IEEE Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units

Sponsor

Energy Development and Power Generation Committee of the IEEE Power Engineering Society

Approved December 5, 1991

IEEE Standards Board

Abstract: Minimum functional and performance characteristics related to speed/load-control systems for steam turbine-generator units that may be interconnected on a power system are recommended. The recommendations apply to the following types of steam turbines, rated at 500 kW and larger, intended to drive electric generators at constant speed without initial steam-pressure control, exhaust steam pressure control, or either: (1) condensing or noncondensing turbines without initial steam-pressure control, exhaust steam-pressure control, or either, including turbines used with reheat, regenerative feedwater heaters, or both; (2) condensing or noncondensing turbines with initial and/or exhaust steam-pressure control, including turbines used with reheat, regenerative feedwater heaters, or both; (3) automatic extraction and/or induction and mixed-pressure turbines. Emergency governors, other overspeed control devices, and, in general, devices that are not responsive to speed are not covered.
Keywords: Automatic extraction turbines, automatic induction turbines, condensing turbines, mixed-pressure turbines, noncondensing turbines

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Foreword

(This foreword is not a part of IEEE Std 122-1991, IEEE Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units.)

The formation of a joint AIEE/ASME committee to prepare a recommended practice covering the speed-governing of prime movers intended to drive electric generators that may, if desired, be included in prime-mover purchase specifications was approved by the AIEE Board of Directors on January 30, 1941, and by the ASME Council on June 15, 1941. The members of this joint committee were appointed jointly by the chair of the AIEE Power Generation Committee and by the ASME Standing Committee on Performance Test Codes under sponsorship of the ASME Division.

The work of the joint committee resulted in the issuance of AIEE No. 600, Recommended Specification for Speed-Governing of Steam Turbines Intended to Drive Electric Generators Rated 500 kW and Larger, in May, 1949.

The joint committee was reorganized in 1955, at which time it updated AIEE No. 600.

The joint committee was again reorganized in January 1980, and was instructed to prepare a revision of the recommended specification under the designation of IEEE Std 122 . This revision was expanded to cover speed and load controls, and the term “governor” was replaced by the term “control systems.”

The joint committee was reformed in 1987 to update the recommended practice. This revision, like the original, is limited in its scope to steam turbine generators rated at 500 KW and larger, designed to operate on a utility type system. The term “control systems” now includes torsional effects, transient response, and influences outside the control system (see Appendix) that should be considered by the purchaser. Users of this text should pay particular attention to the parts of Section 4. that indicate the need to specify or agree upon limits with the manufacturer. Such specification or agreements should be made before the manufacturer bids on the proposal.

This recommended practice does not cover emergency governors, other overspeed control devices, or, in general, devices that are not responsive to speed. Exceptions to the latter were made for turbines designed to operate with controlling steam pressures, as in the case of turbines with initial or exhaust steam pressure control, automatic-extraction and mixed-pressure turbines, or a combination of these, since the performance of the speed-governing system is affected by the performance of the steam pressure-regulating system.

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CLAUSE PAGE

IEEE Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units

1. Purpose and Scope

1.1 Purpose

The purpose of this recommended practice is to recommend functional and performance characteristics related to speed/load-control systems for steam turbine-generator units that may be interconnected on a power system, such that this recommended practice may be included in prime-mover purchase specifications.

1.2 Scope

These recommendations apply to the following types of steam turbines, rated at 500 kW and larger, intended to drive electric generators at constant speed:

1) Condensing or noncondensing turbines without initial steam-pressure control, exhaust steam, pressure control, or either, including turbines used with reheat, regenerative feedwater heaters, or both. (See Figs 1 and 2).
2) Condensing or noncondensing turbines with initial steam-pressure control, exhaust steam-pressure control, or both, including turbines used with reheat, regenerative feedwater heaters, or both. [See Figs 3, 7, 8(a), and 8(b)].
3) Automatic extraction, induction, or both, and mixed-pressure turbines. [See Figs 4, 5, and 8(c)].

2. References

This recommended practice should be used in conjunction with the following publications.

[1] ANSI C50.10-1990, American National Standard General Requirements for Synchronous Machines.[1]

[2] ASME PTC 20.1-1977 (Reaf 1982), Speed and Load Governing Systems for Steam Turbine-Generator Units.[2]

[3] ASME PTC 20.2-1965 (Reaf 1986), Overspeed Trip Systems for Steam Turbine-Generator Units.

[4] ASME PTC 20.3-1970 (Reaf 1980), Pressure-Control Systems Used on Steam Turbine-Generator Units.

[5] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms.[3]

[6] NEMA SM 23-1985, Steam Turbines for Mechanical Drive Service.[4]

[7] NEMA SM 24-1985, Land Based Steam Turbine Generator Sets, 0 to 33 000 kW.

3. Definitions and Descriptions of Terms

All definitions, except as specifically covered in this section, are defined in IEEE Std 100-1988 [5].[5]

3.1 Types of Steam Turbines

3.1.1 Straight Condensing Turbine: All the steam enters the turbine at one pressure and leaves the turbine exhaust at a pressure below atmospheric pressure. (See Fig 1).

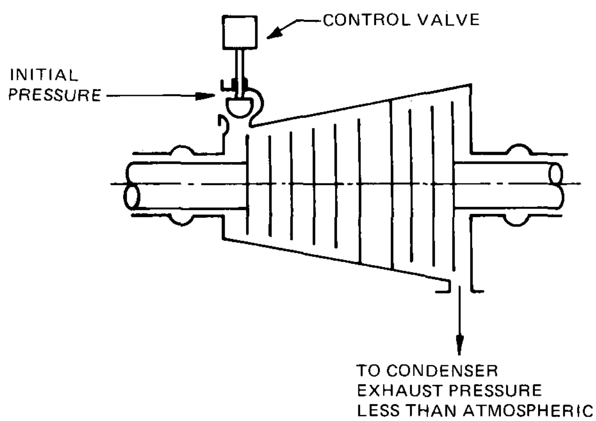


Figure 1—Straight Condensing Turbine

3.1.2 Straight Noncondensing Turbine: All the steam enters the turbine at one pressure and leaves the turbine exhaust at a pressure equal to or greater than atmospheric pressure. (See Fig 2).

[1]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.
[2]ASME publications are available from the American Society of Mechanical Engineers, 22 Law Drive, Fairfield, NJ 07007, USA.
[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.
[4]NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.
[5]The numbers in brackets correspond to the references in Section 2.

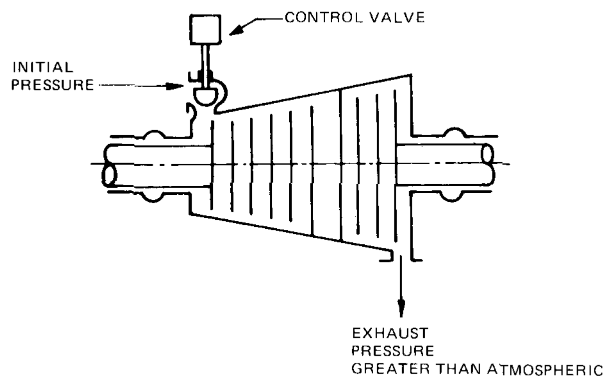


Figure 2—Straight Noncondensing Turbine

3.1.3 Nonautomatic Extraction Turbine — Condensing or Noncondensing: Steam is extracted from one or more stages without means for controlling the pressures of the extracted steam. (See Fig 3).

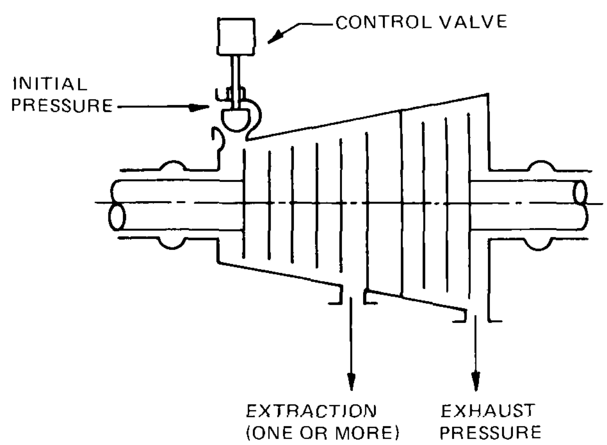


Figure 3—Nonautomatic Extraction Turbine — Condensing or Noncondensing

3.1.4 Automatic Extraction Turbine — Condensing or Noncondensing: Steam is extracted from one or more stages with means for controlling the pressure(s) of the extracted steam. (See Fig 4).

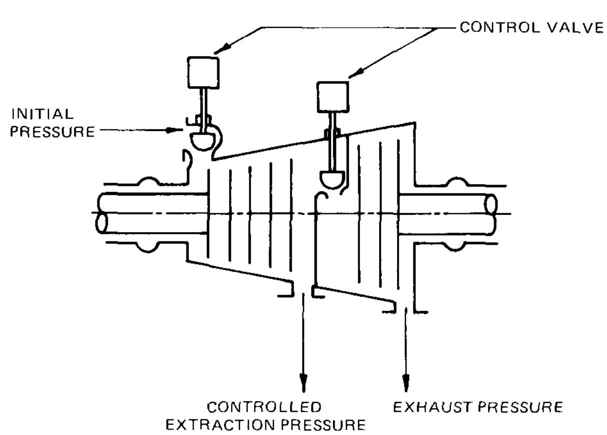


Figure 4—Automatic Extraction Turbine — Condensing or Noncondensing

3.1.5 Automatic Extraction and/or Induction Turbine — Condensing or Noncondensing: Steam is extracted from or inducted into one or more stages with means for controlling the pressure(s) of the extraction steam, induction steam, or both. (See Fig 5).

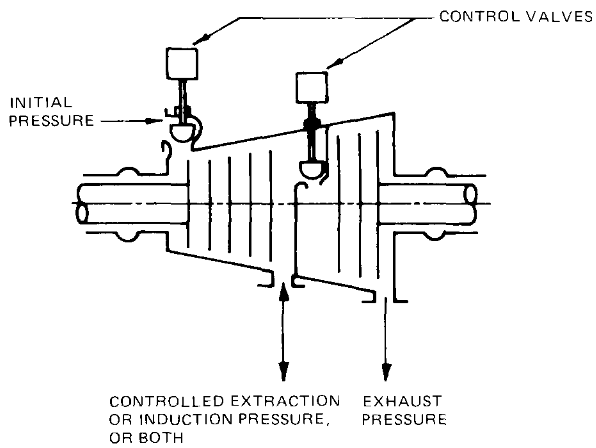


Figure 5—Automatic Extraction and/or Induction Turbine — Condensing or Noncondensing

3.1.6 Mixed-Pressure Turbine — Condensing or Noncondensing: Steam enters the turbine at two or more pressures through separate inlet openings with means for controlling the inlet steam pressures or turbine power output. (See Fig 6).

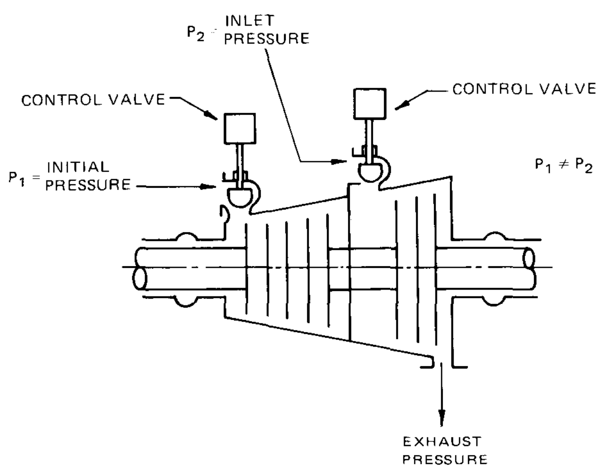


Figure 6—Mixed-Pressure Turbine — Condensing or Noncondensing

3.1.7 Reheat Turbine — Condensing or Noncondensing: Steam enters the turbine initially at one pressure, and is then extracted at a lower pressure and temperature and reheated. The steam is then readmitted into the turbine. (See Fig 7).

NOTE — Other types of turbines that are combinations of Fig 1 through Fig 7 may be included.

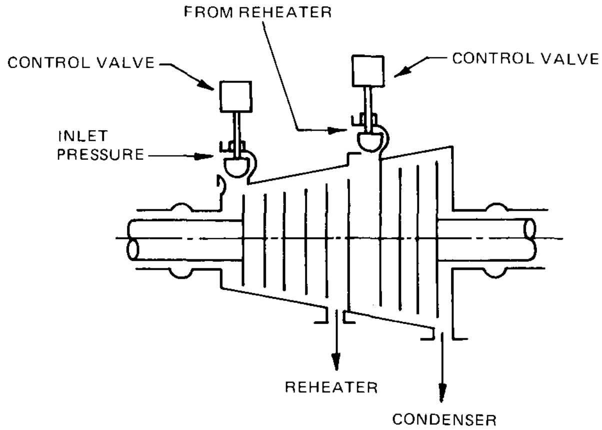


Figure 7—Reheat Turbine — Condensing or Noncondensing

3.2 Speed/Load-Control System Components

3.2.1 Compensated Control System: An interconnected system that controls two or more variables (speed, load, pressure, etc.) with compensation designed to minimize the interaction between the controlled variables.

3.2.2 Control Mechanism: The control mechanism includes all systems, devices, and mechanisms between a controller and the controlled valves.

3.2.3 Control Valves: Those valves that control the energy input to the turbine and are actuated by a controller through the control mechanism.

3.2.4 High-Speed Limit (Speed/Load Reference): A device or input that limits the speed/load reference setting to a predetermined upper limit. This device may establish the upper limit of the synchronizing speed range.

3.2.5 Load Controller: The load controller includes only those components and control elements that are responsive to energy output and load reference and that furnish an input signal to the control mechanism for the purpose of controlling the load.

3.2.6 Low-Speed Limit (Speed/Load Reference): A device or input that limits the speed/load reference setting to a predetermined lower limit. This device may establish the lower limit of the synchronizing speed range.

3.2.7 Pressure Control System: A system that controls the pressure at a sensing point in a designated location. Typically, it includes the pressure-sensing element, the controller, the control mechanism, and the control valve(s). [See Figs 8(a), 8(b), and 8(c)].

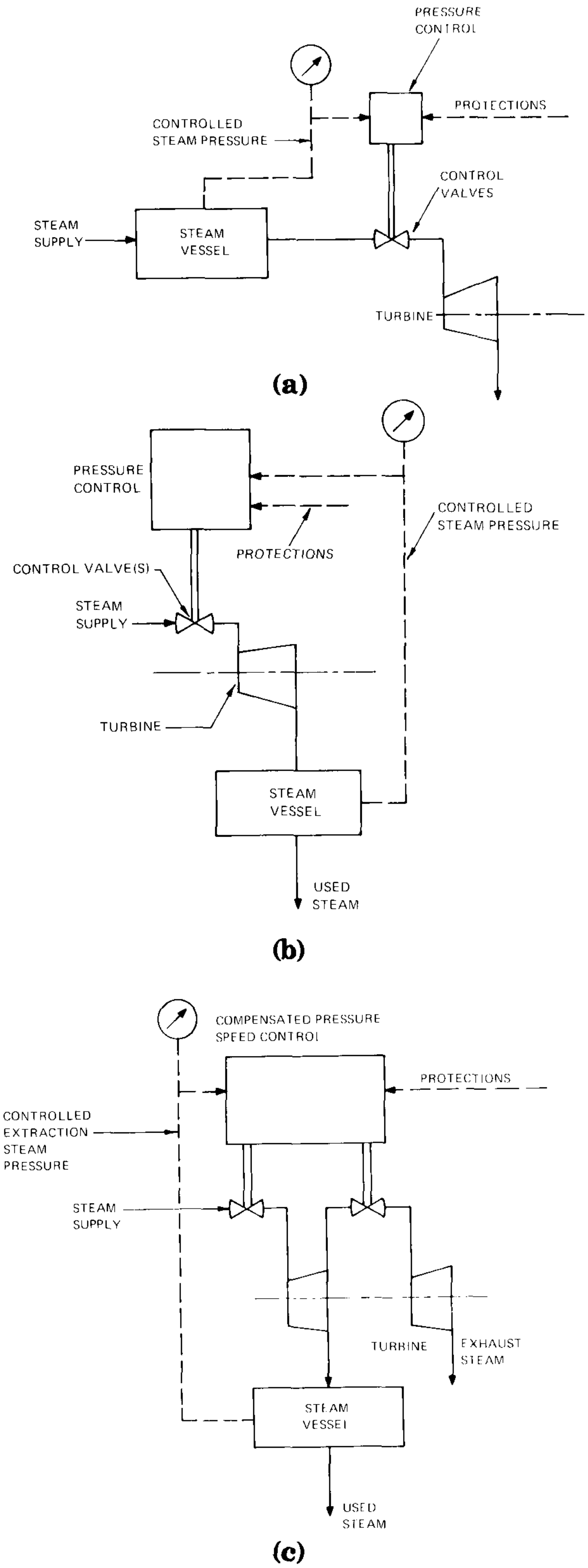


Figure 8—Pressure Control Systems (a) Initial Pressure Control (b) Back Pressure Control (c) Typical Extraction Pressure Control (Single Automatic)

3.2.8 Pressure Controller: The pressure controller includes only those components and control elements that generate one or more signal(s) for the control mechanism, in response to pressure set point and pressure feedback signals, to control pressure.

3.2.9 Pressure Reference Changer: A device for producing the pressure reference signal to the pressure controller in response to a manual or automatic adjustment.

3.2.10 Speed Controller: The speed controller includes only those components and control elements that are responsive to speed and speed reference and that supply an input signal to the control mechanism for the purpose of controlling speed.

3.2.11 Speed/Load Control System: A system that controls the speed and load of a steam turbine-generator. The system typically includes the speed and load sensing and referencing elements, the controller(s), the control mechanism(s), and the control valve(s).

3.2.12 Speed/Load Reference Changer: A device or devices by which the control system reference may be adjusted to change the speed or load of the turbine while the turbine is in operation.

3.2.13 Stop or Throttle Valves(s): Those valve(s) that normally provide fast interruption of the main energy input to the turbine. Throttle valves are sometimes used for turbine control during start-up.

NOTE — A throttle valve apportions its opening so that it can modulate flow. The term stop valve is defined as an open or closed valve that is either in the fully-open or fully-closed position when in operation.

3.2.14 Valve Position Limiter (Load Limit): A device that acts on the speed/load-control system to prevent the control valve(s) from opening beyond a preset limit. This device is sometimes known as the load limiter.

3.3 Functions, Characteristics, and Definitions

Term and Description	Symbol	Unit
3.3.1 Dead Band (Speed/Load-Control System). The total magnitude of the change in steady-state speed within which there is no resulting measurable change in the position of the control valve(s). Dead band is the measure of the insensitivity of the speed/load-control system and is expressed in percent of rated speed. (See Fig 9).	N_d	%

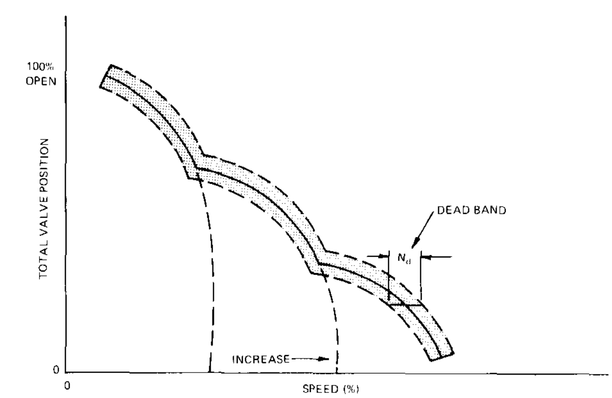


Figure 9—Dead Band

Term and Description	Symbol	Unit
3.3.2 Flow (Rated). Rated steam flow is the steam flow at a specified location in the system when the unit is operating at rated steam and load conditions. Rated steam conditions are defined as the normal, initial steam pressure, initial steam temperature, exhaust steam pressure, and, in the case of automatic extraction and mixed-pressure turbines, the extraction steam pressure and induction pressure, respectively, on which the steam or heat rate performance is based.	Q_r	kg/s lb/h
3.3.2.1. For automatic extraction and mixed-pressure turbines, the specified maximum extraction or induction steam flow at rated conditions is referred to as *rated extraction or induction flow*.		
3.3.2.2. For noncondensing turbines, the throttle flow corresponding to the rated power output of the turbine is called *rated flow*.		
3.3.2.3. For initial pressure-controlled turbines, the throttle flow corresponding to the rated power output of the turbine is called *rated flow*.		
3.3.3 Normal Operating Conditions. Operation of the unit at rated speed with all throttle/stop valves and shut-off valves in a fully open position (their normal operating position, see 3.2.13) with specified or agreed upon values of steam pressure(s) and temperature(s), and with all feedwater heaters in service.		
3.3.4 Overspeed. The maximum increase in speed from rated speed following a sudden loss of load (expressed in percent of rated speed).	ΔN_z	%
3.3.4.1 $\Delta N_z = \frac{N_m - N_r}{N_r} \cdot 100$ where N_m = maximum speed N_r = rated speed N_z = overspeed		% r/min r/min %
3.3.5 Power Output. The electrical output of the turbine-generator as measured at the generator terminals.	P	M W
3.3.6 Power Output (Rated). The power output that the turbine-generator should be capable of developing at rated flow, rated steam conditions, and rated generator conditions.	P_r	M W
3.3.7 Regulation, Steady-State Speed (General). The change in steady-state speed (expressed in percent of rated speed), corresponding to the power output change from rated power output to zero power output, is called steady-state speed regulation. The steady-state speed regulation may vary with different settings of the speed/load reference changer. For the purpose of this recommended practice, the percentage regulation derived from the formulas of 3.3.8 and 3.3.9 should be based on the speed/load reference changer (see 3.3.12) being set to give rated speed with rated power output. (See Fig 10).		

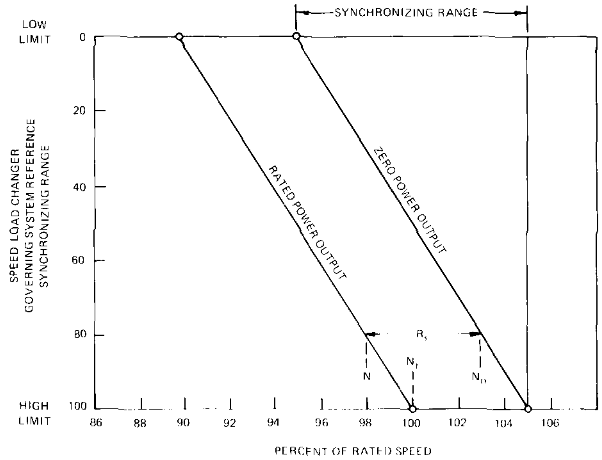
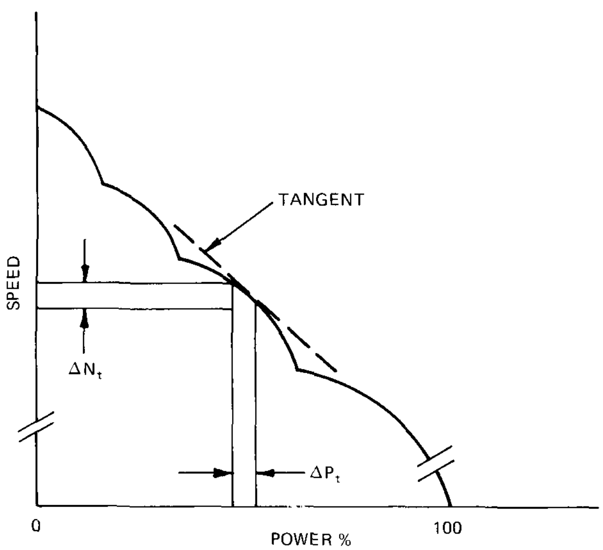
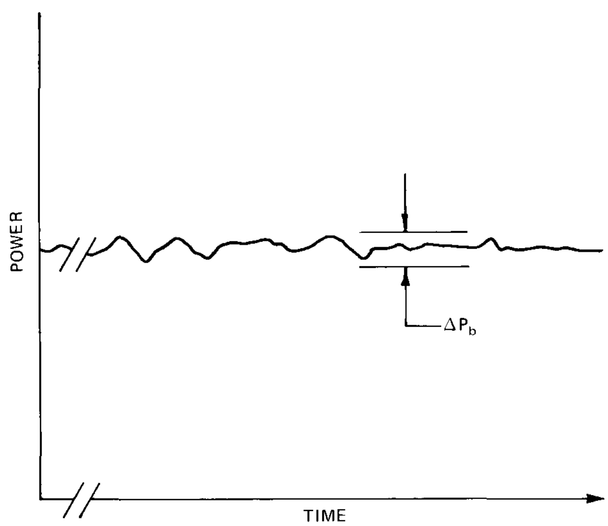


Figure 10—Illustration of Steady-State Speed Regulation of 5%

Term and Description	Symbol	Unit
NOTE — Speed regulation is considered positive when speed increases with decrease in power output. All definitions concerning speed regulation are based on zero dead band.		
3.3.8 Regulation, Steady-State Speed (For all types of turbines except automatic extraction and mixed-pressure). The change in steady-state speed, expressed in percent of rated speed, when the power output is reduced from rated power output at rated speed to zero output with identical settings of all adjustments of the speed/load-control system(s).	R_s	%
$R_s = \frac{N_o - N}{N_r} \cdot 100$ where R_s = steady-state speed regulation N_o = speed at zero power output N = speed at rated power output N_r = rated speed		% % r/min r/min r/min
3.3.9 Regulation, Steady-State Speed (for automatic extraction and mixed-pressure turbines). The change in steady-state speed, expressed in percent of rated speed, corresponding to the power output change from rated power output to zero power output with zero extraction or induction now(s), with the pressure-control system(s) inoperative and locked in the position corresponding to rated extraction or induction pressures at rated power output, and with identical settings of all adjustments of the speed/load-control and pressure-control system(s). It is the speed change expressed in percent of rated speed when the load is reduced from maximum power output at which zero extraction or induction conditions are permitted to zero power output, multiplied by the ratio of rated power output to this power output change. See 3.3.7 for a general definition and Fig Auto for a typical illustration showing steady-state speed regulation of 5%.	R_s	%
$R_s = \frac{N_o - N_m}{N_r} \cdot \frac{P_r}{P_m} \cdot 100$ where R_s = steady-state speed regulation N_o = speed at zero power output N_r = rated speed N_m = speed at P_m P_m = maximum power output at which zero extraction or induction conditions are permitted P_r = rated power output		% % r/min r/min r/min M W M W

Term and Description	Symbol	Unit
3.3.10 Regulation — Steady-State Incremental Speed. The rate of change of the steady-state speed with respect to the power output at a given steady-state speed and power output. It is the slope of the tangent to the steady-state speed versus the power-output curve at the point of power output under consideration. It is expressed in percent of rated speed when the difference in steady-state speed, expressed in percent of rated speed for any two points of the tangent, is divided by the corresponding difference in power output expressed in per unit of rated power output. The several points of power output at which the values of steady-state incremental speed regulation are derived are based on rated speed at each point of power output. (See Fig 11).	R_i	%
 **Figure 11—Incremental Speed Regulation**		
$R_i = \frac{\Delta N_t}{\Delta P_t} \cdot \frac{P_r}{N_r} \cdot 100$ where R_i = steady-state incremental speed regulation ΔN_t = speed difference on the tangent ΔP_t = power difference on the tangent P_r = rated power output N_r = rated speed		% % r/min M W M W r/min
3.3.11 Regulation — Steady-State Pressure. The sustained steam-pressure change that will actuate the pressure-control system from maximum flow at rated pressure to minimum flow with a constant pressure set point and with the turbine operating at rated speed.	R_p	kPa psi
3.3.11.1. For an extraction control system, the pressure change is from rated extraction flow to zero extraction flow.		
3.3.11.2. For an extraction/induction pressure-control system, the pressure change is from rated extraction flow to rated induction flow.		
3.3.12 Regulation — Relative Steady-State Pressure. The value of the steady-state pressure regulation, R_p, referred to rated pressure, P_{r1}, where P_{r1} is rated pressure in psi, (kPa).	δ_p	%

Term and Description	Symbol	Unit
$\delta_p = R_p \cdot \frac{100}{P_{r1}}$		
3.3.13 Speed/Load Reference Change. An input to the control system representing a desired speed or load.	%	%
3.3.14 Speed (Rated). The speed corresponding to the required nominal system frequency.	N_r	r/min
3.3.15 Stability — Pressure-Control System. The capability of a system to actuate the pressure controls so that sustained oscillations of the system pressure or of the energy input to the turbines do not exceed a specified value under steady-state pressure (or load demand) or following a change to a new steady-state pressure (or load demand).		
3.3.16 Stability — Speed/Load-Control System. Capability of the speed/load-control system to position the control valve(s) so that a sustained oscillation of the turbine speed or of the power output, as produced by the speed/load-control system, stays within a specified range during operation under steady-state load demand or following a change to a new steady-state load demand.		
3.3.17 Steady State. The state of a variable when its value exhibits only negligible change over an arbitrarily long interval of time.		
 **Figure 12—Steady-State Load-Control Band**		
3.3.18 Steady-State Load-Control Band. The peak-to-peak magnitude of sustained oscillation of load, expressed in percent of rated power output, that can be attributed to the speed/load control system only when the generator is operating in parallel with other generators and under steady-state load demand. (See Fig 12).	ΔP_b	%
3.3.19 Steady-State Oscillations. The peak-to-peak magnitude of sustained oscillations of turbine speed, expressed in percent of rated speed, at rated speed that can be attributed to the speed/load-control system only when the generator is operating isolated under steady-state load demand.	N_b	%
3.3.20 Synchronizing Range. The range of speed within which the speed can be synchronized, as outlined in 4.4.8.1 and as illustrated in Fig 10.		

4. Equipment and Performance Specifications — Turbines Without Initial and/or Exhaust Steam-Pressure Control

The information in this section is applicable to condensing and noncondensing turbines without initial steam-pressure control, exhaust steam-pressure control, or either, including turbines used with reheat, regenerative heating cycles, or both.

4.1 Terms and Definitions

All terms and definitions used in this section are in accordance with the terms and definitions adopted by the joint IEEE/ASME committee on a recommended specification for prime-mover speed controls and are in accordance with ASME Performance Test Codes ASME PTC 20.1–1977 [2], ASME PTC 20.2–1965 [3], and ASME PTC 20.3–1970 [4].

4.2 Standard Equipment

The manufacturer shall equip the turbine-generator unit with the following standard equipment:

1) *Speed/Load-Control System*. A speed /load-control system capable of controlling and regulating the speed of the turbine in conformity with the performance characteristics hereinafter specified.
   The speed/load-control system should include means by which the steady-state speed regulation may be adjusted to values within the limits hereinafter specified. Adjustment of the steady-state speed regulation, while the turbine is in operation, is not required by this recommended practice unless otherwise agreed upon between the manufacturer and the purchaser.
2) *Speed/Load Reference Changer*. A speed/load changer by means of which the speed or power output of the turbine may be changed within the limits hereinafter specified while the turbine is in operation.
   The speed/load reference changer shall be equipped with means for manual adjustment and should be equipped to accept input(s) for remote control.
3) *Valve Position Limiter (Load Limit)*. For turbines rated over 10 MW, a valve position limiter manually adjustable to limit the degree of opening of the control valves to any value within the full range of valve travel while the turbine is in operation. If this device is used for load-limiting purposes, the speed-control system will not necessarily control the overspeed of the turbine, as covered in 4.4.7, if the speed/load reference changer is set at its high-speed stop.
4) *Miscellaneous*. At the discretion of the manufacturer, any instruments, controls, or safety devices not specified as standard equipment in (1), (2), and (3) may be included.

4.3 Optional Equipment

The following devices or other optional devices may be specified by the purchaser:

1) *Valve Position Limiter*. For turbines rated 10 MW or under, a valve position limiter as described in 4.2.3.
2) *Adjustment of Steady-State Regulation*. A means by which, in the speed/load-control system (see 4.2.1) the steady-state speed regulation may be adjusted, within limits agreed to by the manufacturer and purchaser, while the turbine is operating at any power output.
3) *Remote or Local Indication*. A means for remote or local indication, or both, of the positions of the control valves or any other element of the control system to be specified by the purchaser.
4) *Remote Control of the Valve Position Limiter*. For turbines rated over 10 MW, a means for remote setting of the valve position limiter (see 4.2.3) within the limits hereinafter specified.
5) *Remote Control of Speed/Load Reference Changer*. For turbines rated over 10 MW, a means for remote control of the speed/load reference changer within the limits hereinafter specified.
6) *Miscellaneous*. At the discretion of the manufacturer, any instruments, controls, or safety devices not previously specified as optional equipment may be included.

4.4 Performance Specifications

It is recommended that the following performance characteristics and numerical values be specified.

4.4.1 Normal Operating Conditions

The performance characteristics hereinafter specified are to apply when all turbine steam admission valves, except the control valve(s), are in a fully-open position, and when the turbine is operating under rated steam conditions of steam pressure, temperature, and specified extraction steam flow conditions (see 3.3.3).

4.4.2 Stability of Speed/Load-Control Systems

The speed/load-control system (see 3.2.11) should be capable of controlling, with stability, the speed of the turbine at power output between zero and maximum, inclusive, when the generator is operating isolated or in parallel with other generators (see 4.4.8.3).

4.4.3 Conditions for Stability

The speed/load-control system (see 4.2.1) should be deemed stable when

1) The generator is operating isolated and under steady-state load demand, provided that the magnitude of the sustained oscillation of turbine speed produced by the speed/load-control system does not exceed the percentage of rated speed indicated below:

Rating (MW)	Percent of Rated Speed
Under 2 MW	0.12
2 MW–5 MW	0.10
Over 5 MW	0.07

2) The generator is operating in parallel with other generators and under sustained load demand, provided that the magnitude of the sustained oscillation of power output produced by the speed/ load-control system (see 4.2.1) does not exceed the value determined from the incremental speed regulation, corresponding to the sustained load demand under consideration, for a speed change equal to 110% of the dead band hereinafter specified. Thus:

$$\Delta P = \frac{1.10 N_d}{R_i} \cdot 100$$

where
ΔP = magnitude of the oscillation of energy output in percent of rated power output
N_d = specified dead band in percent of rated speed
R_i = steady-state incremental speed regulation in percent of rated speed

4.4.3.1

Turbine speed is defined as the speed that exists at the turbine-generator coupling. The instantaneous speed measured by the speed/load control system may not be identical to this speed because of the torsional flexibility of the turbine shaft between the coupling and the point of speed measurement made by the speed/load control system. (See 4.4.9, 4.4.10, and Fig 13).

4.4.4 Steady-State Speed Regulation

The normal factory setting of the steady-state speed regulation should be in the range of 3.5% to 5.0% when the speed/load reference changer (see 4.2.2) is set to give rated speed at rated power output.

4.4.4.1

If specified by the purchaser, the steady-state speed regulation may be adjusted to a value less than that specified in 4.4.4, when agreed to be practicable by the manufacturer.

4.4.4.2

Steady-state speed regulation should be adjustable between 2.5% and 7% when the speed/load reference changer (see 4.2.2) is set to give rated speed with rated power output.

4.4.4.3

The manufacturer should specify the permissible maximum value of the steady-state speed regulation for which the speed/load-control system (see 4.2.1) may be adjusted to meet the requirement for controlling the overspeed of the turbine as specified in 4.4.7.

4.4.4.4

If specified by the purchaser, the steady-state speed regulation may be adjusted to a value greater than that specified in 4.4.4.3. In such a case, the requirements of 4.4.7 should not apply.

4.4.5 Steady-State Incremental Speed Regulation

With the speed/load-control system (see 4.2.1) adjusted to give a value within the limits of 3.5% to 5.0% steady-state speed regulations, the steady-state incremental speed regulation should be, at any power output, not less than the minimum values and not more than the maximum values stated below:

	Regulation, in %	
	Minimum	**Maximum**
(1) For all units rated 10 MW and under	0.75	8.0
(2) For units rated 10 MW–12.5 MW	0.95	10.0
(3) For units rated over 12.5 MW	1.90	10.0

except that

1) For the last 10% of power output resulting from the opening of any control valve(s) controlling any arc(s) of steam admission other than the last, the average steady-state incremental speed regulation should not exceed 15%.
2) For the last 10% of power output resulting from the opening of any control valve(s) controlling the last arc of steam admission, it should be permissible for the average steady-state incremental speed regulation to be at any value.

3) For the first 15% of rated power output, it should be permissible for the steady-state incremental speed regulation to be at values up to 13% inclusive, to facilitate the synchronizing of the turbine-generator unit for parallel operation and to limit the magnitude of the load fluctuations that may be imposed upon the turbine while it is operating in this range of power output.

4.4.6 Dead Band

The dead band at rated speed and at any power output within the rated power output should not exceed the following values:

Rating (MW)	Dead Band Percent of Rated Speed
Under 2 MW	0.10
2 MW–5 MW	0.08
Over 5 MW	0.06

4.4.7 Overspeed

With the turbine operating under the conditions that were specified in 4.4.1, and with the speed/load reference changer (see 4.2.2) set to give rated speed with maximum guaranteed power output, the speed/load-control system (see 4.2.1), upon the sudden and complete loss of electrical load, should be capable of controlling the overspeed of the turbine to a value that is less than the specified setpoint of the emergency overspeed trip device. If the purchaser chooses to use the valve position limiter to set maximum guaranteed power output and adjusts the speed/load reference changer to its high-speed limit, the requirements of this section do not apply.

4.4.8 Range of Speed/Load Reference Changer Adjustment

It should be possible by means of the speed/load reference changer (see 4.2.2) to open the control valves to the position corresponding to maximum guaranteed capacity when the turbine is operating at speeds up to and including 102% of rated speed. With the turbine operating at zero power output, it should be possible, by the same means, to operate the turbine at speeds down to and including 95% of rated speed.

4.4.8.1

It should be possible, by means of the speed/load reference changer (see 4.2.2), to adjust the speed of the turbine, while operating at zero power output, to any value between 95% and 105%, inclusive, of rated speed for synchronizing the generator for parallel operation with other generators. The upper limit of the range should not exceed the overspeed trip limit. This speed range constitutes the synchronizing range shown in Fig 10.

4.4.8.2

For turbines rated over 10 MW, the speed/load reference changer (see 4.2.2) should be capable of being operated at a rate that will reduce the turbine power output from rated power output to zero power output in not less than 30 s and not more than 40 s.

4.4.8.3

For turbines rated over 10 MW, the speed/load changer operation should produce a uniform speed/load response to inputs in both the reference point raise and lower directions without the necessity of corrective inputs to achieve the required reference point setting. A speed/load changer dead band requirement should be part of any specification.

4.4.9 Torsional Effects

The presence of torsional vibration modes in the shaft system of a turbine-generator should be recognized, and appropriate allowance should be made in the design of the turbine and generator control systems.

4.4.9.1

The location of the speed transducer system(s) and the frequency response of the associated turbine or generator control system should be so designed that continuous excitation of any torsional modes under any condition of loading is avoided.

4.4.9.2

When necessary, the method of speed measurement should be chosen to avoid problems with any torsional mode of significance.

4.4.9.3

When measurements of machine acceleration are derived by differentiation of the speed signal, or otherwise, appropriate filtering or other means should be employed such that components of shaft torsional vibrations are reduced to sufficiently low levels to avoid spurious operation.

4.4.10 Transient Response — Considerations

When specifying a speed/load-control system, there is a need to specify speed/load-control transient response. However, the vehicle through which transient response should be defined is beyond the scope of this recommended practice. Optimum transient response of a closed-loop control system to an external disturbance depends not only on the transfer function of the controller, but also on all other transfer functions in the control loop. In the speed/load-control system, this will include all of the transfer functions such as turbine generator, reheater, and steam flow control valves. See Appendix A for further information.

5. Equipment and Performance Specifications — Turbines With Initial and/or Exhaust Steam-Pressure Control

This section is applicable to condensing or noncondensing turbines with initial steam-pressure control, exhaust steam-pressure control, or both, including turbines used with reheat, regenerative feedwater heaters, or both.

5.1 Standard Equipment

The manufacturer should equip the turbine-generator unit with the following standard equipment in addition to the standard equipment specified in Section 4..

1) *Steam-Pressure-Control System*. A steam-pressure-control system by which the controlled steam pressures may be regulated in conformity with the performance characteristics hereinafter specified.

2) *Pressure Reference Changer.* A pressure reference changer for each pressure controller by means of which the controlled steam pressures and flows may be changed within the limits hereinafter specified while the steam-pressure-control system is in operation.
   Each pressure reference changer should be equipped with means for manual adjustment.

5.2 Optional Equipment

Remote control of the pressure reference changer, which is a means for the remote setting of each pressure reference changer (see 5.1.2) within the limits hereinafter specified, as well as other optional devices, may be specified by the purchaser in addition to the optional devices specified in Section 4.

5.3 Performance Specifications

It is recommended that the following performance characteristics and numerical values be specified as additions to or modifications of those specified in Section 4.

5.3.1 Stability of Steam-Pressure-Control System

The steam-pressure control system (see 5.1.1) should be capable of controlling, with stability, each steam pressure specified to be controlled as well as the energy input to the turbine, when the turbine is operating under sustained steam flow demand and power output or following a change to another sustained steam flow demand or power output.

5.3.1.1

The steam-pressure-control system (see 5.1.1) should be considered stable when the turbine is operating under sustained steam flow demand or following a change to a different sustained steam flow demand, provided that

1) The magnitude of the sustained oscillation of controlled steam pressure does not exceed 1.72 kPa (0.25 Lb^f/in^2) for a vacuum system, or, for a nonvacuum system, 2% of the specified absolute steam pressure specified to be controlled.
2) The sustained oscillation of energy input to the turbine does not exceed 3.2% of the rated power output.

NOTE —

1 lb^f/in^2 = 6.88 kPa
1 kPa = 0.15 lb^f/in^2

5.3.1.2

Under a sustained steam flow demand, the difference between oscillation existing with steam-pressure-control system in service and that existing when the steam-pressure-control system is blocked or inoperative is considered the sustained oscillation of controlled steam pressure or of energy input produced by the steam-pressure-control system.

5.3.2 Steady-State Pressure Regulation

The steam-pressure-control system (see 5.1.1) should have a steady-state pressure regulation, expressed in pounds per square inch, not to exceed the greater of a pressure of 3.44 kPa (0.5 lb^f/in^2) or 4% of the rated absolute steam pressure.

When the steam-pressure-control system (see 5.1.1) must operate in parallel with other steam-pressure-control systems, it may be necessary to use larger values of steam-pressure regulation than those previously recommended to obtain stable operation.

5.3.3 Range of Pressure Reference Adjustment

It should be possible by means of the pressure reference changer (see 5.1.2), to adjust each steam pressure specified to be controlled to any value within the greater of either a pressure of ± 34.4 kPa (5.0 lb^f/in^2) or ± 10% of the specified absolute steam pressure under control; except that the steam pressure under control need not be adjusted to values less than that of the atmosphere.

6. Equipment and Performance Specifications — Automatic Extraction, Automatic Extraction Induction, and Mixed-Pressure Turbines

This section is applicable to automatic extraction, automatic extraction induction, and mixed-pressure turbines.

6.1 Standard Equipment

The manufacturer should equip the turbine-generator unit with the following standard equipment specified in Sections 4. and 5. Other equipment could include a *compensated control system* capable of meeting the requirements hereinafter specified.

6.2 Optional Equipment

Some of the following devices, or other optional devices, may be specified by the purchaser in addition to the optional devices specified in Sections 4. and 5.

6.2.1 Megawatt Control System

A means by which the load on the turbine-generator may be controlled so as to maintain a specified megawatt level independent of frequency fluctuations in the utility bus or other disturbances.

6.2.2 Isochronous Speed Control System

A means by which the speed of the turbine-generator is maintained at a constant value that is independent of the load. This mode of operation is specified for situations in which the turbine-generator is isolated from the main utility bus and is carrying local or islandized load only.

6.2.2.1 Bumpless Transfer Mechanism

A means by which transfer from control mode to another can be accomplished with no corrective transient maneuver in the control valves.

6.2.3 Valve Ramp Control System

A means for slowly ramping the starting, control, or extraction valves from the closed position(s) to the operating positions.

6.2.4 Other Optional Features

A means to accept and respond to inputs from other devices that is not limited to but could include some of the following:

1) *Import/Export Tie Line Control*. An input to which the turbine-generator may be adjusted to maintain a specified level of imported or exported power on the local tie line

2) *Automatic Synchronizing Control*. A means to bring a unit up to synchronous speed, then, without manual intervention, synchronize the unit with the local power system
3) *Inlet, Exhaust, or Back Pressure Control*. A means to respond to the needs of inlet, exhaust, or back pressure requirements while maintaining the integrity of the designed control function

6.3 Performance Specifications

It is recommended that the following performance characteristics and numerical values be specified as additions to or modifications of those specified in Sections 4. and 5.

6.3.1 Stability of Speed/Load-Control System

The following values of sustained oscillations should replace those specified in 4.4.3(1).

Rating (MW)	Percent of Rated Speed
Under 2 MW	0.20
2 MW–5 MW	0.16
Over 5 MW	0.11

6.3.2 Steady-State Speed Regulation

A steady-state speed regulation range of not less than 2.5% and not more than 5% should replace the ranges specified in 4.4.4 for all units.

6.3.3 Steady-State Incremental Speed Regulation

With the speed-control system (see 4.2.1) adjusted to give a value within the limits of steady-stead speed regulation specified in 4.2, the steady-state incremental speed regulation should, at any power output, be not less than 0.95% and not more than 10%.

6.3.4 Dead Band

The following values should replace those specified in 4.4.6:

Rating (MW)	Dead Band Percent of Rated Speed
Under 2 MW	0.16
2 MW–5 MW	0.13
Over 5 MW	0.10

6.3.5 Performance of Compensated Control System

The compensated control system (see 6.1) should be considered to meet the requirements of this recommended practice when

1) The turbine-generator is operated isolated and under sustained load demand, provided that the sustained speed of the turbine at any power output does not change more than one percent of rated speed for any change in sustained steady-state extraction or induction steam flow that occurs within the limits of 5%–95%, inclusive, of the maximum extraction or induction steam flow specified for the given power output.
2) The turbine-generator is operated in parallel with other turbine-generators, at rated speed, and at any sustained power output, provided that the sustained power output of the turbine does not change more than 20% for any change in sustained steady-state extraction or induction steam flow which occurs within the limits of 5%–95%, inclusive, of the maximum extraction or induction steam flow specified for the given sustained power output.

7. Descriptive Literature

The manufacturer shall furnish, with the proposal, descriptive diagram(s) or drawing(s), or both, of the speed/load-control and pressure-control system(s) and any other equipment specified to be furnished by the manufacturer, together with written description(s) clearly explaining the principle(s) of operation.

8. Acceptance Tests

Tests to determine the performance specified herein by the purchaser and guaranteed by the manufacturer should be governed by the provisions of the latest available ASME performance test code, at the date of proposal, with such exceptions as may be mutually agreed upon by the manufacturer and the purchaser.

9. Bibliography

[B1] Hammons, T. J., Fleming, R. J., and Ewer, M. H. “Bibliography of Literature (with Abstracts) on Steam Turbine-Generator Control Systems.” IEEE Committee Report. *IEEE Transactions on Power Apparatus and Systems*. vol. PAS-102, 1983, pp. 2959–2970.

[B2] Hammons, T. J., Fleming, R. J., and Ewer, M. H. “Update of Bibliography of Literature (with Abstracts) on Steam Turbine-Generator Control Systems.” IEEE Committee Report. *IEEE Transactions on Energy Conversion*. vol. EC-3, 1988, pp. 560–567.

Annex A Transient Response Considerations (Informative)

(This appendix is not a part of IEEE Std 122-1991, IEEE Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units.)

Transient response considerations will vary from machine to machine. A typical consideration for shaft torsional parameters is shown in Fig A1. Other types of transient response considerations could include voltage regulation, speed of valving, response to fault conditions, network oscillations, etc.

The purchaser should consider the necessary characteristics of the shaft torsional parameters from the variables considered important to the unit in question. To amplify this need, consider Fig A1 as a guideline.

The physical design characteristics of control valves are represented by the transfer functions Vi(s) and Vh(s), and could be simplified by using V(s).

The angular inertias of the turbine-generator are represented by Th(s), Tip(s), Tlp(s), and Tg(s).

The reheater parameters are represented by R(s).

When the transfer functions in Fig A1, V(s), T(s), and R(s), are linear, the speed/load controller C(s), and the intercept valve controller, Ci(s), can be tuned to provide an optimized or specified speed/load transient response. In this case, the transient response specification does not have to address the issue of V(s), T(s), and R(s).

When the transfer functions V(s), T(s), R(s), or any combination of these become nonlinear in spite of incorporating valve nonlinear compensations Fi(s) and Fh(s), then the controllers C(s) and Ci(s), irrespective of optimized tuning, will be ineffective in producing a desired stable speed/load transient response over the desired speed/load range. The issue of the nonlinearity of transfer functions V(s), T(s), and R(s), or a combination of these will then have to be addressed.

Torsional inertia constants represented by Tip(s), Tlp(s), and Tg(s) should be considered when the simulated system reveals any problems with speed/acceleration measurement due to the flexibility of the shaft. Torsional and other internal responses are as much dependent upon the utility grid and operating methods as on the turbine-generator itself. (See 4.4.3.1, 4.4.9, and Fig A1).

It is preferable to specify the transient response requirements as part of an actual test performance specification, as is currently provided under ASME PTC 20.1-1977 [2]. Inclusion of applicable performance testing codes such an ASME PTC 20.1-1987 [2] in the turbine-generator acceptance specification has the effect of satisfying the speed/load transient performance requirement on a broader base than that which can be provided for if transient response specifications were included in this recommended practice.

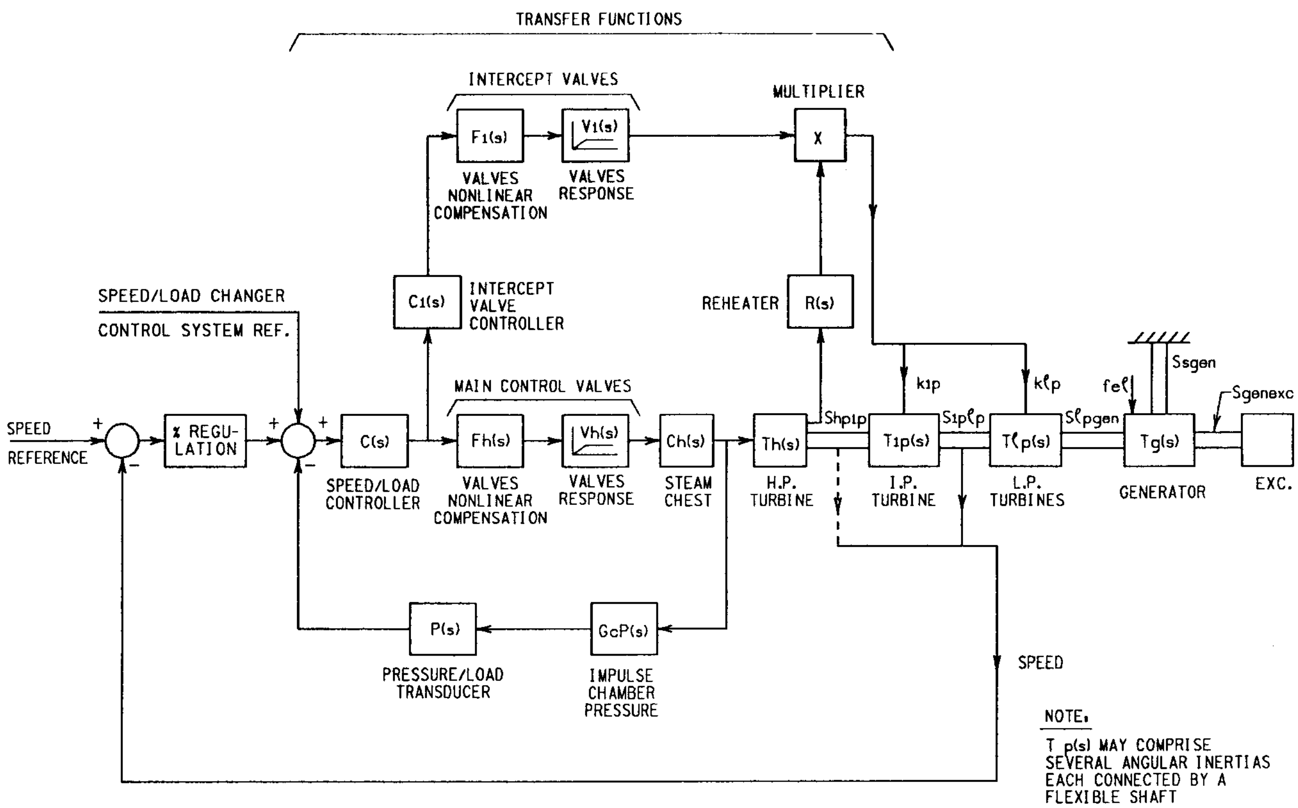


Figure 13—Typical EHC Speed/Load-Control System