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IEEE Guide for the Application of Turbine Governing Systems for Hydroelectric Generating Units

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Sponsored by the
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IEEE-SA Standards Board

Abstract: This guide is intended to complement IEEE Std 125™-1988, providing application details and addressing the impact of plant and system features on hydroelectric unit governing performance. It provides guidance for the design and application of hydroelectric turbine governing systems. There is a heightened awareness within the electric utility industry of the importance in the effective application of governing systems for dynamic stability. The need exists to provide guidance in the effective governing system application for a better understanding among users.
Keywords: control, governor, governing system, hydroelectric, speed, stability

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Introduction

(This introduction is not part of IEEE Std 1207-2004, IEEE Guide for the Application of Turbine Governing Systems for Hydroelectric Generating Units.)

This document is a guide for the application of turbine governing systems for hydroelectric generating units. The Hydroelectric Power Subcommittee of the IEEE Energy Development and Power Generation Committee began to look into forming a working group to draft an application guide for hydroelectric units at the 1987 Winter Power Meeting. Subsequently, a PAR was issued and work began on the guide.

As progress was being made on the guide, governing technology was at the same time changing rapidly from mechanical to analog electronic to digital electronic controllers. Also, during this time period, new guides produced by working groups of the Hydroelectric Power Subcommittee addressed some portions of the original scope of this guide. Therefore, in 1998, the PAR for this Working Group was revised, and the Working Group's efforts were focused on producing a guide that acted as a companion document to IEEE Std 125-1988.

The final format of this guide contains four major clauses, which are directly related to the subject matter addressed in IEEE Std 125-1988. Clause 4 discusses the functions and characteristics of the turbine governing system and of the equipment related to the design of the turbine governing system. Clause 5 is somewhat tutorial in nature, discussing the major elements of the turbine governing system from a control theory perspective. Clause 6 provides some application insights to specifying a turbine governing system. Clause 7 provides a discussion of the issues related to the stability of the turbine governing system. Numerous bibliographic citations related to the subject matter are also provided, and examples are included to illustrate many of the systems and concepts discussed. Some more specialized information, dealing with the impact of turbine characteristics, system modeling and tuning, and performance auditing is presented within the informative annexes of the guide.

This guide is designed to be a reference document for practicing engineers in the hydroelectric industry. It is intended to offer application insight for applying turbine governing systems for hydroelectric units. IEEE Std 125-1988 offers guidance for what elements of a turbine governing system need to be specified, and this guide offers some experience-based guidance on the impact on system performance of these specifications.

Members of this Working Group represent a cross-section of the hydroelectric industry, including power plant owners, plant designers, equipment manufacturers, engineering consultants, and academic personnel.

The members of this Working Group wish to dedicate this guide to the memory of Bernard “Bud” Crittenden. Bud worked in the area of governing system design for 45 years. His numerous contributions to the industry involve many of the issues addressed by this guide. Perhaps Bud’s greatest contribution to the industry was his mentoring of a number of young engineers entering the field of governing system design and application. This guide can be viewed as a continuation of Bud’s work.

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A speed regulation unit is inherently less stable than a permanent speed droop governor because additional dynamic influences from the water column are included in the primary feedback path (generated power) of the turbine governing system. The differences in these control systems can be seen by comparing Figure 2 with Figure 7. This difference in control loops generally requires that the speed regulation governor's damping adjustments (e.g., proportional plus integral plus derivative (PID) gains) be tuned for slower governor compensating action to achieve stable control using speed regulation. Additionally, dynamic water conditions such as draft tube surging have an influence on the generated power of the unit. These influences can result in undesirable movement of the turbine control actuator unless appropriate compensating measures are taken within the governor controller.

It is important to note that if a speed regulation governor controller uses a generation setpoint calibrated in units of generation (e.g., megawatts), the unit controls at its setpoint generation level only when the unit speed is at the 100% reference level. The composite error input to the governor controller algorithm is the summation of the generation error (multiplied by the speed regulation constant) and the speed error. Thus, the steady-state unit generation is a linear function of the unit speed, similar in nature to the permanent speed droop curve shown in Figure 3. The slope of the power droop characteristic response is determined by the speed regulation constant R_S.

4.6 Governor speed deadband

The governor speed deadband is a measure of the smallest speed change that can be detected and responded to by the turbine governing system. For a hydroelectric generating unit operating into an isolated system, the governor speed deadband determines the smallest band within which the unit can maintain the system frequency under steady-state loading conditions. Typically, a governor speed deadband of 0.02% is achievable and is commonly specified for hydroelectric turbine governing systems. Increasing the amount of speed deadband in a turbine governing system decreases the accuracy of frequency control that the governing system can achieve. Increased deadband also results in an increase in governor deadtime.

4.7 Blade control deadband

The blade control deadband is a measure of the smallest change in blade position setpoint that can be detected and responded to by the blade servomotor positioning system. The blade control deadband determines the accuracy of the gate/blade relationship for an adjustable-blade turbine. The accuracy of the gate/blade relationship determines the efficiency of the turbine as well as the amount of vibration and cavitation produced by off-peak operation. Typically, a blade control deadband of 1.0% is achievable and is commonly specified for hydroelectric turbine governing systems. Increasing the amount of blade control deadband decreases the accuracy of positioning the blades as a function of gate position. The resulting deviation from the ideal blade position reduces the efficiency of the turbine. This reduction in turbine efficiency may result in loss of revenue due to the reduced efficiency, increased cavitation damage to the turbine runner, and increased vibration damage to the turbine, generator, and bearings.

4.8 Governor deadtime

The governor deadtime is a measure of the amount of time elapsed between a change in speed to the first corrective action by the hydroelectric turbine governing system. The governor deadtime affects the peak overspeed after a load rejection as a result of the delay in governor response to the rising speed of the unit. The governor deadtime also affects the stability limit as achieved via the governor gain (or compensation) settings. Deadtime adds phase lag to the governing control system without a corresponding decrease in gain. This limits the amount of compensating gain that can be used in the governor controller. This limitation in governor stability requires the governor gains to be reduced to maintain control system stability. Reduction of governor gains makes the governor system slower to respond to system disturbances. Typically, a governor deadtime of 0.2 s is achievable and is commonly specified for hydroelectric turbine governing systems. However, modern control systems can often achieve shorter deadtimes due to improved control valve and control algorithm design.

4.9 Stability

The stability of a turbine governing system can be expressed as a damping ratio or as a settling time. These quantities cannot be measured directly, but they can be deduced from the measured response of the unit in response to a specified disturbance. Another method of specifying the stability of a governing system is to specify the relative size of successive peak deviations of the controlled speed after a disturbance. Typically, specifying the desired damping ratio and the settling time sufficiently defines the desired stability and responsiveness of the unit. As with many control systems for nonlinear processes, turbine speed governing systems may exhibit small oscillations around a steady-state operating point that are more related to the deadbands and nonlinearities of the system rather than to the stability of the control system.

4.10 Rated speed

The rated speed is the speed at which the generator frequency is at its rated value. If the generator is directly coupled to the turbine, the rated speed of the turbine is the same as the rated speed of the generator. If a speed increaser is used, the rated speed of the generator is greater than the rated speed of the turbine.

4.11 Overspeed

Any speed greater than the rated speed is referred to as overspeed and is typically expressed as a percent of the rated speed (e.g., 125% of rated speed is an overspeed condition). Sometimes, overspeed is expressed as a percent of unit speed in excess of 100% rated speed (e.g., 10% overspeed = 110% of rated speed).

4.12 Underspeed

Any speed less than the rated speed is referred to as underspeed and is expressed as a percent of the rated speed (e.g., 25% of rated speed is an underspeed condition).

4.13 Maximum momentary speed variation

The maximum momentary speed variation is the maximum change in unit speed when the unit load is changed by a specified amount. This variation is expressed as a percent of rated speed. The size of the load change, the characteristics of the turbine, the rotating inertia of the unit, the water column inertia, and the responsiveness of the unit governor determine this maximum momentary speed variation. The maximum momentary speed variation generally occurs when the unit governor responds to the change in unit speed and begins to return the unit speed toward its rated value.

4.14 Runaway speed

The runaway speed of a unit is influenced primarily by the turbine characteristics. Typical runaway speeds for reaction turbines range from 140% to 190% of rated speed for fixed-geometry turbines, and from 200% to 350% of rated speed for adjustable-blade turbines. Typical runaway speeds for impulse turbines range from 180% to 200% of rated speed. To avoid false operation of speed-related functions, the turbine governing system should be able to accurately measure and display unit speeds up to the runaway speed of the unit.

