PAKISTAN STANDARD

ROTATING ELECTRICAL MACHINES –
PART 3: SPECIFIC REQUIREMENTS FOR SYNCHRONOUS GENERATORS DRIVEN BY STEAM TURBINES OR COMBUSTION GAS TURBINES

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ROTATING ELECTRICAL MACHINES –
PART 3: SPECIFIC REQUIREMENTS FOR SYNCHRONOUS GENERATORS DRIVEN BY STEAM TURBINES OR COMBUSTION GAS TURBINES

0. FOREWORD

0.1 This Pakistan Standard was adopted by the authority of the Board of Directors for Pakistan Standards and Quality Control Authority after approval by the Technical Committee for "Rotating Electrical Machines Part 3: Specific requirements for synchronous Generator driven by steam turbine or combustion gas turbine" had been approved and endorsed by the Electrotechnical National Standards Committee on **19 January 2012.**

0.2 This Pakistan Standard was adopted on the basis of IEC: 60034-3-2004 since IEC Standard have been established in 2010, hence it is deemed necessary to adopt the International standard to keep abreast with the latest technology and as par with IEC standard.

0.3 This Pakistan Standard is an adoption of IEC: 60034-3-2010 "Rotating Electrical Machines Part 3: Specific requirements for synchronous Generator driven by steam turbine or combustion gas turbine" and its use hereby acknowledged with thanks.

0.4 This standard is subject to periodical review in order to keep pace with the development in industry. Any suggestions for improvement shall be recorded and placed before the revising committee in due course.

0.5 This standard is intended chiefly to cover the technical provisions relating to this standard and it does not include all the necessary provisions of a Contract.

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ROTATING ELECTRICAL MACHINES –

Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines

1 Scope

This part of IEC 60034 applies to three-phase synchronous generators, having rated outputs of 10 MVA and above driven by steam turbines or combustion gas turbines. It supplements the basic requirements for rotating machines given in IEC 60034-1.

Common requirements are prescribed together with specific requirements for air, for hydrogen or for liquid cooled synchronous generators.

This part of IEC 60034 also gives the precautions to be taken when using hydrogen cooled generators including:

– rotating exciters driven by synchronous generators;

– auxiliary equipment needed for operating the generators;

– parts of the building where hydrogen might accumulate.

NOTE 1 These requirements also apply to a synchronous generator driven by both a steam turbine and a combustion gas turbine as part of a single shaft combined cycle unit.

NOTE 2 These requirements do not apply to synchronous generators driven by water (hydraulic) turbine or wind turbine.

NOTE 3 The precautions to be taken when using hydrogen are valid for all cases where hydrogen is used as a coolant.

2 Normative references

The following referenced documents are indispensable for the application 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.

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-4, *Rotating electrical machines – Part 4: Methods for determining synchronous machine quantities from tests*

IEC 60045-1, *Steam turbines – Part 1: Specifications*

IEC 60079 (all parts), *Electrical apparatus for explosive gas atmospheres*

3 Terms and definitions

For the purposes of this document, the terms and definitions in IEC 60034-1 together with the following additions apply.

3.1
mechanical start
change in speed from zero or turning gear speed to rated speed

3.2
turning gear operation
rotation at low speed to maintain thermal equilibrium of the turbine and/or rotor

4 General

4.1 General rules

Turbine driven synchronous generators shall be in accordance with the basic requirements for rotating machines specified in IEC 60034-1 unless otherwise specified in this standard. Wherever in this standard there is reference to an agreement, it shall be understood that this is an agreement between the manufacturer and the purchaser.

4.2 Rated conditions

The rated conditions are given by the rated values of

- the apparent power;
- frequency;
- voltage;
- power factor;
- primary coolant temperature (40°C unless otherwise agreed upon);

and where applicable,

- site altitude;
- hydrogen pressure;
- range of hydrogen purity, see IEC 60034-1.

4.3 Rated voltage

The rated voltage shall be fixed by agreement.

4.4 Power factor

The power factor shall be agreed upon between the purchaser and manufacturer. Standardised rated power factors at the generator terminals are 0,8, 0,85 and 0,9 overexcited.

NOTE 1 Other values may be agreed upon, the lower the power factor the larger will be the generator.

NOTE 2 It is recommended that the generator should be capable of providing 0,95 underexcited power factor at rated MW.

4.5 Rated speed

The rated speed shall be

$3\ 000/p$ min^{-1} for 50 Hz generators;

$3\ 600/p$ min^{-1} for 60 Hz generators;

where p is the number of pole pairs.

4.6 Ranges of voltage and frequency

Generators shall be capable of continuous rated output at the rated power factor over the ranges of ±5 % in voltage and ±2 % in frequency, as defined by the shaded area of Figure 1.

The temperature rise limits in Tables 7 and 8, or the temperature limits in Table 12 of IEC 60034-1 shall apply at the rated voltage and frequency only.

NOTE 1 As the operating point moves away from the rated values of voltage and frequency, the temperature rise or total temperatures may progressively increase. Continuous operation at rated output at certain parts of the boundary of the shaded area causes temperature rises to increase by up to 10 K approximately. Generators will also carry output at rated power factor within the ranges of ±5 % in voltage and $^{+3}_{-5}$ % in frequency, as defined by the outer boundary of Figure 1, but temperature rises will be further increased. Therefore, to minimize the reduction of the generator's lifetime due to the effects of temperature or temperature differences, operation outside the shaded area should be limited in extent, duration and frequency of occurrence. The output should be reduced or other corrective measures taken as soon as practicable.

If an operation over a still wider range of voltage or frequency or deviations from rated frequency and voltage are required, this should be the subject of an agreement.

NOTE 2 It is considered that overvoltage together with low frequency, or low voltage with over-frequency, are unlikely operating conditions. The former is the condition most likely to increase the temperature rise of the field winding. Figure 1 shows operation in these quadrants restricted to conditions that will cause the generator and its transformer to be over- or under-fluxed by no more than 5 %. Margins of excitation and of stability will be reduced under some of the operating conditions shown. As the operating frequency moves away from the rated frequency, effects outside the generator may become important and need to be considered. As examples: the turbine manufacturer will specify ranges of frequency and corresponding periods during which the turbine can operate; and the ability of auxiliary equipment to operate over a range of voltage and frequency should be considered.

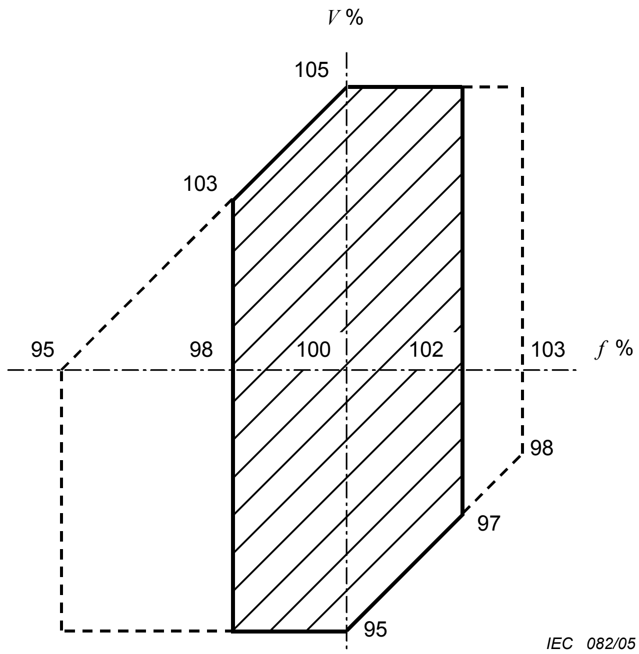


Figure 1 – Operation over ranges of voltage and frequency

4.7 Direction of rotation

The direction of rotation shall be shown on the generator or on its rating plate, and the time-phase sequence of the stator voltage shall then be indicated by marking the terminals in the sequence in which their voltages reach maximum, for example, U_1, V_1, W_1.

NOTE Terminal markings may not be consistent with IEC 60034-8.

For generators having one driving end, this shall be the reference end for the direction of rotation.

For generators having two drive ends, the more powerful drive end shall be the reference end. If not applicable, the end opposite to the excitation leads shall be the reference end for the direction of rotation.

The sense of rotation (clockwise or counter-clockwise) shall be defined when facing the generator rotor coupling from the reference side.

4.8 Stator winding

Unless otherwise agreed upon, rated generator voltage corresponds to star connection. All winding ends shall be brought out and arranged in an agreed arrangement of the external connections to the generator.

4.9 Generator rated field current and voltage

The generator rated field current and voltage are those values needed for the generator to operate at rated conditions.

4.10 Winding insulation

4.10.1 Thermal class

Insulation systems used for the windings shall be of thermal class 130 or higher.

4.10.2 Withstand voltage tests

Withstand voltage tests shall be in accordance with IEC 60034-1, Table 16.

4.11 Insulation against shaft current

Suitable precautions shall be taken to prevent harmful flow of shaft current and to earth the rotor shaft adequately. Any insulation needed shall preferably be arranged so that it can be measured while the generator is operating. Shaft voltage spikes caused by static excitation with controlled rectifiers shall be kept down by suitable means to non-critical values. These spikes could cause damage, for example the bearing Babbitt by breaking through the bearing oil film.

4.12 Over-speed test

Rotors shall be tested at 1,2 times rated speed for 2 min.

4.13 Critical speeds

Critical speeds of the combined shaft train shall not cause unsatisfactory operation within the speed range corresponding to the frequency range agreed upon in accordance with 4.6 (see also IEC 60045-1).

4.14 P-Q capability diagram

The manufacturer shall supply a P-Q capability diagram indicating the limits of operation. The P-Q diagram shall be drawn for operation at rated conditions. A typical P-Q diagram is shown in Figure 2, its boundaries are set by the following limitations:

– curve A represents operation with constant rated field current and therefore with approximately constant temperature rise of the field winding;

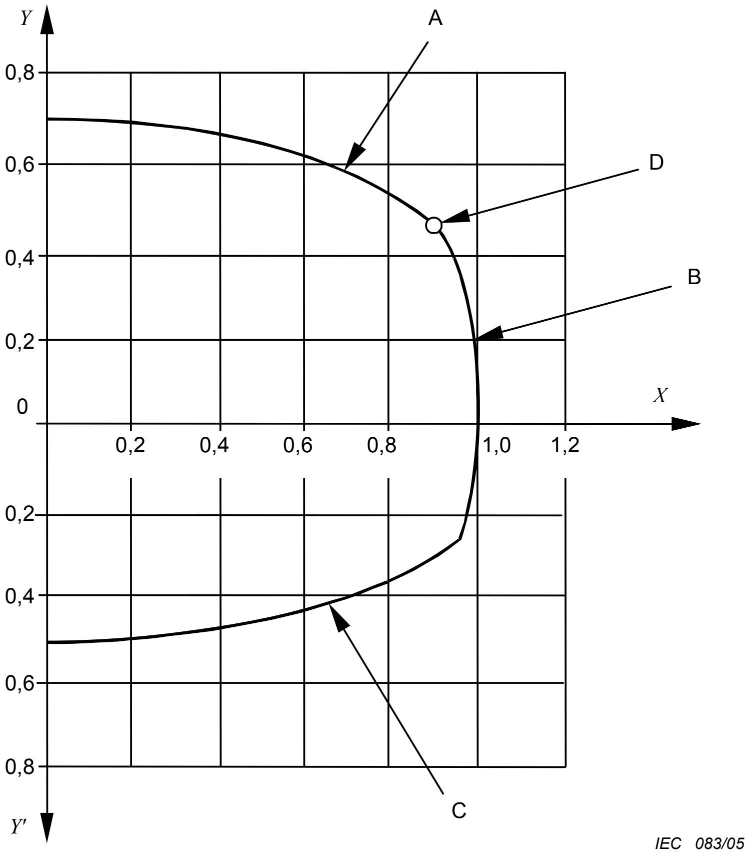
– curve B represents constant rated stator current and consequently approximately constant temperature rise of the stator winding;
– curve C indicates the limit set by localized end region heating, or by steady-state stability, or by a combination of both effects.

NOTE 1 Figure 2 may contain other operational limits such as maximum turbine limits and minimum excitation limits.

By agreement between the manufacturer and the purchaser, other diagrams may be provided for operation at agreed upon conditions within the voltage and frequency ranges agreed upon in accordance with 4.6, and for cooling and temperature conditions and where applicable hydrogen pressures other than rated.

NOTE 2 The generator should be operated within the boundaries of the diagram appropriate to the chosen conditions of voltage, frequency and cooling, and hydrogen pressure if applicable. Operation outside these boundaries will shorten the life of the generator.

NOTE 3 For a generator with a water cooled stator winding at reduced hydrogen pressure, the maximum water pressure within the winding can become higher than the hydrogen pressure. Hence, in the case of a leak, water can move from the water circuit towards the hydrogen environment within the casing. This could cause failure.



Key

A limited by field winding temperature

B limited by armature winding temperature

C limited by the temperatures of the core end parts or by steady state stability

D rated output

X per unit kW

Y per unit kvar overexcited

Y′ per unit kvar underexcited

Figure 2 – Typical P-Q capability diagram

4.15 Overcurrent requirements

Generators with rated outputs up to 1 200 MVA shall be capable of carrying, without damage, a stator current of 1,5 per unit (p.u.) for 30 s.

For ratings greater than 1 200 MVA, agreement should be reached on a time duration less than 30 s, decreasing as the rating increases, to a minimum of 15 s, the current remaining at 1,5 per unit for all ratings.

The generator shall be capable of other combinations of overcurrent and time that give the same degree of additional heat above that caused by 1 p.u. current.

Thus, for generators up to 1 200 MVA,

$$(I^2 - 1)t = 37{,}5 \text{ s}$$

where

I is the stator current per unit (p.u.);

t is its duration in seconds.

This relationship shall apply for values of t between 10 s and 60 s.

NOTE It is recognized that stator temperatures will exceed rated load values under these conditions, and therefore the generator construction is based upon the assumption that the number of operations to the limit conditions specified will not exceed two per year.

4.16 Sudden short circuit

The generator shall be designed to withstand without failure a short circuit of any kind at its terminals, while operating at rated load and 1,05 p.u. rated voltage, provided the maximum phase current is limited by external means to a value which does not exceed the maximum phase current obtained from a three-phase short circuit. 'Without failure' means that the generator shall not suffer damage that causes it to trip out of service, though some deformation of the stator winding might occur.

If it is agreed upon between purchaser and manufacturer that a sudden short-circuit test shall be made on a new generator, it shall be done after the full voltage dielectric acceptance test as described below.

A generator that is to be connected directly to the system shall have a 3-phase short circuit applied at its terminals when excited to rated voltage on no-load. For a generator that will be connected to the system through its own transformer or reactor, usually by an isolated phase bus, the test at the terminals shall be carried out at reduced voltage, agreed upon between the purchaser and the manufacturer, in order to produce the same stator current as would result in service from a three-phase short circuit applied at the high voltage terminals of the transformer.

This test shall be considered satisfactory if the generator is subsequently judged to be fit for service without repairs or with only minor repairs to its stator windings, and if it withstands a high-voltage test of 80 % of the value specified in IEC 60034-1 for a new generator. The term “minor repairs” implies some attention to end-winding bracing and to applied insulation, but not replacement of coils.

NOTE Abnormal high currents and torques can occur as a result of a short circuit close to the generator in service, or of clearance and re-closure of a more distant fault, or of faulty synchronizing. If such conditions do actually impose severe overcurrents, it would be prudent to examine the generator thoroughly, with particular attention to the stator windings. Any loosening of supports or packings should be made good before returning the generator to service, to avoid the possibility of consequential damage being caused by vibration. It may also be desirable to check for possible shaft balance changes and deformation of the coupling bolts and couplings.

4.17 Short-circuit ratio

For generators of all sizes and types of cooling covered by this standard, the value of the short-circuit ratio shall be not less than 0,35. Higher minimum values may be specified and agreed upon (for example by a grid demand), but, for a given cooling system, these usually require an increase in generator size and higher losses.

4.18 Direct axis transient and subtransient reactances for generators

When the direct axis transient or subtransient reactances are specified having regard to the operating conditions, the following values should be agreed upon:

– a minimum value of the direct axis subtransient reactance at the saturation level of rated voltage;
– a maximum value of the direct axis transient reactance at the unsaturated conditions of rated current.

Since the two reactances depend to a great extent on common fluxes, care should be taken to ensure that the values specified and agreed upon are compatible, that is, that the upper limit of the subtransient reactance is not set too close to the lower limit of the transient reactance.

When the value of the direct axis subtransient reactance is not specified, it shall be not less than 0,1 p.u. at the saturation level corresponding to rated voltage.

The value of each of these reactances may be specified and agreed upon at another saturation level in accordance with IEC 60034-4. If it is agreed that values are to be determined by test, the test shall be in accordance with IEC 60034-4.

4.19 Tolerances on short-circuit ratio and direct axis transient and subtransient reactances

Where the limit values of this standard, or other limits, have been specified or agreed upon, there shall be no tolerance in the significant direction, that is, no negative tolerance on minimum values and no positive tolerance on maximum values. In the other direction, a tolerance of 30 % shall apply.

If values are specified but not declared to be limits, they shall be regarded as rated values, and shall be subject to a tolerance of ±15 %.

Where no values have been specified by the purchaser, the manufacturer shall give values, subject to a tolerance of ±15 %.

4.20 Mechanical conditions for rotors

4.20.1 Number of starts

Unless otherwise agreed upon, the rotor shall have a mechanical design capable of withstanding during its lifetime:

– normally not less than 3 000 starts;
– for those designed for regular start-stop duties such as daily service not less than 10 000 starts.

4.20.2 Turning gear operation

Before start-up and after shut-down, turning gear operation of the turbine generator set may be unavoidable primarily due to prime mover needs. However, prolonged turning gear operation may make the generator rotor susceptible to damage and should be limited. Susceptibility to turning gear operation damages can be influenced by the design. If a longer turning gear operation is considered additional design efforts for minimizing the harmful effects should be the subject of an agreement.

4.21 Coolers

Unless otherwise agreed upon, coolers shall be suitable for cold water intake temperatures up to 32 °C and a working pressure of not less than:

– 2,7 bar absolute (270 kPa) for air cooled generators;

– 4,5 bar absolute (450 kPa) for hydrogen and liquid cooled generators;

The test pressure shall be 1,5 times the maximum working pressure, and shall be applied for 15 min.

If the water pressure in the cooler is controlled by a valve or pressure-reducing device connected to a water supply where the pressure is higher than the working pressure of the cooler, the cooler shall be designed for the higher pressure, and tested at 1,5 times the higher pressure value, unless otherwise agreed upon. This pressure shall be specified by the purchaser.

Coolers shall be designed so that, if one section is intended to be taken out of service for cleaning, the unit can carry at least two-thirds (or, by agreement, another fraction) of rated load continuously, without the permissible temperatures of the active parts of the generator being exceeded. Under these conditions, the primary coolant temperature may be higher than the design value. For hydrogen and liquid cooled generators, attention should be paid to the fact that under some conditions of operation, for example during maintenance or while purging the casing of gas, a cooler might be subjected to gas pressure without water pressure. It shall therefore be designed for a differential pressure of 8 bar (800 kPa) on the gas side.

NOTE Increasing concentrations of chemicals in the water, for example salts or glycol can affect the cooling performance.

5 Air-cooled generators

5.1 General

This clause applies to generators, the active parts of which are cooled by air, either directly or indirectly or by a combination of the two methods.

5.2 Generator cooling

The system of ventilation should preferably be a closed air circuit system. If an open air system is specified or agreed upon, care shall be taken to avoid contaminating the ventilation passages with dirt, to avoid overheating and pollution of insulated surfaces.

When slip rings for excitation are provided, they should be ventilated separately to avoid contaminating the generator and exciter with carbon dust.

5.3 Temperature of primary coolant

Generators other than those driven by gas turbines shall be in accordance with IEC 60034-1.

If the maximum temperature of the ambient air, or of the primary cooling air where an air-to-water cooler is used, is other than 40 °C, the relevant clauses of IEC 60034-1 apply.

Particular requirements for generators driven by gas turbines are given in 7.2 and 7.3.

5.3.1 Temperature detectors

In order to monitor the temperature of the stator winding, at least six embedded temperature detectors (ETD) shall be supplied in accordance with IEC 60034-1.

The number of temperature detectors in the air intakes to the generator shall be agreed upon.

6 Hydrogen-cooled or liquid-cooled generators

6.1 General

This clause applies to generators the active parts of which are cooled directly or indirectly by hydrogen, gas or liquid, or by a combination of both. Some generators may use a gas other than hydrogen, if so, the same rules apply where appropriate.

6.2 Hydrogen pressure and purity in the casing

The manufacturer shall indicate the absolute hydrogen pressure and purity in the casing, at which the generator produces its rated output.

The following absolute values of hydrogen pressure are preferred:

bar	2	3	4	5	6	7
kPa	200	300	400	500	600	700

NOTE It is recognized that a conversion from absolute pressure to local gauge pressure is required. The reduced ambient air pressure at altitudes exceeding 1 000 m above sea level must be taken into account when designing the auxiliaries.

6.3 Generator housing and cover plates

The complete generator housing, and any pressure-containing cover plates (for example over coolers) for use with hydrogen as a coolant, shall be designed to withstand an internal explosion, with the explosive mixture initially at atmospheric pressure, without danger to personnel. A hydrostatic pressure test shall be made to check the strength of the housing and cover plates. A suitable test would be the application of 9 bar absolute (900 kPa) for 15 min.

NOTE In some countries, established codes or standards may impose different test requirements.

6.4 Stator winding terminals

The terminals for hydrogen-cooled generators shall be designed to withstand a gas pressure of at least 9 bar absolute (900 kPa).

Terminal insulators shall be electrically tested independently of the generator windings, and they shall withstand for 60 s a power-frequency dry dielectric test in air of not less than 1,5 times the 1 min test voltage of the generator winding.

NOTE When the terminals are liquid-cooled, the coolant connections need not be made for the high voltage test.

6.5 Temperature of primary coolants, temperatures and temperature rises of the generator

Generators other than those driven by gas turbines shall be in accordance with IEC 60034-1.

The maximum temperatures of the primary coolants, hydrogen or liquid, may be other than 40 °C (for example to obtain an economical design of cooler with the specified maximum temperature of the secondary coolant). If so:

a) for indirectly cooled generators, the appropriate clauses of IEC 60034-1, concerning adjustment of temperature rises for air-cooled generators, shall apply;
b) for directly cooled generators, the temperature specified in the appropriate table of IEC 60034-1 shall apply unchanged.

NOTE In order to avoid excessive temperature rises, or excessive ranges of temperature, the maximum temperature of the coolant usually should not deviate from 40 °C by more than ±10 K.

Particular requirements for generators driven by gas turbines are given in 7.2 and 7.3.

6.6 Temperature detectors

At least six embedded temperature detectors (ETD) shall be supplied in accordance with IEC 60034-1. For directly cooled generators, it is important to note that the temperature measured by ETD is no indication of the hot-spot temperature of the stator winding.

Observance of maximum coolant temperatures given in item 1 in Table 11 of IEC 60034-1 will ensure that the temperature of the winding is not excessive. The limit of permissible temperature measured by ETD between the coil sides is intended to be a safeguard against excessive heating of the insulation from the core. The ETD temperature readings may be used to monitor the operation of the cooling system of the stator winding.

The number of temperature detectors measuring the coolant temperature where it enters the generator shall be agreed upon.

For generators with direct cooling of the stator winding, the temperature of the cooling medium at the outlet of this winding shall be measured with at least three temperature detectors. These detectors should be in intimate contact with the coolant. Therefore, if the winding is gas-cooled, they should be installed as close to the exit duct from the coil as is consistent with electrical requirements. If the winding is water cooled, they should be installed on the piping inside the generator frame or as near as practicable to where the coolant leaves the frame, care being taken that there is no significant temperature difference between the point of measurement and the point where the coolant leaves the winding.

6.7 Auxiliary system

Some or all of the following equipment will be required for satisfactory operation of generators covered by Clause 6, depending on the design of the coolant and auxiliary systems. The list is not intended to be complete in all details, and other items may be provided.

a) A complete coolant gas system (hydrogen or other gas), with suitable regulators to control the gas pressure in the generator, suitable for connecting to the gas supply, a gas dryer and a means of checking or monitoring the daily gas consumption.
b) A complete system for the purging gas (usually carbon dioxide) suitable for connecting to the gas supply, to permit the casing to be safely filled with and scavenged of hydrogen.

   If the pressurized air system of the power station is used to drive the scavenging gas from the casing, the connection to the air system shall be arranged to ensure that air cannot be released into the generator except to remove the scavenging gas, for example by having a removable pipe connection.
c) Necessary indicators and alarm devices to enable the required degree of purity of hydrogen to be maintained and to enable the purity of the scavenging gas to be monitored while the casing is being emptied of hydrogen. Two independent means for indicating purity should be provided.
d) A complete seal oil system including equipment for monitoring the seal oil and, if required, for removing gas and water from it.

An emergency supply of seal oil shall be provided, to operate automatically if the main supply fails.

e) A complete liquid cooling system (or systems) with pumps, coolers and filters, and with suitable regulators to control the temperature of the cooling liquid.

f) Means of detecting the reduction or loss of flow of liquid through the windings.

g) Means of measuring the conductivity of water used for cooling the windings and maintaining it at a sufficiently low value.

h) Measuring instruments and alarms to indicate the functioning of all auxiliary apparatus and the presence of liquid in the generator; also means for removing the liquid.

7 Generators for combustion gas turbines or combined cycle applications

7.1 General

This clause applies to generators driven by gas turbines or for combined cycle applications with open-circuit air cooling, or closed-circuit cooling using air or hydrogen where the requested generator output is a function of the ambient temperature.

7.2 Service conditions

7.2.1 General

A generator driven by a combustion gas turbine and conforming to this part of IEC 60034 will be suitable for carrying a load in accordance with its rating and capabilities under the following service conditions.

7.2.2 Primary coolant temperature

For open-circuit air-cooled generators, the primary coolant temperature is the temperature of the air entering the generator. This will normally be the ambient air temperature. The range of this temperature shall be specified by the purchaser, it will normally be –5 °C to +40 °C.

For generators with closed-circuit cooling, the primary coolant temperature is the temperature of the air or hydrogen entering the generator from the coolers. The range of this coolant temperature shall be determined by the manufacturer, to obtain optimum design of generator and coolers, based upon the range of secondary coolant temperature (ambient air or water) specified by the purchaser.

7.2.3 Number of starts

The number of starts per year should not exceed 500, except by agreement.

7.2.4 Application of load

The load may be applied rapidly and the rate of generator loading is limited only by the ability of the turbine to take up the load.

7.3 Rated output

The combustion gas turbine is normally rated at an air intake temperature of 15 °C, and the generator is normally rated at an air intake temperature of 40 °C. Therefore, a combustion gas turbine and a generator with equal capabilities will have different ratings.

At rated output, the temperature rises in Tables 7 and 8 or the temperatures in Table 12 of IEC 60034-1 shall not be exceeded.

The generator parameters shall be defined with respect to this rating unless otherwise agreed upon.

7.4 Capabilities

7.4.1 General

The capability of a generator is its highest acceptable loading in apparent power under specified conditions of operation.

7.4.2 Base capability

The base capability is the range of continuous output expressed in apparent power available at the generator terminals:

- at the operating site at rated frequency, rated voltage and rated power factor;
- hydrogen pressure and purity in accordance with IEC 60034-1 where applicable

corresponding to the range of primary or secondary coolant temperature specified for the operating site, see 7.2.2, with temperature rises or temperatures (as appropriate) not exceeding the values specified in 7.4.3.

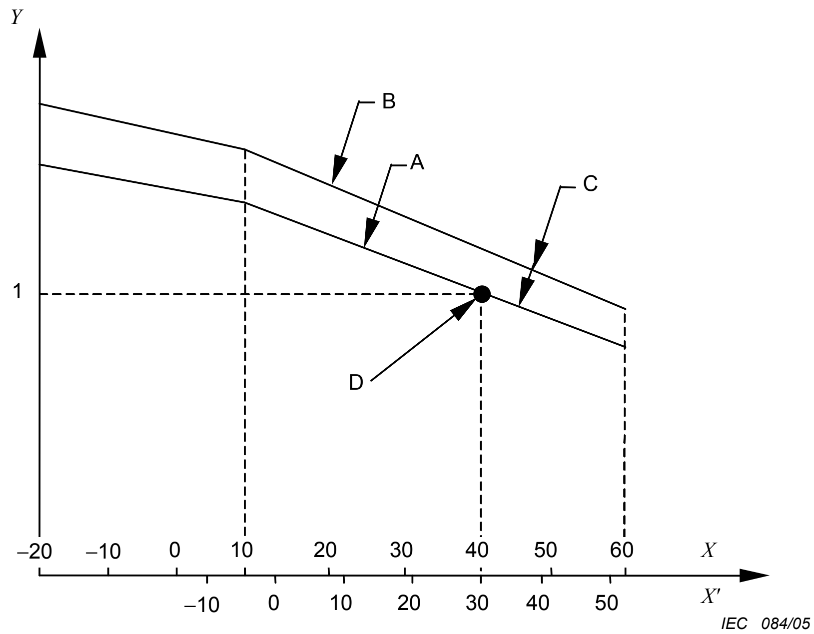
The active power component of the base capability of the generator divided by the generator efficiency shall equal or exceed the base capability of the combustion gas turbine over the specified range of air temperature at the intake to the turbine at site.

It may be agreed that beyond some submitted low or high air temperature, it is not necessary for the base capability of the generator to equal that of the turbine. It may then be possible to meet all other requirements with a slightly smaller generator.

The manufacturer shall supply a curve of base capability under site conditions over the specified range of primary or secondary coolant temperature (see Figure 3). For a generator with open-circuit air cooling, this coolant temperature can be taken to be the same as that of the air at the turbine intake (Figure 3, scale X). Where automatic re-circulation of air is fitted for low ambient temperature applications, the curve shall refer to the actual cooling air temperature differing from the ambient air at the turbine intake.

In a generator with closed-circuit cooling, using a water-cooled heat exchanger, the temperature of the water (the secondary coolant) may not have a direct correlation with the ambient air temperature. Figure 3, as an example, shows generator capability plotted against secondary coolant temperatures in scale X'. Hence, as the ambient air temperature falls, the generator capability may not change or may rise more slowly than the turbine capability. If the generator size is determined by the turbine output at low air temperatures, its output capability will be considerably in excess of that required at normal ambient temperatures.

For all these reasons, agreement should be made regarding the extent to which the generator capability should match that of the turbine.



Key

A base capability

B peak capability

C temperature difference 15 K

D rating point

X primary coolant temperature (°C)

X′ secondary coolant temperature (°C) for a closed-circuit cooled generator using air or hydrogen as primary coolant

Y generator apparent power p.u.

NOTE 1 The curves supplied for a particular generator will extend only over the range of coolant temperature specified. For a generator with a heat exchanger, it is not intended that a scale of primary coolant temperature be shown also. The two scales of primary or secondary coolant temperature are included here merely to show forms of the diagram.

NOTE 2 These typical curves do not extend beyond primary coolant temperatures of –20 °C and +60 °C, because outside this range performance requirements should be by agreement.

Figure 3 – Typical generator capability curves

7.4.3 Temperature rise and temperature at base capability

For indirectly cooled windings, the temperature rises when operating at site shall be in accordance with Tables 7, 8 and 9 of IEC 60034-1 as appropriate, adjusted as follows:

a) for primary coolant temperatures from 10 °C to 60 °C: add (40 – primary coolant temperature) K;

b) for primary coolant temperatures below 10 °C but not below –20 °C: add 30 K + 0,5 (10 – primary coolant temperature) K;

c) for primary coolant temperatures above 60 °C or below –20 °C, an agreement shall be reached;

For windings directly cooled by air or hydrogen the total temperatures when operating on site shall be in accordance with the limits of Table 12 of IEC 60034-1, adjusted as follows:

d) for primary coolant temperatures from 10 °C to 60 °C: no adjustment;

e) for primary coolant temperatures below 10 °C but not below –20 °C: subtract 0,3 (10 – primary coolant temperature) K;

f) for primary coolant temperatures above 60 °C or below –20 °C, an agreement shall be reached.

7.4.4 Peak capability

The peak capability is the generator rating obtained when operating the generator at an increased temperature or temperature rise not exceeding 15 K with respect to temperature or temperature rise at base capability.

NOTE Operation at peak capability will decrease the lifetime of the generator because insulation ages thermally at about three to six times the rate that occurs at base capability temperatures.

The consideration set out in 7.4.2 concerning the relationship between the generator and the turbine base capabilities applies also to peak capabilities.

7.5 Rating plate

The rating plate shall show the information stipulated in IEC 60034-1, plus the value of the peak capability output at the primary coolant temperature on which the rating is based.

7.6 Temperature tests

Temperature tests shall be made by agreement. Temperatures or temperature rises shall be in accordance with 7.4.3, corrected, if necessary, for difference in altitude between the test site and the operating site, in accordance with IEC 60034-1.

Annex A
(normative)

Precautions to be taken when using hydrogen cooled turbine-driven synchronous generators

A.1 General

This annex gives guidance on some design features and operating procedures that are intended to avoid the occurrence, or ignition of an ignitable mixture of hydrogen and air, either in the generator itself or in and around associated equipment. It is not, however, intended as a complete specification or code of practice sufficient for the safe design and operation of the installation. Responsibility for the safe design of the generator and its auxiliaries rests primarily with the manufacturer. Responsibility for the safe design of other parts of the installation should be agreed upon between the parties concerned.

The manufacturer is responsible for providing the official operating and maintenance instructions. Any modification of the manufacturer's instructions to suit a particular application should only be done through the manufacturer's formal revision procedure.

The responsibility for safe operation rests with the user of the equipment.

A.2 Hydrogen supply purity

The purity of the supplied hydrogen shall be not less than 99 % by volume.

A.3 Normal operating conditions

Normal operating conditions are:

– filling of the generator with hydrogen;
– operation of the hydrogen-filled generator;
– start-up, shut-down and standstill of the generator when filled with hydrogen;
– purging of gas from the generator.

A.4 Protective measures for sliprings and coupled exciters

If the exciter or sliprings are situated in a housing into which hydrogen may leak, the accumulation of an explosive hydrogen-air mixture shall be prevented, for example by maintaining a flow of air through the enclosure, see Clause A.7.

The flow can usually be produced easily while the shaft rotates at normal speed. Additional means may be needed when the generator contains hydrogen and the shaft is stationary or rotating slowly. An intake and exhaust duct may be provided to vent hydrogen leakage through natural convection and buoyancy. If local fans are used to ensure ventilation, their motors shall have a type of protection for explosive gas atmospheres in accordance with the appropriate part of IEC 60079. The fans shall not exhaust the air. They shall provide a forced draft from a clean air source.

A.5 Auxiliary equipment

A.5.1 General

The auxiliary equipment, when used, shall comply with the requirements prescribed in A.5.2 to A.5.8.

A.5.2 Degassing tanks

The degassing tanks of the hydrogen and seal oil systems shall be suitable for a test pressure of 1,5 times the maximum operating absolute pressure or an absolute pressure of 900 kPa, whichever is the greater.

Brittle or possibly porous materials, such as cast iron, shall not be used for components subject to hydrogen or seal oil pressure.

A.5.3 Gas dryer

The gas dryer shall be suitable for a test pressure of 1,5 times the maximum operating absolute pressure or an absolute pressure of 900 kPa whichever is the greater.

Several different systems may be used to maintain a sufficiently low humidity within the generator casing, using equipment called here ‘the gas dryer’. The equipment shall comply with the following general safety rules:

– if the gas dryer is of a type in which a drying agent needs periodic reactivation, means shall be provided to show when this is needed and when it is complete;
– if air is used in the reactivation process, there shall be some means provided to ensure that air is not accidentally admitted into the generator casing. This requires valves to be interlocked or pipe connections to be readily removable and of a special type;
– if a heater is used, precautions shall be taken to ensure that it operates at a temperature well below the ignition temperature of any hydrogen-air mixture that may be formed. Typically, the allowable limit is 300 °C. A lower limit may be needed to avoid damage to a drying agent such as activated alumina. The heater shall be arranged, for example by interlocking its switch with the valves, so that it can operate only during the regeneration period;
– if means are provided to allow condensate to be drained from a chamber that is subjected to hydrogen pressure, the construction and operation shall prevent any significant escape of hydrogen;
– measuring instruments and control devices which have electrical circuits inside and which during operation might contain ignitable gas mixtures shall be made to withstand bursting.

  NOTE Measuring instruments and control devices are not related to the gas dryer. They might be covered in a separate subclause of a future edition of this standard.

  Suitable types are, for example ‘flameproof enclosure’ or ‘intrinsically safe’ devices according to IEC 60079. This applies, for instance, to the following devices: electrical devices supervising the degree of hydrogen purity, contact electrical manometers or thermometer pressure gauges provided with electrical tele-transmitters.

A.5.4 Connections

The connections to components in all electrical circuits shall be made so that temperature rise during operation, vibration or ageing of insulating materials will not cause deterioration of the connection. For appropriate examples, see IEC 60079. Electrical connections shall be designed to prevent inadvertent disconnection or loosening that may cause sparking.

NOTE Gas may travel down the cores of electrical cables.

A.5.5 Containment of hydrogen

To avoid large volumes of hydrogen being accidentally released, either into the generator if a control valve fails, or into the surrounding area if a leak into the atmosphere occurs, the following rules shall apply.

A.5.5.1 The pipework should be arranged and supported so as to protect it as much as possible from accidental damage. If any hydrogen pipework is in ducts or buried underground, it shall be arranged so that any leaking hydrogen may be detected and safely dispersed.

A.5.5.2 If the generator is supplied individually from a rack of hydrogen cylinders located inside the generator house (each usually having a capacity of from 6 m^3 to 10 m^3 at normal temperature and pressure, NTP), the rack should contain only the number of cylinders that would contain about 80 m^3 NTP in total, with only two or three (corresponding to about 20 m^3 NTP) in service at the same time.

A.5.5.3 A larger supply unit, feeding one or several generators, shall be located outside the generator house. If the hydrogen supply is continuously open to the generator, the operating pressure being maintained by a pressure control valve, the supply pipes placed outside the buildings shall be provided either with

a) an automatic stop valve (operated, for example by excessive gas flow), or

b) a magnetic valve that can be manually closed from a remote point in an emergency.

Thus, if a large leak occurs, the main supply of hydrogen will be cut off. A possible schematic arrangement according to item a) above is shown in Figure A.1.

If the plant is fitted with manually operated opening stop valves, preferably those on the supply cylinders, hydrogen shall be supplied to the pressure control valve periodically to keep the gas pressure within the defined band.

A.5.5.4 Indoor as well as outdoor supply units require a safety valve at the low pressure side of the hydrogen supply system.

It is common practice to reduce the pressure from the storage cylinders to the generator frame in two stages.

There should be a safety valve on the low pressure side of each stage which shall be vented to a safe place, see A.5.7.

A.5.5.5 Special attention shall be paid to any national rules for storage of the hydrogen and of the inert gas, the cylinders and their connections, pressure reducing and safety valves and the connections to the gas system.

A.5.6 Accumulation of hydrogen-air mixture

The accumulation of an ignitable hydrogen-air mixture in the bearing oil system and seal oil system (including, of course, the bearing brackets themselves) shall be prevented. Continuously-operating exhausting devices shall be installed in appropriate places.

The generator bushings, the connections to them and any enclosures shall be designed so that hydrogen cannot accumulate in the event of a leak.

If phase isolated busbars are used, the design of these shall be such that hydrogen cannot accumulate in the trunkings or conduits.

A.5.7 Vent pipes

Vent pipes carrying hydrogen or hydrogen-air mixtures shall be routed so as to prevent any accumulation of hydrogen-air mixtures at locations where the gas is being discharged. In the discharging area, there shall be no windows or air intakes, and no sources of ignition, for example, open flames or sources of corona discharge or electrical sparking.

A.5.8 Adjacent area

All areas in and around the generator foundation, and any spaces into which hydrogen might leak (including walkways and control or instrument cubicles) shall be so constructed and/or adequately ventilated so that, no harmful concentration of hydrogen can occur.

Forced ventilation may be necessary in some circumstances, see Clause A.6. If so, it should be provided by non-sparking forced draught fans or, if compressed air is used, the discharge nozzle should be earthed.

Particular attention shall be paid to any areas containing equipment operating at high temperatures or in which sparking could occur.

A.6 Operation of the generator and its auxiliary equipment

A.6.1 Sources of ignition

Open flames, welding, smoking, or other means of ignition shall not be allowed within the vicinity of the generator and its auxiliaries.

A.6.2 Hydrogen-air mixture

There shall be no ignitable hydrogen-air mixture within the generator. Under normal service conditions, the purity of the hydrogen shall be not less than 95 % by volume. If the purity degree drops below 90 % by volume of hydrogen and it is not possible to raise it quickly, the unit shall be shut down before the purity has fallen to less than 85 % by volume and the hydrogen shall be purged.

There shall be provision for at least two independent purity measurement systems. If all measurement systems fail, the generator shall be shut down and purged.

A.6.3 Air or hydrogen displacement

There shall be no direct displacement of air by hydrogen or vice versa. In both cases, the generator shall be purged with an inert gas such as CO_2. The purging shall continue until the concentration of the purging gas reaches a safe level when monitored at the discharge pipe.

NOTE According to established international practice, this is achieved when the content of the monitored inert gas is between 75 % and 90 % by volume.

During purging operations, all kinds of electrical testing on the generator shall be prohibited until the final conditions of air or hydrogen in the generator have been reached.

If a compressed air supply is used to remove the inert gas, the connection to the air supply shall be such that air cannot enter the generator except when it is required to do so for this purpose. This can be arranged by suitable interlocking between the supply valves for air, inert gas and hydrogen, or by having an easily disconnectable air pipe. This pipe shall be connected only while the inert gas is being removed, and shall be disconnected immediately afterwards.

Covers giving access to the generator, bearing brackets and the like shall not be removed until the inert gas content has been reduced to 5 % and the pressure in the generator has fallen to atmospheric in order to prevent people from suffocating in areas below the generator.

Before any person enters the generator, any pockets of inert gas in the bottom should be dispersed by local ventilation, using compressed air or a non-sparking fan to prevent people from suffocating inside the generator.

The generator is not designed to run in an inert gas atmosphere, hence it should not be run in an inert gas at speeds and pressures greater than the maximum recommended by the manufacturer.

In an emergency shutdown that requires the generator to be purged of hydrogen, inert gas may be admitted only below the speed limit recommended by the manufacturer. This procedure is only permitted when there is enough inert gas available to allow for increased losses through the vent pipe caused by the mixing of the two gases as opposed to buoyancy displacement.

A.6.4 Seal oil supply and hydrogen pressure

The seal oil supply system normally has a duty and a series of stand-by pumps.

The generator shall not be operated at a hydrogen pressure greater than the pressure capable of being covered by the next available back-up seal oil pump.

The generator shall be shut down and purged when all back-up seal-oil pumps are not available.

A.6.5 Gas tightness

The gas tightness of the generator shall be monitored continuously by maintaining a record of the rate of hydrogen consumption. If gas consumption increases significantly above the level that has been established as normal for the generator when it is in good condition, the cause of the increased loss shall be identified without delay.

If the leak is not quickly found and corrected, areas where hydrogen might collect shall be tested for hazardous accumulations. If leaks are seen to be developing, action shall be taken to disperse them safely. If the leak persists, and cannot be sufficiently reduced by reducing the hydrogen pressure and the load, the generator should be shut down to allow fuller examination of areas (for example near terminal bushings) not accessible while it is in operation. The generator may then have to be purged of hydrogen to allow repairs to be made.

The absolute rate of leakage should not be allowed to exceed the order of 18 m^3 NTP per 24 h. Hydrogen losses that are measurable and are discharged through well-defined vents without constituting a hazard may be deducted from the measured total gas loss before applying this limit.

NOTE 1 Large generators operating at high hydrogen pressures could exceed the above leakage rate. For such generators, it is recommended that the manufacturer's expected rate of hydrogen consumption be used as a reference value.

NOTE 2 Where no distinction between hydrogen consumption (gas provided into the generator) and leakage rate (gas leaving by unidentified leaks), the hydrogen consumption rate may be higher than the leakage rate, due for example to gas lost by the seal oil.

All repair work shall be carried out after the area has been declared safe from gas.

A.6.6 Water system

If the generator hydrogen pressure exceeds the pressure of water in the hydrogen coolers or the lowest pressure in the water-cooled windings where applicable, hydrogen will leak into the water systems and it may travel considerable distance away from the generator. The water systems should be checked for this possibility when the cause of high hydrogen consumption is being sought.

A safe gas escape shall be provided to cater for normal leakage rates. The possibility of large gas escapes following a defect should be recognized.

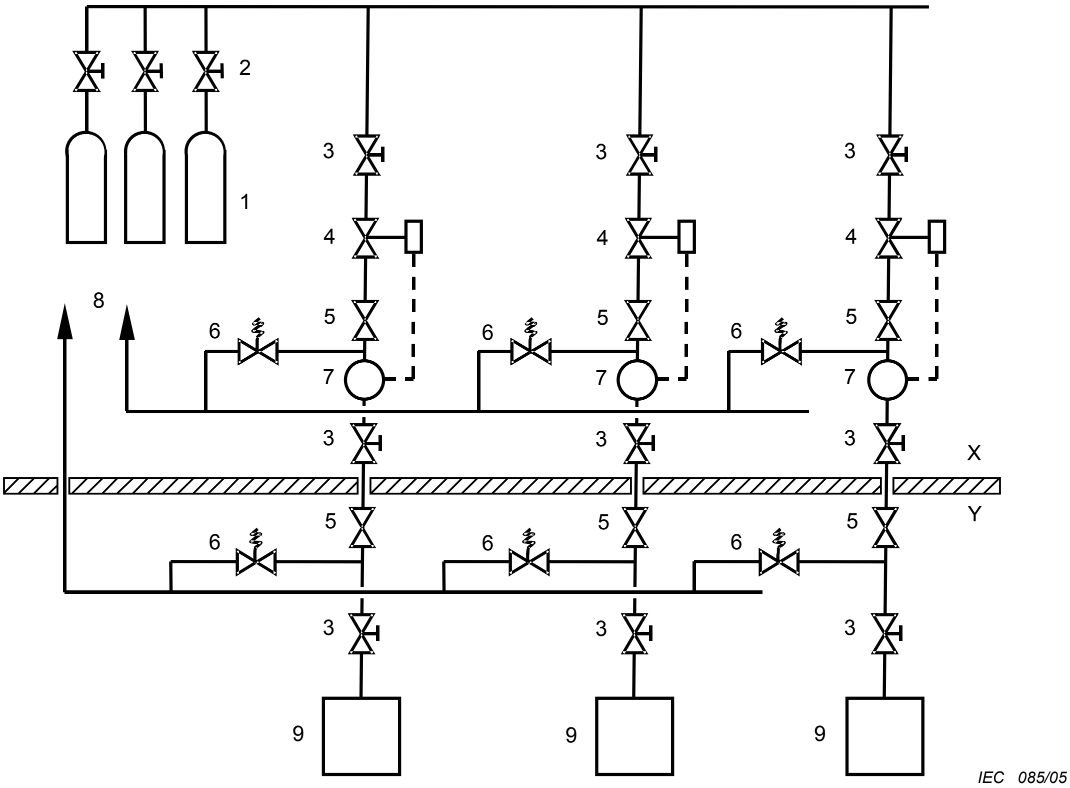
A.7 Guidance for adequate ventilation

If a volume of leaking hydrogen L cubic metres is thoroughly mixed with a volume of 100 L/p cubic metres of air, the hydrogen concentration is p %, and p can be kept down to safe levels by ensuring that the hydrogen is dispersed from the space in which it may collect by an appropriate flow of air through the space.

For example, if the total permissible leak of 18 m^3 per 24 h is assumed to leak into a given space, a flow of 125 m^3 of air per hour through the space will maintain a hydrogen concentration p of 0,6 %, well below the lower explosive limit of 4 %.

In terms familiar to ventilating engineers, if the space concerned has a volume of V cubic metres, the air within will need to be changed λ times per hour, where $V\lambda$ = 125 m^3 per hour. Hence

V/m^3	1	5	25	125	500
λ (times per hour)	125	25	5	1	0,25



Key

1 bank of H_2 cylinders or bulk storage
2 supply shut-off valves
3 shut-off valves for each generator
4 automatic stop valves
5 pressure reducing valves
6 safety valves
7 flowmeter
8 vent pipes to safe area
9 generators
X outdoor
Y indoor

Figure A.1 – Example of a large hydrogen supply unit feeding one or more generators (simplified diagram)

Bibliography

IEC 60034-8, *Rotating electrical machines – Part 8: Terminal markings and direction of rotation*