

Guide to specification of hydroturbine control systems

The European Standard EN 61362:1998 has the status of a
British Standard

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National foreword

This British Standard is the English language version of EN 61362:1998. It is identical with IEC 61362:1998.

The UK participation in its preparation was entrusted to Technical Committee MCE/15, Hydraulic turbines, which has the responsibility to:

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- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
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Summary of pages

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**Guide to specification of hydraulic turbine control systems
(IEC 61362:1998)**

Guide pour la spécification des
régulateurs des turbines hydrauliques
(CEI 61362:1998)

Leitfaden zur Spezifikation der
Regelungssysteme für hydraulische
Turbinen
(IEC 61362:1998)

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European Committee for Electrotechnical Standardization
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Foreword

The text of document 4/119/FDIS, future edition 1 of IEC 61362, prepared by IEC TC 4, Hydraulic turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61362 on 1998-01-01.

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- latest date by which the national standards conflicting
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Annexes designated "normative" are part of the body of the standard.
In this standard, annexes A and ZA are normative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61362:1998 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

Recent developments have led to more stringent control system requirements with respect to power frequency regulation and to isolated network operation. These requirements essentially concern the primary control, which due to the use of modern, mostly electronic components, can be tasked with some additional control functions. Also the primary control responds to a superimposed large network control system (secondary control).

This guide mainly deals with primary control specifications; additional tasks are covered but the guide does not elaborate on specific details.

Specifically the primary control can include some or all of the following functions:

- unit start-up and shut-down;
- idling before synchronizing and after separation from the network and synchronizing;
- isolated network operation;
- parallel operation on large networks in speed control and power output control mode;
- head water level and/or flow control;
- operating mode transitions;
- monitoring and safety functions.

The guide also deals with aspects of the actuating energy supply.

The controlled system in a hydroturbine control loop, i.e., the respective transfer function, is characterized by:

- the unit(s), i.e. turbine(s) and generator(s);
- the water passage system;
- the network to which the unit(s) is (are) connected;
- the modes of operation as mentioned above.

The parameters of the primary control system (speed governor, power output governor, etc.) are to be carefully matched to the prevailing system conditions in order to:

- achieve adequate stability;
- satisfy performance requirements with respect to damping, response and accuracy;
- provide safety with respect to limitations in hydraulic transients, etc.

To achieve the above, in many cases modeling and simulations are valuable. The guide refers to some important aspects in this respect.

Since the governors have to be able to cope with a range of conditions, it is suitable practice to specify that a certain range for the setting of parameters is available in the governors. The guide follows this practice in the relevant part.

Specifically, in this guide, the performance-relevant definitions refer to the PID-controller, which can be implemented by analog or digital means. With appropriate microcomputer technology, higher control algorithms also can be implemented. Although it is deemed difficult to set up specific rules at the time of the issue of this guide, the general criteria for the adequate performance of a control system are essentially independent of the control strategy used. This means that they remain applicable as described in this guide and that the PID-controller can be regarded and used as a reference governor to gauge the control performance of a system.

The guide makes reference to IEC 60308 on hydraulic turbine control systems. It relies on it for the methods of system identification and verification of performance, etc. It is the intention of this guide to supplement IEC 60308 by recommending performance criteria and ranges for the setting of parameters.

To facilitate the setting up of specifications, this guide also includes data sheets, which are to be filled out by the customer and the vendor in the various stages of the project and the contract.

GUIDE TO SPECIFICATION OF HYDRAULIC TURBINE CONTROL SYSTEMS

1 General

1.1 Scope and object

This guide includes relevant technical data necessary to describe hydraulic turbine control systems and define their performance. It is aimed at unifying and thus facilitating the bidding specifications and technical bids. It will also serve as a basis for setting up technical guarantees.

In case of separate vendors for different segments of a system, the interface between them is especially important.

The guide is not confined to the control loop functions proper but includes all important functions of a control system, i.e., it also treats sequencing functions, etc. Hydraulic turbine control is thus understood to include:

- speed, power, water level and discharge control for reaction and impulse-type turbines including double regulated machines;
- means of providing actuating energy;
- safety devices for emergency shut-down, etc;
- environmental performance criteria.

The guide aids the selection of some important parameters to be specified and checked in relation to the different types of installations.

Excluded topics are acceptance tests, specific test procedures and guarantees.

1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreement based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60068-2-6:1995, *Environmental testing – Part 2: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60308:1970, *International code for testing of speed governing systems for hydraulic turbines*

IEC 61000-3-2:1995, *Electromagnetic compatibility (EMC) – Part 3: Limits – Section 2: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*

IEC 61000-3-3:1994, *Electromagnetic compatibility (EMC) – Part 3: Limits – Section 3: Limitation of voltage fluctuations and flicker in low-voltage supply systems for equipment with rated current ≤ 16 A*

IEC 61000-4-1:1992, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 1: Overview of immunity tests*

CISPR 11:1990, *Limits and methods of measurement of electromagnetic disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment*

ISO 3448:1992, *Industrial liquid lubricants – ISO viscosity classification*

2 Terms, definitions, symbols and units

2.1 General definitions

This guide uses as far as possible the terms and definitions of IEC 60308. For clarification, the simplified differential equation of the idealized PID-governor as used in this guide in comparison with that of an idealized PI-governor used in IEC 60308 is given in annex A.

For the purpose of this International Standard the following definitions, as well as the definitions given in IEC 60308, apply.

2.1.1

differential equation

equation describing the dynamic system behavior in the time-domain, as shown in annex A.

2.1.2

transient response

system response (output) to a step change of the input.

2.1.3

frequency response

dynamic response of the linearized system to a sinusoidal change of the input signal derived from the differential equation by applying the Fourier transformation.

2.1.4

transfer function

dynamic response of the linearized system to an arbitrary variation of the input signal derived from the differential equation by applying the Laplace transformation.

2.2 List of terms, definitions, symbols and units

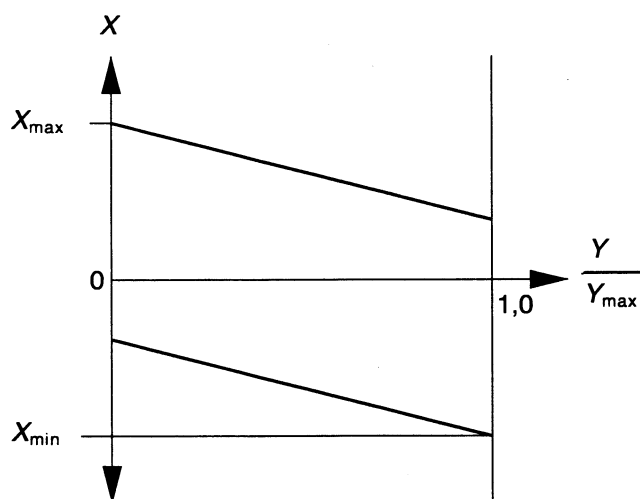
Sub-clause	Term	Definition	Symbol	Unit
2.2.1	Rated	Subscript indicating the rated operation point of the system.	r	–
2.2.2	Maximum Minimum	Subscript indicating maximum or minimum values of any term.	max. min.	–
2.2.3	Deviation	Deviation of any term from a steady-state value	Δ	–
2.2.4	Guide vanes	Subscript associating a quantity to wicket gate	ga	–
2.2.5	Runner	Subscript associating a quantity to runner	ru	–
2.2.6	Nozzle	Subscript associating a quantity to nozzle	nz	–
2.2.7	Deflector	Subscript associating a quantity to deflector	de	–

2.3 Terms relating to the plant and the machines

Sub-clause	Term	Definition	Symbol	Unit
2.3.1	Specific energy of machine	Specific energy of hydraulic water available between the high- and low-pressure side sections of the machine	E	$\text{J} \cdot \text{kg}^{-1}$
2.3.2	Turbine head	$H = E/g$ definition of E , see 2.3.1 g = acceleration due to gravity. = $9,81 \text{ m} \cdot \text{s}^{-2}$ (at sea level)	H	m
2.3.3	Discharge	Volume of water per unit time flowing through any section in the system	Q	$\text{m}^3 \cdot \text{s}^{-1}$
2.3.4	Rotational speed	Number of revolutions per unit time	n	$\text{t} \cdot \text{min}^{-1}$
2.3.5	Frequency	Cycles per second	f	Hz
2.3.6	Generator output	Generator power measured at generator terminals	P_G	W
2.3.7	Moment of inertia of mass	Moment of inertia for calculation of fly-wheel effect. $I = M D^2/4 = MR^2$ (M = mass, D = diameter of gyration, R = radius of gyration)	I	$\text{kg} \cdot \text{m}^2$

2.4 Terms relating to the control system

Sub-clause	Term	Definition	Symbol	Unit
2.4.1	Controlled variable	Variable which has to be controlled as speed n , output P_G , water level h : – absolute, dimensional value – relative deviation from a steady-state value, $x = \Delta X/X_r$ Rotational speed Output Water level	X x x_n x_p x_h	var. – – – – –
2.4.2	Command signal	A signal which can be set by an external adjustment: – absolute, dimensional value – relative deviation from a steady-state value, $c = \Delta C/C_r$ Rotational speed Output Water level	C c c_n c_p c_h	var. – – – –
2.4.3	Servomotor stroke	Stroke of the main servomotor which moves the gate/runner blades/nozzles/deflectors – absolute value – relative deviation from a steady-state value, $y = \Delta Y/Y_{\max}$	Y y	m –
2.4.4	Controlled variable range	Adjusting range for the setting of the controlled variable with an average setting of the permanent droop: – maximum value of the controlled variable for $Y/Y_{\max} = 0$ – minimum value of the controlled variable for $Y/Y_{\min} = 1,0$ (see figure 1)	$X_{\max}$ $X_{\min}$	– –



IEC 320/98

Figure 1 – Controlled variable range

Sub-clause	Term	Definition	Symbol	Unit
2.4.5	Governor output signal	Output signal at the governor = input signal of the following servo-positioner Relative deviation from a steady-state value	s	–
2.4.6	Output signal of a pilot servo-positioner	Output signal of a pilot servo-positioner = input signal of the following main servo-positioner Relative deviation from a steady-state value	s_v	–

2.4.7 droop graph: A graph showing the relative controlled variable as a function of the relative servomotor stroke/the relative output under steady-state conditions (see figure 2).

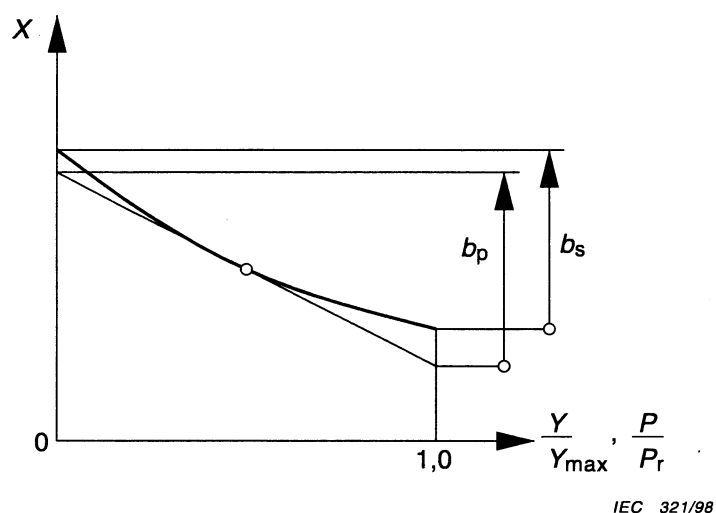


Figure 2 – Permanent droop

Sub-clause	Term	Definition	Symbol	Unit
2.4.8	Permanent droop	Slope of the droop graph (see figure 2): – at a specific point of operation, – defined by the end values of the droop graph	b_p b_s	% %
2.4.9	Proportional gain¹⁾	Proportional amplification, defined by the step of the governor transient function with $b_p = 0$, $p_p = 0$, $T_v = 0$ and input signal $x = 1$ (see figure 3)	K_p	–

¹⁾ Reciprocal value of the temporary speed droop, b_t , as per 5.3.5 of IEC 60308.

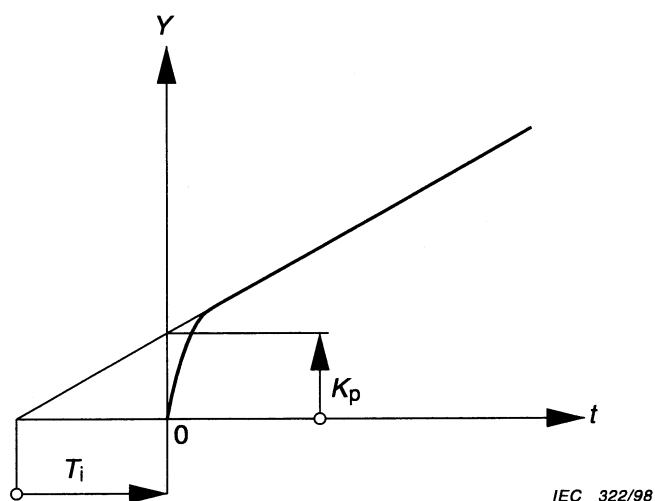


Figure 3 – Integral time constant

Sub-clause	Term	Definition	Symbol	Unit
2.4.10	Integral action time¹⁾	Time constant of the integral action of the governor, defined by the slope of the governor step response curve with $b_p = 0$, $T_D = 0$ and input signal $x = 1$ (see figure 3)	T_i	s
2.4.11	Derivative²⁾ action time	Time constant of the derivative action of an idealized PID-governor according to annex A. T_v can be realized approximately only by a derivative term multiplied by a first-order delay³⁾ according to the transfer function of the derivative part $\frac{k_D \cdot T_{1d} p}{1 + T_{1d} p}$ For small values of $T_{1d} p$, then $T_d = K_D \cdot T_{1d}$ The step response of an idealized PID-governor according to annex A, the proportional and integral term being zero, is shown in figure 4.	T_d	s
¹⁾ Damping time as per 5.3.4 of IEC 60308, $T_d = K_p/K_i$, K_i integral gain. $T_d \cdot T_i$ (IEC 60050-351). ²⁾ Realization also by second-order delay. ³⁾ $T_d = K_D/K_P$ (IEC 60050-351) in parallel structured governors with gain adjustment, K_D = differential gain. In IEC 60308, no derivative action time is defined.				

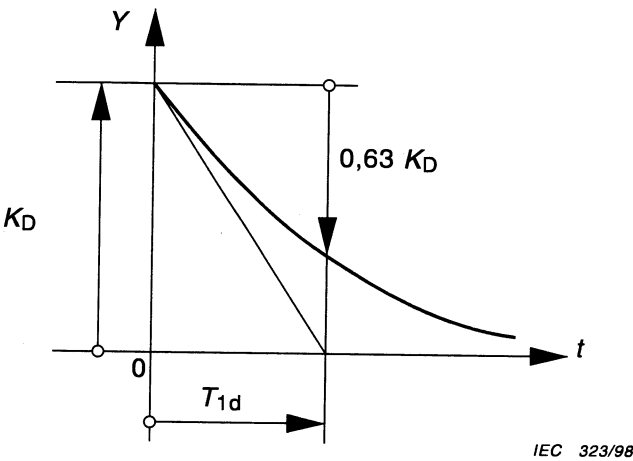


Figure 4 – Derivative time constant

Sub-clause	Term	Definition	Symbol	Unit
2.4.12	Dead band	The maximum band between two values inside of which the variation of the controlled variable does not cause any governing action (see figure 5).	i_x	–

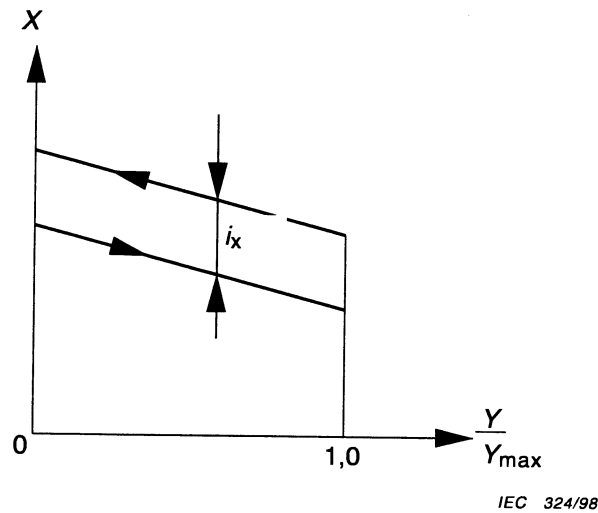
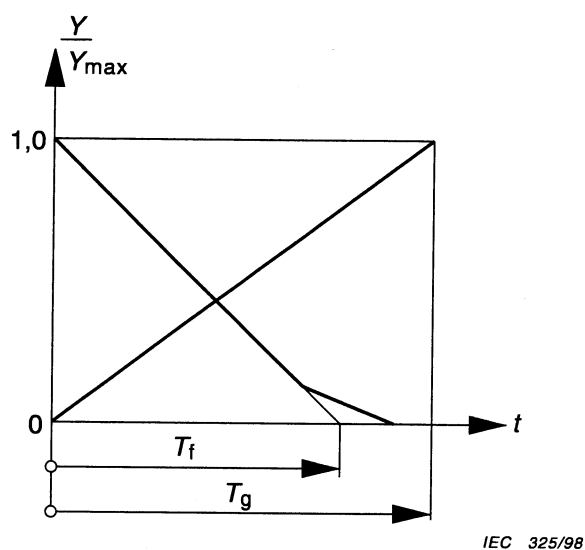


Figure 5 – Dead band

Sub-clause	Term	Definition	Symbol	Unit
2.4.13	Insensitivity	One-half of the dead band	$i_x/2$	–
2.4.14	Minimum servo-motor opening/closing time	The opening/closing time for one full servo-motor stroke at maximum velocity cushioning times disregarded (see figure 6).	T_g, T_f	s



NOTE – In case of stepped opening/closing velocities a diagram may be provided.

Figure 6 – Minimum servomotor opening/closing time

Sub-clause	Term	Definition	Symbol	Unit
2.4.15	Time constant of the servo-positioner¹⁾	The reciprocal value of the slope of the curve showing the servomotor velocity dy/dt as a function of the relative deviation of the position of the control valve, s , s_v , from the zero position related to s , $s_v = 1$ (s , $s_v = 1$ theoretical relative spool stroke in the absence of feedback) (see figure 7)	T_y	s
¹⁾ Servomotor response time as per 5.3.1 of IEC 60308.				

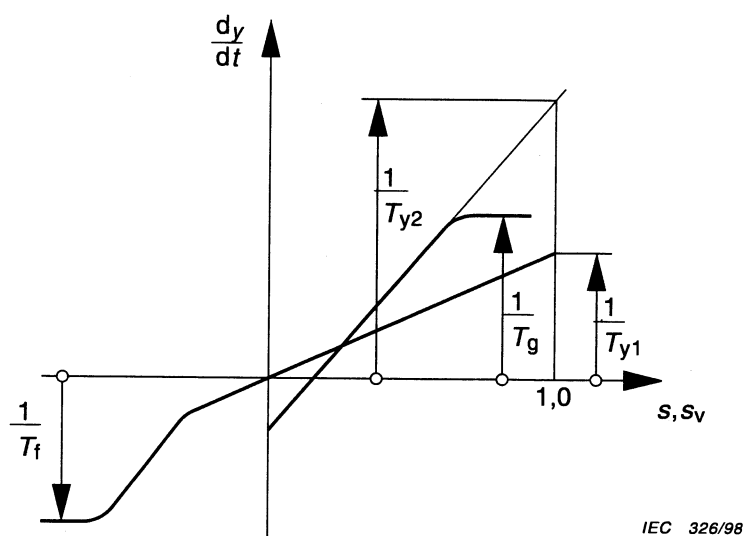


Figure 7 – Time constant of the servo-positioner

Sub-clause	Term	Definition	Symbol	Unit
2.4.16	Amplifier dead band	The maximum band between the main servo-positioner defined positions which can occur for a constant input signal (see figure 8)	i_a	–

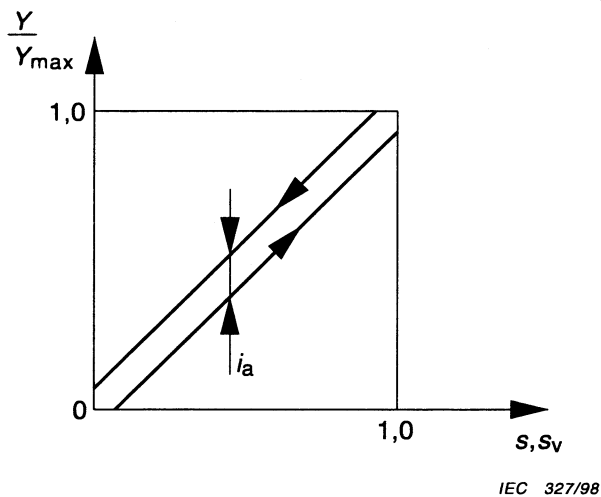


Figure 8 – Amplifier dead band

Sub-clause	Term	Definition	Symbol	Unit
2.4.17	Amplifier inaccuracy	One half of the dead band	$i_a/2$	–
2.4.18	Control system dead time	Time interval between a specified change in speed or command signal and the first detectable movement of the servomotor (see figure 9)	T_q	s

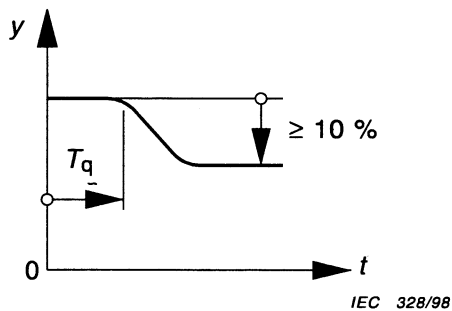


Figure 9 – Control system dead time

Sub-clause	Term	Definition	Symbol	Unit
2.4.19	Actuating energy	Required energy for one servomotor stroke under the minimum required pressure $p_R = E_R/V_S$	E_R	N · m
2.4.20	Servomotor volume	Oil volume of the servomotors	V_S	m ³
2.4.21	Tripping oil volume	Oil volume of the pressure tank at the tripping point (between p_T and p_R , see figure 20)	V_T	m ³
2.4.22	Usable oil volume (figure 20)	Usable oil volume between $p_{O \min}$ and p_R	V_u	m ³
2.4.23	Residual (not usable) oil volume (figure 20)	Oil volume of the pressure tank after a full-load shut-down from the tripping point	V_{res}	m ³
2.4.24	Design oil pressure	Design pressure of the oil pressure tank	p_D	Pa ¹⁾
2.4.25	Operating oil pressure	Operating oil pressure under normal operating condition	p_O	Pa ¹⁾
2.4.26	Tripping oil pressure	When the tripping pressure p_T is reached after a full-load emergency shut-down, it implies $p_R < p_T < p_O < p_D$	p_T	Pa ¹⁾
2.4.27	Minimum required pressure	Minimum required pressure in the oil servo system	p_R	Pa ¹⁾
1) The unit bar is also used.				

3 Control system structure

In the hydraulic turbine control, various tasks can be specified with varying priority. Realization leads to certain typical control system structures and in turn to some basic rules to be adhered to.

Such typical arrangements are compiled for clarification.

3.1 Main control functions

In hydraulic turbine control, these major control functions can be distinguished:

- speed control;
- power output control;
- level control;
- opening and flow control.

In some systems combinations of these control functions also occur.

3.2 Speed control

The purpose of the speed control basically is to maintain constant frequency. In the various modes of operation this means that:

- in the isolated network mode, the actual speed and therefore the frequency corresponds to the command signal setting;
- in the operation on the grid, where the speed is determined by the network frequency, the speed control contributes to the network frequency control through the permanent droop and the dynamic characteristics of the controlled system;
- in the idling mode (before synchronization and after separation from the network), the actual speed corresponds to the command signal or the existing network frequency with some slip.

3.2.1 Power output control

The power output control with a separate power governor is applied with the unit connected to the grid, its purpose is to control the power output of the unit according to a power command signal irrespective of head variations. Any frequency variations influence the power level additionally via the permanent droop.

It is noted that in the cases where head variations can be ignored, a closed loop power output control, i.e., a power output governor, may not be necessary. In such a case, linearization between command signal and power output may suffice (see 3.2.1). In this case also, any frequency variations influence the power level additionally via the permanent speed droop.

3.2.2 Level/flow/opening control

The purpose of a level/flow/opening control is to keep the level, flow or opening constant or to make it follow a command signal.

3.3 Configurations of combined control systems

In combined systems, each control function can be assigned to a separate controller. However, the controllers all actuate the same main servo-positioner through the opening setpoint.

Thereby, a bump-free switch-over between modes requires attention. In case of separate controllers, parameters shall be set according to the respective control loop. Level and power output control, etc, are often incompatible with the maintenance of speed in an isolated network. The speed governor always remains functional for safety reasons, e.g., to take over in the case of a load rejection.

3.3.1 Parallel structure

Two governors are arranged in parallel and actuate one or several servo-positioners via a selector or a summing point. If a selector is applied, it often includes a max./min. function for the speed control loop to prevail in the case of a load rejection.