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IEEE Guide for Abnormal Frequency Protection for Power Generating Plants

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Foreword

(This Foreword is not a part of ANSI/IEEE C37.106-1987, IEEE Guide for Abnormal Frequency Protection for Power Generating Plants.)

This standard is the result of the valuable input of not only the listed working group members who had this status at the time of its approval, but those also who are listed as past members of the working group. One who deserves special recognition is C. M. Shuster, who served as the first working group chairman and thus gave early guidance on the format and substance of the proposed guide.

Preparation of the guide began in 1978 shortly after the publication of a report by the National Electric Reliability Council (NERC) in July 1978. The title of the report was "Underfrequency and Undervoltage Relay Applications to Large Turbine-Generators." The guide thus responds to concerns and issues raised by the NERC report.

Some of the more important subjects that came under working group discussion and were accorded a place in the guide were:

- 1) Generator over-/underfrequency capabilities
- 2) Turbine over-/underfrequency capabilities with a need to establish operating limits of turbine blades during abnormal frequency operation
- 3) Components of the power plant that may be frequency sensitive
- 4) Generator/turbine underfrequency protection relay schemes
- 5) Coordination of generator/turbine protection schemes with existing system load shedding schemes
- 6) Generator/transformer volts/hertz protection
- 7) Special underfrequency considerations in nuclear power plants

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IEEE Guide for Abnormal Frequency Protection for Power Generating Plants

1. Introduction and Scope

This guide has been prepared to assist the protection engineer in applying relays for the protection of generating plant equipment from damage caused by operation at abnormal frequencies including overexcitation. Emphasis is placed on the protection of the major generating station components at steam generating stations, nuclear stations, and on combustion-turbine installations. Consideration is also given to the effect of abnormal frequency operation on those associated station auxiliaries whose response can affect plant output.

The guide also presents background information regarding the hazards caused by operating generation equipment at abnormal frequencies. It documents typical equipment capabilities and describes acceptable protective schemes. Recommended methods for coordinating the underfrequency protective scheme with system load shedding schemes are also included. Sufficient information is provided to apply suitable coordinated protection for given specific situations.

2. References

- [1] ANSI C50.13-1977, American National Standard Requirements for Cylindrical-Rotor Synchronous Generators.¹
- [2] ANSI/IEEE C57.12.00-1980, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.²
- [3] BAUMAN, H. A., HAHN, G. R., and METCALF, C. N. The Effect of Frequency Reduction on Plant Capacity and on System Operation. *AIEE Transactions on Power Apparatus and Systems*, vol PAS-74, Feb 1955, pp 1632–1637.
- [4] BUTLER, O. D. and SWENSON, C. J. Effect of Low Frequency and Low Voltage on Thermal Plant Capability and Load Relief During Power System Emergencies—Effect of Reduced Voltage and/or Frequency Upon Steam Plant Auxiliaries. *AIEE Transactions on Power Apparatus and Systems*, vol PAS-72, Feb 1955, pp 1628–1632.
- [5] Electric Power Research Institute. *RP 764—Research in Long-Term Power System Dynamics*. Final Report No EL 367, prepared by General Electric Company, Feb 1977 and Final Report No EL 983, vols I and II, prepared by General Electric Company, July 1982.

¹ANSI publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

²ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Institute of Electrical and Electronics Engineers, Service Center, Piscataway, NJ 08854.

[6] Electric Power Research Institute. *RP 745—Development of Short-Term and Mid-Term Simulation Techniques for Large Interconnected Power Systems*. Final Report No EL 596, prepared by Arizona Public Service and Arizona State University, June 1979.

[7] Electric Power Research Institute. *RP 849—Determining Load Characteristics for Transient Performances*. Final Report No EL 849, vols I–III, prepared by University of Texas at Arlington, May 1979; Final Report No EL 850, vols I–IV, prepared by General Electric Company, Mar 1981; Final Report No EL 851, vol 1, prepared by Institut de Recherche de l'Hydro Quebec, Nov 1980; and Final Report No EL 851, vol II, prepared by Institut de Recherche de l'Hydro Quebec, Mar 1981.

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[10] SCHROEDER, T. W. Steam Plant Operation at Reduced Voltage and Frequency. *Electric Light and Power*, vol 29, Aug 1951, pp 70–74.

[11] SMAHA, D. W., ROWLAND, C. R., and POPE, J. W. Coordination of Load Conservation with Turbine Generator Underfrequency Protection. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-99, May/June 1980, pp 1137–1145.

[12] UDREN, E. A. Load-Shedding and Frequency Relaying. *Applied Protective Relaying*, Westinghouse Electric Corporation, 1979, chap 21, p 2.

3. Steam Generating Plant—Abnormal Frequency Operation

3.1 General Background

There are two major considerations associated with operating a steam generating station at abnormal frequency. They are

- 1) Protection of equipment from damage that could result from operation at abnormal frequency
- 2) Prevention of a cascading effect that leads to a complete plant shutdown as long as limiting conditions are not reached during abnormal frequency operation

The major components of a steam plant that are affected by abnormal frequency operation are the generator and unit step-up transformer, the turbine, and the station auxiliaries. In this section, the effect of abnormal frequency operation on the various station components is discussed and various protective schemes are presented.

3.2 Generator Over-/Underfrequency Capability

While no standards have been established for abnormal frequency operation of synchronous generators, it is recognized that reduced frequency results in reduced ventilation; therefore, operation at reduced frequency should be at reduced kilovoltamperes (kVA). Figure 1 shows typical recommended maximum continuous loading at various frequencies for 2-pole or 4-pole cylindrical rotor generators as published by two manufacturers.

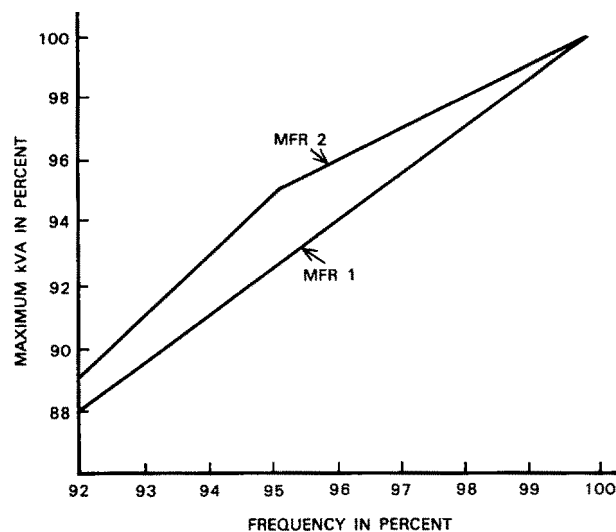


Figure 1—Generator Capability Versus Frequency

In view of reduced generator capability and expected increased loading during underfrequency conditions, the short-time thermal capability of a generator could be exceeded. Operating precautions should be taken to stay within the short-time thermal rating of the generator rotor and stator. The permissible short-time operating levels for both the stator and rotor for cylindrical rotor synchronous generators are specified in ANSI C50.13-1977 [1]³ and are shown in Fig 2.

The underfrequency limitations on the generator, however, are usually less restrictive than the limitations on the turbine, which are discussed in the next section.

Overfrequency is usually the result of a sudden reduction in load and, therefore, corresponds to light-load or no-load operation of a generator. During overfrequency operation, machine ventilation is improved and the flux density required for a given terminal voltage is reduced. Therefore, operation within the allowable overfrequency limits of the turbine will not produce generator overheating as long as operation is within rated kilovoltamperes and 105% of rated voltage.

³The numbers in brackets correspond to those of the references listed in Section 2; when preceded by B, they correspond to the bibliography in Section 6

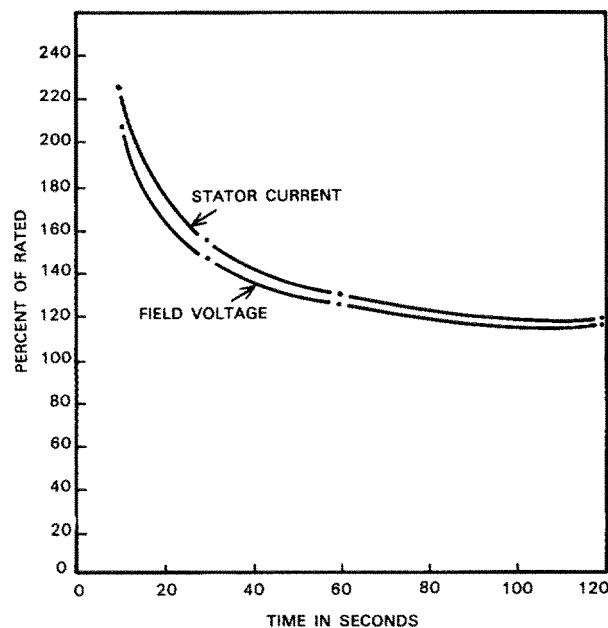


Figure 2—Generator Short-Time Thermal Capability

3.3 Turbine Over-/Underfrequency Capability

A turbine blade is designed to have its natural frequencies sufficiently displaced from rated speed and multiples of rated speed (that is, the rated fundamental frequency and its harmonics) to avoid a mechanical resonant condition that could result in excessive mechanical stresses in the blade. Excess stress can occur if the system damping is insufficient to overcome the excitation stimulus produced by turbine steam flow. For a resonant condition, the vibratory stress can be 300 times greater than the stress during nonresonant operating conditions.

Figure 3 is a Campbell diagram for a particular blade design that illustrates how a change in turbine speed can produce excitation frequencies that coincide with the natural frequency of that blade. With sufficient stimulus, the mechanical stresses produced in the blade can be potentially damaging and can lead to destructive failure after a period of time. The number of natural frequency bands plotted is generally limited to those for which the turbine would likely produce a sufficient level of stimulus to cause excessive stresses. The curves labeled 1 through 6 indicate the points where the frequency is an integral multiple (that is, a harmonic) for a given turbine speed. The rated speed line illustrates that this blade design does not have natural frequencies that coincide with 60 Hz or any harmonics up through the sixth. However, speed deviations from rated speed would eventually cause an intersection with one or more of the natural frequency bands at some multiple of the changed operating speed. Point A illustrates such a condition, and the magnitude of stress in the vicinity about point A for a given stimulus will follow that of a typical resonance curve, as shown in Fig 4.