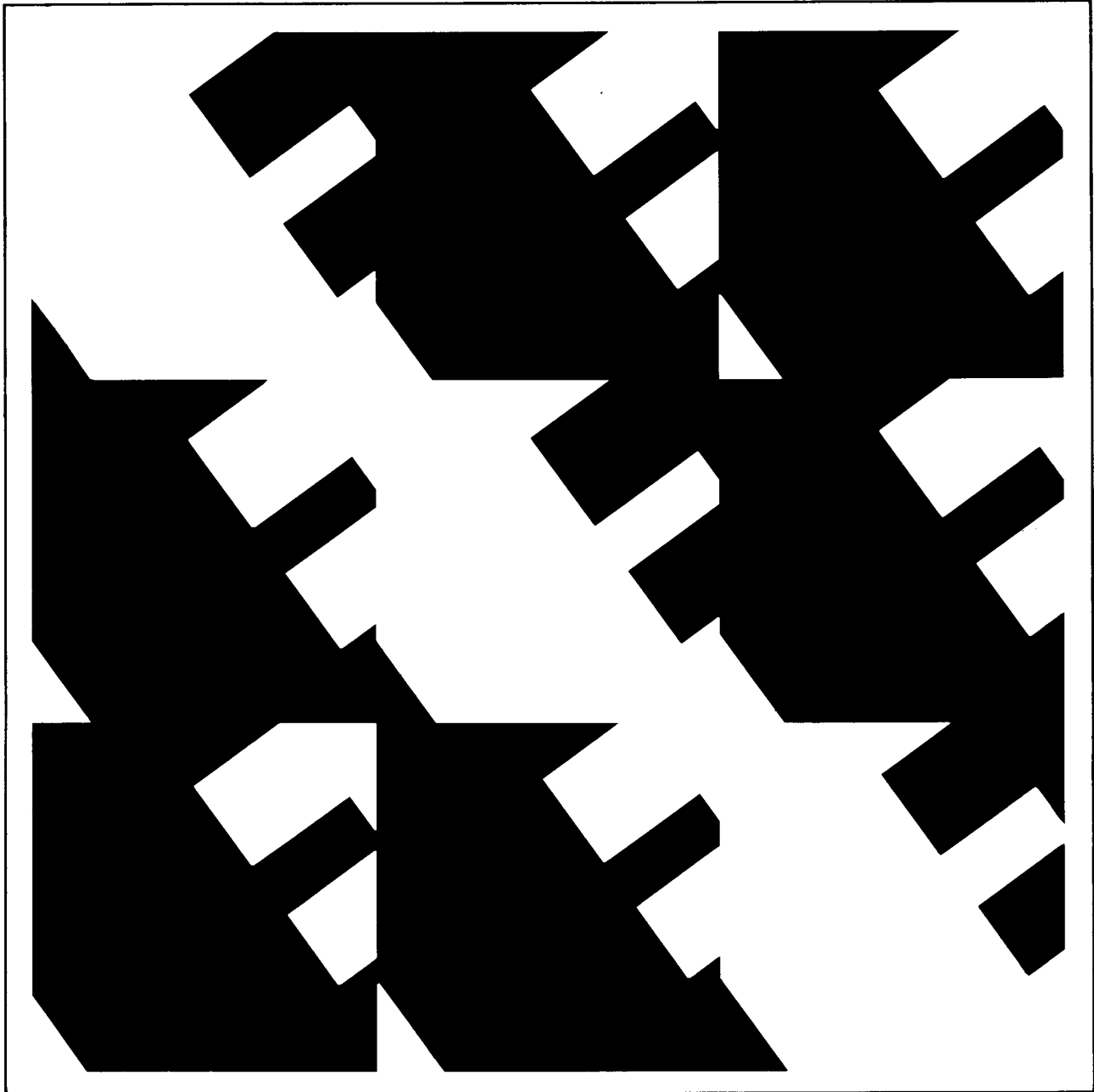


IEEE Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units



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

Sponsor

**Power Generation Committee of the
IEEE Power Engineering Society**

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Foreword

(This Foreword is not a part of IEEE Std 122-1985, IEEE Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units.)

The formation of a joint AIEE/ASME committee for the purpose of preparing 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 personnel of this joint committee was appointed jointly by the Chairman 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 and resulted in the update of AIEE No 600, Recommended Specifications for Speed-Governing of Steam Turbines Intended to Drive Electric Generators Rated 500 kW and Larger.

The joint committee was again reorganized in January, 1980 and instructed to prepare a revision of the Recommended Specification with its designation to be IEEE Std 122. 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. However, this revision has been expanded to include speed and load controls. In addition, the term *governor* has been replaced by the term *control systems* in the title and in the text to advance the understanding that control systems need not be limited to rotating flyweights but include mechanical, hydraulic, and electronic components. Users of this text should pay particular attention to the parts of Section 4 that indicate the need to specify or agree to limits with the manufacturer. Such specifications or agreements should be made before the manufacturer bids on a proposal.

This recommended practice does not cover emergency governors, or other overspeed control devices, and, in general, devices which are not responsive to speed. Exceptions to the latter were made for turbines designed to operate with controlled 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.

Transient response was considered as a recommended specification and is represented in Appendix A. *Torsional* and other internal responses are beginning to be understood by the industry but are as much dependent upon the utility grid and operating methods as on the turbine generator itself, so they are not included as part of this recommended practice.

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

1. Object and Scope

1.1 Object. The object of this recommended practice is to recommend minimum functional and performance characteristics related to speed/load-control systems for steam turbine-generator units that may be interconnected on a power system, so 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 or exhaust steam-pressure control, or both, including turbines used with reheat, or regenerative feedwater heaters, or both. See Figs 1 and 2.

(2) Condensing or noncondensing turbines with initial or exhaust steam-pressure control, or both, including turbines used with reheat or regenerative feedwater heaters, or both. See Figs 3, 7, 8(a) and (b).

(3) Automatic extraction, or induction, or both, and mixed-pressure turbines. See Figs 4, 5, and 8(c).

2. References

This recommended practice is supplemented by the following codes and standards.

[1] ANSI C50.10-1977, American National Standard General Requirements for Synchronous Machines.¹

[2] ANSI/ASME PTC 20.1-1977 (R1982), Speed and Load Governing Systems for Steam Turbine-Generator Units.

[3] ANSI/ASME PTC 20.2-1965, Performance Test Codes Overspeed Trip Systems for Steam Turbine-Generator Units.

[4] ANSI/ASME PTC 20.3-1970 (R 1980), Performance Test Code Pressure-Control Systems Used on Steam Turbine-Generator Units.

[5] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.²

[6] NEMA SM 12-1967 (R-1977), Direct Connected Steam-Turbine Synchronous Generator Units, Air Cooled.³

¹ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

²IEEE publications are available from the IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

³NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street, NW, Washington, DC 20037.

3. Definitions and Descriptions of Terms

All terms not defined in this section will be used as they are defined in ANSI/IEEE Std 100-1984. [5].⁴

3.1 Types of Steam Turbine

Term and Description

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

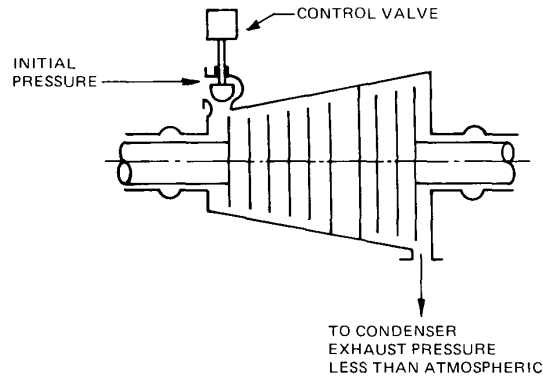


Fig 1
Straight Condensing Turbine

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

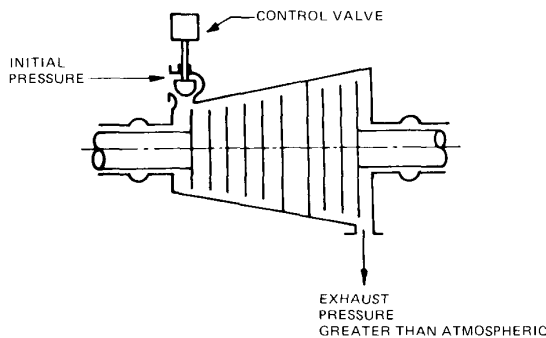


Fig 2
Straight Noncondensing Turbine

⁴The numbers in brackets correspond to those of the references listed in Section 2.

3.1.3 Nonautomatic Extraction Turbine, Condensing or Noncondensing. Steam is extracted from one or more stages, but without means for controlling the pressure(s) of the extracted steam. See Fig 3.

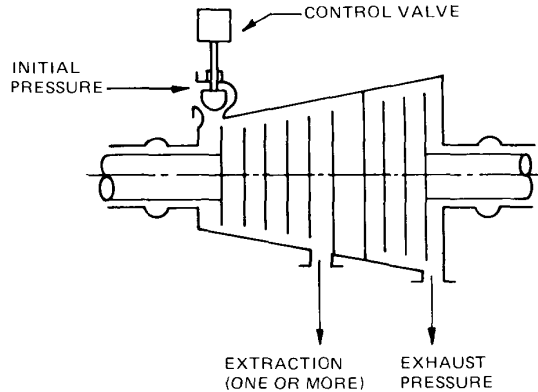


Fig 3
Nonautomatic Extraction Turbine, Condensing or Noncondensing

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.

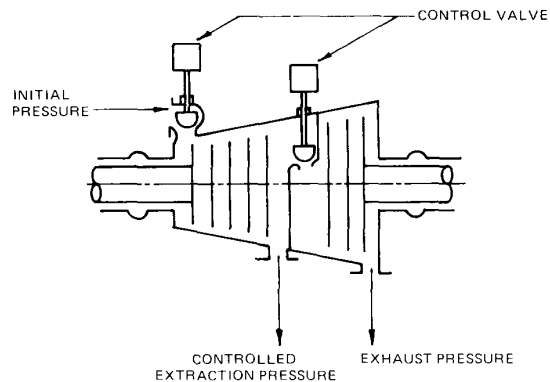


Fig 4
Automatic Extraction Turbine, Condensing or Noncondensing

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

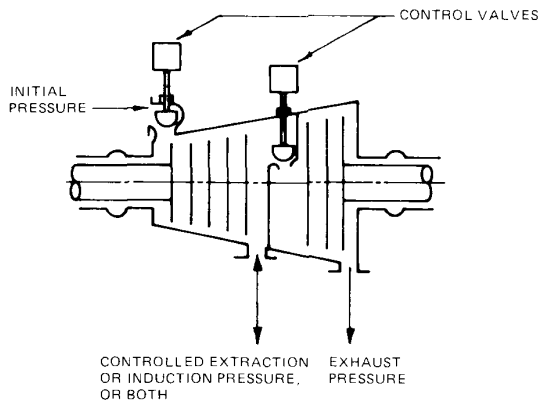


Fig 5
Automatic Extraction or Induction Turbine,
or Both—Condensing or Noncondensing

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.

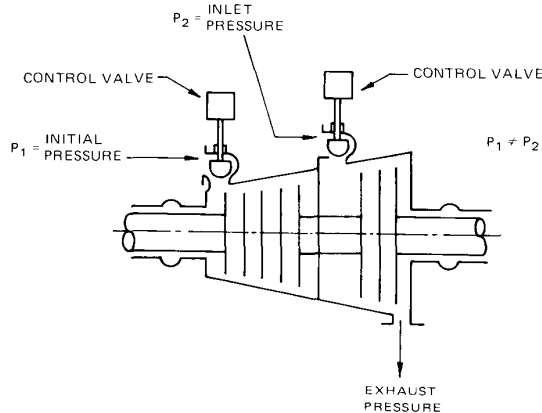


Fig 6
Mixed-Pressure Turbine,
Condensing or Noncondensing

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

NOTE: Other types of turbines, that are combinations of Figs 1 through 7, may be included in these definitions.

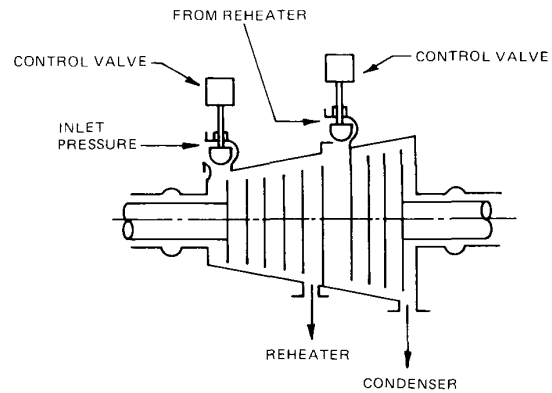


Fig 7
Reheat Turbine,
Condensing or Noncondensing

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 Valve. Those valves that control the energy input to the turbine and that 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, 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 pres-

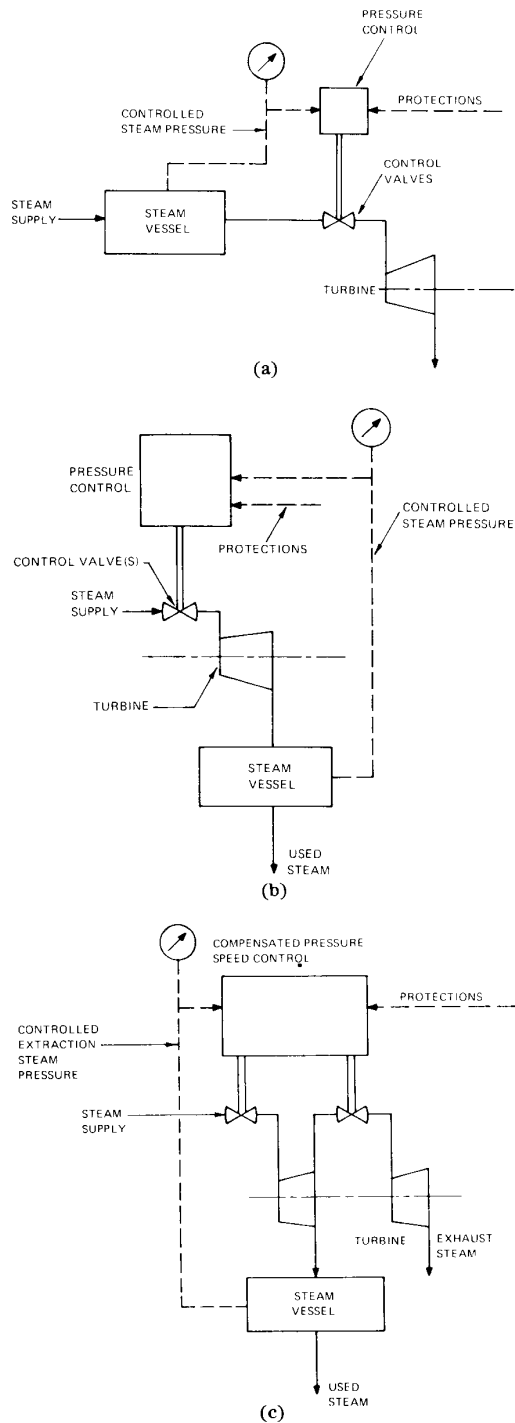


Fig 8

Pressure-Control Systems

- (a) Initial Pressure Control (b) Back Pressure Control (c) Typical Extraction Pressure Control (Single Automatic)

sure-sensing element, the controller, the control mechanism, and the controlled valve(s). See Fig 8(a), (b), and (c).

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 for the purpose of controlling 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 supplies 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).

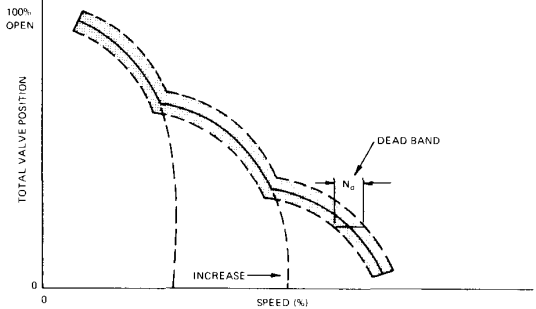
3.2.12 Speed/Load Reference Changer. A device or devices by means of which the control system reference may be adjusted to change the speed or load of the turbine while the turbine is in operation.

3.2.13 Stop or Throttle Valve(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.

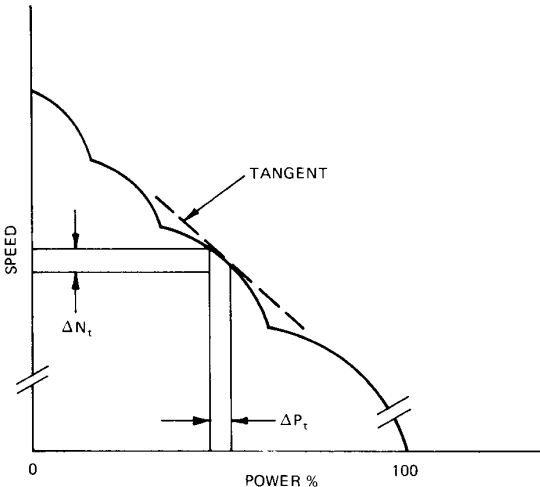
NOTE: The term *stop valve* is defined as an open or closed valve. A *throttle valve* has some portion of its opening through which it can modulate flow.

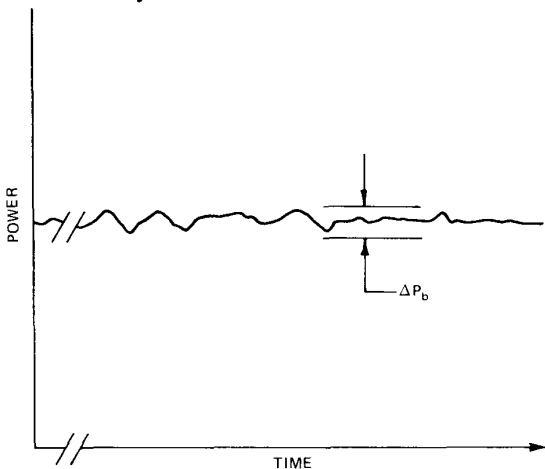
3.2.14 Valve Position Limiter (Load Limit). A device that acts on the speed/load-control system to prevent the control valve(s) from opening beyond a preset limit. This device is sometimes known as the *load limiter*.

3.3 Functions, Characteristics, and Definitions

Term and Description	Symbol	Unit
<p>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.</p>  <p style="text-align: center;">Fig 9 Dead Band</p>	N_d	percent
<p>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, and 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.</p> <p>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 <i>rated extraction or induction flow</i>.</p> <p>3.3.2.2 For noncondensing turbines, the throttle flow corresponding to the rated power output of the turbine is called <i>rated flow</i>.</p> <p>3.3.2.3 For initial pressure-controlled turbines, the throttle flow corresponding to the rated power output of the turbine is called <i>rated flow</i>.</p> <p>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 values of steam</p>	Q_r	lb/h kg/s

Term and Description	Symbol	Unit
<p>pressure(s), temperature(s), and with all feed-water heaters in service.</p> <p>3.3.4 Overspeed. The maximum increase in speed expressed in percent of rated speed, from rated speed following a sudden loss of load.</p> <p>3.3.4.1</p> $\Delta N_z = \frac{N_m - N_r}{N_r} \cdot 100$ <p>N_m = maximum speed N_r = rated speed N_z = overspeed</p> <p>3.3.5 Power Output. The electrical output of the turbine-generator as measured at the generator terminals.</p> <p>3.3.6 Power Output, Rated. The power output that the turbine-generator should be capable of developing at rated flow, steam conditions, and rated generator condition.</p> <p>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 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 3.3.13, the speed/load changer being set to given rated speed with rated power output. See Fig 10.</p>	<p>ΔN_z</p> <p>P</p> <p>P_r</p>	<p>percent</p> <p>percent</p> <p>r/min</p> <p>r/min</p> <p>percent</p> <p>kW</p> <p>kW</p>
<p style="text-align: center;">Fig 10 Illustration of Steady-State Speed Regulation of 5%</p> <p>NOTE: Speed regulation is considered positive when speed increases with decrease in power output. All definitions concerning speed regulations are based on zero dead band.</p>		

Term and Description	Symbol	Unit
<p>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.</p>  <p>Fig 11 Illustration of Incremental Speed Regulation</p> $R_i = \frac{\Delta N_t}{\Delta P_t} \cdot \frac{P_r}{N_r} \cdot 100$ <p> 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 </p> <p>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.</p> <p>3.3.11.1 For an extraction control system the pressure change is from rated extraction flow to zero extraction flow.</p> <p>3.3.11.2 For an extraction/induction pressure-control system, the pressure change is from rated extraction flow to rated induction flow.</p>	<p>R_p</p>	<p>percent percent r/min kW kW r/min psi kPa</p>

Term and Description	Symbol	Unit
<p>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).</p> $\delta_p = R_p \cdot \frac{100}{P_{r1}}$ <p>3.3.13 Speed/Load Reference Changer. An input to the control system representing a desired speed or load.</p> <p>3.3.14 Speed, Rated. The speed corresponding to the required nominal system frequency.</p> <p>3.3.15 Stability, Pressure-Control System. The capability of a system to actuate the pressure controls so that any sustained oscillations of the system pressure or of the energy input to the turbines does 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).</p> <p>3.3.16 Stability (Speed/Load-Control System). The 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 does not exceed a specified value during operation under steady-state load demand or following a change to a new steady-state load demand.</p> <p>3.3.17 Steady State. The state of a variable where its averaged value exhibits only negligible change over an arbitrarily long interval of time.</p>	<p>δ_p</p> <p>percent</p> <p>percent</p> <p>N_r</p> <p>r/min</p>	
<p style="text-align: center;">Fig 12 Steady-State Load-Control Band</p>  <p>3.3.18 Steady-State Load-Control Band. The peak-to-peak magnitude of sustained oscillation of</p>	<p>ΔP_b</p>	<p>percent</p>

Term and Description	Symbol	Unit
<p>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.</p> <p>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.</p> <p>3.3.20 Synchronizing Range. The range of speed within which the speed can be synchronized, and as outlined in 4.4.8.1 and illustrated in Fig 10.</p> <p style="text-align: center;">4. Equipment and Performance Specifications</p> <p style="text-align: center;">Part A</p> <p>The information in this section is applicable to condensing and noncondensing turbines without initial or exhaust steam-pressure control, or both, including turbines used with reheat, or regenerative heating cycles, or both.</p> <p>4.1 Terms and Definitions. All terms and definitions used in these specifications 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 ANSI/ASME PTC 20.1-1977 (R 1982) [2], ANSI/ASME PTC 20.2-1965 [3], and ANSI/ASME PTC 20.3-1970 (R 1980) [4].</p> <p>4.2 Standard Equipment Specification. The manufacturer shall equip the turbine-generator unit with the following standard equipment:</p> <p>4.2.1 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.</p> <p>The speed/load-control system shall include means by which the steady-state speed regulation may be adjusted to values within the limits here-</p>	N_b	percent

inafter 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.

4.2.2 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 should be equipped with means for manual adjustment and should be equipped to accept input(s) for remote control.

4.2.3 Valve Position Limiter (Load Limit). For turbines rated 10 001 kW and larger, a valve position limiter manually adjustable for the purpose of limiting 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 changer is set at its high-speed stop.

4.2.4 Miscellaneous. At the discretion of the manufacturer, any instruments, controls, or safety devices not specified as standard equipment in 4.2.1, 4.2.2, and 4.2.3 may be included.

4.3 Optional Equipment. The following devices or other optional devices may be specified by the purchaser.

4.3.1 Valve Position Limiter. For turbines rated less than 10 001 kW a valve position limiter as described in 4.2.3.

4.3.2 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.

4.3.3 Remote or Local Indication. A means for the 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.

4.3.4 Remote Control of the Valve Position Limiter. For turbines rated 10 001 kW and larger, a means for remote setting of the valve position limiter (see 4.2.3) within the limits hereinafter specified.

4.3.5 Remote Control of Speed/Load Reference Changer. For turbines rated 10 001 kW and larger, a means for remote control of the speed/

load reference changer within the limits hereinafter specified.

4.3.6 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 hereinafter specified is 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.

4.4.3 Conditions for Stability. The speed/load-control system (see 4.2.1) should be deemed stable:

(1) When 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 (kW)	% of Rated Speed
500–1999	0.12
2000–5000	0.10
5001 and larger	0.07

(2) When 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 and for a speed change equal to 110% of the dead band hereinafter specified, thus:

$$\Delta P = \frac{1.10N_d}{R_1} \cdot 100$$

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

4.4.4 Steady-State Speed Regulation. The normal factory setting of the steady-state speed regulation should be in the range of 3.5%–5% 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 to the extent 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 (4.2.2) is set to give rated speed with rated power output.

4.4.4.3 The manufacturer shall 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 steady-state speed regulation specified in 4.4.4, the steady-state incremental speed regulation should, at any power output, be not less than the minimum values and not more than the maximum values stated below:

	Regulation, %	
	Min	Max
(1) For all units rated 10 000 kW and smaller	0.75	8.0
(2) For units rated 10 001 kW–12 500 kW	0.95	10.0
(3) For units rated 12 501 kW and larger	1.90	10.0

except that:

(a) 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%.

(b) 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.

(c) 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, in order 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 (kW)	Dead Band % of Rated Speed
500–1999	0.10
2000–5000	0.08
5001 and larger	0.06

4.4.7 Overspeed. With the turbine operating under conditions that were specified in 4.4.1 and with the speed/load reference changer (4.2.2) set to give rated speed with maximum guaranteed power output, upon the sudden and complete loss of electrical load, the speed/load-control system (see 4.2.1) 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. This speed range constitutes the synchronizing range shown in Fig 10.

4.4.8.2 For turbines rated 10 001 kW and larger, the speed/load reference changer (4.2.2) should be capable of being operated at a rate that will reduce the turbine power output from rated to zero power output in not less than 30 s and not more than 40 s.

4.4.8.3 For turbines rated 10 001 kW and larger, the speed/load reference changer overshoot, should be kept at a level so as not to interfere with the response of the control system.

5. Equipment and Performance Specifications

Part B

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

5.1.1 Steam-Pressure-Control System. A steam-pressure-control system, by means of which the controlled steam pressures may be regulated in conformity with the performance characteristics hereinafter specified.

5.1.2 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. The following and other optional devices may be specified by the purchaser in addition to the optional devices specified in Section 4.

Remote Control of Pressure Reference Changer. A means for the remote setting of each pressure reference changer (see 5.1.2) within the limits hereinafter specified.

5.3 Performance Specification. It is recommended that the following performance characteristics and numerical values be specified as additions to or as 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 and 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 deemed stable when the turbine is operating under sustained steam flow demand or is following a change to a different sustained steam flow demand, provided:

(1) The magnitude of the sustained oscillation or controlled steam pressure does not exceed 0.25 lbf/in² (1.72 kPa) 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 lbf/in² = 6.88 kPa
(1 psi = 6.88 kPa)

5.3.1.2 Under a sustained steam flow demand, the difference between oscillation existing with the 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 0.5 lbf/in² (3.44 kPa) or 4% of the rated absolute steam pressure.

When the steam-pressure-control system (see 5.1.1) is required to 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 ± 5.0 lbf/in² (34.4 kPa) or $\pm 10\%$ 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

Part C

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 not specified in Sections 4 and 5.

Compensated Control System. A compensated control system capable of meeting the requirements hereinafter specified.

6.2 Optional Equipment. Other optional devices may be specified by the purchaser in addition to the optional devices specified in Sections 4 and 5.

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 (kW)	% of Rated Speed
500–1999	0.20
2000–5000	0.16
5001 and larger	0.11

6.3.2 Steady-State Speed Regulation. The steady-state speed regulation should replace those specified in 4.4.4 for all units; they should be not less than 2.5% and not more than 5%.

6.3.3 Steady-State Incremental Speed Regulation (Modifying 4.4.4). With the speed-control system (see 4.2.1) adjusted to give a value within the limits of steady-state 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 (kW)	Dead Band % of Rated Speed
500–1999	0.16
2000–5000	0.13
5001 and larger	0.10

6.3.5 Performance of Compensated Control System. The compensated control system (see 6.1) should be deemed to meet the requirements of this recommended practice.

(1) While the turbine-generator is operated isolated and under sustained load demand, provided 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 which occurs within the limits of 5%–95% inclusive, of the maximum extraction or induction steam flow specified for the given power output.

(2) While the turbine-generator is operated in parallel with other turbine-generators, at rated speed and at any sustained power output, provided 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. Description Literature

The manufacturer shall furnish, with his 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, (9), pp 2959–2970.

Appendix

(This Appendix is not a part of IEEE Std 122-1985, IEEE Recommended Practice for Functional and Performance Characteristics of Control Systems for Steam Turbine-Generator Units.)

Recommendations on Transient Response Considerations
for a Speed/Load-Control System

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 the other transfer functions in the control loop. In the case of the speed/load-control system, this will include the transfer functions of the turbine-generator, the reheater, and the steam flow control valves as shown in Fig A1.

The purchaser should consider the responsibility to define

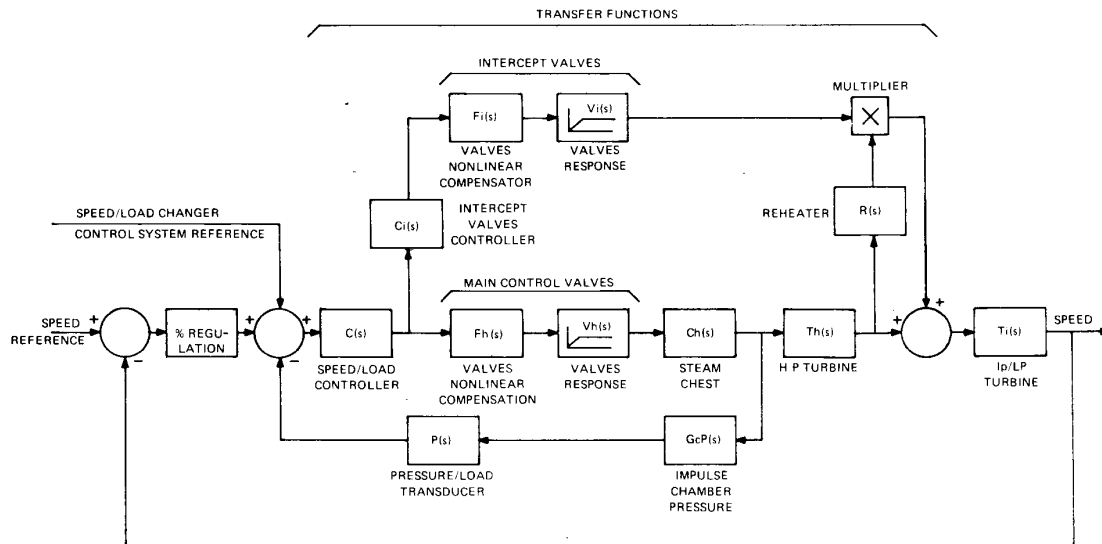
(1) The physical design characteristics of the control valves such as valve steam flow coefficients from which transfer functions $V_i(s)$ and $V_h(s)$ are derived.

(2) The turbine-generator physical design characteristics such as turbine-generator inertia from

which $T_h(s)$ and $T_i(s)$ generally referred to as $T(s)$ are derived.

(3) The reheater physical design characteristics such as reheater heat transfer coefficients from which transfer function $R(s)$ is derived. When $V(s)$, $T(s)$, and $R(s)$ are linear transfer functions, the speed/load controller $C(s)$ and the intercept value controller $C_i(s)$ can be tuned to provide an optimized or specified speed/load transient response. In this case, the transient response specifications do not have to address the issue of $V(s)$, $T(s)$, and $R(s)$. If, however, $V(s)$ or $T(s)$, or both, or $R(s)$ or a combination of these, were to remain nonlinear transfer functions, in spite of incorporating valve nonlinear compensators $F_i(s)$ and $F_h(s)$, then the controllers $C(s)$ and $C_i(s)$, 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 $V(s)$ or $T(s)$, or both, or $R(s)$ or a combination of these, will then have to be addressed.

Fig A1
Typical EHC Speed/Load-Control System



With this in mind, it is preferable to specify the transient response requirements as part of an actual test performance specification, as is currently provided for under ANSI/ASME PTC 20.1-1977 (R1982) [2]. Inclusion of applicable performance testing codes such as ANSI/ASME PTC

20.1-1977 (R1982) [2], in the turbine-generator acceptance specification, has the effect of satisfying the speed/load transient performance requirements on a broader base than that which can be provided for, if transient response specification were included in this recommended practice.

