STANDARDS / MANUALS / GUIDELINES FOR SMALL HYDRO DEVELOPMENT

SPONSOR:
MINISTRY OF NEW AND RENEWABLE ENERGY
GOVERNMENT OF INDIA

GUIDELINES FOR SELECTION OF HYDRO GENERATOR FOR SHP

LEAD ORGANIZATION:
ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE
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Guide for Selection of Hydro-Generators and Excitation System Upto 25MW

1 GENERAL

The electric generator converts the mechanical energy of the turbine into electrical energy. The two major components of the generator are the rotor and the stator. The rotor is the rotating assembly to which the mechanical torque of the turbine shaft is applied. By magnetizing or “exciting” the rotor, a voltage is induced in the stationary component, the stator. The principal control mechanism of the generator is the exciter-regulator which sets and stabilizes the output voltage. The speed of the generator is determined by the turbine selection, except when geared with a speed increaser. In general, for a fixed value of power, a decrease in speed will increase the physical size and cost of the generator.

The location and orientation of the generator is influenced by factors such as turbine type and turbine orientation. For example, the generator for a bulb type turbine is located within the bulb itself. A horizontal generator is usually required for a tube turbine and a vertical shaft generator with a thrust bearing is appropriate for vertical turbine installations.

Conventional cooling on a generator is accomplished by passing air through the stator and rotor coils. Fan blades on the rotating rotor assist in the air flow. For larger generator (generally above 5 MW capacity) and depending on the temperature rise limitations of the winding insulation of the machine, the cooling may be assisted by passing air through surface air coolers, which have circulated water as the cooling medium.

The Generators interconnected with the grid should need grid standards issued by CEA Relevant extracts – Schedule for operation and maintenance are enclosed as annexure-1)

1.1 References and Codes

Latest edition of the following standards are applicable.

IEC-34-1: 1983 – Rotating Electrical Machines, Rating and Performance
IEC-34-2A-1972 - Rotating Electrical Machines
IEC-34-5-1991 – Classification of degrees of protection provided by enclosures for rotating electrical machines (IP Code)
2 HYDRO GENERATOR ABOVE 5 MVA

2.1 General

Hydraulic turbine driven generators for hydro plants are salient pole synchronous alternating current machines. Large salient pole generators are relatively slow speed machines in the range 80-375 rpm with large number of rotor poles. These generators are normally specifically designed and generally interconnected with grid.

2.2 Site Operating Conditions (as per IEC: 60034 & IEEE C-50-12)

Rated operation condition specified in the standards are as follows: Site operating conditions if deviating from these value, correction have to be applied.

**Maximum Ambient Temperature Steady State duty:** Salient-pole open ventilated air-cooled synchronous generators operate successfully when and where the temperature of the cooling air does not exceed 40°C.

Salient-pole totally enclosed water to air cooled (water) synchronous generators operate successfully when and where the secondary coolant temperature at the inlet to the machine or heat exchanger do not exceed 25°C.

If the cooling air temperature (ambient) exceeds 40°C, or cooling water temperature exceeds 25°C then maximum allowable temperature based on temperature rise on reference temperature (40°C/25°C) of the insulation class be specified instead of temperature rise.

The minimum temperature of the air at the operating site is – 15°C, the machine being installed and in operation or at rest and de-energized.

**Note:** If temperatures different from above are expected. The manufacturer should be informed of actual site conditions.

**Generators:** Generators should operate successfully at rated MVA, frequency, power factor, and terminal voltage. Generators at other service conditions should be specified with the standards of performance established at rated conditions.
Altitude: Height above sea level not exceeding 1000 m. For machines intended for operation on a site where the altitude is in excess of 1000 m. should be specifically brought out.

Number of starts and application of load: The purchaser should specify the anticipated no. of starts and maximum MVA, power, and reactive power loading rate of change requirements for the manufacturer to take into account in the machine design. The method of starting must be identified in the case of peaking stations.

Variation from rated voltage and frequency: Generators should be thermally capable of continuous operation within the capability of their reactive capability curves over the ranges of ± 5 % in voltage and ± 2 % in frequency, as defined by the shaded area of figure 2.2.

a) As the operating point moves away from rated values of voltage and frequency, the temperature rise of total temperatures of components may progressively increase. Continuous operation near certain parts of the boundary of the shaded area in figure 2.2 (a) at outputs near the limits of the generator’s reactive capability curve may (figure 2.2 b) cause insulation to age thermally at approximately two times to six times its normal rate.

b) Generators will also be capable of operation within the confines of their reactive capability curves within the ranges of ± 3 %/ -5 % in frequency as defined by the outer boundary (zone B) in figure 2.2 (a) with further reduction of insulation life.

c) To minimize the reduction of the generator’s lifetime due to the effect of temperature and temperature differentials, 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.

d) The boundaries of figure 2.2 (a) result in the magnetic circuits of the generator to be over fluxed under fluxed by no more than 5%. The sloped boundaries in figure (2.2 (a) correspond to constant voltz per hertz.

e) The machine may be unstable or margins of stability may be reduced under some of the operating conditions shown in fig. 2.2 (a). Excitation margins may also be reduced under some of the operating conditions shown in figure 2.2 (a).

f) As the operating frequency moves away from the rated frequency, effects outside the generator may become important and need to be considered. For example, the turbine manufacturer will specify ranges of frequency and corresponding periods during which the turbine can operate, and the ability of the auxiliary equipment to operate over a range of voltage and frequency should be considered.

g) Operation over a still wider range of voltage and frequency, if required, should be subject to agreement between the purchaser and the manufacturer and need to be specifically brought out in tender specification.
2.3 Transient event and emergency duty requirements

A generator confirming to these guidelines will be suitable for withstanding exposure to transient event and emergency duty imposed on a generator because of power system faults.

**Sudden short circuit at the generator terminals:** A generator will be capable of withstanding, without injury, a 30 second, 3 phase short circuit at its terminals when operating at rated MVA and power factor and at 5% over voltage, with fixed excitation. The machine shall also be capable of withstanding, without injury, any other short circuit at its terminals of 30 s duration or less in accordance with IEEE C 50. 12-2005. Generator circuit breaker need to be selected accordingly.
SYSTEM STABILITY LIMIT

LINE CHARGING LIMIT

OVEREXCITED (LAGGING)

UNDEREXCITED (LEADING)

MEGAWATTS

MEGAVARS

CAVITATION LIMIT

LIMITED BY FIELD HEATING

POWER FACTOR

RATED MVA LIMITED BY STATOR HEATING

SHAFT STRESS OR HYDRAULIC LIMIT

MINIMUM EXCITATION LIMIT

SEE NOTE-1

SYSTEM STABILITY LIMIT

SEE NOTE-2

Fig. 2.2 (b) Typical Hydro-Generator capability Curve
Synchronizing

a. Generators are designed to be fit for service without inspection or repair after synchronizing that is within the limits given below:

i) Breaker closing angle \( \pm 10\% \)

ii) Generator side voltage relative to system \( 0\%\) to \( +5\% \)

iii) Frequency difference \( \pm 0.067\) Hz

Additional information on synchronizing practices can be found in IEEE std. C37. 102TM-1995.

b. Faulty synchronizing is that which is outside the limits given above. Under some system conditions, faulty synchronizing can cause intense, short duration currents and torques that exceed those experienced during sudden short circuits. These currents and torques may cause damage to the generator.

c. Generators shall be designed so that they are capable of coasting down from synchronous speed to a stop after being immediately tripped off-line following a faulty synchronization. Any generator that has been subject to a faulty synchronization shall be inspected for damage and repaired as necessary before being judged fit for service after the incident. Any loosening for stator winding bracing and blocking and any deformation of coupling bolts, couplings, and rotor shafts should be corrected before returning the generator to service. Even if repairs are made after a severe out-of-phase synchronization, it should also be expected that repetition of less severe faulty synchronizations might lead to further deterioration of the components.

d. It should be that the most severe faulty synchronizations, such as \( 180^\circ \) or \( 120^\circ \) out-of-phase synchronizing to a system with low system reactance to the infinite bus, might require partial or total rewind of the stator, or extensive or replacement of the rotor, or both.

Check synchronizing relay and auto synchronizing equipment need to be set accordingly. Normally synchronizing closing angle is kept \( \pm 7\% \).

**Short-time volts/hertz variations:** The manufacturer shall provide a curve of safe short-time volts/hertz capability. Identify the level of overflux above which the machine should never be operated, to avoid possible machine failure. Unless otherwise specified, the curve apply for time intervals of less than 10 min.

2.4 Rotor Surface Heating

Continuous phase current unbalance: Generator above 5 MVA are normally capable of withstanding, without injury, the effects of a continuous phase current unbalance
corresponding to a negative current of the values in table 1, providing the rated MVA is not exceeded and the maximum as expressed as a percentage of rated stator current.

Table –1 Continuous negative sequence current capability

<table>
<thead>
<tr>
<th>Type of generator or generator/motor</th>
<th>Permissible $I_2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-connected amortisseur winding</td>
<td>5</td>
</tr>
<tr>
<td>Connected amortisseur winding</td>
<td>10</td>
</tr>
</tbody>
</table>

These values also express the negative-sequence current capability at reduced generator MVA capabilities, as a percentage of the stator current corresponding to the reduced capability.

Continuous performance with nonconnected amortisseur windings is not readily predictable. Therefore, if unbalanced conditions are anticipated, machines with connected amortisseur windings should be specified. Negative sequence relays (phase unbalance) be set accordingly.

2.5 Types of Generators and Configuration (Vertical or Horizontal)

Vertical shaft generators are generally used. There are two types of vertical shaft hydro generators distinguished by bearing arrangements.

Umbrella type generators: These generators have combined bottom thrust and guide bearings and confined to low operating speeds (upto 200 rpm) and is the least expensive generator design. In semi umbrella type generators a top guide bearing is added. Umbrella/Semi Umbrella design is being increasingly used for slow speed vertical generator.

Conventional generators: Prior to introduction of umbrella and semi umbrella designs conventional design comprised of top-mounted thrust and guide bearing supported on heavy brackets, capable of supporting total weight of generator. A bottom guide bearing combined with turbine shaft is usually provided. This conventional design is used for high speeds (upto 1000 rpm) generators. Some medium size low flow turbine and tube turbine generators are horizontal shaft. Direct driven bulb turbine generators are also horizontal shaft generators located in the bulb. Pelton turbine coupled generators are mostly horizontal shaft.

2.6 Capacity and Rating

kW Rating: kW capacity is fixed by turbine rated output. In a variable head power plant the turbine output may vary depending upon available head. In general the generator is rated for turbine output at rated head. In peaking power plant higher generator kW rating could be specified to take care of possible higher turbine output. Economic analysis is
required for this purpose as the cost will increase and generator capacity remains unutilized when heads are low.

The kilowatt rating of the generator should be compatible with the kW rating of the turbine. The most common turbine types are Francis, fixed blade propeller, and adjustable blade propeller (Kaplan). Each turbine type has different operating characteristics and impose a different set of generator design criteria to correctly match the generator to the turbine. For any turbine type, however, the generator should have sufficient continuous capacity to handle the maximum kW available from the turbine at 100-percent gate without the generator exceeding its rated nameplate temperature rise. In determining generator capacity, any possible future changes to the project, such as raising the forebay (draw down) level and increasing turbine output capability, should be considered. Typical hydro generator capability curve is shown in figure 2.2 (b).

**kVA Rating and power factor:** kVA and power factor is fixed by consideration of interconnected transmission system and location of the power plant with respect to load centre. These requirements include a consideration of the anticipated load, the electrical location of the plant relative to the power system load centers, the transmission lines, substations, and distribution facilities involved. A load flow study for different operating condition would indicate operating power factor, which could be specified.

\[
\text{Generator MVA} = \frac{(\text{Turbine output in MW}) \times (\text{Generator efficiency})}{\text{Generator power factor}}
\]

### 3 ELECTRICAL CHARACTERISTICS

Electrical Characteristics e.g. voltage, short circuit ratio, reactance’s, line charging capacity etc. must conform to the interconnected transmission system. Large water wheel generators are custom designed to match hydraulic turbine prime over. Deviation from normal generator design parameters to meet system stability needs can have a significant effect on cost. The system stability and other needs can be met by modern state excitation high response systems and it is a practice to specify normal characteristics for generators and achieve stability requirements if any by adjusting excitation system parameter (ceiling voltage/exciter response). Generally these special requirements do not arise in the range under discussion.

#### 3.1 Generator Terminal Voltage

Generator terminal voltage should be as high as economically feasible. Standard voltage of 11 kV is generally specified for hydro generator in the range under considerations.

#### 3.2 Insulation and Temperature Rise

Modern hydro units are subjected to a wide variety of operating conditions but specifications should be prepared with the intention of achieving a winding life
expectancy of 35 years or more under anticipated operating conditions. Class B insulation with organic binding material was specified with conservative temperature rise for stator and rotor winding insulations in the machines up to 1965. Present practice is to specified class F insulation system for the stator and rotor winding with class B temperature rise over the ambient. Ambient temperature rise should be determined carefully from the temperature of the cooling water etc.

If may be noted that as per IS the temperature rise specified over an ambient of 40°C. Accordingly maximum temperature for the insulation class under site conditions should be specified.

Thermosetting insulation systems materials are hard and do not readily conform to the stator slot surface, so special techniques and careful installation procedures must be used in applying these materials to avoid possible slot discharges. Special coil fabrication techniques, installation, acceptance and maintenance procedure are required to ensure long, trouble-free winding life.

3.3 Short Circuit Ratio

The short circuit ratio of a generator is the ratio of field current required to produce rated open circuit voltage to the field current required to produce rated stator current when the generator terminals are short circuited and is the reciprocal of saturated synchronous reactance. Normal short circuit ratios are given below. Higher than normal short circuit ratio will increase cost and decrease efficiency.

<table>
<thead>
<tr>
<th>Generator Power factor</th>
<th>Normal short circuit ratio</th>
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<tbody>
<tr>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>0.9</td>
<td>1.10</td>
</tr>
<tr>
<td>0.95</td>
<td>1.17</td>
</tr>
</tbody>
</table>

In general, the requirement for other than nominal short-circuit ratios can be determined only from a stability study of the system on which the generator is to operate. If the stability study shows that generators at the electrical location of the plant in the power system are likely to experience instability problems during system disturbances, then higher short-circuit ratio values may be determined from the model studies and specified.

3.4 Line Charging and Synchronous Condensing Capacity

This is the capacity required to charge an unloaded line. Line charging capacity of a generation having normal characteristics can be assumed to equal 0.75 of its normal rating multiplied by its short circuit ratio. If the generator is to be designed to operate as synchronous condenser. The capacity when operating over excited as condensers can be as follows:
### 3.5 Reactance

The eight different reactances of a salient-pole generator are of interest in machine design, machine testing, and in system stability model studies. Lower than normal reactances of the generator and step-up transformer for system stability will increase cost and is not recommended.

Both rated voltage values of transient and subtransient reactances should be used in computations for determining momentary rating and the interrupting ratings of circuit breakers.

Typical values of transient reactances for large water wheel generators are given below. Guaranteed values of transient reactances will be approximately 10% higher.

<table>
<thead>
<tr>
<th>Power Factor</th>
<th>Condenser Capacity</th>
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<tr>
<td>0.80</td>
<td>65%</td>
</tr>
<tr>
<td>0.90</td>
<td>55%</td>
</tr>
<tr>
<td>0.95</td>
<td>45%</td>
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### 3.6 Damper Winding

A short circuit grid copper conductor in face of each of the salient poles is required to prevent pulling out of step the generator interconnected to large grid. Two types of damper windings may be connected with each other, except through contact with the rotor metal. In the second, the pole face windings are connected at the top and bottom to the adjacent damper windings.

The damper winding is of major importance to the stable operation of the generator. While the generator is operating in exact synchronism with the power system, rotating field and rotor speed exactly matched, there is no current in the damper winding and it essentially has no effect on the generator operation. If there is a small disturbance in the power system, and the frequency tends to change slightly, the rotor speed and the rotating field speed will be slightly different. This may result in oscillation, which can result in generator pulling out of step with possible consequential damage.

The damper winding is of importance in all power systems, but more important to systems that tend toward instability, i.e. systems with large loads distant from generation resources, and large intertie loads.

In all cases, connected damper windings are recommended. If the windings are not interconnected, the current path between adjacent windings is through the field pole and...
the rotor rim. This tends to be a high impedance path, and reduce the effectiveness of the winding, as well as resulting in heating in the current path. Lack of interconnection leads to uneven heating of the damper windings, their deterioration, and ultimately damage to the damper bars.

The damper winding also indirectly aids in reducing generator voltage swings under some faults conditions. It does this by contributing to the reduction of the ratio of the quadrature reactance and the direct axis reactance, \( X'_q/X'_d \). This ratio can be as great as 2.5 for a salient pole generator with no damper winding, and can be as low as 1.1 if the salient pole generator has a fully interconnected winding practice is to provide \( X'_q/X'_d > 1.3 \).

3.7 Efficiency

As high an efficiency as possible which can be guaranteed by manufacturer should be specified. Calculated values should be obtained from the manufacturer.

For a generator of any given speed and power factor rating, design efficiencies are reduced by the following:

i. Higher Short-Circuit Ratio
ii. Higher WR²
iii. Above-Normal Thrust

3.8 Total Harmonic Distortion (THD)

This is required only for synchronous machines having rated outputs of 300 kW (or kVA) or more.

**Limits:** When tested on open circuit and at rated speed and voltage, the total harmonic distortion (THD) of the line-to-line terminal voltage, as measured according to the methods laid down in IS should not exceed 5%.

4 MECHANICAL CHARACTERISTICS

4.1 Direction of Rotation

The direction of the rotation of the generator should suit the prime mover requirements.

4.2 Rotor Assembly Critical Speeds

A rotor dynamic analysis of the entire shaft system should be performed. This analysis should include the prime mover, generator, and any other rotating components. This analysis should include lateral and torsional shaft system response to the various excitation that are possible within the operational duties allowed by the standards. When the turbine generator is purchased as a set, it would be typical that the manufacturer
should perform this analysis. When shaft components are purchased from different manufacturers, the purchaser should arrange to have this analysis. Critical speeds of the generator rotor assembly should not cause unsatisfactory operation within the speed range corresponding to the frequency range agreed in accordance with 4.1.5. The generator rotor assembly shall also operate satisfactorily for a reasonable period of time at speeds between standstill and rated speed upon by the prime mover and generator designers. The turbine generator set shaft vibration at operating speed should be limits specified by ISO 7919-5 for machine sets in hydraulic power generating and pumping plants.

4.3 Phase Sequence

Phase sequence defines the rotor in which the phase voltages reach their positive maximum at the terminals of the machine, and shall be agreed upon the manufacturer and purchaser. Typically this is given as a three letter sequence, R, C, L, (right, center, left) or L, C, R (left, center, right), as defined by an observer looking at the terminals from outside the machine. In the case of terminals on the top or bottom of the machine, the sequence is defined looking from the end of the machine nearest the terminals toward the centerline of the machine.

Care must be exercised to ensure that the defined phase sequence of the machine is consistent with that of the connected equipment, particularly in situations where the plant layout requires otherwise identical machines to have different phase sequence.

4.4 Noise Level and Vibration

Under all operating conditions, the noise level of generator should be in the range 95 dB (A). In order to prevent undue and harmful vibrations, all motors shall be statically and dynamically balanced.

Mechanical characteristics of the generator are based on the hydraulic turbine data to which the generator will be coupled. Characteristics regarding speed, flywheel effect have been discussed in chapter 2. Special characteristics are discussed below.

4.5 Over speed withstand

It is general practice in India to specify all hydro generators to be designed for full turbine runaway conditions. The stresses during design runaway speed should not exceed two-thirds of the yield point.

American practice as per Army Corps Engineers Design Manual is as follows;

Generators below 360 rpm and 50,000 kVA and smaller are normally designed for 100% over speed.
4.6 Flywheel Effect

The flywheel effect \((WR^2)\) of a machine is expressed as the weight of the rotating parts multiplied by the square of the radius of gyration. The \(WR^2\) of the generator can be increased by adding weight in the rim of the rotor or by increasing the rotor diameter. Increasing the \(WR^2\) increases the generator cost, size and weight, and lowers the efficiency. The need for above-normal \(WR^2\) should be analyzed from two standpoints, the effect on power system stability, and the effect on speed regulation of the unit. Speed regulation and governor calculation are discussed in chapter 2.

Electrical system stability considerations may in special cases require a high \(WR^2\) is only one of several adjustable factors affecting system stability, all factors in the system design should be considered in arriving at the minimum overall cost. Sufficient \(WR^2\) must be provided to prevent hunting and afford stability in operation under sudden load changes. The index of the relative stability of generators used in electrical system calculations is the inertia constant, \(H\), which is expressed in terms of stored energy per kVA of capacity. It is computed as:

\[
H = \frac{kW \cdot s}{kVA} = 0.231(WR^2)(r/\text{min})^2 \times 10^{-6}
\]

The inertia constant will range from 2 to 4 for slow-speed (under 200 rpm) water wheel generators. Transient hydraulic studies of system requirements furnish the best information concerning the optimum inertia constant, but if data from studies are not available, the necessary \(WR^2\) can be computed or may be estimated from a knowledge of the behavior of other units on the system. Increased in normal \(WR^2\) will increase generator cost.

4.7 Cooling

Losses in a generator appear as heat which is dissipated through radiation and ventilation. The generator rotor is normally constructed to function as an axial flow blower, or is equipped with fan blades, to circulate air through the windings. Small-generators up to 5 MW may be partially enclosed, and heated generator air is discharged into the generator hall, or ducted to the outside. Adequate ventilation of the generator hall preferably thermostatically should be provided in this case.

Water to air coolers normally are provided for all modern hydro generators rated greater than 5 MVA. The coolers are situated around the outside periphery of the stator core. Generators equipped with water-t-air coolers can be designed with smaller physical dimensions, reducing the cost of the generator. Automatic regulation of the cooling water flow in direct relation to the generator loading results in more uniform machine operating temperatures, increasing the insulation life of the stator windings. Cooling of the generator can be more easily controlled with such a system, and the stator windings and ventilating slots in the core kept cleaner, reducing the rate of deterioration of the stator winding insulation system. The closed system also permits the addition of automatic fire...
protection systems, attenuates generator noise, and reduce heat gains that must be accommodated by the powerhouse HVAC system.

Normally, generators should be furnished with one more cooler than the number required for operation at rated MVA. This allows one cooler to be removed for maintenance without affecting the unit output.

The generator cooling water normally is supplied from the penstock via a pressure reducing station or pumped from the tailrace. In either case, automatic self-cleaning filters must be provided in the cooling water supply lines to avoid frequent fouling or plugging of the water-to-air coolers.

4.8 Fire Extinguishing System

All hydroelectric generators greater than 25 MVA should be furnished with either a water deluge or carbon dioxide (CO₂) fire extinguishing system, to minimize the damage caused by a fire inside the machine. Generators 25 MVA or below should be evaluated individually to ensure installation of a cost effective system.

5 SMALL HYDRO GENERATOR UPTO & BELOW 5 MVA

5.1 General

Standardized or upgraded mass-produced machine should be used where possible. Most “off-the-shelf” or mass-produced machines are designed for lower overspeed values (typically 1.25 to 1.50 times rated speed) than are experienced with hydraulic turbines. Therefore, such generator designs should be checked for turbine runaway conditions.

Special Design Features as per IEC 1116 for these generators is as follows:

i) Designed to mechanically withstand continuous overspeed of 200 to 300% of rated speed of the turbine.
ii) These generators should be factory assembled that are shipped to the field as two integral component parts, rotor and stator. So that assembled work at site is minimize.
iii) Class F insulation with class B temperature rise
iv) Self lubricated journal type maintenance -free pedestal bearing
v) Open ventilation
vi) Fully assembled and dynamically balanced

Standard BHEL generators confirming to the IEC standards are given in table 5.1.

5.2 Classification Of Generators

There are basically two types of alternating current generator: synchronous and asynchronous (or induction) generators. The choice of the type to be used depends on the
characteristics of the grid to which the generator will be connected and also on the generator’s operational requirements.

Synchronous generators are used in the case of stand alone schemes (isolated networks). In case of weak grids where the unit may have significant influence on the network synchronous generator are used.

For grid connected schemes both types of generator can be used. In case grid is weak; Induction generators be used if there are two units, one of the unit can be synchronous so that in case of grid failure; supply could still be maintained. Unit size be limited to 250 kW. In case of stronger grids induction generators upto a 2001 kW or even higher can be used.

In case of isolated units, small capacity Induction generators with variable capacitor bank may be used upto a capacity of about 20 kW especially if there is no or insignificant Induction motor load i.e. less than about 20%.

Before making a decision on the type of generator to be used, it is important to take the following points into consideration:

- A synchronous generator can regulate the grid voltage and supply reactive power to the network. It can therefore be connected to any type of network.
- An induction generator has a simpler operation, requiring only the use of a tachometer to couple it to the grid as the machine is coupled to the grid there is a transient voltage drop, and once coupled to the grid the generator absorbs reactive power from it. Where the power factor needs to be improved, a capacitor bank will be necessary. The efficiency of an asynchronous generator is generally lower than that of a synchronous one.
### Table 5.1 STANDARD SHP GENERATORS MANUFACTURED BY M/S BHEL INDIA Ltd. (*)

**A. SHP**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Rating in kW</th>
<th>300</th>
<th>333.3</th>
<th>375</th>
<th>426</th>
<th>500</th>
<th>600</th>
<th>750</th>
<th>1000</th>
<th>1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>500</td>
<td>230M20</td>
<td>230M20</td>
<td>183M20</td>
<td>183M20</td>
<td>145M20</td>
<td>145M20</td>
<td>145M20</td>
<td>145M20</td>
<td>132M25</td>
</tr>
<tr>
<td>3.</td>
<td>1500</td>
<td>230M35</td>
<td>230M35</td>
<td>183M50</td>
<td>183M50</td>
<td>183M50</td>
<td>145M75</td>
<td>145M57</td>
<td>145M57</td>
<td>132M50</td>
</tr>
<tr>
<td>4.</td>
<td>2000</td>
<td>230M45</td>
<td>230M45</td>
<td>183M70</td>
<td>183M70</td>
<td>183M60</td>
<td>145M75</td>
<td>145M75</td>
<td>145M75</td>
<td>132M50</td>
</tr>
<tr>
<td>5.</td>
<td>2500</td>
<td>230M70</td>
<td>230M70</td>
<td>230M60</td>
<td>183M70</td>
<td>183M60</td>
<td>203M70</td>
<td>145M75</td>
<td>145M75</td>
<td>132M100</td>
</tr>
<tr>
<td>6.</td>
<td>3000</td>
<td>230M70</td>
<td>230M70</td>
<td>230M50</td>
<td>254M50</td>
<td>254M50</td>
<td>254M40</td>
<td>203M70</td>
<td>145M100</td>
<td>132M100</td>
</tr>
<tr>
<td>7.</td>
<td>3500</td>
<td>230M90</td>
<td>230M70</td>
<td>230M60</td>
<td>254M50</td>
<td>254M50</td>
<td>254M50</td>
<td>203M70</td>
<td>145M100</td>
<td>132M100</td>
</tr>
<tr>
<td>8.</td>
<td>4000</td>
<td>230M90</td>
<td>230M90</td>
<td>230M80</td>
<td>254M50</td>
<td>254M50</td>
<td>203M95</td>
<td>203M70</td>
<td>145M100</td>
<td>-</td>
</tr>
<tr>
<td>9.</td>
<td>4500</td>
<td>230M90</td>
<td>230M90</td>
<td>230M80</td>
<td>230M65</td>
<td>254M50</td>
<td>203M95</td>
<td>203M70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10.</td>
<td>5000</td>
<td>230M90</td>
<td>230M90</td>
<td>230M80</td>
<td>230M65</td>
<td>254M50</td>
<td>203M95</td>
<td>203M70</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**B. Mini Micro**: generators 200-500 kW; speed 300 to 1500 RPM; power factor 0.67 lag.; Voltage 415 to 11 kV

(*) A. M. Gupta BHEL, Bhopal - Small Hydro Generators – International course on technology selection for small hydro power development at Alternate Hydro Energy Centre (AHEC) during Feb. 18-28, 2003
Merits and demerits of synchronous and induction is given in table 5.2.

**Table 5.2 MERITS & DEMERITS SYNCHRONOUS V/S INDUCTION GENERATORS**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Item</th>
<th>Syn. Generator</th>
<th>Ind. Generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rotor construction</td>
<td>Salient pole type</td>
<td>Squirrel cage type</td>
</tr>
<tr>
<td>2</td>
<td>Excitation</td>
<td>Required</td>
<td>Not required</td>
</tr>
<tr>
<td>3</td>
<td>Isolated operation</td>
<td>Possible</td>
<td>Not possible</td>
</tr>
<tr>
<td>4</td>
<td>Stability</td>
<td>To be maintained by excitation</td>
<td>No problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>control</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Maintenance</td>
<td>More because of excitation &amp;</td>
<td>Less because of squirrel case</td>
</tr>
<tr>
<td></td>
<td></td>
<td>control equipments</td>
<td>rotor</td>
</tr>
<tr>
<td>6</td>
<td>Efficiency</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>7</td>
<td>Inertia</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>Cost</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>Power factor</td>
<td>Adjustable by excitation control</td>
<td>Not adjustable determined by load</td>
</tr>
<tr>
<td>10</td>
<td>Suitability for highly fluctuating loads</td>
<td>Ideal</td>
<td>Not suitable</td>
</tr>
<tr>
<td>11</td>
<td>Loads</td>
<td>Highly capacitive</td>
<td>Only inductive</td>
</tr>
<tr>
<td>12</td>
<td>Voltage variation</td>
<td>Possible</td>
<td>Not possible</td>
</tr>
</tbody>
</table>

Climatic conditions (ambient temperature, altitude, humidity) can affect the choice of the class of insulation level and temperature rises.

The cooling system of the generator should be evaluated. In the case where heat from the generator is expelled into the powerhouse sufficient powerhouse ventilation shall be provided.

If necessary, a braking system (either air or oil operated) should be considered.

**5.3 Selection and Characteristics**

Small hydro upto 5000 kW may be further sub classified as follows:

- Micro hydel upto 100 kVA
- Small hydro upto 5000 kVA

h) Microhydel generators may be selected in accordance with quality standard issued by AHEC extracts enclosed as Annexure 2. These generators are generally factory assembled and classified as category-1 generator in American Practice. They are shipped to site completely assembled depending on the rpm selected, unit speed/weights and method of transportation to site.
i) Small hydro up to 5 MVA are generally category-2 generators. These generators are factory assembled that are shipped to the field as two integral component parts, rotor and stator.

5.4 Vertical/Horizontal Configuration

With all turbines, a vertical or horizontal configuration is possible. The orientation becomes a function of the turbine selection and of the power plant structural and equipment costs for a specific layout. As an example, the Francis vertical unit will require a deeper excavation and higher power plant structure. A horizontal machine will increase the width of the power plant structure yet decrease the excavation and overall height of the unit. It becomes apparent that generator orientation and setting are governed by compatibility with turbine selection and an analysis of overall plant costs.

5.5 Speed (rpm): The speed of a generator is established by the turbine speed. The hydraulic turbines should determine the turbine speed for maximum efficiency corresponding to an even number of generator poles. Generator dimensions and weights vary inversely with the speed. For a fixed value of power a decrease in speed will increase the physical size and cost of generators. Low head turbine can be connected either directly to the generator or through to a speed increaser. The speed increaser would allow the use of a higher speed generator, typically 500, 750 or 1000 (1500) r/min, instead of a generator operating at turbine speed. The choice to utilize a speed increaser is an economic decision. Speed increasers lower the overall plant efficiency by about 1% for a single gear increaser and about 2% for double gear increaser. (The manufacturer can supply exact data regarding the efficiency of speed increasers). This loss of efficiency and the cost of the speed increaser must be compared to the reduction in cost for the smaller generator. It is recommended that speed increaser option should not be used for unit sizes above 3 MW capacity.

5.6 Dimension

Three factors affect the size of generator. These are orientation, kVA requirements and speed. The turbine choice will dictate all three of these factors for the generator.

The size of the generator for a fixed kVA varies inversely with unit speed. This is due to the requirements for more rotor field poles to achieve synchronous speed at lower rpm.

5.7 Overspeed Withstand

In the interest of safety, units with synchronous generators should be designed to withstand continuous runaway conditions.

5.8 Ratings and Electrical Characteristics

5.8.1 kW Rating: The kilowatt rating of the generator should be compatible with the kW rating of the turbine. The most common turbine types are Francis, fixed blade propeller,
and adjustable blade propeller (Kaplan). Each turbine type has different operating characteristics and imposes a different set of generator design criteria to correctly match the generator to the turbine. For any turbine type, however, the generator should have sufficient continuous capacity to handle the maximum kW available from the turbine at 100-percent gate without the generator exceeding its rated nameplate temperature rise. In determining generator capacity, any possible future changes to the project, such as raising the forebay (draw down) level and increasing turbine output capability, should be considered.

In a variable head power plant the turbine output may vary depending upon available head. In general the generator is rated for turbine output at rated head.

5.8.2 kVA Rating and power factor: kVA and power factor is fixed by consideration of location of the power plant with respect to load centre. These requirements include a consideration of the anticipated load, the electrical location of the plant relative to the power system load centers, the transmission lines, substations, and distribution facilities involved.

5.8.3 Frequency and Number of Phases: In India standard frequency is 50 cycle, 3 phase power supply.

5.8.4 Generator Terminal Voltage: Generator terminal voltage should be as high as economically feasible. Generator of less than 5000 kVA should be designed for 6.6 kV, 3.3 kV or 415 volts depending upon requirement of generator WR² or generator reactance. Economical terminal voltage for small hydro generators recommended by CBI & P (publication no. 280 – 2001) is as follows:

- Upto 750 kVA – 415 volts
- 751 – 2500 kVA - 3.3 kV
- 2501 – 5000 kVA - 6.6 kV
- Above 5000 kVA - 11 kV

Preferred voltage rating of generator as per IEC 60034-1 is as follows:

- 3.3 kV - Above 150 kW (or kVA)
- 6.6 kV - Above 800 kW (or kVA)
- 11 kV - Above 2500 kW (or kVA)

5.8.5 Stator Winding Connection: Star, stator winding connection are providing for both grounded or ungrounded operation and six terminal (3 on line side and 3 on neutral side) are brought out, except for small generators below 100 kW unit size when only one neutral is brought for ground connections.

5.8.6 Excitation Voltage: Rated generator rotor voltage is specified by the manufacturer, based on the rotor winding resistance and the excitation current required for full load operation at rated voltage and power factor, including suitable margin. Ceiling voltage is
as agreed upon by the manufacturer and purchaser. Standard voltage of excitation system are 62.5, 125, 150, 250 V DC.

5.8.7 Short Circuit Ratio, Line Charging and synchronous condenser capacity and damper windings considerations are discussed in Para 3.6.

5.9 Synchronous Generators

a) Stator:

Class F insulation level and Class B temperature rises are recommended. The American practice is to provide Class H insulation with a temperature of not more than 80°C.

b) Rotor:

The insulation level should normally be Class-F and temperature rises Class-B.

c) Excitation equipment:

It is recommended that a system requiring the least maintenance be chosen (e.g. static brushless excitation). Coupled excitation armature with rotating rectifier assembly and stationary excitation field suitable for voltage and power factor control is recommended.

d) Voltage regulating equipment:

The aim should be simplicity with a view to maintenance. This equipment could be included in the control system.

e) Synchronising equipment

May be manual and/or automatic. The synchronization should cover the voltage, frequency and phase. Normally this equipment is included in the automatic control system.

f) Power Factor

Between 0.8 and 1.0 depending on the reactive power requirements.

5.10 Asynchronous (Induction) Generator

a) Stator

Class F insulation level and Class B temperature rises are recommended.

b) Rotor
Squirrel cage construction, Class F insulation and Class B temperature rises are recommended.

These units should be designed to withstand continuous runaway conditions.

c) Voltage and Speed

The selection of voltage and speed affects the possibility of using a standard machine.

5.11 Guide and Thrust Bearings

The shaft system should be designed to minimize the number of bearings. It is essential to study the turbine and generator bearings as a systems is the choice between journal, ball or roller bearings, attention should be given to their ability to withstand vibrations, eddy currents and runaway conditions.

If the unit size is small and for reasons of simplicity, the use of self-lubricating bearings should be preferred.

5.12 Generator Efficiencies

The efficiency of an electrical generator is defined as the ratio of output power to input power. Efficiency values for commercially available generators are included in section 3. There are five major losses associated with an electrical generator. Various test procedures are used to determine the magnitude of each loss. Two classes of losses are fixed and therefore independent of load. These losses are (1) windage and friction and (2) core loss. The variable losses are (3) field copper loss, (4) armature copper loss and (5) stray loss or load loss.

Windage and friction loss is affected by the size and shape of rotating parts, fan design, bearing design and the nature of the enclosure. Core loss is associated with power needed to magnetize the steel core parts of the rotor and stator. Field copper loss represents the power losses through the dc resistance of the field. Similarly, the armature copper loss is calculated from the dc resistance of the armature winding. Stray loss for load loss is related to armature current and its associated flux. Typical values for efficiency range from 91 to 98%. This efficiency value is representing throughout the whole loading range of a particular machine; i.e., the efficiency is approximately the same at $\frac{1}{4}$ load or at $\frac{3}{4}$ load.

5.13 Testing of Generator

Factory and field tests before commissioning required to be performed depends upon the method of generator assembly required at site. There are usually 2 categories of generators for this purpose.
a. **Category – 1** Factory assembled generators supplied to site completely assembled. These are generally below 3 MW unit size.

b. **Category – 2** Factory assembled generators supplied at site as two integral component parts, rotor and stator. These are generally between 3 MW and 15 MW unit size.

### 5.13.1 Factory Assembly Test

Following factory and final acceptance tests are recommended to ensure proper performance and guarantees for category 1 & 2 types of generators.

- a. Resistance test of armature and field windings.
- b. Dielectric test of armature and field windings.
- c. Insulation resistance of armature and field windings.

This should include the polarization index values for both armature and field windings.

- d. Stator core loop test at rated flux for one hour.
- e. Phase rotation check
- f. No load saturation test
- g. Short circuit saturation test
- h. Mechanical balance of rotor
- i. Dynamic balancing of rotor at 125% rated speed
- j. Current transformer test
- k. Efficiency test
- l. Non Destructive Test of rotor tests of rotor shaft and shaft coupling bolts
- m. Material test certificates of various component parts.
- n. Temperature rise test

### 5.13.2 Field Acceptance Test

Field acceptance tests (all units). These tests consist of:

- a. Stator dielectric tests. These tests consist of: Insulation resistance and polarization index, Corona probe test, Corona visibility test, Final AC high potential test, Partial discharge analysis (PDA) test, and Ozone detection (optional).
- b. Rotor dielectric tests.
- c. Stator and rotor resistance tests.

Special field test (one unit of series). These tests consist of:

- a. Efficiency tests.
- b. Heat run tests.
- c. Machine parameter tests.
- d. Excitation test.
- e. Overspeed tests (optional)
6 EXCITATION SYSTEM

6.1 General

Excitation systems supply and regulate the amount of D. C. current required by generator field windings and include all power regulating control and protective elements. The excitation system should be specified to meet the power requirements and required response characteristics to meet the power system to which generator will be connected. Overall performance and capacity of the excitation system represented earlier by excitation response and response ratio is now expressed as nominal system response (ANSI/IEEE std. 421-1-1996). Standard excitation system voltages defined in ANSIC50-12 are 62.5, 125, 250, 375 and 500 V DC.

6.2 Excitation System Type

Modern static excitation have completely replaced older shaft mounted rotating exciters with DC field current controlled by motor operated field rheostat. Brushless excitation system and static excitation systems are being used in modern systems.

**Brushless Exciter:** An alternator-rectifier exciter employing rotating rectifiers with a direct connection to the synchronous machine field thus eliminating the need for field brushes, is typically shown in Fig 6.2 (a). Brushless system may be used for small hydro generators upto about 10 MVA where large DC current Capacity is not required. Unless the field of the exciter IS supplied from the PMG, a provision for field flashing the field of the rotating exciter for startup purposes is required.

**Static Excitation System:** The static excitation system is the most commonly used excitation system for hydro generators. It is typically shown in figure 6.2 (b). Static excitation systems consist of two basic types depending upon the speed of generator field suppression required. The full inverting bridge type uses six thyristor connected in a three-phase full wave bridge arrangement. It allows reversed DC voltage to be applied to the generator filed to force faster field suppression, thereby quickly reducing the generator terminal overvoltage during a full load rejection. The semi-inverting type uses three thyristor and three diodes connected in a three-phase full wave bridge. The semi-inverting type drives the positive DC voltage to zero during a full load rejection, but does not allow negative field forcing. Potential excitation source systems (from generator leads) are common for new generators and requires slip ring for supplying power to the field winding. Field flashing equipments is necessary for potential source excitation system which obtain power from machine terminals. in such cases, adequate self-cooling may be specified for startup without the need for auxiliary cooling power.

Digital controllers have proved to be more reliable and should be preferred.
Fig. 6.2(a)

Fig. 6.2 (b)
A comparison of the characteristics of two-excitation system is given in table 6.2.

**TABLE 6.2**

<table>
<thead>
<tr>
<th>Features</th>
<th>Exciter performance characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Potential controlled rectifier</td>
</tr>
<tr>
<td></td>
<td>Brush less exciter (rotating rectifier exciter)</td>
</tr>
<tr>
<td>High initial response</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No (see note 1)</td>
</tr>
<tr>
<td>Sustained fault current support</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>No (see note 1)</td>
</tr>
<tr>
<td>Online rectifier maintenance</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Spare exciter user</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Field monitoring ground relaying</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Yes, if Aux. Slip rings, or opto/EM/RF coupling is used</td>
</tr>
<tr>
<td>Rapid de-excitation</td>
<td>Yes, for half wave control, field breaker discharge resistor is required</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>General maintenance</td>
<td>Brushes and collectors</td>
</tr>
<tr>
<td></td>
<td>Exciter diode check</td>
</tr>
</tbody>
</table>

*Note 1:* may be possible with special provisions (refer IEEE std. 421.4-2004)

6.3 **Steady State Excitation System Requirement**

6.3.1 **Rated Field Current:** The direct current in the field winding of the generator when operating at rated voltage, current, power factor and speed.

6.3.2 **Exciter Rated Current:** Continuous current rating should be specified to equal or exceed the maximum required by the synchronous generator field under any allowed continuous operating condition including continuous overload rating.

6.3.3 **Exciter rated Voltage:** Exciter voltage rating should be sufficient to supply necessary continuous current to generator field at its maximum under rated load conditions.

6.3.4 **Rated Field Voltage:** The voltage required across the terminals of the field winding of the synchronous machine under rated continuous load conditions of the synchronous machine with its field winding at (1) $75^\circ$C for field windings designed to operate at rating with a temperature rise of $60^\circ$C or less; or (2) $100^\circ$C for field windings designed to operate at rating with a temperature rise greater than $60^\circ$C.

6.4 **Transient Requirements**

6.4.1 Transient requirements excitation system of generator is determined from following considerations.
The stability of a hydro turbine generator set while connected to its power system is critically important. However, the designer must also consider the unit’s characteristics when operating alone, or in an isolated “island” much smaller than the normal power system.

One example of a unit operating is a main unit serving as the station service source in a plant that becomes separated from its power distribution system. The unit will have to accept motor starting loads, and other station service demands such as gate and valve operation, while maintaining a safe and stable output voltage and frequency. All this will be accomplished while operating at a fraction of its rated output.

When operating in an “island” the unit may be required to operate in parallel with other units while running at speed-no-load in order to provide enough capacity to pick up blocks of load without tripping off line. In this case, stable operation without the stabilizing effect of a very large system is critically important to restoring service, and putting the system back together.

6.4.2 Ceiling Voltage

The maximum direct voltage, which the excitation system is able to supply from its terminals under following conditions.

1. No-load conditions
2. The ceiling voltage under load with the excitation system-supplying ceiling current.
3. Under power system disturbance conditions: System studies are normally required for fixing excitation system parameters for large generators from stability considerations. For small generators under consideration producing energy for a very large system, stability is not so critical since system voltage support will be beyond the small unit’s capability. Nonetheless, for its own safe operation, good voltage control is important. An extremely high response system is not necessary, but the system should respond rapidly enough to prevent dangerous voltage changes.
4. For excitation systems employing a rotating exciter, the ceiling voltage is determined at rated speed.

The ceiling voltage of high initial response static excitation system is normally specified directly after system studies as the ceiling voltage is reached in less than 0.1 second. Ceiling voltage for potentials source (from generator bus) static excitation system with high initial response for the generator under considerations may be specified 1.5 – minimum recommended by IEEE Std.

For brushless system, it may be considered a function of the nominal response, which could be specified.
6.4.3 Excitation System Nominal Response

The excitation system nominal response is defined as the rate of increase of the excitation system output voltage determined from the excitation system voltage response curve, divided by the rated field voltage (formerly called exciter response ratio). The rate, if maintained constant, would develop the same voltage time area as obtained from the actual curve over the first half-second interval. This may be specified for brushless excitation system only.

Excitation systems response based on a ceiling voltage for high initial response static excitation system and for the brushless system is compared in 6.4.3.

6.5 Power System Stabilizer

The excitation system stabilizer is used for fast acting high initial excitation system to stabilize oscillations that may occur between the machine and the systems by providing damping at power system frequency to control oscillation in the post fault period. IEEE std. 421.4-2004 requires power system stabilizer for grid connection at 66 kV and above so as to avoid oscillations in post fault period.

Fig. 6.4.3
6.6 **Under Excitation Limiter**

Under excitation limiter should be provided on all small hydro generators which are normally equipped with VAR (power factor control) and disconnected from the system on system disturbances to feed local loads/station service systems.

6.7 **Over excitation limiter**

Over excitation limiter should be provided on all generators to avoid overheating of the generator field winding in case of faults.

6.8 **Volts-per Hertz (V/Hz) Limiter**

The Volts-per Hertz (V/Hz) Limiter may be provided to prevent overheating that may arise from excessive magnetic flux due to under frequency operation or overvoltage operation, or both.

6.9 **VAR or PF Control System**

The generators under consideration cannot follow the changes in the system voltage and therefore must be equipped with power factor control regulators. These Grid connected power units require a power factor regulator as well as field current regulator with automatic change over from voltage control mode to power factor control mode after synchronizing with the grid. Further minimum and maximum field exciter limit are also required.

6.10 **Redundancy of Equipment**

Manual control is a back up to excitation controller failure is generally adequate.

Power rectifier bridge redundancy is generally provided by providing parallel rectifiers of which at least one is redundant. Redundant cooler should also be provided to ensure adequate cooling. This may be provided for generators above 5 MVA.

6.11 **Environmental Considerations**

Environmental considerations to be specified include electrical transients, radio interference, temperature extremes, humidity, altitude, vibration, corrosive atmosphere etc.

Special requirement include tropicalization, seismic considerations etc.
6.12 Equipment Tests

Complete factory assembly of the excitation system is generally not required. Routine, type and special tests may be carried out as per IEEE std. 421.4-2004. In addition factory tests and type tests for the excitation system recommended are given below:

6.12.1 Static Excitation (potential source rectifier exciter) system

a) Excitation transformer - factory tests

Factory tests may be carried out as per relevant IS: std. Routine tests should include measurement of following.

i) Winding resistance
ii) Ratio
iii) Polarity and phase relationships
iv) No-load loss (if capable)
v) Magnetizing current at rated voltage
vi) High potential test in accordance with IEEE std. 421.3-1997
vii) Induced potential

b) Type Tests (certified test report if type test is performed)

i) Impedance, load loss, and regulation
   ii) Temperature rise, i.e., heat run
   iii) Impulse test (s)

6.12.2 Rectifier Assembly

a) Excitation transformer - factory tests

Factory tests may be carried out as per relevant IS: std. Or IEEE std. C57.12.91-2001 Routine tests should include measurement of following.

i) Continuity of rectifier fuses
ii) Polarity and phase relationships
iii) Range and stability of rectifier phase control
iv) High potential test in accordance with IEEE std. 421.3 - 1997

b) Type Tests (certified test report if type test is performed)

i) Rated current, watt losses
   ii) Temperature rise, i.e. heat run
   iii) Burn in, 48 hours unless otherwise specified (designate if current or voltage burn in is required)
   iv) Verify current balance between parallel bridge
6.12.3 Brushless Excitation System

a) Factory tests

i) Insulation resistance
ii) Resistance of all windings at a specified temperature
iii) Resistance of all external current limiting resistors and field rheostats, where applicable
iv) Air gap
v) No-load saturation curve, from residual voltage to exciter ceiling voltage
vi) Phase rotation
vii) Continuity of rectifier fuses
viii) Rectifier leakage
ix) Range and stability of rectifier phase control, where applicable
x) High potential test
xi) Operation at anticipated overspeed

b) Type tests

i) Audible noise
ii) Load saturation curve, up to 110% of nominal ceiling voltage
iii) Main exciter regulation
iv) Heat run
v) Exciter time constant
vi) Excitation system voltage response time and response
vii) Operation at anticipated overspeed, at the anticipated maximum

7 EXAMPLE

7.1 Type and rating, electrical characteristics, mechanical characteristics, insulation and temperature rise and speed rise and run away speed specified for a 10 MVA grid connected powerhouse is enclosed as Annexure-3.

7.2 Brush less excitation system for 1.5 MW Pacha project in Arunchal Project (grid connected) is attached Annexure 4.

7.3 Static excitation system – Block diagram for 9 MW, 11 kV, 0.9 PF is at Annexure 5.
Annexure-I

Grid standard for operation and maintenance of transmission lines as per CEA (grid Standard) Regulation –2006

CEA (Grid Standards) Regulations, 2006

Schedule

Grid Standards for Operation and Maintenance of Transmission Lines

1. Frequency.-

The standard frequency of system operation is 50 Hz and all efforts shall be made to operate at frequency close to nominal as possible. The frequency shall not be allowed to go beyond the range 49.0 to 50.5 Hz, except during the transient period accompanying tripping or connection of load.

2. Voltage.-

(1) The steady state voltage shall be maintained within the limits given below:

<table>
<thead>
<tr>
<th>Nominal System Voltage (kV rms)</th>
<th>Voltage Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>765</td>
<td>+/- 3%</td>
</tr>
<tr>
<td>400</td>
<td>+/- 3%</td>
</tr>
<tr>
<td>220</td>
<td>+/- 5%</td>
</tr>
<tr>
<td>132 and below</td>
<td>+/- 10%</td>
</tr>
</tbody>
</table>

(2) Temporary over voltage due to sudden load rejection shall be within the limits specified below:

<table>
<thead>
<tr>
<th>Nominal System Voltage (kV rms)</th>
<th>Phase to Neutral Voltage (kV peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>765</td>
<td>914</td>
</tr>
<tr>
<td>400</td>
<td>514</td>
</tr>
<tr>
<td>220</td>
<td>283</td>
</tr>
<tr>
<td>132</td>
<td>170</td>
</tr>
</tbody>
</table>
(3) For the voltage level below 132 kV, the voltage variation limits as given in (2) above shall be decided by the State Commission in the respective State Grid Code.

3. **Voltage Unbalance.**

(1) The maximum permissible values of voltage unbalance shall be as under:

| Nominal System Voltage (kV rms) | Voltage Unbalance (%)
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>765 and 400</td>
<td>1.5%</td>
</tr>
<tr>
<td>220</td>
<td>2%</td>
</tr>
<tr>
<td>132</td>
<td>3%</td>
</tr>
</tbody>
</table>

(2) Bulk consumers shall ensure balanced load during operation.

(3) Low Voltage Single phase loads shall be balanced periodically at the distribution transformer by Distribution licensees.

4. **Protection Standards.**

(1) The Transmission Licensee and Users shall provide standard protection systems having the required reliability, selectivity, speed and sensitivity to isolate the faulty equipment and protect all components from any type of faults, within the specified fault clearance time. Protection coordination shall be done by the RPC.

(2) **Fault Clearance Time:**

The maximum fault clearance times are as given below:

<table>
<thead>
<tr>
<th>Nominal System Voltage (kV rms)</th>
<th>Maximum Time (in milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>765 and 400</td>
<td>100</td>
</tr>
<tr>
<td>220 and 132</td>
<td>160</td>
</tr>
</tbody>
</table>
(3) In the event of non-clearance of the fault by a circuit breaker within the time limit prescribed in 4(i) above, the Breaker Fail Protection shall initiate tripping of all other breakers in the concerned bus-section to clear the fault in next 200 milliseconds.


The following minimum security criterion shall be followed for operation and maintenance planning of the elements of the grid:

The Grid System shall be capable of withstanding one of the following contingencies without experiencing loss of stability:

(a) Outage of one single largest generating unit of the system or
(b) Outage of a 132 kV Double circuit line or
(c) Outage of a 220 kV Double circuit line or
(d) Outage of a 400 kV Single circuit line or
(e) Outage of a 400 kV Single circuit line with series compensation or
(f) Outage of 765 kV Single circuit line without series compensation or
(g) Outage of one pole of HVDC Bipolar line or
(h) Outage of an Interconnecting Transformer

6. Transient Stability.

Under any one of the following contingencies the system shall remain stable and sustain integrity (i.e., no generator shall lose synchronism and no part shall get isolated from the rest of the system):

(a) Tripping of a single largest generating unit or
(b) Transient ground fault in one phase of a 765 kV Single Circuit Line close to the bus or
(c) A sustained single phase to ground fault in 400 kV single circuit line followed by 3 pole opening of the faulted line or
(d) A sustained fault in one circuit of a 400 kV Double Circuit Line when both circuits were in service in the pre-contingency period or

(e) A transient single phase to ground fault in one circuit of a 400 kV Double Circuit Line when the second circuit is already under outage or

(f) A three-phase sustained fault in a 220 kV or 132 kV or

(g) A sustained fault in one pole of HVDC bipolar in a HVDC Converter Station.


The voltage wave-form quality shall be maintained at all points in the Grid.

(1) In this Standard Harmonic Content limits are stipulated as follows:

Total Harmonic Distortion = \( V_{THD} \) (expressed as percentage)

\[
V_{THD} = \sqrt{\sum_{n=2}^{\infty} \frac{V_n^2}{V_1^2} \times 100}
\]

'I' refers to fundamental frequency (50 Hz)

'n' refers to the harmonic of \( n^{th} \) order (corresponding frequency is 50 x \( n \) Hz)

(2) Maximum Limits of total Harmonic Distortion

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>Total Harmonic Distortion</th>
<th>Individual Harmonic of any particular Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV rms</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>765</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>400</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>220</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>132</td>
<td>3.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

This Standard shall come into force not later than five years from the date of the publication in the official Gazette.
8. Voltage Fluctuations.

(1) The permissible limit of voltage fluctuation for step changes which may occur repetitively is 1%.

(2) For occasional fluctuations other than step changes the maximum permissible limit is 2%.

The limits prescribed in (a) and (b) above shall come into force not later than two years from the date of the publication of these Standards in the official Gazette.
Annexure-2

Generator for Micro Hydel
(as per AHEC Micro Hydro Quality Std.)

A. Synchronous Generators and Induction Motors as Generators

1. **Brand.** The brand and power rating of the generator or motor should be approved by the manufacturer of the turbines and by the purchaser.

2. **Nameplate.** The original manufacturer’s nameplate for the generator or motor must be retained. New nameplates can be added but must not replace the originals.

3. **Over-rating.** The power rating given on the original nameplate must be at least 10% more than the scheme rated power.

4. **Generator voltage.** The “power house voltage” is the voltage at the generator terminals with powerhouse-consumer isolation switch in off position. This must be between the nominal national voltage (415 V) and +10% of 415 V.

5. Generator rotational speeds to be selected shall be 1500 rpm (+slip) or lower. In cases of direct coupling 750 rpm or 1000 rpm generators should be preferred.

B. Synchronous Generators

1. **Frequency.** The operating frequency should be between 47.5 and 52.5 Hz.

2. **Pf.** The power factor rating should be 0.8 when an ELC is in use except where all loads and the ELC present a unity power factor.

3. Brushless generators shall be supplied with regulator (AVR). The unit proposed for interconnection with grid shall have in addition automatic power factor Regulator (APFR) with automatic change over from AVR to APFR when grid interconnection circuit breaker.

4. The generator shall be capable of continuous withstand against runaway speed.

C. Induction Motors as Generators

1. **Frequency.** The frequency should be between 50 and 52.5 Hz. The frequency should be within this range under all operating conditions, including minimum and maximum power output, zero consumer load and worst-case consumer load power factor.

2. The induction generator must be **over-voltage protected** to avoid excessive currents to flow through the excitation capacitors and induction machine. A protection system is required that disconnects all or some of the capacitors, to limit the currents flowing to below the limits for the induction machine windings and the capacitors. Provide MCBs of suitable current rating in the series with excitation capacitors.

   The generator shall be capable of continuous withstand against runaway speed.
A. CAPACITY AND RATING

A net capacity of 10,000 kVA at rated conditions is required. The generator nameplate rating shall reflect the necessary additional capacity to supply the excitation equipment. The generator shall be capable of 10% continuous overload capacity.

(a) Power factor 0.9 lagging
(b) Frequency 50 cycles
(c) Number of phases 3
(d) Voltage between phases, rated (kV) 11
(e) Speed (RPM) To match turbine speed
(f) Stator winding connections Star, (suitable both for grounded or ungrounded operation)
(h) Excitation voltage, not to exceed 250 VDC
(g) Guaranteed unsaturated (rated current) Direct axis transient reactance not more than

B. ELECTRICAL CHARACTERISTICS

Each generator shall have the following principle characteristics.

1. Rated continuous rating at kVA 10,000
   0.9 lagging power factor and at
   normal rated terminal voltage
2. Continuous overload capacity 10 %
3. Terminal voltage at which the maximum Continuous rating must be achieved
   11 kV
4. Minimum terminal voltage under Operating continuous with unloaded system
   10 % lower then the normal rated voltage
5. Excitation at maximum leading KVA expressed as percentage of that required at rated output and power factor
   Not less then 12 %
6. Terminal voltage at which the maximum Continuous rating must be achieved
   5 % higher then the normal rated voltage
7. Short circuit ratio on rated KVA Base, not less then
   1.0
8. Total Harmonic Distortion (THD) Not to exceed 5%
9. Deviation factor of wave form, measured in percent of open circuit at rated voltage and frequency, not more then
   5
10. Efficiency at 10,000 kVA 0.9 power factor lagging at normal rated voltage and frequency not less then percent
    97 %
11. Normal exciter response for the To suit above ratio
exciter, not less then

12. Ceiling voltage of exciter when connected to the generator field and with rated exciter current delivered (80 degree C)

8. Line charging capacity of the generator, when charging a transmission line, at rated speed and voltage, without being completely self excited or unstable not less then KVA

9. Maximum ambient air temperature degrees centigrade

C. MECHANICAL CHARACTERISTICS

1. Flywheel effect (WR²) of rotating parts of the generator and exciter Normal
2. Direction of rotation To match turbine
3. Maximum runway speed r.p.m. To match turbine
4. Maximum temperature of inlet cooling water for air cooling system 36°C
5. Design mechanically to withstand Continuously. Without exceeding the specified normal operating stress, a load of kW (1.0 pf) 9000 kW
6. Design mechanically to withstand temporary overloads, with stress not exceeding one – half the yield point corresponding to turbine output of not less then (provided that the duration of such overload is not sufficient to cause injurious heating) kW. 9900 kW
7. Designed for operation with a turbine having the following rated output kW. 9250 kW at 0.9 gate opening the rated head

D. INSULATION AND TEMPERATURE RISE

a. Insulation shall be provided as follows:

   (i) Stator Winding Material corresponding to class F
   (ii) Rotor Winding Material corresponding to class F

b. The generator shall be capable of delivering rated output at any voltage and frequency in the operating range at rated power factor without exceeding the following values of temperature rise over ambient temp. Cooling air entering the generator at not more than 40°C (Cooling water maximum temperature 36°C).

   (i) Stator Winding 70°C
(ii) Rotor Winding 70°C
(iii) Stator core 75°C

c. The maximum temperature rise when the generator is delivering maximum output corresponding to continuous overload capacity for conditions rated above shall not exceed 90°C for both for stator and rotor winding respectively. Temperature rise shall be guaranteed in the tender and shall be measured on site in accordance with IEC 340 or relevant IS.

E. SPEED RISE AND RUNAWAY SPEED

The moment of Inertia of the generator together with the moment of inertia of the turbine shall be such that the maximum momentary speed rise under Governor Control on full load rejection shall not exceed 45% of rated speed for the grid connected generator as station power is supplied from main generator and adverse effect of this speed rise on motor driven station auxiliaries is not desirable. Additional flywheel required shall be built in the rotor. Separate flywheel shall not be permitted.

The maximum runaway speed shall be stated and guaranteed by the supplier. All rotating parts and bearings shall be capable of withstanding the forces and stresses occurring during runaway speed for at least 30 minutes without any damage to any part. The guide bearing and guide cum thrust bearing shall be capable to withstand runaway speed for 30 minutes without supply of cooling water and continuously with cooling water without abnormal increase of vibrations and temperature.
Annexure-4

Brushless Excitation System for 1.5 MW, 3.3 kV, 750 RPM, 50 Hz, 0.8 PF, 8 poles Generators (Pacha Project)
Static Excitation System - Block Diagram for 9 MW, 11 kV, 0.9 PF, 125 RPM Generators