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AUTOMATIC GENERATION CONTROL OF TWO-AREA POWER SYSTEM BY USING MULTI-OBJECTIVE EVOLUTIONARY ALGORITHMS

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ABSTRACT

One of the method of having good quality of power system is fixing frequency at desired value, irrespective of changes in loads that occurs randomly. Paper for the design and performance analysis of Multi-objective Differential Evolution (MODE) algorithm based PID controllers for Automatic Generation Control(AGC) of an interconnected power system. A Two area Thermal system is considered for the design and analysis purpose by taking two performance criteria for the objective function to tune the controller which are Integral squared Error(ISE) and Integral of Time multiplied Absolute Error(ITAE) is used as a simulation tool. it shows the proposed method has less overshoot, less rise time, less settling time &has less steady state error as compared here with Multi-objective Particle Swarm Optimization(MOPSO)

Keywords: Automatic generation control (AGC), Integral squared error (ISE) Integral absolute time error (IATE), multi-objective evolutionary algorithm based on differential evaluation (MODE), multi-objective particle swarm optimization (MOPSO)

INTRODUCTION

The early aim of the automatic generation control (AGC) is to regulate the power output of the electrical generator within a prescribed area in response to changes in system frequency, tie-line loading, so as to maintain the scheduled system frequency and interchange with the other areas with predetermined limits [1, 2]. As mentioned by Kundur [1], 'this function is commonly referred to as load-frequency control (LFC)'.

The problem of automatic frequency and tie-line flow regulation in power systems has a long history, from a control theoretic perspective. It is often viewed as one of the first and foremost large-scale, decentralized, robust controllers in engineering practice.

Generally, the LFC is accomplished by two different control actions of the primary speed control and supplementary speed control in an interconnected power system. The primary speed control performs the initial readjustment of the frequency. By its actions, the various generators in the control area track a load variation and share it in proportion to their capacities. The speed of the response is only limited by the natural time lags of the turbine, governor and the system itself. The supplementary speed control takes over the fine adjustment of the frequency by resetting the frequency error to zero through an integral action [the proportional-plus-integral (PI) controller] [2]. The main drawback of this supplementary controller is that the dynamic performance of the system is highly dependent on the selection of its gain. A high gain may deteriorate the system performance having large oscillations and in most cases it causes instability [2–4]. Thus, the integrator gain must be set to a level that provides a compromise between a desirable transient recovery and low overshoot in the dynamic response of the overall system preventing instability [5, 6]. A lot of approaches have been reported in the literature to tune the gain of the PI controllers [1].

2 PID controllers

The PID controllers are the most effective and powerful control tool in industry because of simple and easy implementation. The transfer function of PID controller is described by the following equation in the continuous *s*-domain

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p + K_i s + \frac{K_d}{s} \quad (1)$$

Where *U(s)* and *E(s)* are the control (controller output) and tracking error signals in *s*-domain, respectively; K_p is the proportional gain, K_i is the integration gain and K_d is the derivative gain. T_i is known as the integral action time or reset time and T_d is referred to as the derivation action time or rate time.

In this paper, output of the PID controller in time domain is given by

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \quad (2)$$

Where *u(t)* and *e(t)* are the control and tracking error signals in time domain, respectively.

Using proportional part of the PID controller, error responses to disturbances is reduced. The integral term of the error eliminates steady-state error and the derivative term of error dampens the dynamic response and thereby improves stability of the system. The gain tuning of a PID controller for optimal control of a plant (process) depends on the plant's behavior. To design the PID controller, the engineer must choose the tuning way of design gains to improve the transient response as well as the steady-state error. In the design of a PID controller, the three gains of PID must be selected in such a way that the closed loop system has to give the desired response. The desired response should have minimal settling time with a small or no overshoot in the step response of the closed loop system.

3 System model

Frequency changes occur because system load varies randomly throughout the day so that an exact forecast of real power demand cannot be assured. The imbalance between real power generation and load demand (plus losses) throughout the daily load cycle causes kinetic energy of rotation to be either added to or taken from the on-line generating units, and frequency throughout the interconnected system varies as a result. Each control area has a central facility called the energy control centre, which monitors the system frequency and the actual power flows on its tie lines to neighboring areas. The deviation between desired and actual system frequency is then combined with the deviation from the scheduled net interchange to form a composite measure called the area control error, or simply ACE [2].

In general, for satisfactory operation of power units running in parallel it is most desirable to have the frequency and tie-line power fixed on their nominal and scheduled values even when the load alters and, therefore to remove area control error (ACE = 0).

To help understand the control actions at the power plants for LFC, let us consider the boiler–turbine–generator combination of a thermal generating unit. Most steam turbo-generators (and also hydro-turbines) now in service are equipped with turbine speed governors. The duty of the speed governor is to monitor continuously the turbine– generator speed and to control the throttle valves which adjust steam flow into the turbine (or the gate position in hydro-turbines) in response to changes in frequency. Since all the movements are small the frequency–power relation for turbine–governor control can be studied by a Linear zed block diagram [1]. However, the computer simulation will be carried out using the actual non-linear system. The linear model is shown in Fig. 1 for a single-machine infinite-bus [1] where the blocks are

Non-reheat steam turbine $=1/(T_T s+1);$

Load and machine $=1/(2Hs+D);$

Governor $=1/(T_g s+1);$

Droop characteristics of governor $=1/R;$

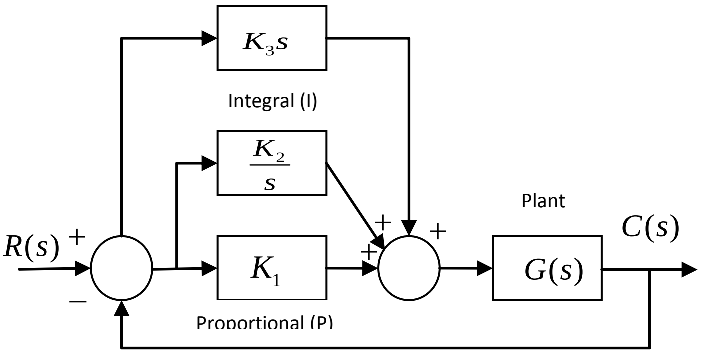


Fig.1 *Block diagram of system of PID controller*

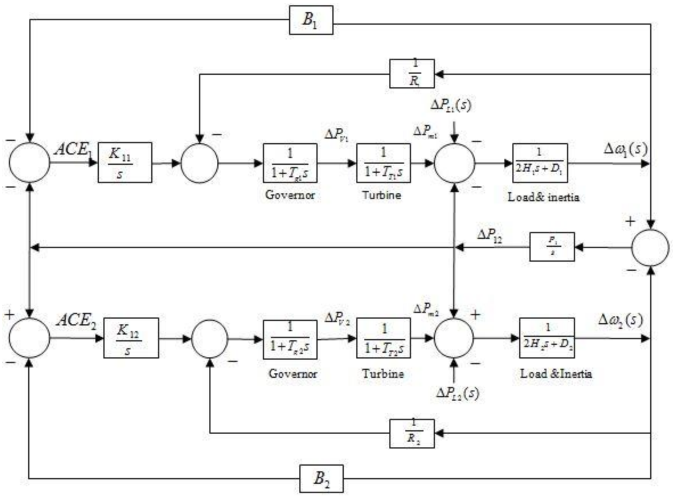


Fig. 2 *block diagram of a two-machine system including turbines, governors load and machines*

In the above equations, T_T and T_G are the turbine and governor time constants, respectively; *H* and *D* are the inertia coefficient of generator and ratio of load changes percentage to frequency changes percentage, respectively.

In the model given in Fig. 2, the generation source of mechanical power which is known as the primary exciter may be hydraulic, gas and thermal turbines. The governor senses changes of generator speed and adjusts the turbine input valve to vary the output mechanical power of turbine. Electrical loads are devices which consume the electrical power generated by the generator (machine). For stable performance, with increasing load, the governor should decrease the speed. The curve slope of speed decrease represents the coefficient of speed regulation *R.* The model includes the effect of generation rate constraint on the generator and limits on the position of the governor valve, which are caused by the mechanical and thermodynamic constraints in practical steam turbines systems [1]. ΔP_m And ΔP_{GV} are the incremental changes in the output mechanical power of turbine and governor valve position, respectively. The control objective in the LFC problem is to keep the change in frequencies as well as the change in tie-line power P_{tie} as close to zero as possible when the system is subjected to load disturbance ΔP_L by manipulating the inputs u_1 an u_2

4 objective function

While designing a controller, the objective function is first defined based on the desired specifications and constraints. The design of objective function to tune PI/PID controller is generally based on a performance index that considers the entire closed loop response. Some of the realistic control specifications for Automatic Generation Control (AGC) are

i. The frequency error should return to zero following a load change.
ii. The integral of frequency error should be minimum.
iii. The control loop must be characterized by a sufficient degree of stability.
iv. Under normal operating conditions, each area should carry its own load and the power exchange between control areas following a load perturbation should maintained at its prescheduled value as quickly as possible.

To meet the above design specifications, the objective function is formulated as minimization of function J given by:

$$J = (J1, J2)$$

Where

$$J1 = ISE = \int_0^{t_{sim}} ((\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta p_{tie})^2)dt \quad (3)$$

$$J2 = ITAE = \int_0^{t_{sim}} (|\Delta f_1| + |\Delta f_2| + |\Delta p_{tie}|).tdt \quad (4)$$

In the above equations, $\Delta f1$ and $\Delta f2$ are the system frequency deviations. Δp_{tie} Is the incremental change in tie line power; t_{sim} is the time range of simulation. The numerical value of $ITAE$ may be greater than others as the absolute error is multiplied by time where as in others (ISE and IAE) the error is squared first thus reducing its numerical value (if the numerical values of errors are in decimals). So time domain analysis should be performed to compare these performance indexes. As $ITAE$ objective function gives a better time domain performance compared to ISE , and IAE .

5 Multi-objective optimization

One way to perform multi-objective optimization is by using an evolutionary algorithm (EA). Evolutionary algorithms are optimizers inspired by Darwinian evolution and with this the concept of survival of the fittest. In an EA, a solution to a given problem is considered individuals of a population, where the fitness of individuals are given by how good they solve the problem at hand. In the population individuals may mate to create offspring, which makes parents and offspring compete for inclusion in the next generation. As only the most fit will survive this fight, the full population is improving iteratively in each passing generation.

More formally, the strength of EAs comes from their use of a set of solutions, not only improving on a single solution. This makes it possible to combine several (good) solutions, when creating a new one. An EA is actually a stochastic metaheuristic, i.e. a general optimization method, basing itself on probabilistic operators. Thus, contrary to deterministic algorithms, EAs may produce different results from different runs.

The greatest difference between single-objective EAs and multi-objective EAs (MOEAs), is that for single-objective optimization, it is simple to return the most optimal solution in a population, as scalar based evaluation automatically implies a total order on solutions. For MOEAs, the situation is very different. Due to the higher dimensionality of the objective space, all resulting individuals of the population may be incomparable to each other, each representing an optimal trade-off between objectives. That is, the result of running a MOEA is typically a set of non-dominated solutions. From this result set, it is up to the decision maker to find out which solution(s) to realize.

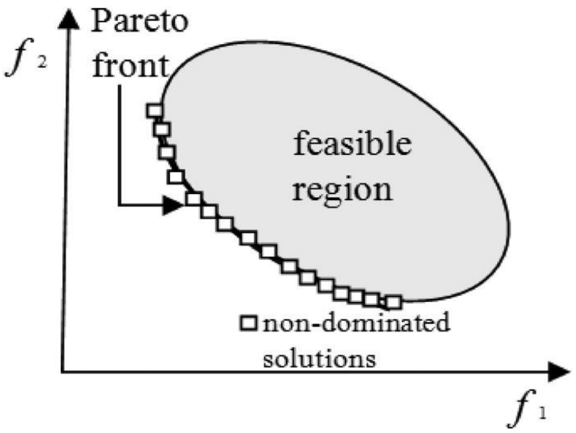


Fig 4: Pareto-optimal front

6 Multi-objective optimization of Differential evaluation

The basic elements of MODE algorithm used in this paper can be briefly stated as follows: To start the optimization process, define the *control parameters* and other parameters used by the algorithm [9].The algorithm steps can be summarized as follow:

Step 1) (Initialization): Generate an initial population using and create the empty external Pareto-optimal set.

$$x_{i,j}(0) = x_j^L + rand(0,1).(x_j^u - x_j^u) \quad (5)$$

Where, *rand* (0, 1) is a uniformly distributed random Number between 0 and 1.

Step 2) (Fitness assignment): Calculate the fitness values of the different individuals (chromosomes). The individuals in the current population are evaluated in the objective space and then assigned a scalar value known as fitness.

Step 3) (External set updating): The external Pareto-optimal set is updated as follows:

1. Search the population for the non-dominated individuals and copy them to an external set called *'external Pareto set'*.(
2. Search the *external Pareto set* for the nondominated individuals and remove all dominated solutions from the set.
3. If the number of the individuals externally stored in the Pareto set exceeds a prespecified maximum size, reduce the set by means of clustering.

Step 4) (Perform DE Mutation): Perform the DE mutation operations according to Eq. (11) to generate the donor vector $\vec{v}_i(t)$ for each i^{th} member $\vec{X}_i(t)$

$$v_{i,j}(t+1) = x_{r1,j}(t) + F.(x_{r2,j}(t) - x_{r3,j}(t)) \quad (6)$$

Step 5) (Perform DE crossover): Perform the DE crossover according to Eq. (12) and find the trial vector u_i .

$$u_{i,j}(t) = v_{i,j}(t) \ if \ rand(0,1) < CR$$
$$x_{i,j}(t) \ else \quad (7)$$

Step 6) (**Selection**): selection between trial vector (child) and target vector (parent) is carried out according to the dominance criteria as follows:

1. If all objectives of solution u_i are better (or at least one) or equal to that of corresponding objectives of $\vec{X}_i$, then u_i dominates $\vec{X}_i$ and replaces it in the new population and vice versa.
2. If all objectives of solution $\vec{X}_i$ are equal or some are better and some are worse, then u_i and $\vec{X}_i$ are not dominated by each other and u_i is retained in the new population.

Step 7) (check stopping criteria): check for the stopping criteria. In this paper, it is chosen to be reaching the maximum number of generations (*GEN*). Problem continuous again and Pareto-optimal set of solutions are updated until the maximum number of generations is reached. [10]

7 Control strategies

$$u_1(t) = K_p ACE_1(t) + K_i \int_0^t ACE_1 d\tau + K_d \frac{dACE_1(t)}{dt} \quad (8)$$

$$u_2(t) = K_p ACE_2(t) + K_i \int_0^t ACE_2 d\tau + K_d \frac{dACE_2(t)}{dt} \quad (9)$$

As a control strategy, the control configuration is depicted in Fig. 2. In this configuration, to achieve the control inputs, the optimal PID controllers are used together with area control errors, $ACE1$ and $ACE2$ in (7) and (8), respectively.

$$ACE1 = B1\Delta w1 + \Delta P_{tie} \quad (10)$$

$$ACE2 = B1\Delta w2 + \Delta P_{tie} \quad (11)$$

In the control strategy, control inputs of the system, u_1 and u_2 are obtained by PID controllers as below

The objective of the obtaining optimal solutions of control inputs is taken as an optimisation problem and MODE algorithm and MOPSO [11] algorithm used to tune the gains of the controllers and objective funtions.in this paper three objective funtions are praposed .

8 RESULTS AND DISCUSSION

In order to optimize the gains of PIDs, 100 and 150 iterations are considered. The optimum gains of the PID are obtained. It should be noted that the MODE [12] algorithm is run several times and then optimal parameters of the PID controller are chosen. The optimal parameters are provided in Table 1.The results show that the PID tuned by the MODE and objective functions makes the power system have admissible dynamic performance.

9 Conclusion

The Multi-objective optimization algorithm is used in this paper to obtain the optimum gains of the PID controller for the LFC problem. At first, the optimization algorithm is explained in detail. Then, a two-area power system is investigated. Two objective functions are introduced. The simulation results emphasize the effectiveness of the MODE and the proposed objective functions and show that using the MODE and the suggested cost functions, the frequency after a disturbance have minimum overshoot and oscillation. Also, simulation results demonstrated that the PID controllers capable to guarantee the robust stability and performance under a wide range of uncertainties and load changes. A comparative study is carried out between the MODE-PID and PID tuned by the other optimization algorithms. The comparison results show that the MODE-PID can provide a better performance than other PIDs in each area. Besides the efficiency of the optimization algorithm and the proposed objective functions, it has the potentiality of implementation in real time environment.

TABLE 1: Optimum gain values of PID controller for Different objective functions

	Best ISE	Best ITAE	Best COMPROMISE SOLUTION
K_p	1.0000	0.0692	0.6195
K_i	1.0000	1.0000	1.0000
K_d	0.6954	0.5475	0.6952
Best ISE	**0.0007**	0.0010	**0.0008**
Best ITAE	0.5941	**0.5236**	**0.5618**

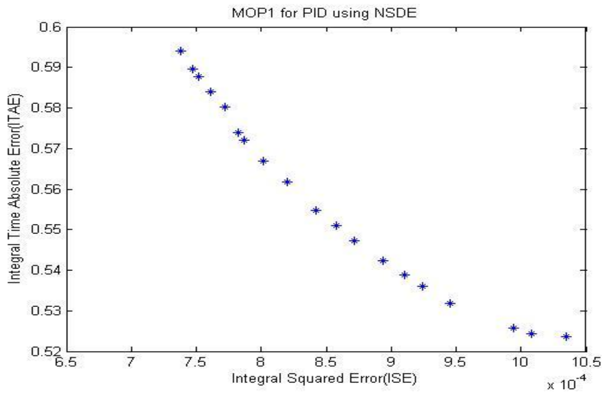
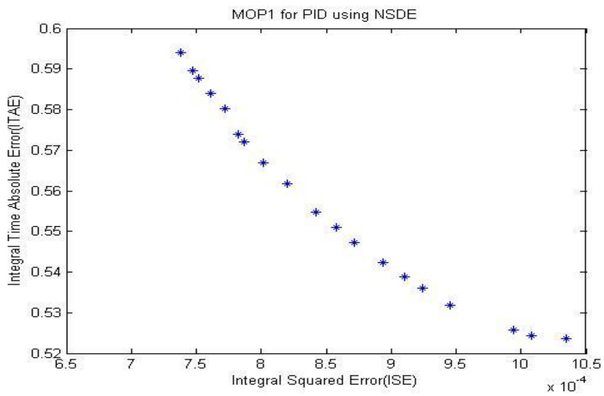


Fig 5: Pareto-optimal front for the proposed algorithm Different Techniques

TABLE 2: Optimum gain values of PID controller for Different objective functions

	Best ISE		Best ITAE	
	MODE	MOPSO	MODE	MOPSO
K_p	1.0000	0.8507	0.0692	0.6195
K_i	1.0000	1.0000	1.0000	1.0000
K_d	0.6954	0.7010	0.5475	0.6952
Best ISE	**0.0007**	**0.0008**	0.0010	0.0008
Best IATE	0.5941	0.5810	**0.5236**	**0.5618**



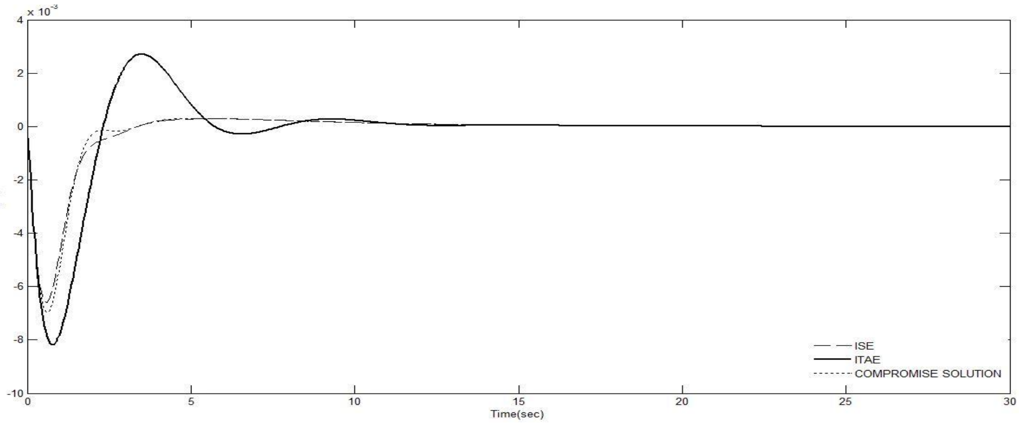


Fig 5: Frequency variations of AREA1 for different objective functions $(\Delta P_{L1} = 0.2 p.u)$

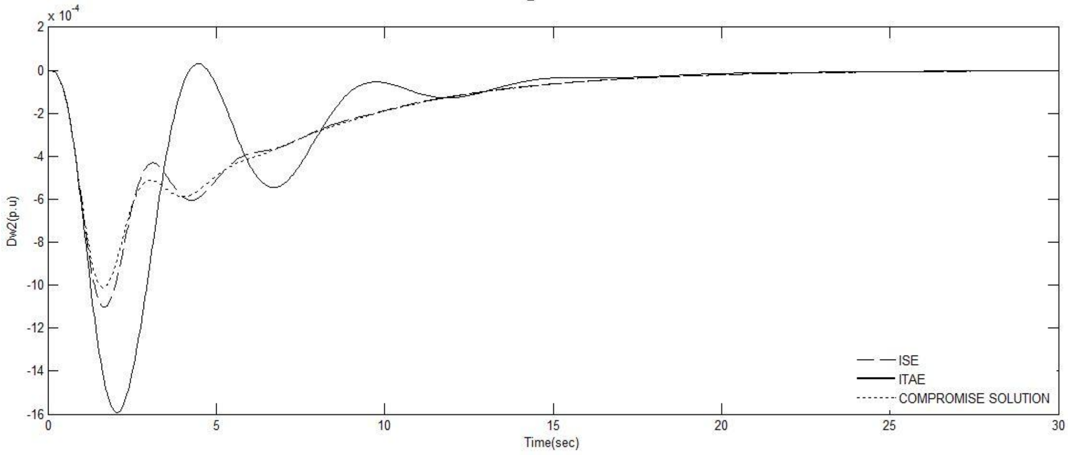


Fig 6: Frequency variations of AREA2 for different objective functions $(\Delta P_{L1} = 0.2 p.u)$

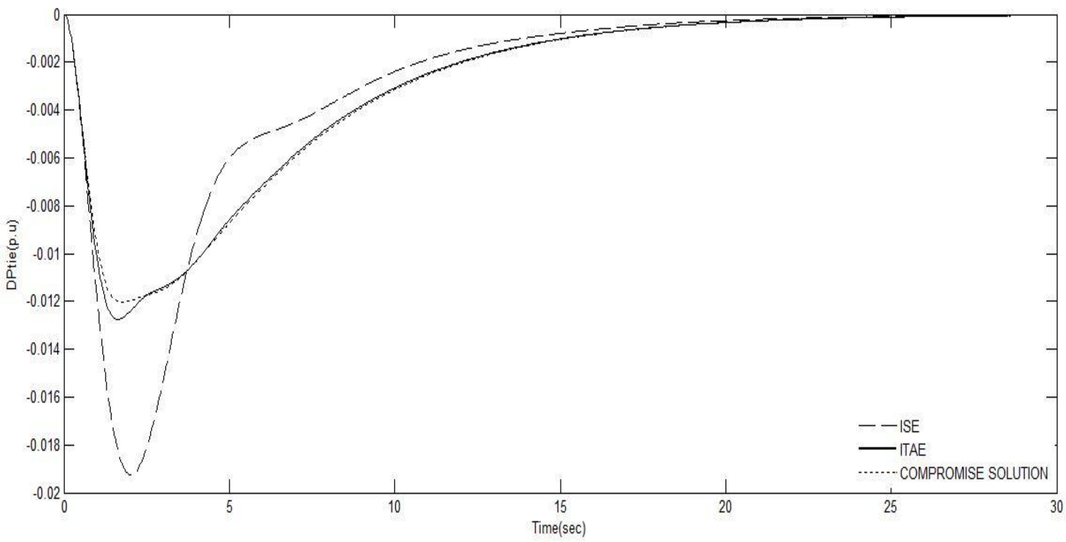


Fig 7: Frequency variations of Tie-Line for different objective functions $(\Delta P_{L1} = 0.2 p.u)$

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Appendix

The system parameters are as $(frequency = 60H_Z, MVA\ base1000)$;[10]

$$Area1: H = 5, D = 0.6, T_g = 0.2, T_\tau = 0.5, R = 0.05, B_1 = 20.6.$$

$$Area2: H = 4, D = 0.9, T_g = 0.3, T_\tau = 0.6, R = 0.0625, B_2 = 16.9.$$