{P_1 + P_{1E} - P_T}{P_1 + P_{1E}} \quad \text{for Motor}$$

$$\eta = \frac{P_2}{P_2 + P_T} \quad \text{for Generator}$$

Where,

P_1 is the input power excluding excitation power from a separate source;

P_2 is the electrical output power;

P_{1E} is the excitation power supplied by a separate source;

P_T is the total loss.

NOTE 1: Input power P_1 and output power P_2 are as follows:

In motor operation: P_1 = Electrical Input; P_2 = Mechanical Output

: $P_2 = P_1 + P_{1E} - P_T = P$

In generator operation: P_1 = Electrical Output; P_2 = Mechanical Input

: $P_1 = P_2 + P_T = P$

NOTE 2: P_T includes the excitation power P_{1E} of the machine in generator operation, where applicable.

P is the mechanical power delivered by the turbine shaft or to the pump shaft, assigning to the hydraulic machine the mechanical losses of the relevant bearings (refer clause 8.2.1.2).

8.1.7. Electrical Power Measurement (P_1, P_2)

The electrical power output of the generator/ input to motor is measured at generator/ motor terminal by a precision–class, 3–phase digital wattmeter/ Digital Power Analyser connected to the secondary voltage and current outputs from the unit Voltage Transformers (Accuracy class 0.2) and Current Transformers (Accuracy class 0.2S). The Wattmeter, Voltmeter and Ammeter shall be of class 0.2S.

8.1.8. Determination of Total Losses (P_T)

The calorimetric test method, in which the efficiency is determined by the summation of separate losses. The respective loss components are:

a) Friction and Windage Losses/Bearing losses (P_{fw}/ P_{br})
b) Iron losses (P_{fe})
c) Stator Winding Losses (P_s) and Rotor Winding Losses (P_f)
d) Additional-Load Losses (Stray-Load Loss) (P_{LL})
e) Excitation Power (P_e)
f) Heat Loss due to Radiation & Convection (P_{rc})

8.1.8.1 Friction and Windage Losses/ Bearing losses ($P_{fw} = P_{br}$)

Bearing (Upper Guide Bearing, Lower Guide Bearing, and Thrust Bearing losses apportioned to Generator/ Motor) losses could be measured using oil as a cooling medium, but there is less uncertainty when measuring on the water side of an oil-to-water heat exchanger because the thermal characteristics of water are better known.

Generator/ Motor shall be run on nominal speed (Zero excitation Heat run).

The test shall be carried out as quickly as possible with the readings taken in descending order of voltage.

$P_{fw} = P_{br} = C_p \times Q \times \rho \times \Delta\theta$

Where,
P_{fw}/ P_{br} is the Friction and Windage Losses/ Bearing losses

Q is the volume rate of flow of the coolant (water) for each calorimeter circuit, (m^3/s),
Δθ is the temperature rise ($\theta_{n+1} - \theta_n$) of the coolant in K, i.e. difference of coolant (e.g. water) temperatures from cooler inlet to cooler outlet for each calorimeter circuit
C_p is the specific heat capacity of the cooling medium in kJ/(kg K) at pressure p,
ρ is the density of the coolant in kg/m^3 at the temperature at the point of flow measurement.

As the different units may have different bearing arrangements/no. of bearing, the bearing losses (P_{br}) may be further subcategorised as follows:

$$P_{br} = P_{brg} + P_{brt}$$

$$P_{brg} = P_{brg1} + P_{brg2} + \dots\dots + P_{brag}$$

$$P_{brt} = P_{brt1} + P_{brt2} + \dots\dots + P_{brat}$$

Where,
P_{brg}= Losses in the generator bearing
P_{brt}= Losses in the turbine bearing
1, 2,…are the no. of bearings
P_{brag}/P_{brat}= Losses in the bearing apportioned to the generator/turbine based on its weight/thrust in the combined bearing for the Generator and Turbine. Further, apportioned weightage for the Generator/Turbine may be calculated below:

$$R_g = \frac{W_g}{W_g + W_t}; R_t = \frac{W_t}{W_g + W_t}$$

Where,
R_g = Apportioned weightage of the Generator
R_t = Apportioned weightage of the Turbine
W_g = Weight/ Thrust of the Generator
W_t = Weight/ Thrust of the Turbine

NOTE: g may be considered as m and t may be considered as p in case of pumping.

NOTE: Friction & Windage losses are considered to be independent of load and the same Friction & Windage loss values may be used for each of the load points.

8.1.8.2 Iron Losses (P_{fe})

8.1.8.2.1 For each of the values of voltage, develop a curve of constant losses (P_k) against voltage. Subtract from this value, the Friction & Windage losses (P_{fw}) to determine the iron losses.

$$P_{fe} = P_k - P_{fw}$$

8.1.8.2.2 Total Losses at No Load Heat Run (P_k)

The machine is run as a generator with its terminals open-circuited.

In the case of synchronous machine with shaft driven exciter, the machine should be separately excited and the exciter disconnected from its supply and from the excitation winding.

Test at a minimum number of eight values of voltage, including rated voltage, so that:

- Four or more values are read approximately equally spaced between approximately 110% and 80% of rated voltage;

- Four or more values are read approximately equally spaced between approximately 70% and 30% of rated voltage; or (for an uncoupled running machine) to a point where the current no longer decreases.

The test shall be carried out as quickly as possible with the readings taken in descending order of voltage.

P_k = Iron Loss + Friction & Windage Loss + Rotor (Field) Winding Loss (P_f)

$P_k = C_p \times Q \times \rho \times \Delta\theta$

Where,

P_k is the Total Losses at No Load Heat Run

Q is the volume rate of flow of the coolant (water) for each calorimeter circuit, (m^3/s),

$\Delta\theta$ is the temperature rise ($\theta_{n+1} - \theta_n$) of the coolant in K, i.e. difference of coolant (e.g. water) temperatures from cooler inlet to cooler outlet for each calorimeter circuit

C_p is the specific heat capacity of the cooling medium in kJ/(kg K) at pressure p,

ρ is the density of the coolant in kg/m^3 at the temperature at the point of flow measurement.

In case of water as a coolant, both C_p and ρ are determined from Figure as given in IEC.

Where there is any doubt as to the accuracy of the factors employed for C_p and ρ, particularly if the cooling water contains salts, it will be necessary for C_p and ρ to be measured.

NOTE: The constant losses (P_k) i.e. Friction loss, Windage loss and Iron Losses remains same in both generating mode and motoring mode.

8.1.8.3 Stator Winding Losses (P_s) and Rotor Winding Losses (P_r)

Before load test, determine the temperature and the winding resistance of the machine with the machine at ambient temperature.

Stator and Rotor (field) Winding Resistance

The Stator and Rotor Winding Resistance are measured using Kelvin's double bridge and readings are as follows:

Stator Winding resistance (R_{so}) at θ_{fs} °C

Arithmetic sum of average measured winding resistance between each pair of terminals (R_s)

Average winding resistance per phase $(R_{so}) = R_s/2$ (for Y-connected three-phase machines)

$= 1.5\ R_s$ (for Δ-connected three-phase machines)

Rotor (field) winding resistance (R_{fo}) at θ_{fr} °C

Temperature measured directly by Embedded Temperature Detector (ETD). The detectors shall be suitably distributed throughout the winding and number of detectors installed should not be less than six. The highest reading from the ETD elements shall be used to determine the temperature of the winding.

Stator winding resistance at 75 ℃ (R_{s75})

$$= \frac{R_{so}\ X\ (235+75)}{(235+\ \theta_{fs})} = \qquad Ohm$$

Rotor winding resistance at 75 ℃ (R_{f75})

$$= \frac{R_{fo}\ X\ (235+75)}{(235+\ \theta_{fr})} = \qquad Ohm$$

θ_{fs} = Stator Winding temperature
θ_{fr} = Rotor Winding temperature

The machine shall be loaded by suitable means, with supply power according to the machine rating and operated until thermal equilibrium is achieved (rate of change of 1 K or less per half hour). The Load will be provided by the Purchaser.

Stator Winding Loss (P_s)

$P_s = 3 \times I^2 R_{\theta fs}$ ……………………………..(at 100% load)

Stator Winding Loss at rated stator current at 75°C

$P_{s75} = P_s \times (235 + 75)/ (235 + \theta_{fs})$

Rotor (Field) Winding Loss (P_r) at 75°C

A. For Synchronous Machine

$P_f = (I_{fm})^2 R_{f75}$

I_{fm} Field Current for a particular load
R_{f75} Field winding resistance at 75 ℃

B. For Asynchronous Machine

$P_r = 3\ (I_{fm})^2 R_{f75}$

NOTE: i) In case of Asynchronous machine, the method for rotor winding loss measurement (slip ring & rotor loss) is similar to the stator winding loss measurement of Synchronous machine.

ii) In case the rating in motoring mode is higher than the generating mode, then the variable losses i.e. stator winding loss and rotor (field) winding loss will be calculated as per rated current of motor rating to determine the efficiency in motoring mode.

8.1.8.4 Additional-Load Loss (Stray-Load Loss) (P_{LL})

It is determined through test in which a machine is run as a generator with its terminals short-circuited to achieve rated armature current. The Machine is operated as a synchronous motor at a fixed voltage, preferably about 1/3 normal or at the lowest value for which stable operation can be obtained. The armature current is varied by control of the field current. The armature current should be varied in about six steps between 125% and 25% of rated current and should include one or two points at very low current. The maximum test current value, traditionally set at 125%, should be obtained from the manufacture since sometimes stator cooling will not permit operation in excess of 100% rated current without damage. The highest readings should be taken first to secure more uniform stator winding temperatures during the test. The supplier should be responsible for any and all damage caused by the short-circuit test to the equipment.

For large machine which cannot be tested at full load, the load test at reduced voltage is an appropriate method. Operate the machine using the maximum available load with a decrease in voltage to achieve rated speed. Operated to achieve thermal equilibrium.

NOTE: For large machines, the maximum step may be limited to 60% to 70% of rated armature current.

8.1.8.4.1 Load losses (P_L) measurement for determining Stray-Load Loss.

$P_L = P_s + P_{LL} + P_{fw} + P_r$

Where,

$P_L = C_p \times Q \times \rho \times \Delta\theta$

P_s Stator/ Armature Winding Loss

P_{LL} Stray-Load Loss

P_{fw} Friction & Windage Loss

P_r Rotor (Field) Winding Loss during the test

Friction & Windage Loss (P_{fw}) = same as that in Clause 8.1.8.1.

Rotor (Field) Winding Loss during the test= Pr (Same as per Clause8.1.8.3)

$$P_{LL} = P_L - P_s - P_{fw} - P_r$$

Excitation Power (P_e)

Run the machine either on minimum load to get maximum field current or overexcite the rotor to get maximum field current.

$P_e = P_r + P_{Ed} + P_{bl}$

P_r Excitation (field) winding loss,
P_{Ed} Exciter loss (Exciter loss for the different excitation system as per clause 3.15.3.3 of IEC 60034-2-1).
P_{bl} Brush loss,

8.1.8.4.2 Electrical losses in Brushes (P_{bl})

In case of brushes, determine brush losses from an assigned voltage drop per brush of each of the two polarities:

$$P_{bl} = 2 \times U_b \times I_e \quad \text{(for Synchronous Machine)}$$
$$P_{bl} = \sqrt{3} \times U_b \times I_{e\prime} \times cos\emptyset \quad \text{(for Asynchronous Machine)}$$

Where,
I_e is the exciting current in Synchronous Machine
$I_{e\prime}$ is the line exciting current in Asynchronous Machine (i.e. average of phase currents for all 3-phases)
U_b is the voltage drop per brush of each of the two polarities depending on brush type: 1.0 for carbon, electric graphitic or graphite; 0.3 for metal-carbon
cosØ is the power factor of phase field current in asynchronous machine

These are measured losses in both generator and motoring mode of operations of the machine.

8.1.8.4.3 Excitation/ Rotor (field) losses (P_r)

As per measurement under clause 8.1.8.3.

8.1.8.5 Heat Loss due to Radiation & Convection (P_{rc})

$P_{rc} = h \times A \times \Delta\theta$

Where,
P_{rc} is the loss dissipated through the "reference surface" by conduction, convection, radiation, leakage, etc.
Δθ is the temperature difference between the average reference surface temperature and the ambient-air temperature;
A is the area of the reference surface;
h is the heat transfer coefficient for losses dissipated from surfaces in contact with air as follows:

For forced-air convection

– for external surfaces:
$h = 11 + 3\,v$ [W/m²K],

where v is the velocity of ambient air in m/s,

– for surfaces entirely within the machine's external surface:

$h = 5 + 3\,v$ [W/m²·K],

where v is the velocity of cooling air in m/s.

For natural convection:

The heat transfer coefficient (h) for losses dissipated from surfaces is generally between 10 W and 20 W/(m² • K). A reasonable assumption being 15 W/(m² • K) when the air currents over the transfer surfaces have been eliminated.

NOTE: The method given in IEEE (Clause 4.5.1) for measurement of heat lost by Radiation and Convection may also be used.

8.1.8.6 Total Losses (P_T)

a) For Synchronous machine

Total losses P_T including excitation losses at each load are:

$$\boldsymbol{P_T = P_{fw} + P_{fe} + P_s + P_{LL} + P_e + P_{rc}} \quad \textbf{kW}$$

Where, $P_e = P_r + P_{Ed} + P_{bl}$

b) For Asynchronous machine

$$\boldsymbol{P_T = P_{fw} + P_{fe} + P_s + P_{LL} + P_r + P_{rc}} \quad \textbf{kW}$$

Where, $P_e = P_r + P_{bl}$

Where,

P_{fw}/ P_{br}	Friction and Windage Losses/ Bearing losses apportioned to Generator as per Clause 8.1.8.1
P_{fe}	Iron Loss
P_{LL}	Additional-Load Loss (Stray-Load Loss)
P_r	Rotor (Field) Winding Loss (I^2R)
P_s	Stator/ Armature Winding Loss (I^2R)
P_{rc}	Loss dissipated through the “reference surface” by conduction, convection, radiation, leakage, etc.
P_{Ed}	Exciter loss for different excitation system as per Cl. 3.15.3.3 of IEC 60034-2-1
P_e	Excitation power in Synchronous Machine/ AC excitation with 3-ph rotor in variable speed Asynchronous Machine
P_{bl}	Brush Loss

NOTE: In case of pumping mode of operation, same Friction, Windage and Iron Losses as measured in generator mode of operation are used for motor efficiency calculation.

8.2. Turbine/ Pump Efficiency Measurement test

Efficiency of the machine which is the ratio of Mechanical Power delivered by the turbine shaft or to the pump shaft, calculated from the electrical power at the generator/motor terminals (as defined in clause 8.1.6), and Hydraulic Power which is calculated from the Specific hydraulic energy of the machine.

8.2.1 Efficiency

a) For a Turbine (η):
It is the ratio of mechanical power to the hydraulic power.

$$\eta = \frac{P}{P_h}$$

b) For a Pump(η):
It is the ratio of hydraulic power to the mechanical power.

$$\eta = \frac{P_h}{P}$$

Where,
P_h= Hydraulic Power (refer clause 8.2.1.1).
P= Mechanical Power delivered by the turbine shaft or to the pump shaft, assigning to the hydraulic machine the mechanical losses of the relevant bearings (refer clause 8.2.1.2).

8.2.1.1 Hydraulic Power (P_h)

The Hydraulic power available for producing power (turbine) or imparted to the water (pump)

$$P_h = E(\varrho Q)_1 \pm \Delta P_h$$

P_h= Hydraulic Power.
ΔP_h= Hydraulic Power correction.
E= Specific hydraulic energy of the machine (refer clause 8.2.1.1.i).
Q= Discharge (Volume flow rate), Volume of water per unit time flowing through any section in the system (refer clause 8.2.1.1.ii).

i) Specific hydraulic energy of the machine (E)

Specific energy of water available between the high and low pressure reference sections of the machine, taking into account the influence of the compressibility and can be calculated as per equation mentioned below:

$$E = \frac{P_{abs1} - P_{abs2}}{\bar{\varrho}} + \frac{{v_1}^2 - {v_2}^2}{2} + \bar{g}(z_1 - z_2)$$

With $\bar{\varrho} = \frac{\varrho_1 + \varrho_2}{2}$ and $\bar{g} = \frac{g_1 + g_2}{2}$

Note - The value of gravity acceleration at the reference level of the machine may be assumed as $\bar{g}$.

The values of ϱ_1 and ϱ_2 can be calculated from P_{abs1} *and* P_{abs2} respectively, taking into account ϑ_1 or ϑ_2 , for both values, given the negligible influence of the difference of the temperature on ϱ.

E =Specific hydraulic energy of the machine

1, 2 = high and low pressure reference sections of the machine

ϑ = Temperature in degree Celsius.

g = Acceleration due to gravity (Local value of g as a function of altitude and lalitude of the place of testing)

ϱ = Density (Mass per unit volume)

P_{abs} = Absolute Pressure (The static pressure of a fluid measurement with reference to a perfect vacuum)

z = reference level of the machine (Elevation of the point of the machine taken as reference for the setting of the machine.

v = Mean velocity (Discharge divided by the area)

ii) Discharge

The measurement of discharge in a hydroelectric or pumped storage plant can be performed with the desired accuracy only when the specific requirements of the chosen method are satisfied. It is therefore in the interest of the parties involved to select the method(s) to be used for an acceptance test at an early stage in the design of the plant because later provision may be expensive or even impracticable.

The discharge measurement shall be made by an absolute method. Nevertheless, it may be useful to resort to relative methods (index methods) either to gain supplementary information or to make easier some operations.

The absolute methods are:

a) the velocity-area method by means of current-meters or Pitot tubes,
b) the pressure-time method (Gibson method),
c) tracer methods either by transit-time or dilution measurement,
d) standardized thin-plate weirs,
e) standardized differential pressure devices,
f) Volumetric gauging,
g) Acoustic method (Ultrasonic 4 path intrusive or non-intrusive only upto and below 15 MW unit size)

Further, the Thermodynamic method of efficiency measurement permits discharge to be obtained as a derived quantity from efficiency, specific energy and power measurements.

Relative methods such as the Winter-Kennedy method, non-standardized differential pressure devices, non-standardized weirs or flumes, certain simple forms of acoustic method or local velocity measurement with a single current-meter may be used to obtain a relative value of the discharge or even an absolute value if they are calibrated in situ by comparison with an absolute method.

Only the velocity-area method by means of current-meters or Pitot tubes and to some extent the acoustic method using several paths provide information on the flow pattern.

NOTE: Suitability and details for selection of methods for discharge measurement shall be in accordance with IS/ IEC.

Mechanical Power (P)

The mechanical power delivered by the turbine shaft or to the pump shaft assigning to the hydraulic machine losses of the relevant bearings.

a) For a Turbine:

$$P = P_2 + P_T + P_{brat} + P_a + P_b - P_c$$

b) For a Pump:

$$P = P_1 - \left(P_T + P_{brap} + P_a + P_b\right) + P_c$$

Where,

P_1 is the input power to the motor as measured at the motor terminals (Ref. Clause 8.1.7).

P_2 is the generator output power as measured at the generator terminals (Ref. Clause 8.1.7).

P_T are the mechanical and electric losses in the generator/motor, including windage losses (Ref. Clause 8.1.8).

P_{brat}/P_{brap} are the Losses in the bearing apportioned to thrust bearing losses due to turbine. (Ref. Clause 8.1.8.1).

P_a are the losses in all rotating elements external to the turbine/pump, such as flywheel, if any, gear, pump impeller in air, if any, etc.
The power losses in the gear, if any more generally in those parts of the transmission located between the electrical machine and the hydraulic machine shall be the object of a separate evaluation by measurement or calculations. Windage losses of an open flywheel and losses of a runner/impeller turning in air are attributed to friction and windage, excluding the bearing losses shall be included in this.

NOTE: Determination of these losses (in detail) shall be in accordance with IS/ IEC.

P_b is the power supplied to any directly driven auxiliary machine. Power supplied to any directly driven auxiliary machine, (P_b) and to the auxiliary equipment of the hydraulic machine if contractually foreseen as chargeable to it P_c

If significant, the power absorbed by the various cooling pumps, governor, etc., driven by electric motors shall be determined by measuring the electrical power used by the motors. In more difficult cases, the power absorbed by pumps shall be estimated by measuring their discharge and specific hydraulic energy, making into account their overall efficiency, as obtained, for instance, by test-stand results. Power absorbed by other accessories-may in most cases be estimated, in view of their small magnitude.

P_c is the electric power supplied to the auxiliary equipment of the turbine/pump (e.g. for the governor) if the contract specifies this to be chargeable to the turbine/pump.

8.2.2 Weighted Average Efficiency

The efficiency calculated from the formula:

$$n_w = \frac{w_1\eta_1 + w_2\eta_2 + w_3\eta_3 + \cdots}{w_1 + w_2 + w_3 + \cdots}$$

where η_1,η_2, η_3, …. are the values of efficiency at specified operating conditions and w_1, w_2, w_3, … are their agreed weighting factors respectively.

9. Instruments for Tests

9.1. The supplier should furnish a complete list of all testing equipment to perform above field tests.

To reduce the uncertainty during the measurements, the measuring instruments/ equipment with the best accuracy (having minimum least count) shall be used.

9.2. Calibration of the Instruments for Tests

All instruments shall be calibrated before the test and both Purchaser and Supplier may witness their calibration. In the case of an off-site calibration, a valid certificate, acceptable to both the Purchaser and the Supplier, shall be provided.

Unless omitted by agreement, all calibrations shall be repeated after the completion of the test. The institutions that have performed the calibrations shall state in writing whether the variations between pre-and post-test calibrations are within acceptable limits.

9.3. Calorimetric instrumentation

a) Flowmeters

The volume rate of flow of fluids is best measured by volumetric or velocity type flowmeters. Other measuring methods with the same or greater accuracy may be used.

The flowmeters shall be calibrated before and after the measurements in conditions similar to those prevailing during the test measurements.

In the case of volumetric measurements, the time shall be measured by means of an electrical timing device. The measuring time shall be at least 5 min during at least 2 intervals. The average values shall be recorded.

When measurement is made with a direct-reading flowmeter, 20 readings shall be recorded and an average value determined.

Provisions shall be made to measure both water pressure and temperature at the flowmeter.

b) Thermal detectors

Thermal measurements shall be made preferably by platinum resistance temperature detectors placed directly in the liquid coolant, and positioned in-line with each other so as to obtain direct readings for determination of the temperature rise of the liquid coolant (water, oil).

The thermal instruments shall be calibrated before and after the tests.
Recording instruments shall be used.

The instrumentation used for measure temperature shall have an accuracy of ± 1K.

c) Coolers

Calorimetric measurements should be performed separately on every cooling circuit (Windage, Bottom guide bearing, Top Guide Bearing, Thrust Bearing etc.). With a single-medium coolant, one or more calorimeters are needed for the bearing oil, and one calorimeter for the cooling water of air- or gas-coolers. The use of two primary coolants, for example, hydrogen and pure water, requires one or several calorimeters depending upon the connection of the coolers and the scope of measurement.

9.4. Measuring instruments for electrical quantities

a) Micro-ohmmeter for resistance measurement
b) Digital Power Analyser
c) Three–phase digital wattmeter
d) Digital Multi–function meter

10. Measures for shortfall in Efficiency obtained from Field Test

10.1. Rectification to Meet Guarantees after Installation

If the field efficiency acceptance test values do not meet the guarantees, the Supplier shall have option of making it good by carrying out the necessary rectification in agreement with Purchaser and again conduct the field acceptance test at his own cost to meet the guarantees. However, in such case, the field acceptance test shall be conducted on each machine of the group of identical machines. Further, if the Supplier fails again to meet the guarantees, then the penalty or rejection shall be applicable as specified in the contract.

10.2. Penalty

The bidder shall guarantee peak efficiency, the weighted average efficiency of turbine/ generator/pump/motor, and cycle efficiency in case of Pumped Storage Project as specified under the Contract, and which shall be verified through field efficiency test. Purchaser has the right to impose the Penalty if the contractor fails to achieve guaranteed values during field acceptance test based on contractually agreed terms.

10.3. Rejection

The Purchaser has right to reject the equipment if the calculated values during the field acceptance test fall below one percent each for the turbine/pump and for the motor/generator of the guaranteed values.

10.4. No credit shall be given if the weighted average efficiency or power is more than the guaranteed weighted average efficiency.

10.5. No tolerance limit shall be permissible over the field-tested figures of rated output. Tolerance limits for efficiency, total losses and power factor for Generator/Motor should be in accordance with the IEC 60034 latest edition. Tolerance limits for efficiency, total losses and uncertainty in the computation of efficiencies for Turbine/ Pump shall be allowed in accordance with IEC 60041 "Field Acceptance Tests for Hydraulic Turbines".

10.6. The Supplier will have the option with the consent of Purchaser to conduct efficiency test on all the units other than the one tested contractually at his own cost to prove that the contractual obligations are fulfilled in which case only turbines not full-filling the contractual guarantee will be subjected to penalty/rejection.

10.7. If the Purchaser decides not to conduct the field acceptance test due to non-availability of rated project parameters/ conditions or load or not being within the contract guarantee period & within 6 months after the trouble free running of the machine, the acceptance shall be based on results of model tests or the already conducted model test results.

11. The Assessment of various Uncertainties, Outliers and Physical Data Parameters

The following uncertainties, outliers and physical data shall be applicable as per IEC 60041/ IEC 60034.

a) Systematic uncertainties in performance measurements at steady state conditions.
b) Rejection of outliers.
c) Analysis of the random uncertainties for a test at constant operating conditions.
d) Analysis of the random uncertainties for a test over a range of operating conditions.
e) Physical data.
f) Uncertainty of determining a true efficiency. It reflects variations in the test procedure and the test equipment. Although uncertainty should be expressed as a numerical value, such a requirement needs sufficient testing to determine representative and comparative values.
g) The following relative uncertainty terms: – "low" applies to efficiency determinations based solely upon test results; – "medium" applies to efficiency

determinations based upon limited approximations; – "high" applies to efficiency determinations based upon assumptions.

h) The measuring equipment shall reach an overall uncertainly of 0.2% of reading at power factor 1.0 and shall include all errors of instrument transformers or transducers, if used.

i) The systematic uncertainty as defined in the IEC shall not exceed the prescribed value. However, in case the uncertainties exceed the limit of values indicated in IS/ IEC 60041 with respect to the guaranteed efficiency, the rectification by supplier/manufacturer may be permissible as per the contract agreement. In case of failure to bring down the uncertainties within the prescribed limit as indicated in IS/ IEC 60041 (provided the input parameters as per IEC are ensured by the Purchaser), the penalty or rejection for the deviation beyond the limiting values shall be applicable as per the contract agreement.

12. Preparation of Final Report

The final report shall include at least for each major test or measurement, the report mentions the method and instrument used along with the test results. For critical measurements, an assessment of the uncertainties of measurement is made. Comparison with guaranteed values shall be reported.

Appendix-I

POWER STATION DATA TO BE SUPPLIED BY THE OWNER/ PURCHASER FOR FIELD EFFICIENCY TEST IN HYDRO POWER PLANTS (INCLUDING PUMPED STORAGE PROJECTS)

A. GENERAL

1. Name of Power Station:

2. Owner of Power Station:
   (With telephone/ email and postal address)

3. Location (Enclose location/route map)

   a) Nearest Town with Distance:
   b) District:
   c) State:
   d) Longitude:
   e) Latitude:
   f) Altitude:

4. Type of Power Station (Run-of-River/Dam based/Canal based):

5. Source of Water:

6. No. of Generating Units with Capacities:

7. Maximum and minimum head:

8. Commissioning Date (for each unit):

B. GENERATING UNITS

1. Turbine/ Pump
   a) Type:
   b) Shaft (Vertical/Horizontal):
   c) Make:
   d) Rated Head:
   e) Rated Discharge:
   f) Rated Power Output:
   g) Rated Speed:

h) Pressure Taps Provided? (Yes/No):

If yes,
Number:
Size:
Locations: upstream, draft tube, spiral casing (if applicable)
(Enclose drawing/photograph)

i) Weighting factor for turbine weighted average efficiency

2. Generator/ Motor

a) Make:
b) Type (Synchronous/ Asynchronous/ Induction): (select one)
c) Rated Speed:
d) Generator Ratings: ______ kW, ____ pf, ____ kVA, ____ Hz, ____ kV, Y or D connected stator windings
e) Designed Overloading (%):
f) Run-away Speed:
g) Excitation System (Brushless/Static/Brush-type) : (select one)
h) Exciter Ratings:
i) Generator cooling method (H2, Forced Air, Natural)
j) Class of Insulation [Stator/ Rotor]
k) Rating of Excitation Transformer
l) Brush type (carbon, metal graphite , metal carbon)
m) Rotor length & Diameter
n) Air gap length
o) Bearing Cooling type
p) Weighting factor for generator weighted average efficiency

3. Governor

a) Type (Digital / Analog/ PLC): (select one)
b) Make:
c) Response Time:
d) Sensitivity:

4. Main Inlet Valve (MIV)

a) Make:
b) Type:
c) Closing time:

5. Guide Vanes/ Wicket Gates/ Nozzles

a) Device (Guide vanes/ Wicket gates/ Nozzles): (select one)
b) Number:
c) Closing time:

6. **Efficiency of Generating Units**
   (Enclose efficiency curves/data for Turbine/ Pump and Generator/ Motor from the manufacturers) Basis of efficiency value i.e. Model test or specify if any other

7. **Any problem observed? If yes, give details:**
   a) Turbine:
   b) Generator:
   c) Main Inlet Valve:
   d) Speed Increaser:
   e) Governor:
   f) Exciter:
   g) Voltage Regulator:
   h) Bearings:
   i) Others:

C. **WATER CONDUCTOR SYSTEM** (Enclose relevant drawings for applicable components)
(Mandatory information)

1. Details of weir: Type, dimensions, inlet gate, design discharge for power generation, design, flood discharge

2. Details of desilting tank: Discharge, dimensions, number of outlets and sizes

3. Head-Race Details: Length, cross section (Width, depth, side slopes) lining, discharge

4. Details of forebay tank: dimensions, number of outlets, sizes, trash rack arrangement,

5. Details of surge tank: Type and dimensions,

6. Tail-Race Details: Length, cross section (Width, depth, side slopes) lining, discharge Presence of Heat exchanger if testing by Thermodynamic method

7. Designed Discharge for power house (in m^3/s):

8. Single Intake or Individual Intakes for Machines:

9. Number and Type of Intake Gates:
   a) Type:
   b) No. of intake gates per turbine
   c) Total no. of intake gates
   d) Size
   e) Type of hoisting

10. Number and Type of Draft Tube (DT) Gates:

    a) Type:
    b) No. of DT gates per turbine:
    c) Total no. of DT gates:
    d) Size
    e) Type of hoisting

11. Common Penstock
    a) Length:
    b) Inside Diameter :
    c) Thickness:
    d) Material:
    e) No of bends

12. Individual Penstocks
    a) Length:
    b) Inside Diameter :
    c) Thickness (various):
    d) Material:

13. Spilling Arrangement and Discharge Capacity

D. DISCHARGE MEASUREMENT PROVISIONS (mandatory information)

1. Do you measure discharge? (Yes / No):

    a) If no, how do you know the discharge?
    b) If yes,
       How frequently?
       - By what method?
       - Location of Measurement :
       - Details of Instrument/Method :
         (Enclose drawing / photograph)

2. Do you have provision for relative discharge measurement? (Yes/No):

    a) If yes,
    b) Method used (Taper section/ Winter-Kennedy/ others):

E. HEAD/ LEVEL MEASUREMENT PROVISIONS (mandatory information)

1. Do you have provisions for head or pressure measurement? (Yes / No):
   If yes,

    a) Location:
    b) Method/ instrument Used:

c) Size of pressure taps :
d) Location of pressure taps:

(Enclose drawing / photograph)

2. Do you have provisions for measurement of free water level? (Yes / No):
   If yes,
   a) Locations:
   b) Method/ Instrument Used:

   (Enclose drawing / photograph)

3. Whether reference elevations marked? (Yes / No):
   If yes,
   a) Location (Machine floor/others):
   b) Levels above MSL (in m):

4. Whether elevation of Centre-line of Penstock Marked? (Yes / No):
   If yes, its level (in m):

5. Whether elevation of Centre-line of Turbine Marked? (Yes / No):
   If yes, its level (in m):