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MODIFIED GA BASED OPTIMIZATION DESIGN OF FUZZY GOVERNOR POWER SYSTEM STABILIZER FOR HYDRO-GENERATOR UNIT

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ABSTRACT

A fuzzy governor power system stabilizer (FGPSS) is designed for a hydro-generator unit based on fuzzy control theory and its parameters are optimized using Genetic Algorithm (GA) to overcome the subjectivity in design of controller. In order to raise search speed and accuracy, the conventional single-point crossover GA is improved and a new GA named Head-and-Tail Alternate Crossover GA is proposed. The head-crossover and tail-crossover is used alternately in the algorithm, which ensures that optimized probability of every parameter is approximately equal. The parameters of FGPSS are optimized using the algorithm and the result indicates that the algorithm is more quickly and precisely than Error-and-Trial method and conventional GA.

Keywords: *GA, Fuzzy control, Power system stabilizer, Hydro-generator*

1. INTRODUCTION

At the present time, the hydraulic resource is being developed at top speed in a number of areas. More and more large hydraulic power stations and fast excitation systems are putting into operation, and the increasing extra-high voltage and long-distance power transmission systems are building. They have brought great economic benefit, but at the same time they have dropped the damping of power systems and brought low frequency electro-mechanical oscillations which deteriorate the stability of power system.

Power system stabilizer (PSS), namely additional controller of power system, is often used as an effective and economic means to improve the stability of power system. Besides of exciter PSS (EPSS), there is another PSS which is fixed on the governor-side (GPSS) [1, 2]. The well-known disadvantages of EPSS are the difficulty of selecting a right installation place and the complexity of harmonizing parameters of multi-machine system. GPSS, which only affects turbine torque of its own machine, has a better decoupled character than EPSS, so it is being regarded by many researchers [3-5]. However, we can take notice of that most studies take steam-turbine generators as study object and the research about hydro-generator GPSS is infrequent.

The effect for enhancement of power system stability by using the conventional hydro-generator governor designed on classical control theory is not satisfied because of the water-hammer effect of hydraulic system and the intense nonlinear characteristic of hydro-turbine

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and the time-variant operating mode. Fuzzy control technology is robust and independent of the exact mathematic model, which makes it suited for the non-linear control system. In recent years, the technology has been applied widely in design of power system controllers [6-8]. In this paper, a fuzzy GPSS (FGPSS) for a hydro-generator unit is proposed based on fuzzy logic theory.

When fuzzy controller is designed, the design of controller parameters is very important. But there is subjectivity because of the difference of designers' knowledge and experience and sense, which affects the performance of controller. In order to find a group of appropriate parameters, it will spend many hours and the results are not always best if we use traditional Error-and-Trial method. As an efficient adaptive probabilistic global searching technique using the natural selection and the biologic genetic mechanics, Genetic Algorithms (Gas) are used for parameters optimization of controllers widely [9,10]. For conventional GA, the crossover operation usually applies single-point crossover method. When the algorithm is used to optimize the parameters of multi-parameter controller, the searching speed and accuracy are not satisfying because of the unbalanced optimization chance of parameters.

To cope with above drawbacks, based on the traditional method, a modified single-point crossover approach named Head-and-Tail Alternate Crossover (HTAC) is proposed in this paper which can overcome the shortcomings of traditional method and improve optimization speed and precision. After the FGPSS was designed, the HTAC-based GA is applied to the optimization of its parameters and the computing results show that the modified algorithm is more quickly and precisely than Error-and-Trial method and conventional GA. The control effect of FGPSS is simulated and the results indicate that the FGPSS optimized with modified GA can enhance stability of hydroelectricity system.

2. DYNAMICAL MODEL OF HYDROELECTRICITY SYSTEM

In this paper, a hydro-generator infinite-bus (HGIB) system shown in Fig.1 is considered because it is relatively simple to study and analyze and it can qualitatively represent the characteristics of multi-machine system. Considering every parts of a HGIB system, the whole linearization model is established as shown in Fig.2. $G_c(s)$, $G_s(s)$, $G_h(s)$ and $G_e(s)$ are transfer functions of conventional PID controller, servomotor, hydraulic system and excitation system respectively. They are represented with following formulae:

$$G_c(s) = k_P + \frac{k_I}{s} + k_D s \tag{1}$$

$$G_s(s) = \frac{1}{T_s s + 1} \tag{2}$$

$$G_h(s) = -\frac{T_w s}{1 + \frac{T_r^2}{8} s^2} \tag{3}$$

$$G_e(s) = \frac{k_e}{T_e s + 1} \tag{4}$$

The description of notations for variables and parameters in Fig.2 and formulae (1)~(4) is given in Appendix 1. The grey pane in Fig.2 is the GPSS designed in this paper.

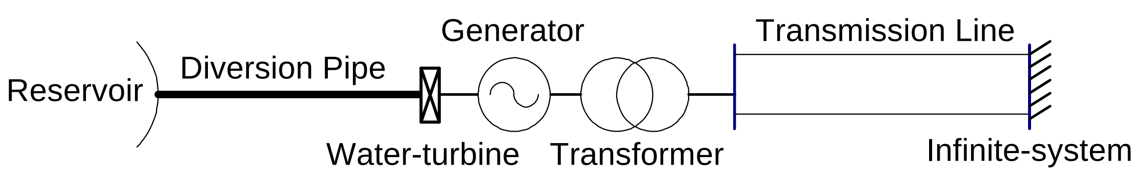


Fig. 1 A hydro-generator infinite bus (HGIB) system

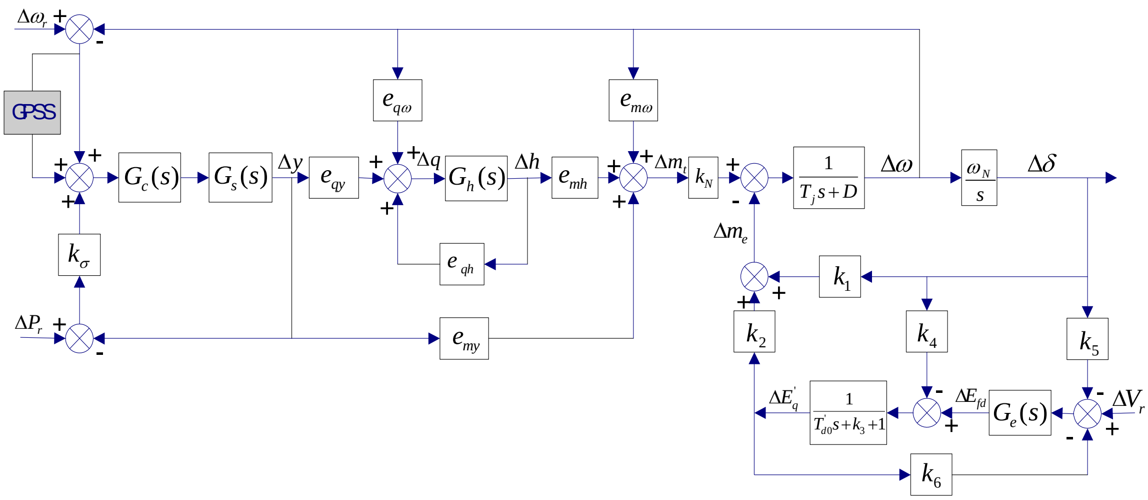


Fig. 2 Linearized model of a hydro-generator infinite bus system

3. DESIGN OF FGPSS

The configuration of proposed FGPSS is illustrated in Fig.3, which have two inputs, which are speed error, $\Delta\omega$, and the derivative of error, $\Delta\dot{\omega}$, and one output, u, which is control variable. The following steps must be designed:

Step1: $\Delta\omega$ and $\Delta\dot{\omega}$ are fuzzified to fuzzy value,W and A, respectively;

Step2: the two fuzzy inputs are processed according to the fuzzy rules and the fuzzy output, U, is produced;

Step3: U is defuzzified to a real value, namely u, which is taken as an additional control signal of conventional PID governor.

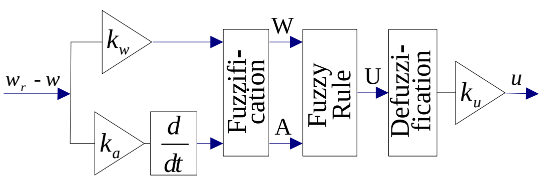


Fig. 3 The configuration of proposed FGPSS

The quantification universes of $\Delta\omega$ and $\Delta\dot{\omega}$ are set in the range from -6 to 6, and from -1 to 1 for u. The fuzzy sets of W and A are {NB, NM, NS, NZ, PZ, PS, PM, PB} and {NB, NS, ZO, PS, PB} respectively, and the fuzzy set of U is {NB, NM, NS, ZO, PS, PM, PB} according to the control expectation. Here, P, N, B, M, S and Z(ZO) are the acronyms of fuzzy linguistic values which are *positive*, *negative*, *big*, *middle*, *small* and *zero* respectively. The triangular function is selected as membership function because of its simplicity. Mamdani's Max-min method and center-of-area method are applied to fuzzification inference and defuzzification respectively.

A very important step in the FGPSS design is the constitution of the fuzzy control rules, which are based on an operator's experience and good understanding of how and what the controller should do. In this paper, there are 35 rules of FGPSS and they can be described in Table 1.

Table 1 Fuzzy control rules

W	A				
	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NM	NS
NM	NB	NM	NM	NS	ZO
NS	NM	NM	NS	ZO	ZO
NZ	NM	NS	ZO	ZO	PS
PZ	NS	ZO	ZO	PS	PM
PS	ZO	ZO	PS	PM	PM
PM	ZO	PS	PM	PM	PB
PB	PS	PM	PB	PB	PB

k_ω and k_α are the quantification factors of input variables between real value and fuzzy value, and k_u is the scale factor of output variable between fuzzy value and real value. The three parameters must be optimized because of their great effect on the performance of FGPSS.

4. DRAWBACKS OF TRADITIONAL CROSSOVER AND HTAC-GA

GA is widely used in optimization of controller's parameters and it has the following strongpoint compared with conventional searching algorithms:
a) the search of GA begins with a group of points in the search space in every iteration, not with a single point;
b)GA uses probabilistic searching rules instead of deterministic ones;
c) GA only uses fitness function information, without need of continuity or derivative or other auxiliary information of the objective function. Owing to these characteristics, GA is a globally search method and can be used to optimize nonlinear problems without complicated procedure. However, the conventional GA is not a perfect algorithm and it has some drawbacks. A well-known one is the significant time consumption caused by iterating over many generations.

Generally, GA has three operators: selection, crossover and mutation. In order to save whole computing time, one or several operators can be improved. In this paper, the crossover operator is modified.

The crossover operation is very important, which is the most main means to obtain new good individuals. Conventional crossover methods are classified for single-point, double-point and multi-point crossover first one is used frequently because of its simplicity and feasibility. With conventional single-point crossover method, a crossover point is selected randomly in a binary string representing an individual. Only the part in front of or behind the point is exchanged (named head-crossover or tail-crossover). They are all very simple and facile, but they also have a shortcoming if they are applied on the optimizing of multi-parameters and the shortcoming can be demonstrated with the example of Table 2. In this example, three parameters *k*1, *k*2 and *k*3 need to be optimized. Every parameter is coded to a string of binary numbers, and thus an individual is represented in a string which consists of 18 binary numbers. If the tail-crossover method is used, the parameter *k*3 must be changed for every crossover. The probability that *k*2 is changed is smaller than *k*3's and *k*1's is the smallest. In the same reason, the probability that *k*1 is altered is the biggest and *k*3's is the smallest if the head-crossover method is applied. The crossover point should be selected randomly, but in Table 2, to explain the operation clearly, the 14^{th} bit is selected as the tail-crossover point and the 8^{th} bit is selected as the head-crossover point. The exchanged part is indicated in boldface font.

The example shows that the probability which three parameters are optimized is inequable if using conventional single-point crossover method, which can slow the optimizing procedure and lower the precision.

Table 2 An example of multi-parameter optimizing

				*k*1							*k*2						*k*3		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Father generation 1		1	0	0	0	1	0	0	0	1	1	0	0	1	0	1	1	1	0
Father generation 2		1	1	0	1	0	1	1	1	0	0	0	1	1	0	1	0	0	1
Tail-	Son generation 1	1	0	0	0	1	0	0	0	1	1	0	0	1	**0**	**1**	**0**	**0**	**1**
crossover	Son generation 2	1	1	0	1	0	1	1	1	0	0	0	1	1	**0**	**1**	**1**	**1**	**0**
Head-	Son generation 1	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	1	1	0	0	1	0	1	1	1	0
crossover	Son generation 2	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	0	0	0	1	1	0	1	0	0	1

5. HEAD-AND-TAIL ALTERNATE CROSSOVER GA

Based on the conventional method, a new single-point crossover method named Head-and-Tail Alternate Crossover (HTAC) is presented to raise the efficiency for multi-parameters system optimizing. Its main contents include that the tail-crossover is applied when the generation number is odd and the tail-crossover when the number is even. Thus, the equality of probability that every parameter is optimized is ensured on the whole, and hence, the optimizing speed is raised. The probability that k1,k2 and k3 are changed is mainly equal if the HTAC method is used for the example in Table 2.

6. HTAC-GA BASED OPTIMIZATION OF PARAMETERS FOR HYDRO -GENERATOR FGPSS

Three parameters (k_ω , k_α and k_u) of the FGPSS for a HGIB system whose parameters are given in Appendix 2 are optimized by using the HTAC based GA. Taken speed as the controlled variable and the integral of time-multiplied absolute-value of error (ITAE) as evaluation function, *population size=20*, *crossover probability=0.6*, *mutation probability=0.05*, three parameters are optimized with the computing program written in MATLAB language. The procedure includes the following steps:

i. An initial binary population is produced randomly;
ii. Every individual is evaluated with evaluation function;
iii. All members in the population are selected in elitist model, and the worst individual is eliminated and the best one is copied to keep the population number constant;
iv. Crossover operator is operated in the HTAC method;
v. Mutation operator is operated in the random-bit mutation method.

A new population has been generated after above 5 steps. Iterate the steps from ii to v in cycle to raise the fitness of population continuously until it fulfils the ending qualification. The given generation number or ITAE index can be taken as the qualification. This paper combines them. If the given ITAE index is attained within the given generation number, the iteration is ended at the number fulfilling given index; if not, the given generation number is taken as the sign of iteration ending and the optimal individuals are taken as the ultimate result.

As a comparison, the parameters of FGPSS are also optimized by using Error-and-Trail method and conventional tail-single-crossover GA. The results in these methods are given in Table 3.

The table indicates that the obtaining of a group of good parameters (ITAE=0.1484) needs very long time if Error-and-Trial method is used, and a group of better parameters (ITAE=0.1364) needs 13 generations on calculation if the conventional GA is used, while the HTAC GA only needs 10 generations in order to attaining equal ITAE value to conventional GA. It is inferred that the HTAC GA is 20 percent faster than conventional GA.

In order to test the control effects of FGPSS, a simulation model is developed with Matlab/Simulink and is used to conduct the simulation study, in which the parameters optimized with HTAC-GA are used. The other coefficients of linearization model under two operating modes are computed and described in Table 4. Fig.4 shows the changes of Δy , $\Delta\omega$, $\Delta\delta$, ΔV_t and ΔP_e derived from a small signal occurred from $t = 1$s to $t = 1.7$s which is 0.1p.u. in size. Obviously, compared with conventional controller, FGPSS can improve dynamic characteristic of hydro-generator units.

Table 3 Parameters of FGPSS using various method

	k_ω	k_α	k_u	ITAE value	the number of genetic generations
Error-and-Trial	93	19	3.6	0.1484	----
Conventional GA	123.7	5.42	11.13	0.1364	13 generations
HTAC GA	151.5	5	9.35	0.1364	10 generations

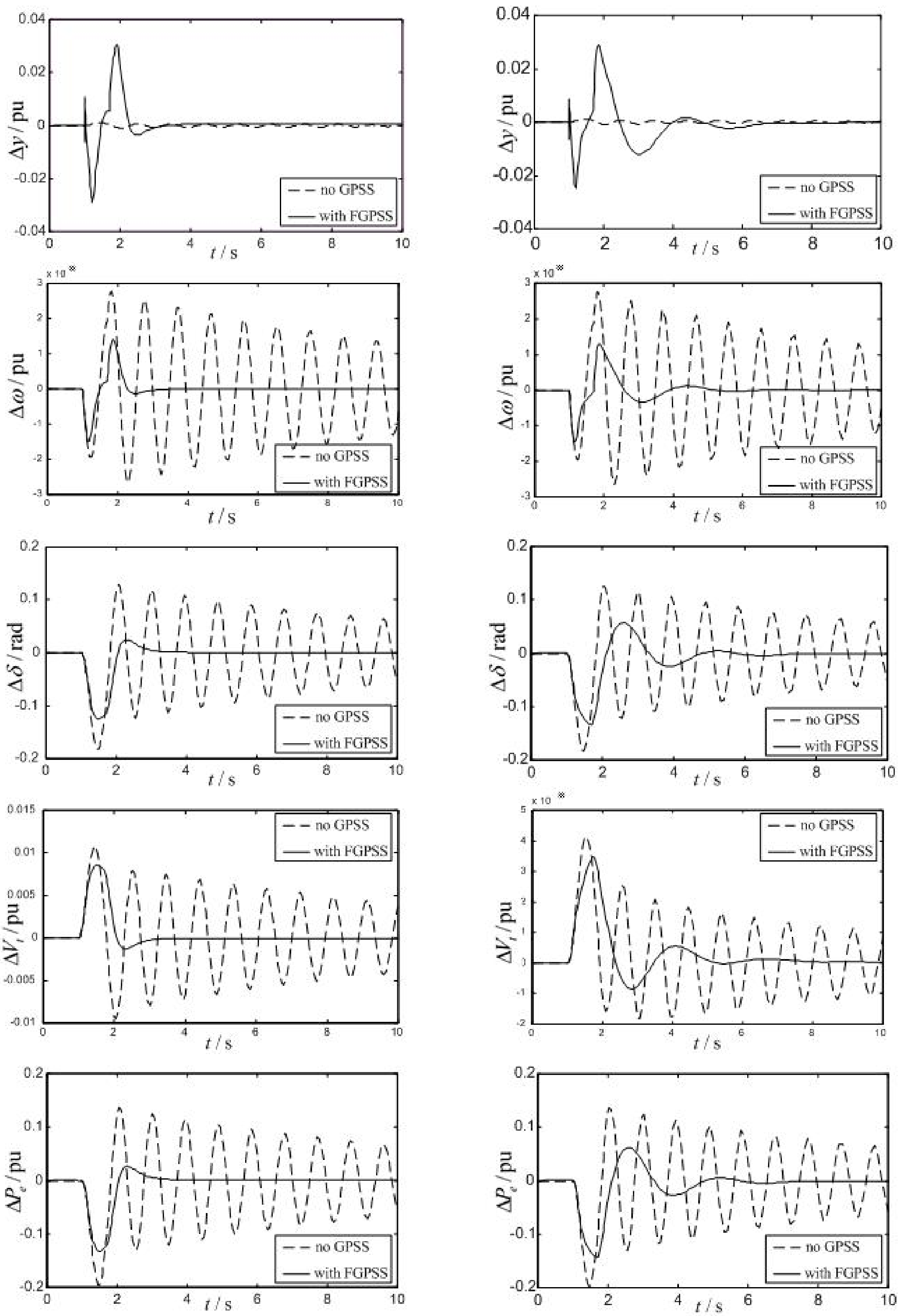
Table 4 Coefficients of linearized model

P_0	Q_0	e_{my}	$e_{m\omega}$	e_{mh}	e_{qy}	$e_{q\omega}$	e_{qh}	k_1	k_2	k_3	k_4	k_5	k_6
0.45	0.22	1.459	-0.512	0.719	1.649	-0.013	0.237	1.079	0.576	1.135	0.451	-0.016	0.71
0.9	0.44	0.957	-1.06	1.523	1.043	-0.058	0.509	1.071	1.004	1.135	0.786	-0.063	0.68

The superiority of HTAC-GA isn't obvious in the example because that the quantity of optimized parameters is less (only 3) and the requirement of optimization precision is lower (that is, the ITAE value is bigger). Obviously, the optimization speed will be raised greatly by using the improved GA if the quantity of system parameters is more and the precision requirement is higher. In addition, it's understandable that the good index will be attained by using HTAC GA when the generation number is fixed.

7. CONCLUSION

In order to enhance the stability of hydroelectric system, a FGPSS for the hydro-generator is designed based on the fuzzy logic theory. GA is used to optimize the parameters of FGPSS to avoid the subjectivity in the design procedure. The conventional single-crossover GA is modified and a HTAC-GA is proposed in order to raising the optimizing speed and precision of multi-parameter system. Its main idea is that the tail-crossover is applied if the generation number is odd and the head-crossover is used if the number is even. The approximate equal probability of parameters optimized can be ensured, and thus the optimizing speed and precision can be raised. Using the modified GA, three parameters of FGPSS of a HGIB system are optimized and the result indicates that the effect of the modified GA is satisfactory. The control effect of FGPSS is simulated compared with conventional controller by using SIMULINK and the results show that the FGPSS can improve dynamic characteristic of hydroelectric system.



a) P_0=0.9/pu Q_0=0.44/pu b) P_0=0.45/pu Q_0=0.22/pu

Fig. 4 Responses of system for a small signal (size: 0.1p.u.; duration: 0.7s)

Appendix 1. List of Symbols

Δ the deviation of a variable
s Laplacian operator
δ rotor angle of the generator in rad
P_r referenced active power in p.u.
V_t terminal voltage in p.u.
V_r referenced terminal voltage in p.u.
y guide vane opening in p.u.
q flow of water-turbine in p.u.
H working head of hydro-turbine in m
h working head of hydro-turbine in p.u.
k_σ difference coefficient of hydro-generator unit
k_N conversion constant of moment base
D damping constant
T_j inertia constant of generator in s
E'_q internal transient voltage in the q-axis of generator in p.u.
E_{fd} virtual open-circuit potential decided by exciting voltage in p.u.
T'_{d0} time-constant of field-winding in s
T_s time-constant of servomotor in s
T_w water-flow inertia time-constant in s
T_r reflection time-constant of water-hammer wave in the penstock in s
k_e amplifier gain of exciter
T_e time constant of exciter in s
x_d direct-axis synchronous reactance in p.u.
x_q quadrature-axis synchronous reactance in p.u.
x'_d direct-axis transient reactance in p.u.
x_e exterior Reactance in p.u.
$\omega, \omega_N, \omega_r$ rotor speed, rated speed and referenced speed in rad/s
m_t, m_e mechanical torque and electro-magnetic moment in p.u.
$e_{qy}, e_{qh}, e_{q\omega}, e_{my}, e_{mh}, e_{m\omega}$ transfer coefficients of water-turbine
$k_1 \sim k_6$ coefficients of Philips-Heffron model of synchro-generator
k_P, k_I, k_D proportional, integral and differential factors of PID controller

Appendix2 . Data of HGIB system

Hydraulic System: $T_w = 2$ s, $T_r = 0.4$ s, H=30.5m

Servomotor: $T_s = 5$ s

PID governor: $k_P = 10$, $k_I = 1.5$, $k_D = 0.1$

Generator: D=1, $T_j = 7.44$ s, $\omega_N = 314$ rad/s, $x_d = 0.973$ p.u., $x_q = 0.55$ p.u., $x'_d = 0.19$ p.u., $T'_{d0} = 7.76$ s

Exciting System: $k_e = 10$, $T_e = 0.05$ s

Transformer and Transmission-line:

$x_e = 0.5\,\text{p.u.}$

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