

STANDARDS/MANUALS/ GUIDELINES FOR SMALL HYDRO DEVELOPMENT

3.2 Electro-Mechanical– Selection of Generators and Excitation Systems

Sponsor:

Ministry of New and Renewable Energy
Govt. of India

Lead Organization:

Alternate Hydro Energy Centre
Indian Institute of Technology Roorkee

July 2012

Contact:

Dr Arun Kumar

Alternate Hydro Energy Centre,
Indian Institute of Technology Roorkee,

Roorkee - 247 667, Uttarakhand, India

Phone : Off.(+91 1332) 285821, 285167

Fax : (+91 1332) 273517, 273560

E-mail : aheciitr.ak@gmail.com, akumafah@iitr.ernet.in

DISCLAIMER

The data, information, drawings, charts used in this standard/manual/guideline has been drawn and also obtained from different sources. Every care has been taken to ensure that the data is correct, consistent and complete as far as possible.

3.2

The constraints of time and resources available to this nature of assignment, however do not preclude the possibility of errors, omissions etc. in the data and consequently in the report preparation.

Use of the contents of this standard/manual/guideline is voluntarily and can be used freely with the request that a reference may be made as follows:

AHEC-IITR, “3.2 Electro-Mechanical – Selection of Generators and Excitation Systems”, standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, June 2012.

PREAMBLE

There are series of standards, guidelines and manuals on electrical, electromechanical aspects of moving machines and hydro power from Bureau of Indian Standards (BIS), Rural Electrification Corporation Ltd (REC), Central Electricity Authority (CEA), Central Board of Irrigation & Power (CBIP), International Electromechanical Commission (IEC), International Electrical and Electronics Engineers (IEEE), American Society of Mechanical Engineers (ASME) and others. Most of these have been developed keeping in view the large water resources/ hydropower projects. Use of the standards/guidelines/manuals is voluntary at the moment. Small scale hydropower projects are to be developed in a cost effective manner with quality and reliability. Therefore a need to develop and make available the standards and guidelines specifically developed for small scale projects was felt.

Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee initiated an exercise of developing series of standards/guidelines/manuals specifically for small scale hydropower projects with the sponsorship of Ministry of New and Renewable Energy, Government of India in 2006. The available relevant standards / guidelines / manuals were revisited to adapt suitably for small scale hydro projects. These have been prepared by the experts in respective fields. Wide consultations were held with all stake holders covering government agencies, government and private developers, equipment manufacturers, consultants, financial institutions, regulators and others through web, mail and meetings. After taking into consideration the comments received and discussions held with the lead experts, the series of standards/guidelines/manuals are prepared and presented in this publication.

The experts have drawn some text and figures from existing standards, manuals, publications and reports. Attempts have been made to give suitable reference and credit. However, the possibility of some omission due to oversight cannot be ruled out. These can be incorporated in our subsequent editions.

This series of standards / manuals / guidelines are the first edition. We request users to send their views / comments on the contents and utilization to enable us to review for further upgradation.

Standards/ Manuals/Guidelines series for Small Hydropower Development

General	
1.1	Small hydropower definitions and glossary of terms, list and scope of different Indian and international standards/guidelines/manuals
1.2 Part I	Planning of the projects on existing dams, Barrages, Weirs
1.2 Part II	Planning of the Projects on Canal falls and Lock Structures.
1.2 Part III	Planning of the Run-of-River Projects
1.3	Project hydrology and installed capacity
1.4	Reports preparation: reconnaissance, pre-feasibility, feasibility, detailed project report, as built report
1.5	Project cost estimation
1.6	Economic & Financial Analysis and Tariff Determination
1.7	Model Contract for Execution and Supplies of Civil and E&M Works
1.8	Project Management of Small Hydroelectric Projects
1.9	Environment Impact Assessment
1.10	Performance evaluation of Small Hydro Power plants
1.11	Renovation, modernization and uprating
1.12	Site Investigations
Civil works	
2.1	Layouts of SHP projects
2.2	Hydraulic design
2.3	Structural design
2.4	Maintenance of civil works (including hydro-mechanical)
2.5	Technical specifications for Hydro Mechanical Works
<i>Electro Mechanical works</i>	
3.1	Selection of Turbine and Governing System
3.2	Selection of Generators and Excitation Systems
3.3	Design of Switchyard and Selection of Equipment, Main SLD and Layout
3.4	Monitoring, control, protection and automation
3.5	Design of Auxiliary Systems and Selection of Equipments
3.6	Technical Specifications for Procurement of Generating Equipment
3.7	Technical Specifications for Procurement of Auxiliaries
3.8	Technical Specifications for Procurement and Installation of Switchyard Equipment
3.9	Technical Specifications for monitoring, control and protection
3.10	Power Evacuation and Inter connection with Grid
3.11	operation and maintenance of power plant
3.12	Erection Testing and Commissioning

PERSONS INVOLVED

1. Dr Arun Kumar, CSO & Principal Investigator ,AHEC,IIT, Roorkee
2. Dr S K Singal, SSO & Investigator,AHEC,IIT, Roorkee

Drafting Group

1. Prof. O.D.Thapar, Consultant, AHEC,IIT, Roorkee
2. Mr. S.K.Tyagi, Consultant, AHEC,IIT, Roorkee

Consultation Group

1. Dr Arun Kumar,AHEC,IIT, Roorkee
2. Mr S.N.Singh, AHEC,IIT, Roorkee
3. Dr S K Singal,AHEC,IIT, Roorkee
4. Mr. S.C.Jain, Consultant, AHEC,IIT, Roorkee
5. Mr. Masum Ali, Consultant, AHEC, IIT, Roorkee
6. Mr. A.K.Chopra, MNRE,GOI, New Delhi
7. Mr. Jugal Kishore, Consultant, Hardwar
8. Mr. S.V. Dinkar, Consultant,Pune
9. Mr. Surendra Singh ,PGCL, PEDA,Chandigarh
10. Mr. Pankaj Kulshreshtha, UJVNL, Dehradun
11. Mr. Himanshu Tiwari, UJVNL, Dehradun
12. Mr. A.K.Singh, UJVNL, Dehradun
13. Mr. P.K.Singhal, UPJVNL, Lucknow
14. Mr. V.K.Sharma, THDC, Rishikesh
15. Mr.D.V.Mane,MSPGC Ltd.Maharashtra
16. Mr. U Ukhal, HPPCL, Himachal Pradesh
17. Mr.J.S.Jabbi, Brindaban Hydropower Pvt. Ltd,Karnataka
18. Mr. K.C.Arora, Pentafo Hydro power Ltd
19. Mr. P.K.malohtra, Pentafo Hydro power Ltd
20. Mr. Sanjeev Handu, Andriz Hydro power Ltd.
21. Mr. Vishnupad Saha, Andriz Hydro power Ltd.
22. Mr. Dinesh Rajput, Andriz Hydro power Ltd.
23. Mr. Pradeep Dube, Tanushree Hydropower Consultants, Noida
24. Mr P.N.Bhardwaj,Consultant,Solan(HP)
25. Mr. T.K.Modak, Jyoti Ltd.,New Delhi
26. Mr. H.M.Sharma, Jyoti Ltd.,Vadodra
27. Mr. Viral B Mahida, Jyoti Ltd.,Vadodra
28. Mr. Nishant Saha, Jyoti Ltd.,Vadodra

CONTENTS

ITEMS		PAGE NO
1.	General	1
1.1	Scope	1
1.2	References and Codes	
2.	Ratings and Electrical Characteristics	2
2.1	kW Rating	2
2.2	kVA Rating and Power Factor	3
2.3	Frequency and Number of Phases	3
2.4	Generator Terminal Voltage	3
2.5	Stator Winding Connection	4
2.6	Excitation Voltage	4
2.7	Others	4
3.	Hydro Generator above 5 MW	4
3.1	General	4
3.2	Electrical Characteristics	9
3.3	Mechanical Characteristics	13
4.	Small Hydro Generator upto & Below 5 MW	16
4.1	General	16
4.2	Classification of Generators	16
4.3	Selection and Characteristics	17
4.4	Vertical / Horizontal Configuration	18
4.5	Speed (rpm)	18
4.6	Dimension	19
4.7	Over Speed Withstand	19
4.8	Synchronous Generator	19
4.9	Asynchronous (Induction) Generator	20
4.10	Guide and Thrust Bearings	20
4.11	Generator Efficiencies	20
4.12	Testing of Generator	20
5.	Excitation System	22
5.1	General	22
5.2	Excitation System Type	22
5.3	Steady State Excitation System Requirement	24
5.4	Transient Requirements	25
5.5	Power System Stabilizer	27
5.6	Under Excitation Limiter (Limit 10-15%)	27
5.7	Over Excitation Limiter	27
5.8	Volts-per Hertz (V/Hz) Limiter	27
5.9	VAR or PF Control System	27
5.10	Redundancy of Equipment	27
5.11	Environmental Considerations	27
5.12	Equipment Tests	28

ITEMS		PAGE NO
6.0	Example	29
6.1	Type and Rating	29
6.2	Brush Less Excitation System	33
6.3	Static Excitation System	34

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
1	Typical Hydro-Generator capability Curve	6
2	Brushless Excitation System	23
3	Static (Potential Controlled Rectifier) Excitation System	24
4	Comparison of Excitation systems response based on a ceiling voltage for high initial response static excitation system and for the brushless system	26
5	Brushless Excitation System for 1.5 MW, 3.3 kV, 750 RPM, 50 Hz, 0.8 PF, 8 Poles Generators	33
6	Static Excitation System - Block Diagram for 9 MW, 11 kV, 0.9 PF, 125 RPM Generators	34

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
1	Voltage and Frequency Limits for Generators (as per IEC: 60034)	5
2	Continuous negative sequence current capability	8
3	Power factor v/s conductor capacity	11
4	Typical values of transient reactances	12
5	Merits & Demerits Synchronous V/S Induction Generators	17
6	Comparison of the characteristics of two-excitation system	23

LIST OF ANNEXURE

ANNEXURE NO.	TITLE	PAGE NO.
1	Grid standard for operation and maintenance of transmission lines as per Central Electricity Authority (grid Standard) Regulation –2010	35
2	Generators for Micro Hydroelectric Plants (As per AHEC Micro Hydro Quality Standard-2005)	48

SELECTION OF GENERATORS AND EXCITATION SYSTEM

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 generator (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 meet grid standards for operation and maintenance of transmission lines issued by Central Electricity Authority (CEA). Relevant extracts are enclosed as Annexure 1.

1.1 Scope

This guide line covers selection criteria for induction generators up to 3 MW capacity and synchronous generators up to 25 MW capacity along with suitable excitation system.

1.2 References and Codes

Latest edition of the following standards are applicable.

- (R1). IEC-61116: 1992 – Electro-Mechanical Equipment Guide for Small Hydro-electric Installation
- (R2). IEC-60034-1: 2004 – Rotating Electrical Machines, Rating and Performance
- (R3). IEC-60034-2A-1987 – Rotating Electrical Machines Methods for determining losses and efficiency of electrical machinery from tests (excluding machines for traction vehicles)

- (R4). IEC-60034-5-1991 – Classification of degrees of protection provided by enclosures for rotating electrical machines (IP Code)
- (R5). IEC-60085-1987 – Classification of materials for the insulation of electrical machines
- (R6). IS-4722 –1992 – Rotating electrical machines
- (R7). IS-325 –1996 – Three phase induction motor
- (R8). IS-8789 –1996 – Values of performance characteristics for three phase induction motors
- (R9). IEEE 1010-2006 – Guide for Control of Hydro Power Plants
- (R10)IEEE C50.12-2005 – Salient –pole50 HZ and 60HZ Synchronous Generator/ Motors for Hydraulic Turbine Applications rated 5 MVA and above
- (R11) IEEE C37.102 (2006) - IEEE Guide for AC Generator Protection
- (R12) IEEE 421.4-2004 - IEEE Guide for the preparation of excitation system specifications
- (R13) IEEE 421.3-1997 - High potential test requirements for excitation systems for synchronous machines
- (R14) IEEE C57.12.91-2001- Test code for dry type distribution and power transformers
- (R10). AHEC IITR – Micro-Hydro Quality Standard-2005
- (R11). CBIP – Manual on Planning and Design of Small Hydro electric Schemes: Publication no. 305 – 2009

Abbreviations:

IEC-International Electro technical Commission

IEEE-Institute of Electrical and Electronics Engineers

IS-Indian Standards

AHEC IITR-Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee

CBIP – Central Board of Irrigation and Power, India

2. RATINGS AND ELECTRICAL CHARACTERISTICS

2.1 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, adjustable blade propeller (Kaplan), Pelton and cross flow. 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 90-percent gate opening without the generator exceeding its rated nameplate temperature rise. In determining generator capacity, any possible future changes to the project, such as raising the fore bay (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.

2.2 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 location of the plant relative to the power system load centers, the transmission lines, substations and distribution facilities involved.

2.3 Frequency and Number of Phases

In India standard frequency is 50 cycles, 3 phase power supply.

2.4 Generator Terminal Voltage

Generator terminal voltage should be as high as economically feasible. Generator of less than 5000 kVA may be designed for 6.6 kV, 3.3 kV or 415 volts depending upon requirement of generator WR^2 or generator reactance. Minimum voltage rating of generator as per IEC 60034-1 and IS: 4722 and Economical terminal voltage for small hydro generators recommended by CBI P (305 – 2009) are as follows:

IEC – 60034-1 (Minimum)	CBIP Publication No. 305 (Economical)
3.3 kV – Above 150 kW (or kVA)	Upto 750 kVA – 415 volts
6.6 kV – Above 800 kW (or kVA)	751 – 2500 kVA – 3.3 kV
11 kV – Above 2500 kW (or kVA)	2501 – 5000 kVA – 6.6 kV
	Above 5000 kVA – 11 kV

Recommended rated economical stator voltages are as follows:

Up to 400 kW (or kVA)	– 415 volts
401 – 2500 kW(or kVA)	– 3.3 kV
2501 – 5000 kW (or kVA)	– 6.6 kV
Above 5000 kW (or kVA)	– 11 kV

2.5 Stator Winding Connection

Star, stator winding connection are provided 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 out for ground connections.

2.6 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, frequency and power factor, including suitable margin. Ceiling voltage is as agreed upon by the manufacturer and purchaser. Voltage of excitation system should be less than 250 V DC.

2.7 Other

Normal short Circuit Ratio, Reactance, Line Charging and synchronous condenser capacity be provided.

3. HYDRO GENERATOR ABOVE 5 MW

3.1 General

Hydraulic turbine driven generators for hydro plants are salient pole synchronous alternating current machines. Large salient pole generators are relatively slow and medium 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.

3.1.1 Site Operating Conditions (as per IS: 4722, 12802)

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 Cooled Temperature: Salient-pole open ventilated air-cooled synchronous generators operate successfully when and where the reference temperature of the cooling air does not exceed 40⁰C.

Salient-pole totally enclosed water to air cooled (water) synchronous generators operate successfully when and where the secondary reference coolant temperature at the inlet to the machine or heat exchanger do not exceed 25⁰C.

If the cooling air temperature (ambient) exceeds 40⁰C, or cooling water temperature exceeds 25⁰C then maximum allowable temperature based on temperature rise on reference temperature (40⁰/25⁰C) of the insulation class B specified instead of temperature rise. Unpredictable hot spot and premature failure of insulation of some large generators requires specifying conservative temperature rise (See Para 3.2.1). The limits of temperature rise/temperature should be agreed between the manufacture and purchaser.

If the minimum ambient temperature of the air at the operating site is – 15⁰C, the machine being installed and in operation or at rest and de-energized or + 5⁰C for machines

having water as primary or secondary coolant than the manufacturer should be informed of actual site conditions for agreed operating 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. Corrections should be made as per clause 6.3 of IS: 12802 as given below.

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.

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 $\pm 5\%$ in voltage and $\pm 2\%$ (Fig. 1) in frequency. These are given in table 1.

Table 1. : Voltage and Frequency Limits for Generators (IEC: 60034)

	Normal	Emergency
Voltage limits	$\pm 5\%$	$\pm 5\%$ to $\pm 8\%$
Frequency limit	$\pm 2\%$	+ 2% to + 3%; - 2% to - 5%

- 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 at outputs near the limits of the generator's reactive capability curve may (figure 1) may 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 % to -5 % in frequency 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 above limits 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 as defined result in the magnetic circuits of the generator to be over fluxed under fluxed by no more than 5%.
- e) The machine may be unstable or margins of stability may be reduced under some of the operating conditions mentioned in 'a' above. Excitation margins may also be reduced under these operating conditions.
- 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.

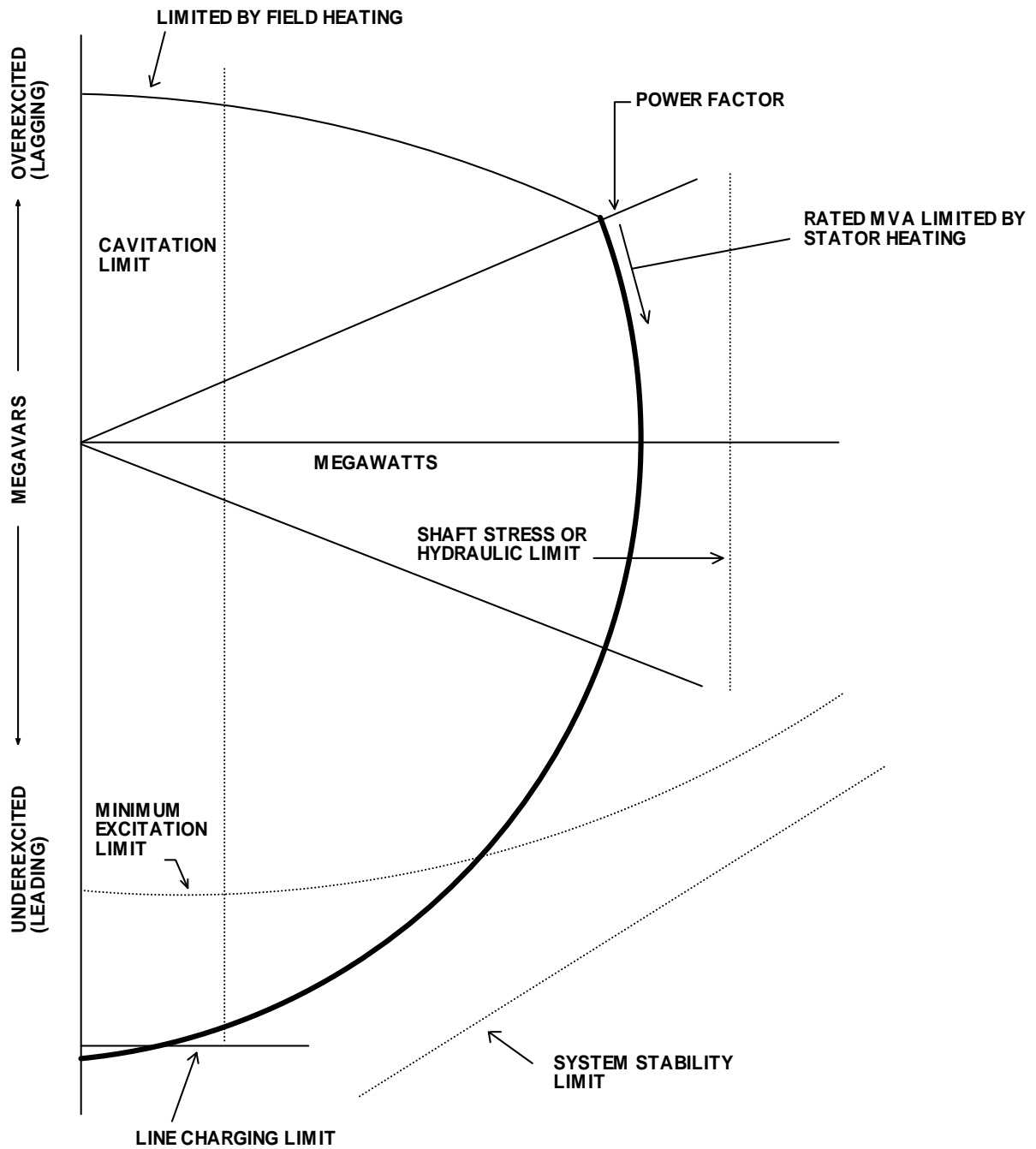


Fig. 1: Typical Hydro-Generator capability Curve
(Source- IEC: 60034)

- 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.

3.1.2 Transient event and emergency duty requirements

A generator conforming 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.

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 | ± 0.067 Hz |

IEEE. C3. 102- 1995 provides additional information on synchronizing practices.

- (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° or 120° 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 curves apply for time intervals of less than 10 min.

3.1.3 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 2, providing the rated MVA is not exceeded and the maximum as expressed as a percentage of rated stator current.

Table 2 : Continuous negative sequence current capability

Type of generator or generator/motor	Permissible I_2 (%)
Non-connected amortisseur winding	5
Connected amortisseur winding	10

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. Machines with connected amortisseur windings should be specified. Negative sequence relays (phase unbalance) be set accordingly.

3.1.4 Types of Generators and Configuration (Vertical or Horizontal)

Vertical shaft generators are generally used in this range (above 5 MW). 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 can be horizontal or vertical but in SHP these are mostly horizontal shaft.

3.1.5 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 Pelton, 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 1.

3.1.6 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.

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

3.2 Electrical Characteristics

Electrical Characteristics e.g. voltage, short circuit ratio, reactance, 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.

3.2.1 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 upto 1965. Present practice is to be specified class F insulation system for the stator and rotor winding with class B temperature rise over the ambient. Ambient temperature should be determined carefully from the temperature of the cooling water etc.

It 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. In practice conservative maximum temperature of insulation for stator and rotor are specified in view of the unpredictable nature of hot spot. Typical specification for a typical site on this basis is given below and on the basis of temperature rise in table 6.1.

Insulation shall be provided as follows:

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

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. Cooling air entering the generator at not more than 50°C (Cooling water maximum temperature 36°C).

(i)	Stator Winding	105°C
(ii)	Rotor Winding	105°C
(iii)	Stator core	100°C

The maximum temperature when the generator is delivering maximum output corresponding to continuous overload capacity for conditions rated above shall not exceed 125°C for both stator and rotor winding respectively. Temperature rise shall be guaranteed in the tender and shall be measured on site in accordance with IEC 60034 or relevant IS. Armature winding by embedded temperature detectors located in armature winding and temperature of field winding by resistance method. Water for cooling purposes will be available at temperatures not exceeding 36°C.

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, reliable winding life.

3.2.2 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 ratio is around 1.0 at 0.9 pf. Higher than normal short circuit ratio will increase cost and decrease efficiency.

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. The generator parameters which have a bearing on stability are the flywheel effect, transient, sub transient reactance and short circuit ratio. Present practice is to specify generators with normal short circuit ratio and other characteristics and achieve requirements of stability by optimizing parameters of excitation system.

3.2.3 Line Charging and Synchronous Condensing Capacity

This is the capacity required to charge an unloaded line. Line charging capacity of a generator 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 given in table 3:

Table 3: Power factor v/s condenser capacity

Power Factor	Condenser Capacity
0.80	60%
0.90	55%
0.95	45%

3.2.4 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 water wheel generators in the range under consideration are given below in table 4. Guaranteed values of transient reactances approximately 10% higher.

Table 4: Typical values of transient reactances

MVA Rating	Rated Sub-transient Reactance - x_d''		
	Speed RPM		
	100	150	300
10 - 25	0.27	0.26	0.25

3.2.5 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 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 inert loads and is generally not applicable to generator size under considerations.

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 greater than 2.0 for a salient pole generator with no damper winding, and can be as low as 1.1. It is recommended that for this range of salient pole generator fully interconnected winding be provided with X_q''/X_d'' not greater than 1.3.

3.2.6 Efficiency

Efficiency as high 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 WR^2
- iii. Higher axial thrust

3.2.7 Irregularities of Waveform (Telephone Harmonic Factor)

This is required only for synchronous machines having rated outputs of 300 kW (or kVA) or more with a view minimizing interference between power lines and adjacent circuit.

Limits: When tested on open circuit and at rated speed and voltage, the telephone harmonic (TH) of the line-to-line terminal voltage, as measured according to the methods laid down in IS: 4722 (Clause 9) should not exceed 1.5 % for this range of generator.

3.3 MECHANICAL CHARACTERISTICS

3.3.1 Direction of Rotation

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

3.3.2 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 and should be at least 10 % above runaway speed. 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 within limits specified in IS: 12075 – 2008/ ISO: 7919-5 for machine sets in hydraulic power generating and pumping plants.

3.3.3 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, Y, B, (right, center, left) or Y, B, 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.

3.3.4 Noise Level

Under all operating conditions, the noise level of generator should be less than 85 dB (A) at a distance of 1 meter radially & 1.5 m from floor of operating. In order to prevent undue and harmful vibrations, all generators shall be dynamically balanced in accordance with IEEE . C50.12-2005. Test procedure for verification shall be based on ISO 3746. Acoustic treatment may be necessary to achieve decreasing sound pressure levels at 90 db.

3.3.5 Over speed withstand

It is general practice in India to specify all hydro generators to be designed for full turbine runaway conditions (IS: 4722-2001). The stresses during design runaway speed should not exceed two-thirds of the yield point.

3.3.6 Flywheel Effect

Flywheel effect is expressed as moment of inertia (GD^2) (in India) as compared to flywheel effect WR^2 (US/English) $GD^2 = \text{weight} \times \text{Diameter}^2$ and $WR^2 = \text{weight} \times \text{Radius}^2$ (lb.ft^2).

$$\text{Accordingly, } WR^2 = \frac{GD^2}{4}$$

Conversion factor for WR^2 (USA) in lb.ft^2 and GD^2 (India) kg. m^2 is as follows:

$$GD^2 = x \times 5.9 = \text{lb.ft}^2 \approx 6x \text{ lb.ft}^2$$

The flywheel effect of the generator can be increased by adding weight in the rim of the rotor or by increasing the rotor diameter to certain value. Increasing the GD^2 increases the generator cost, size and weight, and lowers the efficiency. The need for above-normal WR^2/GD^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 guidelines for turbine selection. In most of the cases power system stability considerations do not arise in small hydro generators.

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 guidelines of turbine selection.

3.3.7 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 modern hydro generators rated greater than 5 MW. The coolers are situated around the outside periphery of the stator core. Generators equipped with water-to-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 MW. 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, suitable filters must be provided in the cooling water supply lines to avoid frequent failing or plugging of the water-to-air coolers.

3.3.8 Thrust Bearing Lubrication

Specifications for generators above 5 MW, and for generators in unmanned plants, should require provisions for automatically pumping oil under high pressure between the shoes and the runner plate of the thrust just prior to and during machine startup, and when stopping the machine.

3.3.9 Fire Extinguishing System

All hydroelectric generators greater than 25 MW 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 MW or below should be evaluated individually to ensure installation on cost effective system.

4. SMALL HYDRO GENERATOR UPTO & BELOW 5 MW

4.1 General

Standardized or upgraded mass-produced machine should be used where possible conforming to IS: 4722. Most “off-the-shelf” or mass-produced machines are designed for lower over speed 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.

Accordingly cylindrical rotor synchronous may be considered upto 3 MW capacity.

Special Design Features as per IEC 61116 or conforming to IS: 4722 for these generators is as follows:

- (i). Designed to mechanically withstand continuous operation at runaway speed.
- (ii). These generators should be factory assembled that are shipped to the field as two integral component parts, rotor and stator so that assembly 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

4.2 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 standalone 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 up to a 2000 kW or even higher can be used.

In case of isolated units, small capacity Induction generators with variable capacitor bank may be used up to 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) A synchronous generator can regulate the voltage and supply reactive power to the network. It can therefore be connected to any type of network.

- (b) 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. 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.

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 power house ventilation shall be provided. If necessary, a braking system (either air or oil operated) should be considered.

Merits and demerits of synchronous and induction is given in table 5.

Table 5: Merits & Demerits Synchronous V/S Induction Generators

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

4.3 Selection and Characteristics

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

- (i) Micro hydro upto 100 kW (kVA)
- (ii) Small hydro upto 5000 kW (kVA)

Microhydro generators may be selected in accordance with quality standards issued by AHEC extracts enclosed as Annexure 2. These generators are generally factory assembled

and classified as category-1 generators, in American Practice. They are shipped to site completely assembled depending on the rpm selected, unit speed/weights and method of transportation to site.

These generators up to 5 MW capacity are classified as category-2 generators. These generators are factory assembled. The stators are transported in two segments and rotors in fully assembled as one integral component.

Small hydro generators above 15MW are shipped in multi parts and are assembled and tested at site.

4.4 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.

4.5 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, 600, 750 1000 or 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.

4.6 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.

4.7 Over speed Withstand

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

4.8 Synchronous Generators

(i) Stator Insulation:

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

(ii) Rotor Insulation :

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

(iii) 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.

(iv) Voltage regulating equipment :

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

(v) Synchronising equipment :

Synchronization 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.

(vi) Power Factor :

Power factor is between 0.8 and 1.0 depending on the reactive power requirements.

4.9 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.

4.10 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 systems the choice is between journal, ball or roller bearings. Attention should be given to their ability to withstand vibrations, eddy currents and runaway conditions including critical speed.

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

4.11 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 90 to 96% depending upon speed and capacity of machine. 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.

4.12 Testing of Generator

There are usually 3 categories of generators for this purpose.

Category –1 Factory assembled and tested generators supplied to site completely assembled. These are generally below 3 MW unit size.

Category – 2 Factory assembled and tested generators supplied at site as two segments of stator and fully assembled rotor. These are generally between 3 and 5 MW

Category –3 Generators above 5 MW are supplied in multi parts. These are assembled and tested at site.

Tests should be carried out in accordance with IS: 4722 and should include following.

4.12.1 Factory Assembly Test

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

- (i) Resistance test of armature and field windings.
- (ii) Dielectric test of armature and field windings.(before rotation)
- (iii) Insulation resistance (IR) of armature and field windings. (before rotation)
- (iv) This should include the polarization index (PI) values for both armature and field windings for machine rated above 3.3 kV and having output more than 1000 kW in accordance with IS: 7816.
- (v) Stator core loop test at rated flux for one hour.
- (vi) Phase rotation check
- (vii) No load saturation test
- (viii) Short circuit saturation test
- (ix) Dynamic balancing of rotor (IS: 4722, 12075-2008)
- (x) Current transformer test
- (xi) Efficiency test
- (xii) Non Destructive Test of rotor shaft and shaft coupling bolts
- (xiii) Material test certificates of various component parts.
- (xiv) Temperature rise test

4.12.2 Field Acceptance Test

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

- (i). 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).
- (ii). Rotor dielectric tests.
- (iii). Stator and rotor resistance tests.

4.12.3 Performance Test

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

- (i). Efficiency tests.
- (ii). Heat run tests.
- (iii). Machine parameter tests.
- (iv). Excitation test.
- (v). Over speed tests (optional)

5. EXCITATION SYSTEM

5.1 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 . 421-1-1996). Standard excitation system voltages are 62.5, 125, and 250.

5.2 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 2. Brushless system may be used for small hydro generators up to about 15 MW where machine speed is 500 rpm & above and large DC current capacity is not required. 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 3. 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 field 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. A comparison of the characteristics of two-excitation system is given in table 6.

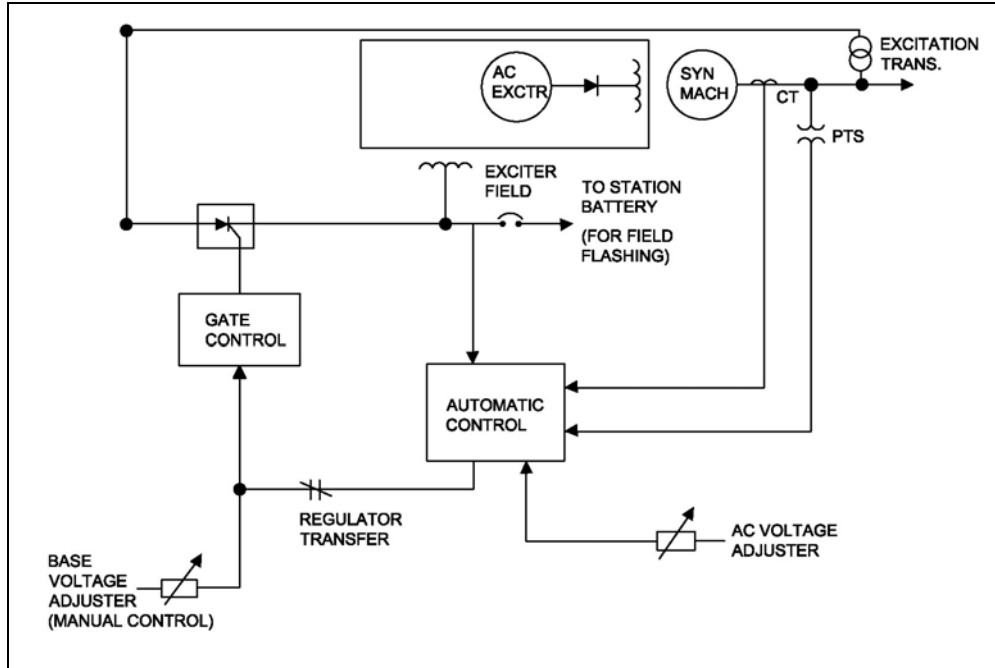


Fig. 2 : Brushless Excitation System

Table 6: Comparison of the characteristics of two-excitation system

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

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

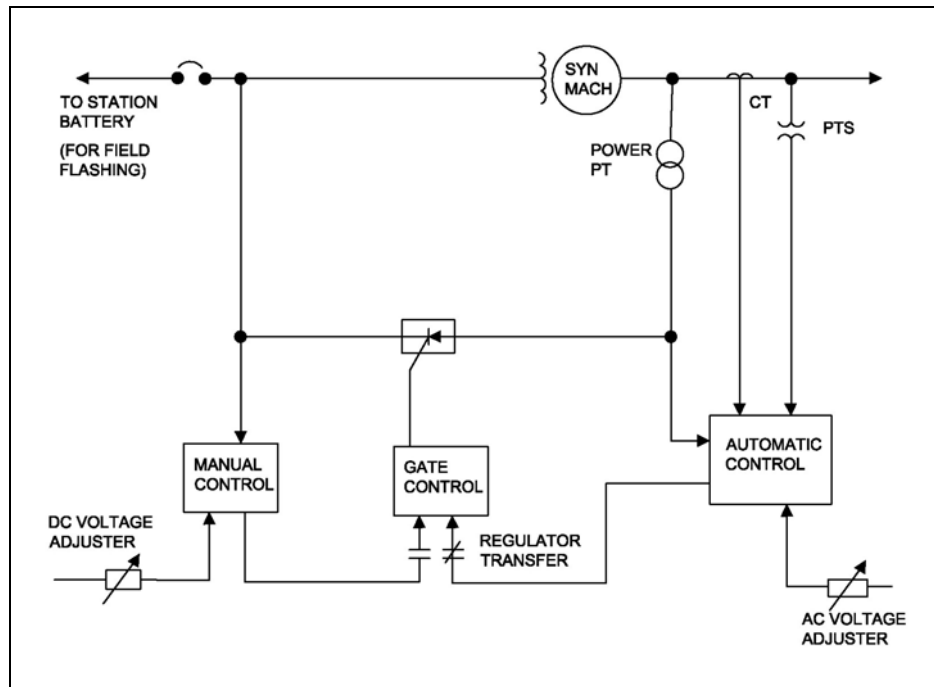


Fig. 3: Static (Potential Controlled Rectifier) Excitation System

5.3 Steady State Excitation System Requirement

5.3.1 Rated Field Current

The direct current in the field winding of the generator when operating at rated voltage, current, power factor and speed.

5.3.2 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.

5.3.3 Exciter rated Voltage

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

5.3.4 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°C for field windings designed to operate at rating with a temperature rise of 60°C or less; or (2) 100°C for field windings designed to operate at rating with a temperature rise greater than 60°C.

5.4 Transient Requirements

5.4.1 Transient Requirements

Transient requirements of excitation system of generator is determined from following considerations.

The stability of a hydro turbine generator 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.

5.4.2 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 .

For brushless system, it may be considered a function of the nominal response, which could be specified.

5.4.3 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 Fig. 4.

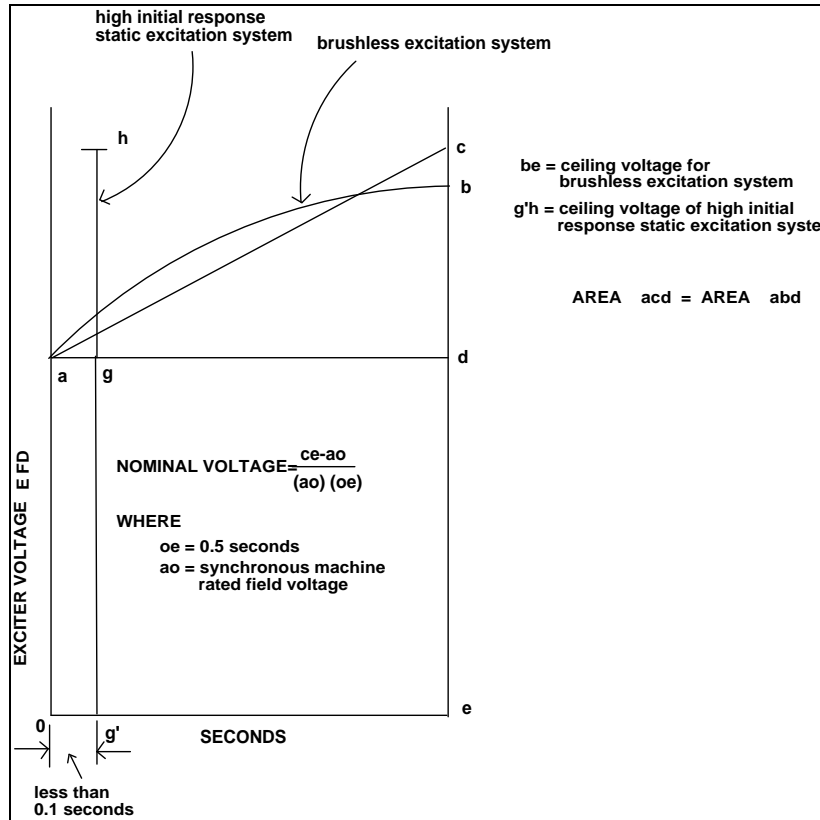


Fig: 4: Comparison of Excitation systems response based on a ceiling voltage for high initial response static excitation system and for the brushless system (Adapted from IEEE-421-1-2007)

5.5 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 . 421.4-2004 requires power system stabilizer for grid connection at 66 kV and above so as to avoid oscillations in post fault period.

5.6 Under Excitation Limiter (Limit 10-15%)

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.

5.7 Over Excitation Limiter

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

5.8 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.

5.9 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.

5.10 Redundancy of Equipment

Manual control, 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.

5.11 Environmental Considerations

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

Special requirements include tropicalization, seismic considerations etc.

5.12 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 421.4-2004. In addition factory tests and type tests for the excitation system recommended are given below:

5.12.1 Static Excitation (potential source rectifier exciter) system

(a) Excitation transformer - factory tests

Factory tests may be carried out as per relevant IS: . 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 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)

5.12.2 Rectifier Assembly

(a) Factory tests

Factory tests may be carried out as per relevant IS: . or IEEE 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 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

5.12.3 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 over speed

(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 over speed, at the anticipated maximum

6.0 EXAMPLE

6.1 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 are given below:

6.1.1 Capacity and rating (Large)

A net capacity of (*specify*) kVA at rated conditions is required. The generator name plate rating shall reflect the necessary additional capacity to supply the excitation equipment. The generator shall be capable of 10% continuous overload capacity.

- | | |
|---|--|
| (i) Power factor | 0.9 lagging |
| (ii) Frequency | 50 cycles |
| (iii) Number of phases | 3 |
| (iv) Voltage between phases, rated (kV) | ----- kV |
| (v) Speed (RPM) | To match turbine speed |
| (vi) Stator winding connections | Star, (suitable both for grounded or ungrounded operation) |
| (vii) Excitation voltage, not to exceed | ----- VDC |
| (viii) Guaranteed unsaturated (rated current) | |

- a. Direct axis transient reactance not more than -----

6.1.2 Electrical characteristics

Each generator shall have the following principle characteristics.

- | | | |
|--------|---|--|
| (i). | Rated continuous rating at lagging power factor and at normal rated terminal voltage | ----- |
| (ii). | Continuous overload capacity | 10 % |
| (iii). | Terminal voltage at which the maximum continuous rating must be achieved | 11 kV |
| (iv). | Minimum terminal voltage under operating continuous with unloaded system | 10 % lower than the normal rated voltage |
| (v). | Excitation at maximum leading KVA expressed as percentage of that required at rated output and power factor | Not less than 10 % |
| (vi). | Terminal voltage at which the maximum continuous rating must be achieved | 5 % higher than the normal rated voltage |
| (vii). | Short circuit ratio on rated KVA base, not less than | 1.0 |
| (viii) | Total Harmonic Distortion (THD) | Not to exceed 5% |
| (ix) | Deviation factor of wave form, measured in percent of open circuit at rated voltage and frequency, not more than | 5 |
| (x) | Efficiency at 10,000 kVA 0.9 power factor lagging at normal rated voltage and frequency not less than percent | 96-97 % |
| (xi) | Normal exciter response for the exciter, not less than | To suit above ratio |
| (xii) | Ceiling voltage of exciter when connected to the generator field and with rated exciter current delivered (80 degree C) | 2 |
| (xiii) | 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 | ----- kVA |
| (xiv) | Maximum ambient air temperature degrees centigrade | ----- |

6.1.3 Mechanical characteristics

- | | | |
|--------|--|------------------|
| (i). | Flywheel effect (WR^2) of rotating parts of the generator and exciter | Normal |
| (ii). | Direction of rotation | To match turbine |
| (iii). | Maximum runaway speed r.p.m. | To match turbine |
| (iv). | Maximum temperature of inlet cooling water for air cooling system | 36°C |
| (v). | Design mechanically to withstand continuously. Without exceeding the specified normal operating stress, a load of kW (1.0 pf) | ----- kW |
| (vi). | Design mechanically to withstand temporary overloads, with stress not exceeding one – half the yield point corresponding to turbine output of not less than (provided that the duration of such overload is not sufficient to cause injurious heating) kW. | ----- kW |
| (vii). | Designed for operation with a turbine having the following rated output kW. | ----- |

6.1.4 Insulation and temperature rise

- (i). Insulation shall be provided as follows:
- | | | |
|-----|----------------|-----------------------------------|
| (a) | Stator Winding | Material corresponding to class F |
| (b) | Rotor Winding | Material corresponding to class F |
- (ii). 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).
- | | | |
|-----|----------------|------|
| (a) | Stator Winding | 65°C |
| (b) | Rotor Winding | 65°C |
| (c) | Stator core | 60°C |
- (iii). 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.

6.1.5 Speed rise and run away 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 10 minutes without any damage to any part. The guide bearing and guide cum thrust bearing shall be capable to withstand runaway speed for 15 minutes without supply of cooling water and 30 minutes with cooling water without abnormal increase of vibrations and temperature.

6.2 Brush less excitation system for 1.5 MW grid connected project is shown in figure 5.

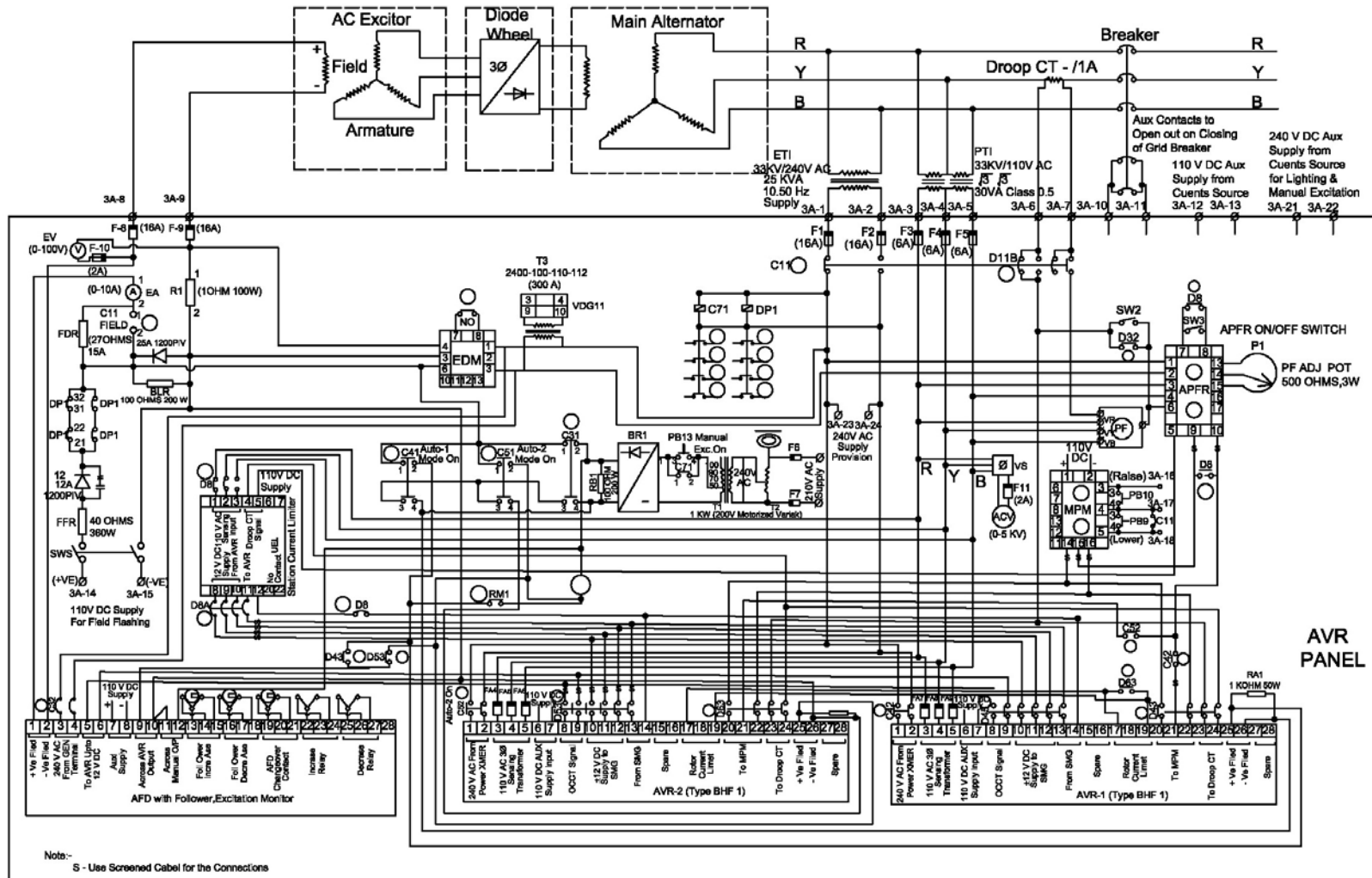


Fig. 5 : Brushless Excitation System for 1.5 MW, 3.3 kV, 750 RPM, 50 Hz, 0.8 PF, 8 Poles Generators

6.3 Static excitation system – Block diagram for 9 MW, 11 kV, and 0.9 PF is shown in figure 6.

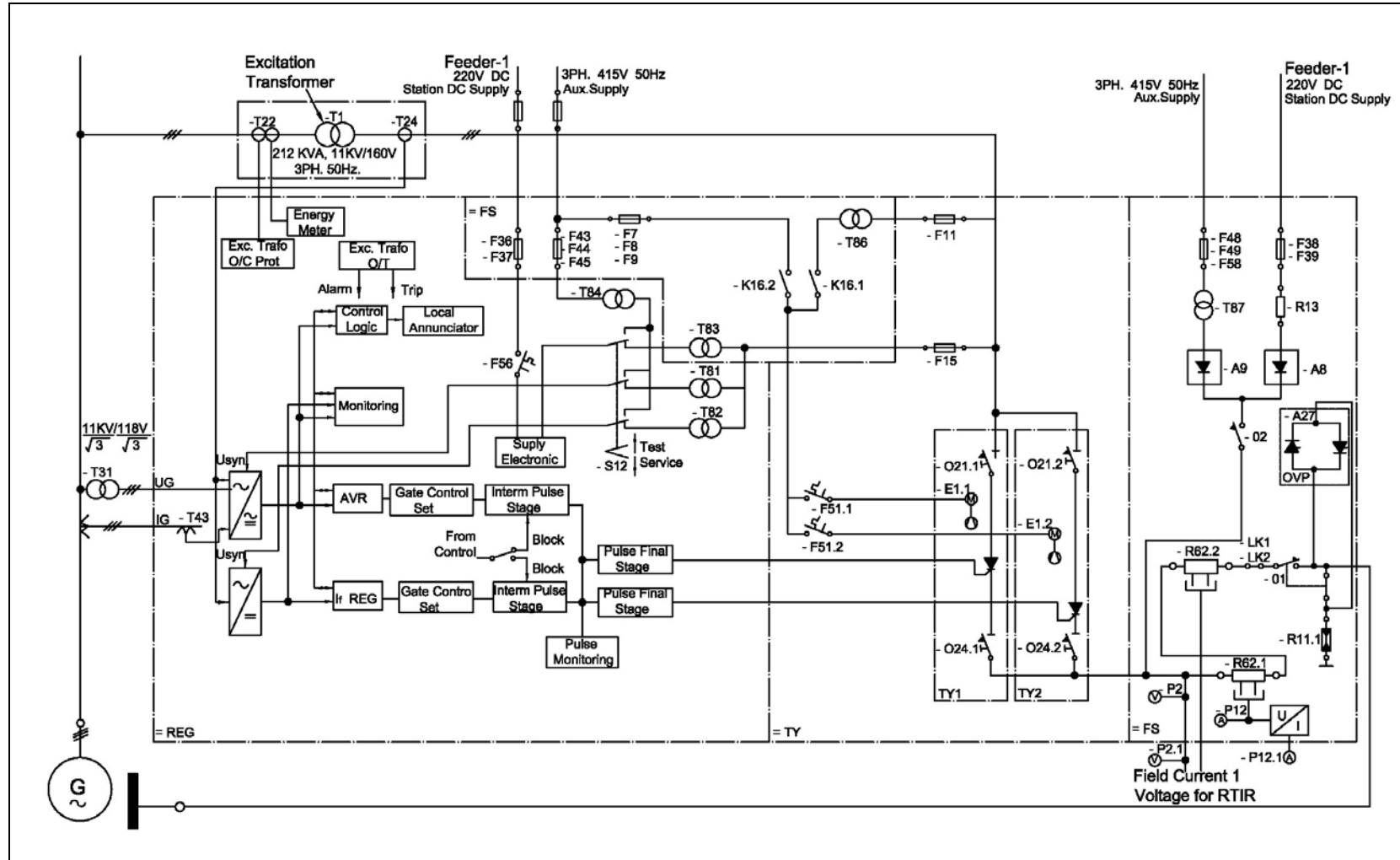


Fig. 6 : Static Excitation System - Block Diagram for 9 MW, 11 kV, 0.9 PF, 125 RPM Generators

Grid standard for operation and maintenance of transmission lines as per Central Electricity Authority (grid Standard) Regulation –2010

THE GAZETTE OF INDIA, JUNE, 26, 2010 (ASADHA, 1936)

No.12/X/ (GRID)/GM/CEA-Whereas the draft of Central Electricity Authority (Grid Standards) Regulation 2006 was published, as required by Sub-section (3) of section 177 of the Electricity Act, 2003, read with rule 3 of the Electricity (Procedure for Previous Publication) Rule, 2005:

Now, therefore, in exercise of the powers conferred by sub-section (2) of Section 177 read with Section 34 and clause (d) of the Electricity Act 2003, the Central Electricity Authority hereby makes the following regulations, namely:-

1. Short title, commencement and application. –

- (1) These regulations may be called the Central Electricity Authority (Grid Standards) Regulation, 2010
- (2) Save as otherwise provided in these regulations, they shall come into force on the date of their publication in the Official Gazette.
- (3) These regulations shall apply to the Entities, Appropriate Load Despatch Centres, and, Regional Power Committees.

2. Definitions.- In these regulations, unless the context otherwise requires,-

- (a) "Act" means Electricity Act 2003;
- (b) "Appropriate load Despatch Centre" means the National Load Despatch Centre, Regional Load Despatch Centre or Area Load Despatch Centre as the case may be;
- (c) "Area Load Despatch Centre" means the centre as established by State Transmission Utility or licensee for load dispatch and control in a particular area of the State;
- (d) "Bulk Consumer" means a consumer who avails supply at a voltage of 33 kV or above;
- (e) "condition based maintenance" means a set of maintenance actions based on continuous or frequent assessment of equipment condition, which is obtained from either of or a combination of embedded sensors, external tests and measurements;
- (f) "disaster management" means the mitigation of the impact of a major breakdown on the system and bringing about restoration in the shortest possible time;
- (g) "Emergency Restoration System" means a system comprising of transmission towers or structures of modular construction, complete with associated components such as insulators, hardware fittings, accessories, foundation plates, guys, anchors or installation tools and they like to facilitate quick restoration of damaged or failed transmission line towers or sections;
- (h) "Entity" means a Generating Company including captive generating plant or a transmission licensee including Central Transmission Utility and State Transmission Utility or a distribution licensee or a Bulk Consumer whose electrical plant is connected to the Grid at voltage level 33 kV and above;
- (i) "grid disturbance" means tripping of one or more power system elements of the grid like a

generator, transmission line, transformer, shunt reactor, series capacitor and Static VAR Compensator, resulting in total failure of supply at a sub-station or loss of integrity of the grid, at the level of transmission system at 220 kV and above (132 kV and above in the case of North-Eastern Region);

- (j) “grid incident” means tripping of one or more power system elements of the grid like a generator, transmission line, transformer, shunt reactor, series capacitor and Static VAR Compensator, which requires re-scheduling of generation or load, without total loss of supply at a sub-station or loss of integrity of the grid at 220 kV and above (132 kV and above in the case of North-Eastern Region);
 - (k) ‘Schedule’ means schedule appended to these regulations;
 - (l) “time based maintenance” means inspection, cleaning and replacement of parts of the equipment based on a predetermined time schedule.
 - (m) ”transient stability” means the ability of the power system to maintain synchronism when subjected to a severe disturbance such as a short circuit on a transmission line;
 - (n) “voltage unbalance” means the ratio of the maximum voltage deviation of the phase voltage from the average phase voltage to the average phase voltage of the three phases;
- (2) Words and expressions used and not defined in these regulations but defined in the Act shall have the meaning assigned to them in the Act.

3. Standards for Operation and Maintenance of Transmission Lines.-(1) All Entities, Appropriate Load Despatch Centres and Regional Power Committees, for the purpose of maintaining the Grid Standards for operation and maintenance of transmission lines, shall,

- (a) make all efforts to operate at a frequency close to 50 Hz and shall not allow it to go beyond the range 49.2 to 50.3 Hz or a narrower frequency band specified in the Grid Code, except during the transient period following tripping.
- (b) maintain the steady state voltage within the limits specified below in Table 1:

Table 1

S. No.	Nominal System Voltage (kV rms)	Maximum (kV rms)	Minimum (kV rms)
1	765	800	728
2	400	420	380
3	220	245	198
4	132	145	122
5	110	121	99
6	66	72	60
7	33	36	30

- (c) ensure that the temporary over voltage due to sudden load rejection remains within the limits specified in Table 2,

Table 2

S. No.	Nominal System Voltage (kV rms)	Phase to Neutral Voltage (kV peak)
1	765	914
2	400	514
3	220	283
4	132	170

Provided that for the voltage level below 132 kV, the temporary over voltage limits as given in Table 2 shall be decided by the State Commission in the respective State Grid Code. (d) ensure that the maximum permissible values of voltage unbalance shall be as specified in Table 3 below:

Table 3

S.No.	Nominal System Voltage (kV rms)	Voltage Unbalance (%)
1	765 and 400	1.5%
2	220	2%
3	33 to 132	3%

Provided that Bulk consumers shall avoid unbalanced load during operation: Provided further that the distribution licensees shall ensure that their loads are not unbalanced.

- (e) provide standard protection systems having the 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 and shall provide protection coordination as specified by the Regional Power Committee.

Explanation.-For the purpose of this regulation “fault clearance time” means the maximum fault clearance times are as specified in the Table 4 below,

Table 4

S.No.	Nominal System Voltage (kVrms)	Maximum Time (in milliseconds)
1	765 and 400	100
2	220 and 132	160

Provided that in the event of non clearance of the fault by a circuit breaker within the time limit specified in Table 4, the breaker fail protection shall initiate tripping of all other breakers in the concerned bus-section to clear the fault in the next 200 milliseconds.

- (f) operate the system in a such a way that the Grid System is capable of withstanding one of the following contingencies without experiencing loss of stability:

- (g) operate the system in a such a way that under any one of the following contingencies, the system remains stable and sustains integrity so that no generator loses synchronism and no part gets isolated from the rest of the
- (h) observe the following permissible limits of voltage fluctuation :
 - (i) the permissible limit of voltage fluctuation for step changes which may occur repetitively is 1.5 percent:
 - (ii) for occasional fluctuations other than step changes the maximum permissible limit is 3 percent:
 - (1) outage of one single largest generating unit of the system or
 - (2) outage of a 132 kV Double circuit line or
 - (3) outage of a 220 kV Double circuit line or
 - (4) outage of a 400 kV Single circuit line or
 - (5) outage of a 400 kV Single circuit line with series compensation or
 - (6) outage of 765 kV Single circuit line without series compensation or
 - (7) outage of one pole of HVDC Bipolar line or
 - (8) outage of an Interconnecting Transformer

system:

- (1) tripping of a single largest generating unit; or
- (2) transient ground fault in one phase of a 765 kV Single Circuit Line close to the bus; or
- (3) a permanent single phase to ground fault in 400 kV single circuit line followed by 3 pole opening of the faulted line; or
- (4) a permanent fault in one circuit of a 400 kV Double Circuit Line when both circuits were in service in the pre-contingency period; or
- (5) 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
- (6) a three-phase permanent fault in a 220 kV or 132 kV line; or
- (7) a permanent fault in one pole of HVDC bipolar in a HVDC Converter Station.

Provided that the standard on voltage fluctuations shall come into force concurrently with clause 4 of Part IV of the Schedule to the Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007.

(2) The transmission licensee shall ensure that the voltage wave-form quality is maintained at all points in the Grid by observing the limits given in Table 5 below,

Table 5

S.No.	System Voltage (kV rms)	Total Harmonic Distortion (%)	Individual Harmonic of any particular Frequency (%)
1	765	1.5	1.0
2	400	2.0	1.5
3	220	2.5	2.0
4	33 to 132	5.0	3.0

Provided that the standard on Harmonic Distortion shall come into force concurrently with clause 3 of Part IV of the Schedule to the Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007.

Explanation : For the purpose of this regulation, Total Harmonic Distortion (VTHD) expressed as percentage, shall be calculated as under,

$$V_{THD} = \sqrt{\sum_{n=2}^{n=40} \frac{V_n^2}{V_1^2}} \times 100$$

'1' refers to fundamental frequency (50 Hz)

'n' refers to the harmonic of nth order (corresponding frequency is 50 x n Hz)

4. Operation Planning.- The Regional Power Committee shall periodically review the performance of the grid for the past period and plan stable operation of the grid for the future, considering various parameters and occurrences such as frequency profile, voltage profile, line loading, grid incident, grid disturbance, performance of system protection schemes and protection coordination.

5. Maintenance Planning.-

- (1) The Regional Power Committees shall, before the commencement of the financial year, prepare an annual maintenance plan for the generating stations and the inter-State transmission system in their respective regions keeping in view the demand pattern and maintenance schedule of the generating units and diversity in demand of the States.
- (2) The Regional Power Committees shall co-ordinate the annual maintenance plan for Inter-Regional transmission system.
- (3) The Regional Power Committees shall review and revise the coordinated generation and transmission system maintenance plan in their monthly operating Committee meetings.

- (4) The State Load Despatch Centre shall in consultation with the concerned transmission licensee, coordinate the annual maintenance plan of Intra-State transmission system taking into account the annual maintenance plan of generating units and inter-state transmission system decided by the Regional Power Committee.
- (5) The State Load Despatch Centre shall also review and coordinate the maintenance plan of intra-state transmission system for the next month, taking into account the monthly maintenance plan of generating units and inter-state transmission system prepared by the Regional Power Committee for the next month.
- (6) The generating company or transmission licensee shall, before actual shut down, obtain the approval of the Appropriate Load Despatch Centre.

6. Coordination in Operations.-

- (1) No Entity shall introduce or take out the element of the grid without the concurrence of the Appropriate Load Despatch Centre except in case of imminent risk of safety of plant and personnel in which case it must intimate Appropriate Load Despatch Centre giving reasons therefore.
- (2) The Appropriate Load Despatch Centre shall inform all affected parties of the outage.

7. Operating Instructions.-

- (1) Every generating company and transmission licensee shall provide written operating instructions for each equipment and operating procedure for sequence of operations of power system equipment in their control room.
- (2) The operating instructions followed shall not be inconsistent with the manufacturer's instructions.
- (3) The operating instructions and procedures may be revised by the generating company or transmission licensee, as the case may be.

8. Instructions by Regional Load Despatch Centres and State Load Despatch Centres to be recorded.-

- (1) All operational instructions given by Regional Load Despatch Centres and State Load Despatch Centres through telephone, Fax, e-mail, etc shall be given a unique operating code number and every Regional Load Despatch Centre and State Load Despatch Centre shall maintain a voice recorder for recording and reproduction of conversation with time tag or stamp.
- (2) The record of instructions referred to in sub-regulation (1) shall be kept for at least six months.

9. Automatic under frequency Relay.-

- (1) All Entities shall set their under-frequency (UF) Relays and rate of change of frequency with time Relays in their respective systems, in accordance with the plan made by the Regional Power Committee, to provide adequate load relief for grid security and ensure the operation of these relays at the set frequencies.
- (2) All constituents shall submit a detailed report of operation of these Relays at different frequencies to Regional Load Despatch Centre and Regional Power Committee on daily basis and the Regional Power Committees shall carry out inspection of these Relays as and when required.

10. Islanding Schemes.-

- (1) The Regional Power Committees shall prepare Islanding schemes for separation of systems with a view to save healthy system from total collapse in case of grid disturbance.
- (2) The Entities shall ensure proper implementation of the Schemes referred to in sub-regulation (1).

Explanation.-For the purposes of this regulation 'Islanding Scheme' means a scheme for the separation of the Grid into two or more independent systems as a last resort, with a view to save healthy portion of the Grid at the time of grid disturbance.

11. Categorisation of grid incidents and grid disturbance based on severity of trippings.-

The categorisation of grid incidents and grid disturbances shall be as follows:

- (1) Categorization of grid incidents in increasing order of severity,

Category GI-1 - Tripping of one or more power system elements of the grid like a generator, transmission line, transformer, shunt reactor, series capacitor and Static VAR Compensator, which requires re-scheduling of generation or load, without total loss of supply at a sub-station or loss of integrity of the grid at 220 kV (132 kV in the case of North-Eastern Region);

Category GI-2 - Tripping of one or more power system elements of the grid like a generator, transmission line, transformer, shunt reactor, series capacitor and Static VAR Compensator, which requires re-scheduling of generation or load, without total loss of supply at a sub-station or loss of integrity of the grid at 400 kV and above (220 kV and above in the case of North-Eastern Region).

- (2) Categorisation of grid disturbance in increasing order of severity, *Explanation:* For the purpose of categorisation of grid disturbances, percentage loss of generation or load, whichever is higher shall be considered.

Category GD-1 When less than ten per cent. of the antecedent generation or load in a regional grid is lost;

Category GD-2 When ten per cent. to less than twenty percent of the antecedent generation or load in a regional grid is lost.

Category GD-3 When twenty per cent. to less than thirty per cent. of the antecedent generation or load in a regional grid is lost;

Category GD-4 When thirty per cent. to less than forty per cent. of the antecedent generation or load in a regional grid is lost ;

Category GD-5 When forty per cent. or more of the antecedent generation or load in a regional grid is lost.

12. Reporting of events affecting grid operation.-

- (1) Any tripping of generating unit or transmission element, along with relay indications, shall be promptly reported by the respective Entity to the Appropriate Load Despatch Centre in the reporting formats as devised by the Appropriate Load Despatch Centre.
- (2) The Appropriate Load Despatch Centre shall promptly intimate the event to the Regional Load Despatch Centres and State Load Despatch Centres of the affected regions and States respectively which shall, in turn, take steps to disseminate this information further to all concerned.

13. Reporting of grid disturbance.-

- (1) The Regional Load Despatch Centre shall inform occurrence of the grid disturbance to the constituents immediately and to the concerned Regional Power Committee at the earliest.
- (2) The grid disturbance resulting in failure of power supply to large areas in a State shall also be reported by the Regional Load Despatch Centre to the Authority within twenty four hours of the occurrence of the grid disturbance.
- (3) The Regional Load Despatch Centre shall also post on its website a brief preliminary grid disturbance report, indicating the affected area or system, extent of outage and the likely cause of initiation for the benefit of the constituents of the region.

14. Restoration of grid following grid incident and grid disturbance.-

- (1) The Regional Load Despatch Centre, in consultation with Regional Power Committee, shall develop procedures for enabling restoration and normalisation of the Grid for inter-State system at the earliest, following grid incident and grid disturbance of the categories specified in regulation 11.
- (2) The State Load Despatch Centre shall also develop procedures accordingly for restoration of intra-State system.
- (3) The restoration procedures shall be reviewed following any addition of generating station or transmission line or at least once in two years, and revised, if considered necessary by the Regional Load Despatch Centre and State Load Despatch Centre, as the case may be.
- (4) The procedures specified in sub-regulations (1), (2) and (3) shall be made available to, and be followed by all concerned Entities, Regional Load Despatch Centres and State Load Despatch Centres.

15. Operational Data during normal operation and during grid incidents and grid disturbances.-

- (1) All real time operational data as required by the Appropriate Load Despatch Center shall be furnished by the Entities.
- (2) All data required by Regional Power Committee, in discharge of the responsibilities assigned to it, shall be furnished by Regional Load Despatch Centre (RLDC).
- (3) All operational data, including disturbance recorder and event logger reports, for analysing the grid incidents and grid disturbance and any other data which in its view can be of help for analysing grid incident or grid disturbance shall be furnished by all the Entities within twenty four hours to the Regional Load Despatch Centre and concerned Regional Power Committee.
- (4) All equipment such as disturbance recorders and event loggers shall be kept in healthy condition, so that under no condition such important data is lost.

- (5) A real time operation display of the grid position shall also be made available to the Regional Power Committee by Regional Load Dispatch Centre.
- (6) Regional Load Dispatch Centre shall classify the grid incidents and grid disturbances according to regulation 11, analyse them and furnish periodic reports of grid incidents and grid disturbances to the Regional Power Committee which shall recommend remedial measures to be taken on the Report of Regional Load Dispatch Centre to prevent recurrences of such grid incidents and grid disturbances.

16. Operational Data Records.-

- (1) Operational data including equipment and system parameters logged manually and electronically shall be preserved for at least three years.
- (2) Logbooks shall be maintained by every manned switchyard and sub-station or at the control centre responsible for operation of the unmanned switchyard and substation.
- (3) All operations conducted shall be recorded in chronological order and the time of each operation and occurrence of each event shall be recorded in such a manner that there shall be no over-writing and any mistake shall be neatly cut by a line and new words written thereafter.
- (4) The observations made during inspection including important parameters and deviation of parameters outside permissible tolerances shall also be recorded in the logbook and all entries must be made in the logbooks immediately.
- (5) A record shall be kept of the number of grid incidents and grid disturbances of various categories by the respective Regional Power Committees for each financial year.
- (6) A compendium of grid disturbances, indicating details such as the date and time of the disturbance, the sequence of tripping, the cause, and the sequence of restoration, remedial measures taken to avert recurrence of such incidents and disturbances shall be maintained by the respective Regional Power Committee.

17. Communication facilities.-The communication facilities installed by the transmission licensees shall be in accordance with Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007 and shall be maintained in good operating condition.

18. Safety Procedure.-

- (1) The Entity shall prepare contingency procedures for use of operators at each sub-station and switchyard and these shall be regularly updated.
- (2) All operating personnel shall be trained in contingency procedures at regular intervals and the entities shall require their personnel to follow the contingency procedures during operation and maintenance.
- (3) The firefighting equipment shall be made available at all sub-stations, switchyards and converter stations and shall be checked periodically for its upkeep and mock exercises in fire fighting shall be carried out at least once in a year and record maintained.

19. Maintenance of Tools and Equipment.-The maintenance staff shall be made aware of the list of tools, devices and equipment for various maintenance and rectification works on transmission lines, sub-stations, switchyards and converter stations and the tools shall be made readily available and certified for usage.

20. Maintenance Procedures.-The Entity shall prepare maintenance procedures for each equipment in line with the manufacturer's recommendations and prudent utility practices.

21. Hot Line Methods.-

- (1) The hot line techniques for maintenance of critical transmission lines and sub-stations shall be adopted wherever possible.
- (2) Only trained staff shall be used for the hot line techniques and the tools employed in such techniques shall have necessary certification from a national or international accredited laboratory before usage.

22. Emergency Restoration System.-Each transmission licensee shall have an arrangement for restoration of transmission lines of 400 kV and above and strategic 220 kV lines through the use of Emergency Restoration System in order to minimise the outage time of the transmission lines in case of tower failures.

23. Inspection and Patrolling.-

- (1) All essential parameters, which indicate the healthiness of the equipment in a sub-station, shall be inspected by the shift engineer once in each shift and periodically by the officer-in-charge.
- (2) Overhead lines shall be patrolled at periodicity decided by the transmission licensee and different patrolling schedules shall be implemented by the transmission licensees for normal terrain, vulnerable terrain and most vulnerable terrain.
- (3) The patrolling schedules for ground inspection of live lines and tower top inspection of de-energised lines shall be separately issued by the licensees.
- (4) The important lines shall be inspected by senior engineers after patrolling by junior staff and maintenance works such as tree cutting and replacement of damaged insulators shall be carried out immediately after patrolling, wherever required.

24. Maintenance schedules.-

- (1) Entities shall identify critical equipment and as far as possible, practice condition based maintenance for such equipment in place of traditional time based maintenance.
- (2) In case of time based maintenance, the periodicity of maintenance of lines shall be fixed based on whether they are passing through normal area or polluted area or coastal area and the transmission lines and sub-stations in polluted or coastal areas shall be maintained more frequently.
- (3) The maintenance of lines passing through and sub-stations located in such areas should be completed once before onset of winter so as to minimise tripping under conditions of fog or due to salt deposit on insulator discs in coastal areas and once before onset of summer.
- (4) Maintenance and cleaning of various equipment fittings, accessories, primary instruments and sensors shall be carried out when they are de-energised during the shut-down of main equipment so as to minimise shutdown time.
- (5) Where defects are observed through condition monitoring or during patrolling and inspection, the maintenance work on various items of equipment may be advanced depending on the condition of the equipment.

25. Use of diagnostic techniques for condition monitoring of equipment.

The diagnostic methods of maintenance shall be preferred over traditional time based maintenance. For purpose of this regulation, devices or methods specified in the Schedule shall be used.

26. Thermo – vision scanning.-The Thermo-vision scanning for hot spots on all overhead lines and sub-station equipment at voltage level of 220 kV and above shall be carried out at least once a year and necessary remedial measures shall be taken where hot spots are detected.

27. Failure analysis.-

- (1) All failures of equipment and tower collapse shall be analysed by the Entity to avoid recurrence and a copy of the report shall be submitted to the Regional Power Committee and the Authority.
- (2) The Authority may appoint a group of experts for investigation and analysis and the representatives of manufacturers may be invited to participate in such analysis.
- (3) All relevant data which may help the group of experts in analysing the failures shall be furnished by the respective Entities.
- (4) The recommendations of the group of experts shall be submitted to the Authority and the recommendations accepted by the Authority shall be implemented and circulated to all within the organisation and to other concerned organisations to prevent recurrence of similar failures.

28. Inventory control and spare part management.-

- (1) The required spare parts shall be kept in stock, to ensure speedy the maintenance of the equipment.
- (2) Computerised materials management system shall be developed by the Entities to optimise inventory.

29. Maintenance Audit.-

- (1) An internal committee may be established by the Entities to verify whether actual maintenance works are carried out at site in compliance of the procedures and the policy of the transmission company.
- (2) The observations of the Committee shall be put up to the management of the Entity for perusal and taking corrective action, if any.

30. Residual life assessment.-The residual life assessment shall be carried out for all major equipments including transformers, reactors, breakers, as envisaged by the relevant standards specified by the Bureau of Indian Standards, manufacturer's instruction or industry best practices and suitable remedial action for breach of the same shall be taken by the management of the Entity.

31. Disaster management.-

- (1) The maintenance staff shall be trained in disaster management and a detailed procedure for the same shall be developed by the Entity and displayed prominently.
- (2) This detailed procedure shall be reviewed periodically and also based on mock exercises carried out by the Entity.
- (3) The maintenance staff shall be trained in emergency restoration procedures for managing

- major failures and breakdowns.
- (4) The equipment including vehicles, diesel generating sets and firefighting equipment and Emergency Restoration System for transmission lines shall be kept available at sub-station or at appropriate location for disaster management.
- 32. Maintenance records.-**The records of all maintenance carried out for each equipment shall be kept in the table and formats in electronic form and hard copy and the next due date for maintenance of each item of work shall be clearly marked in such tables and formats.
- 33. Training.-**
- (1) Every person involved in operation and maintenance of transmission lines shall be trained at the induction level and at least once in a year.
- (2) The shift staff shall be trained to make them thorough in carrying out operations at each sub-station and every person concerned with real time operation shall be trained.
- (3) Every grid operator shall undergo training in real time digital simulator and a refresher course at least once in two years.
- (4) The maintenance personnel of every entity shall also be trained in preventive and breakdown maintenance of various equipment and the personnel shall be trained in various detailed maintenance procedures.

Secretary
Central Electricity Authority

SCHEDULE
(See regulation 25)

The Devices and Methods for Condition Based Monitoring of Equipment

- (1) Hot line puncture detection of insulators
- (2) Vibration measurement of the line
- (3) Pollution measurement of the equipment
- (4) Dissolved Gas Analysis of Transformer oil
- (5) Frequency response analysis of transformers/reactors
- (6) Tan δ and capacitance measurement
- (7) Circuit breaker operational analyzer
- (8) Dynamic contact resistance measurements of breakers
- (9) Third harmonic resistive current measurements of surge arresters
- (10) Recovery voltage measurements of transformers/reactors
- (11) Vibration measurements of the reactors
- (12) Steady state and Dynamic testing of protective relays
- (13) Signature Analysis
- (14) Partial Discharge measurement for transformers/Gas insulated Switchgear
- (15) Static resistance meter for circuit breakers, isolators, bus bar joint, earth switches etc.
- (16) Ground tester for measurement of resistivity of soil and ground resistance
- (17) Battery impedance test equipment
- (18) Insulator tester
- (19) SF₆ gas leakage detector and dew point
- (20) Power quality Analyzer
- (21) Fibre optic cable testing devices

**Generators for Micro Hydroelectric Plants
(As per AHEC-IITR Micro Hydro Quality Standard-2005)**

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 to automatic power factor Regulator (APFR), automatic change over from AVR to APFR when grid interconnection circuit breaker is switched off.
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.