Short Research Article

Optimized Proportional Integral Derivative Based Power System Stabilizer Using Jaya Algorithm for Angular Stability Enhancement

ABSTRACT

This study presents an optimized Proportional Integral Derivative Based Power System Stabilizer (PIDPSS) using Jaya Algorithm for angular stability enhancement. Jaya algorithm is an optimization technique with few control parameters which is used to minimize the objective function F(K); it was introduced by Zwe-Lee Gaing. The modeling and simulation was done using Matlab/Simulink software version R2021b on IEEE 14-Bus system and Single Machine Infinite Bus (SMIB). A three-phase fault was introduced into the network at system runtime of 5s with a fault clearing time of 0.1s. The result of the simulation of the IEEE 14 Bus system showed a 74% and 24% reduction in overshoot time of speed deviation for generators 1 and 2, with settling times of 2.5s and 4s, respectively, in the presence of PIDPSS. The load angle experienced a 14% and 19% reduction in overshoot with settling times of 2s and 2.5s, respectively in the presence of PIDPSS for generators 1 and 2, respectively. The Electrical Power result showed 27% and 6% reduction in overshoot time as well as settling times of 2.5s and 4s, respectively, for generator 1 and 2 in the presence of PIDPSS. The result of the simulation of SMIB system also showed a 25% reduction in overshoot time in relation to deviation speed at a settling time of 4s in the presence of PIDPSS. The Load Angle showed- a 13% decrease in overshoot time at 2s settling time in the presence of PIDPSS. Also, the Electrical Power result highlighted a 15% drop-in overshoot time and settles within 2s. These results affirms that the PIDPSS introduced improved overall system stability.

Keywords:Jaya Algorithm, Power System Stabilizer, Proportional Integral Derivative (PID), SMIB, MATLAB.

1. INTRODUCTION

The increasing complexity and interconnectivity of power systems has necessitated continuous improvement in power stability. Among the consequences of instability, those derived from transient and dynamic instability are the most widespread. The interconnectivity often done through weak tie lines results in inadequately damped Low-Frequency Oscillation (LFO) typically in the range of 0.1-3Hz [1] Loss of synchronism is inevitable when LFO increase above a threshold [1]. To address this problem engineers employed an Automatic Voltage Regulator (AVR) at the generator excitation system. This however, did not eliminate LFOs, as high gain AVR in synchronous generators decreases rotor damping torque creating LFO.[1]

Power System Stabilizers (PSS) became a viable solution as a result, in solving these oscillatory stability problems [2]. The parameters of PSS are typically fixed and this does not give them room for flexibility and adaptability in non-linear environment of the power system [3]. To provide optimization of the PSS values for system stability, several studies have been carried out such as the use of metaheuristic methods, chiefly for their ability to resolve complex continuous optimization problems successfully [4]-[5]. Another performance improvement measure employed in the AVR system is the Proportional Integral Derivative (PID) whose lack of prior knowledge of the process, ease of implementation and low cost makes it popular in industrial control systems.[6]

In this study, Jaya Algorithm introduced as a heuristic algorithm in 2015 by Rao [7] is used to tune the parameters of the PIDPSS based on Single Machine Infinite Bus (SMIB) and IEEE 14 Bus systems. It is an algorithm that seeks the optimal solutions by approximation and requires only the common regulating parameters like population size and number of generations, eschewing algorithm-specific parameters. A time domain objective function introduced by Zwe-Lee Gaing[8] was minimized using the Jaya Algorithm. The SMIB and IEEE 14-Bus systems models incorporated with PIDPSS were simulated in MATLAB Simulink while Jaya Algorithm was scripted in MATLAB programming language. The electrical power, load angle and speed deviation profiles for the two models were obtained after the introduction of a three-phase fault at 5s.

2. REVIEW OF RELATED LITERATURE

With the advent of Artificial Intelligence (AI) technology, Power Engineers have embraced it in solving power system issues[9]. Notably, it has been applied in the areas of efficient dispatch, capacitor placement, sizing, and evaluation, and improvement of voltage and angle stability. Different algorithms have been used to solve stability issues in power system. Ref [10] used Firefly Algorithm to tune the parameters of PID-based PSS controller for two cases of parametric bounds. Various other algorithms have been also used like Chaotic Particle Swarm Optimization (CPSO)[11], Kho-Kho Optimization[12], Search and Rescue Algorithm[13], Cuckoo Search Algorithm[14], Fuzzy Particle Swarm Optimization[7], Henry Gas Solubility Optimization[15], Farmland Fertility Algorithm[16], Differential Evolution Algorithm[17], [18], Ant Colony Optimization[19], Sine Cosine Algorithm[20], Particle Swarm Optimization[21], Archimedes Optimization Algorithm[22], Water Cycle Moth-Flame Optimization[23], Immune Genetic Algorithm[24], etc.

This plethora of algorithms application for optimization in power stability however, have not closed out research in the usage of conventional PSS[25]. As a result, different controller structures have been successfully implemented with PSS to improve LFOs. PID based PSS have been quite successful in this regard because of its relative facility and cost effectiveness[6], [26].

Most operations of objective functions in frequency domain may indicate a bias in overshoot rather than a shorter settling time because of their independence of time. In time domain, the function has a capacity of been formed by different performance specification like rise time, settling time, overshoot and steady state error[6]. Jaya Algorithm is implemented in this research on a suitable objective function in time domain on SMIB and IEEE 14 Bus system to demonstrate its suitability in handling instability problems.

3. METHODOLOGY

3.1 Mathematical Modelling of SMIB

The Swing Equation describing the SMIB is given as[27] :

$$M\frac{d\omega}{dt} + \Delta\omega \cong P_m - P_e \quad (1)$$

$$\frac{d\delta}{dt} = \omega_r - \omega_0 = \omega_0\omega \quad (2)$$

Where M isthe angular momentum,$\omega$is thedifference between rotor speed and synchronous speed in p.u, $P_m$is the mechanical power, $P_e$is the electrical power, δ is the rotor angle, ω_r is the angular velocity of the rotor and $\omega_0$is the rated angular velocity.

These are based on an input-state-output classical 2nd order model of a single generator coupled to an infinite bus. We can also have an input-output mode with the substitution of ω in (1) as:

$$\frac{M}{\omega_0} \cdot \frac{d^2\delta}{dt^2} + \frac{D}{\omega_0} \cdot \frac{d\delta}{dt} \cong P_m - P_e \qquad (3)$$

Where D is the damping torque component.Equation (2) and (3) can be written as:

$$\dot{x}_1 = \omega_0 x_2 \qquad (4)$$

$$\dot{x}_2 = -\frac{\omega_0}{M} P_e(x_1) - \frac{D}{M} x_2 + \frac{\omega_0}{M} P_m \qquad (5)$$

$$x = [x_1 \quad x_2]^{\mathsf{T}} = [\delta \quad \omega]^{\mathsf{T}} \qquad (6)$$

From Equation (6) the block diagram of the SMIB can be obtained using Laplace Transform and Transfer Function Algebraic rules as:

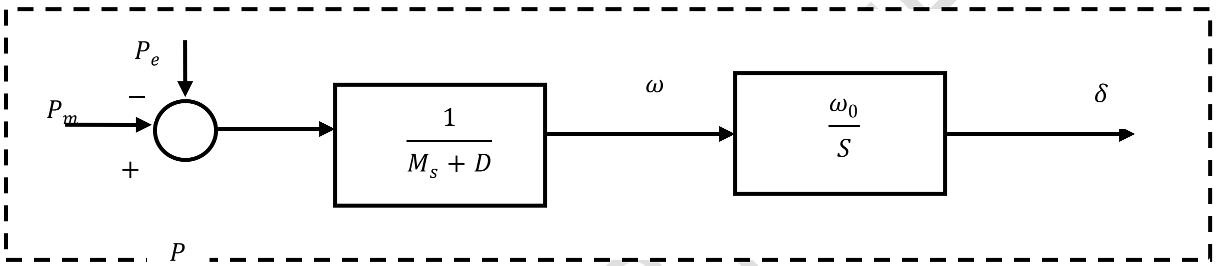


Figure 1. Block Diagram of SMIB

3.2 IEEE 14 Bus System

The IEEE 14 Bus system is a power network of 5 generators, 11 loads and 14 buses. Three of the generators are connected to synchronous compensation exciters, which are only utilized to support reactive power, using IEEE type-1 exciters. The configuration of the IEEE 14 Bus is shown in Figure 2.[28]

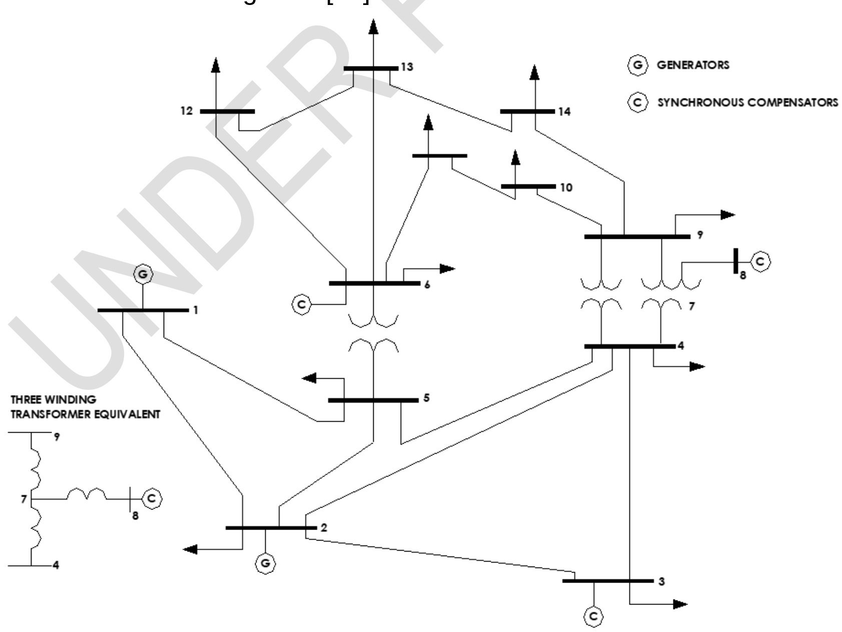


Figure 2. Configuration of IEEE 14 Bus System

3.3 Objective Function for PIDPSS

PIDPSS is minimized to obtain the best value that will offset LFO in the power network. LFO usually expresses itself through variations in load angle, speed and electrical power. The work of the objective function is to achieve minimization of PIDPSS. The objective function F(K), introduced by Zwe-Lee Gaing is expressed as[8]:

$$F(K) = (1 - e^{-\rho})\left(M_p + E_{SS}\right) + e^{-\rho}(t_S - t_r) \quad (7)$$

where K = (K_p, K_i, K_d) or (K, T_1, T_2) for the control parameters of PID and PSS respectively, M_p is maximum overshoot, E_{SS} is Steady-state error, t_S is settling time, t_r is the rise time and ρ is a weighting coefficient which controls the significance of related parameters. A ρ value greater than 0.7 indicates the tendency to reduce M_p and E_{SS}, while a ρ value smaller than 0.7 indicates a decrease in t_r and t_S. In this study, ρ is set at 0.5. The purpose is to obtain the optimal values of PID and PSS parameters while minimizing the objective function F(K).

3.4 Jaya Optimization Algorithm

Jaya Algorithm is based on the concept of searching and updating the best solution to the optimization problem while avoiding the worst solution[29]. It combines the features of evolutionary algorithm, of survivability of the fittest principle, and the Swarm Intelligence, in which the swarm normally follows the leader during the search for optimal solution.

It is expressed mathematically as:

(**Error! Reference source not found.** (8)

where $X_{i,j}^{k}$ is the jthdecision for an arbitrary ithcandidate for k^{th} iteration, $x_{j,best}^{k}$ is the best among all the candidate solutions for an arbitrary k^{th} iteration, $x_{j,worst}^{k}$ is the worst of all the candidate solution for k^{th} iteration, $\mu_{1,j}^{k}$ and $\mu_{2,j}^{k}$ are random numbers in the range [0 1] during k^{th} iteration.

The Jaya Algorithm flowchart is illustrated in Figure 3:

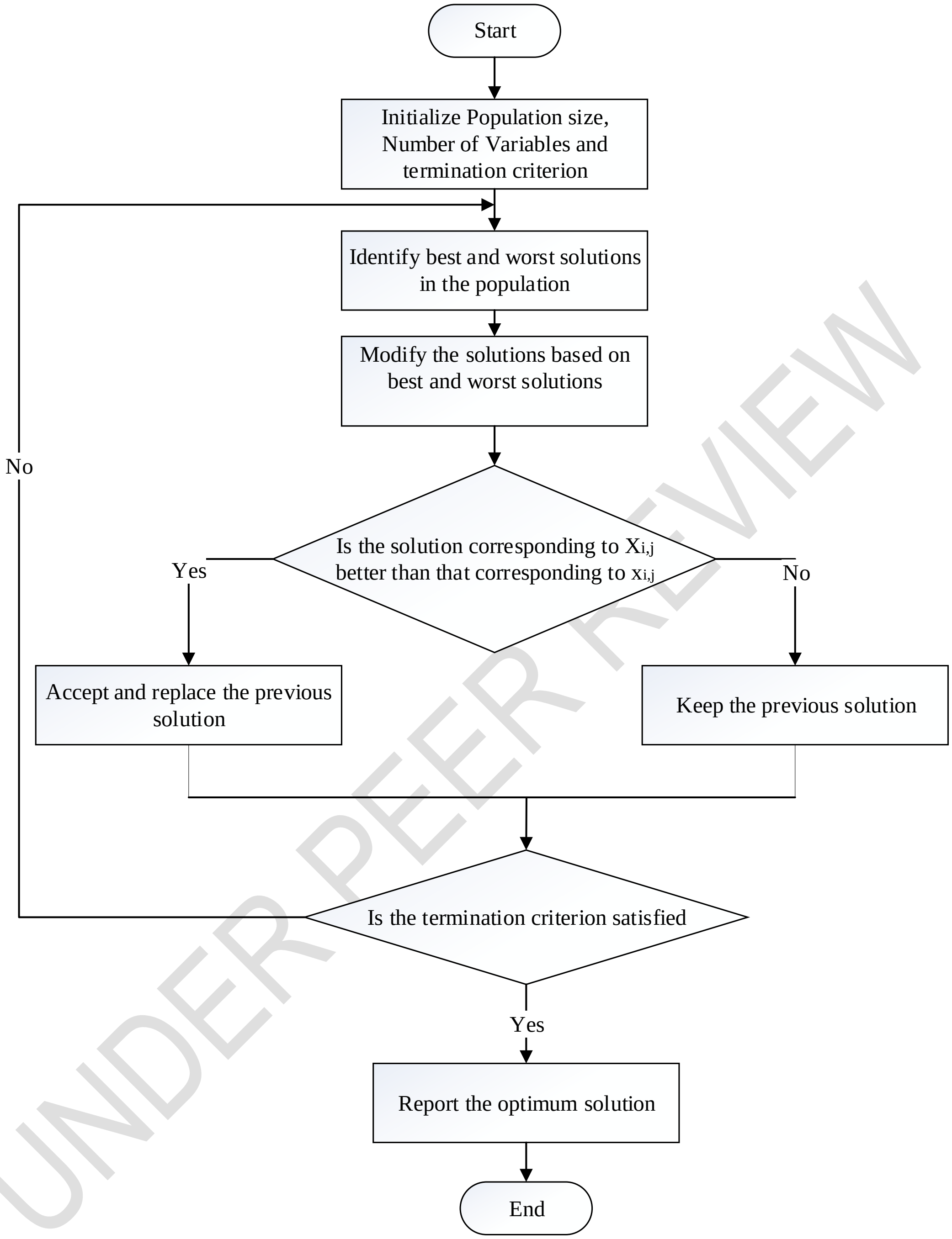


Figure 3. Flowchart of Jaya Algorithm

3.5 IEEE Bus System Model

The IEEE 14 Bus system configuration has PIDPSS installed at generators 1 and 2 as shown in Figure 4. The simulation was done for two scenarios: without PIDPSS and with PIDPSS. A three-phase fault was introduced at 5s with a downtime of 0.1s. The bus and line data for the IEEE 14 Bus System are presented in the appendix.

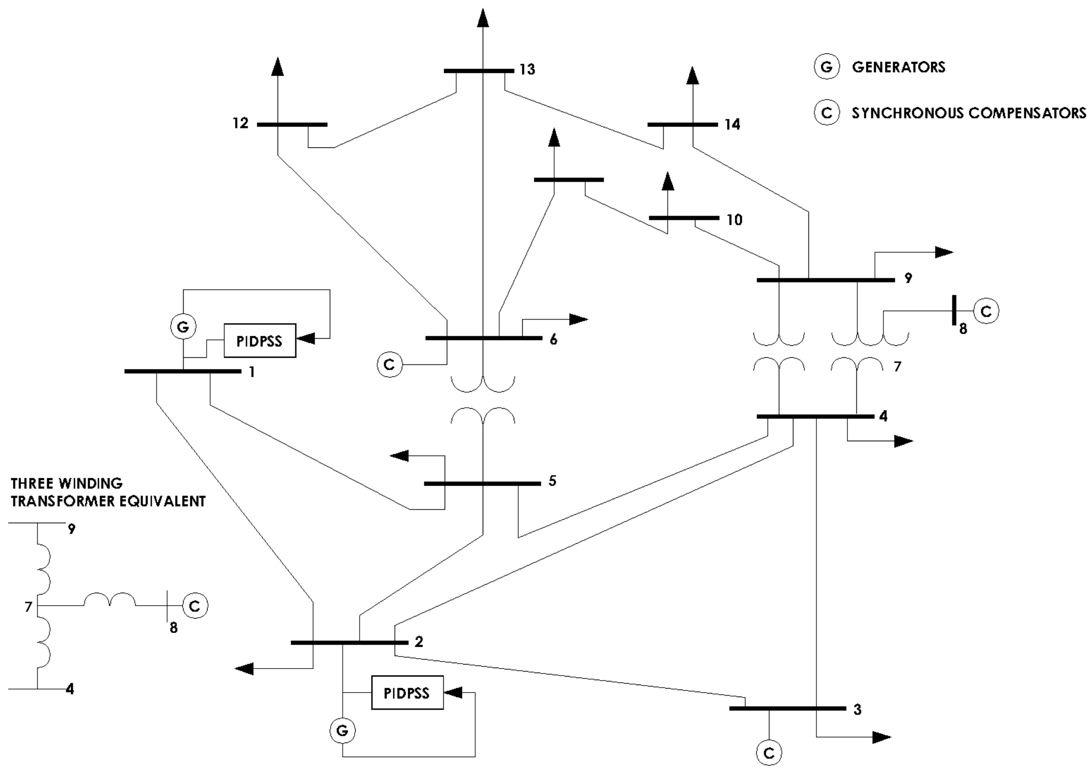


Figure 4. IEEE 14- Bus system configuration

3.6 SMIB Model

The configuration of the SMIB model is presented in Figure 5showing thePIDPSS connected to the excitation system. The simulation was done with the model presented in Figure 6 for 25s giving sufficient time to see the effect of the three-phase fault which was introduced at 5s and cleared within 0.1s. The data for the SMIB model is attached in Appendix.

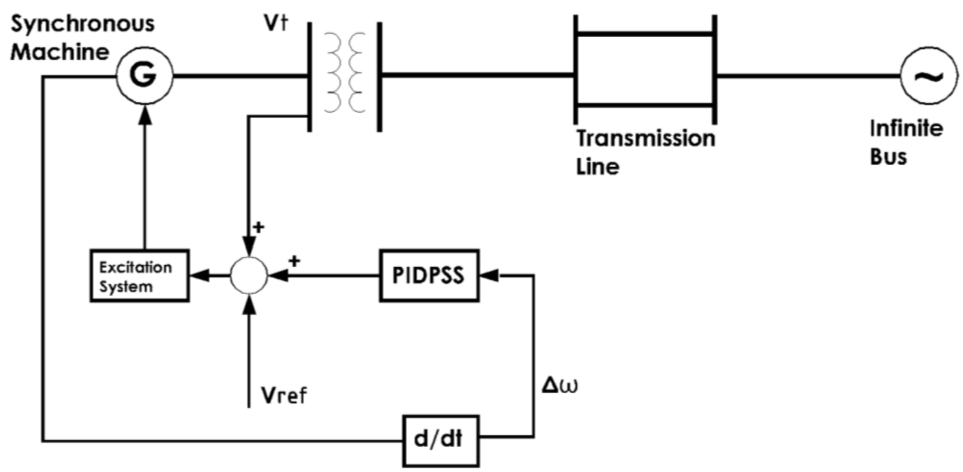


Figure 5. Configuration of SMIB system

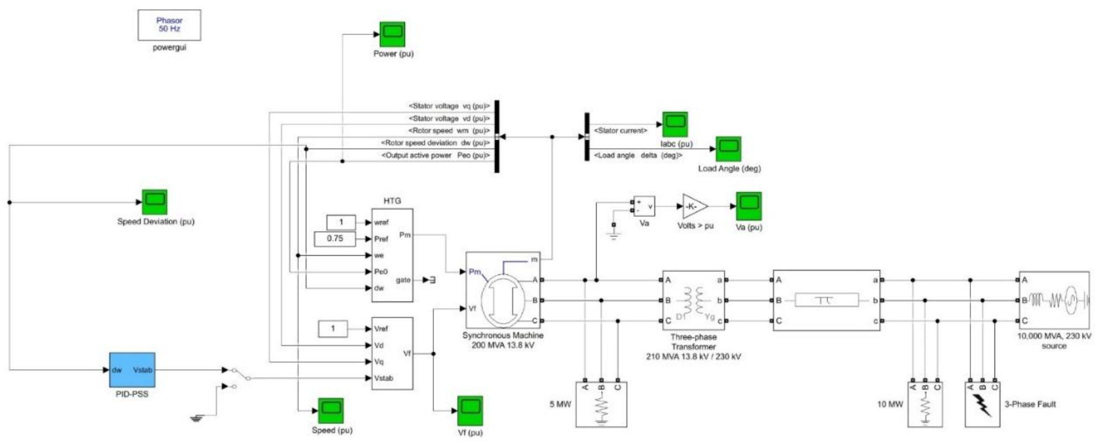


Figure 6. SMIB Simulink model

3.7 Parameters of PID and PSS

The optimized parameters of PID and PSS are presented in the table

Table 1. PID and PSS Parameters

Parameters	Value		PID	
	IEEE 14 BUS SYSTEM	**SMIB**	**Parameters**	**Value**
K_A	9.9453	10	K_P	0.9818
T_W	0.7	1.6	K_I	0.5216
T_1	0.006	0.1	K_D	0.9892
T_2	0.5	0.5		
T_3	0.05	0.05		
T_4	0.05	0.05		

4. RESULTS AND DISCUSSION

Comparison is analyzed for overshoot and settling time for the Electrical Power, Load Angle and Speed Deviation profile for both SMIB and IEEE 14 Bus System. The overshoot percentage is derived from the following relation:

$$\%Overshoot\ Reduction = \frac{Overshoot\ without\ PIDPSS - Overshoot\ with\ PIDPSS}{Overshoot\ without\ PIDPSS}\ x\ 100 \qquad (9)$$

4.1 Simulation Results for IEEE 14 Bus System

Generator 1

Figure 7 is the graph of speed deviation versus time for generator 1. The result shows that the oscillation of the system with PIDPSS was attenuated within 2.5s after the fault was cleared for speed deviation while without PIDPSS the system settled within 15s. Furthermore, the application of PIDPSS reduces the overshoot time by 74% without the PIDPSS.

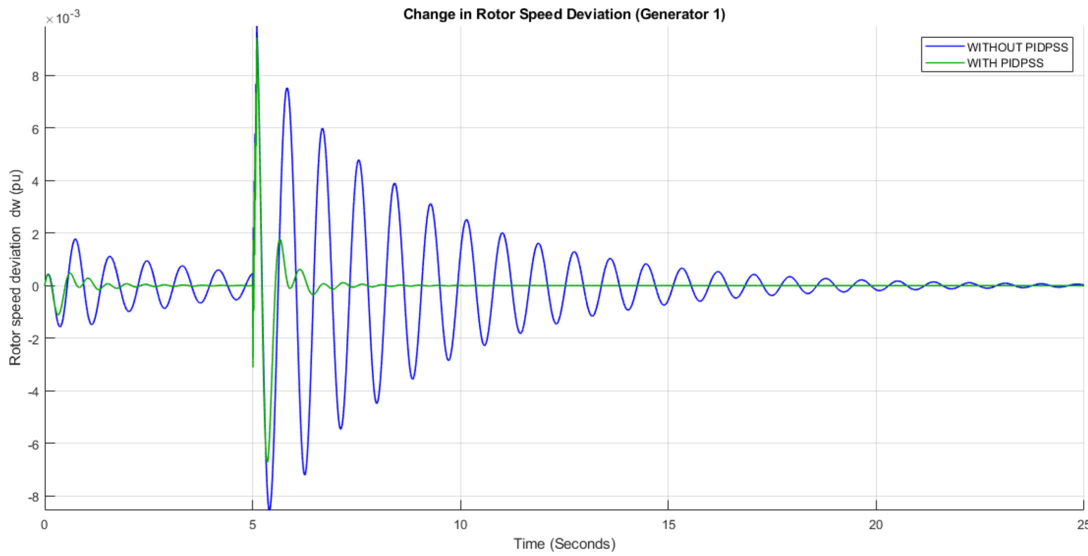


Figure 7. Generator 1 IEEE 14 Bus System Speed Deviation vs Time graph

Figure 8 shows the load angle vs Time graph of Generator 1. The result shows that the damping time in the presence of PIDPSS is within 2s with a reduction in overshoot of 14%.

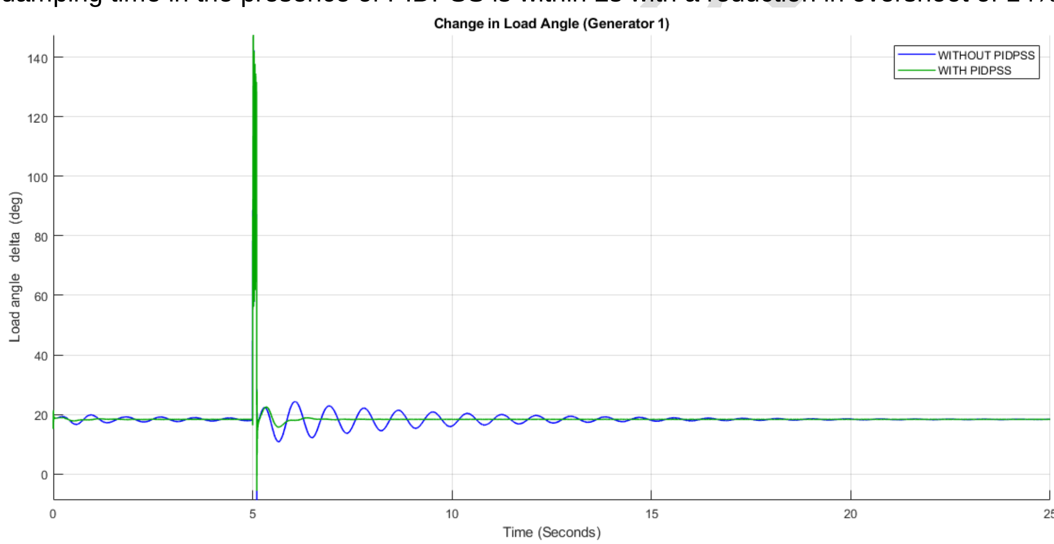


Figure 8. Generator 1 IEEE 14 Bus System Load Angle vs Time graph

Figure 9 is the Electrical Power vs Time graph for Generator 1. Here also the presence of PIDPSS has shown improvement in the ability of the system to return to stability fast with overshoot reduction of 27% and settles within 2.5s.

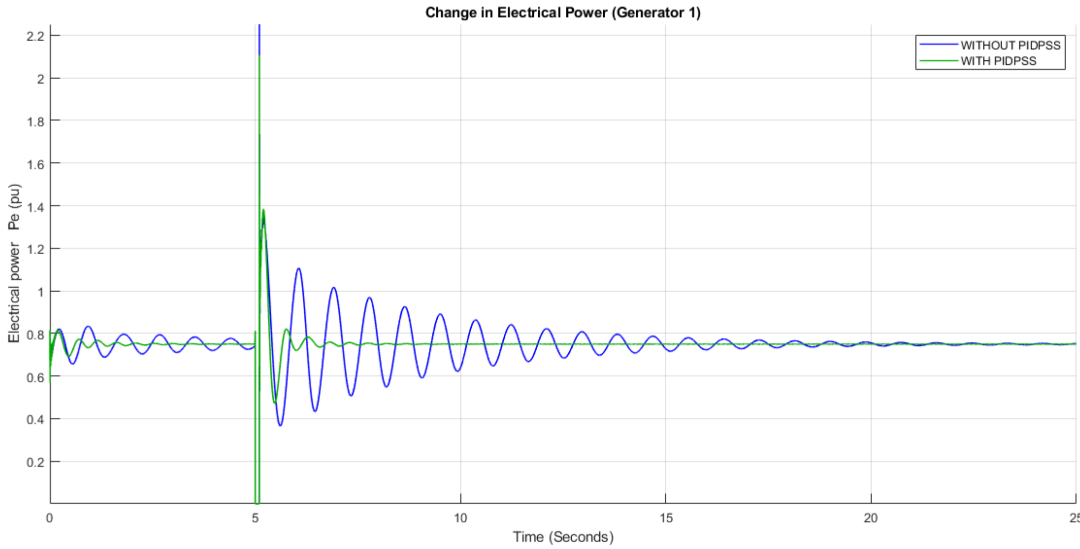
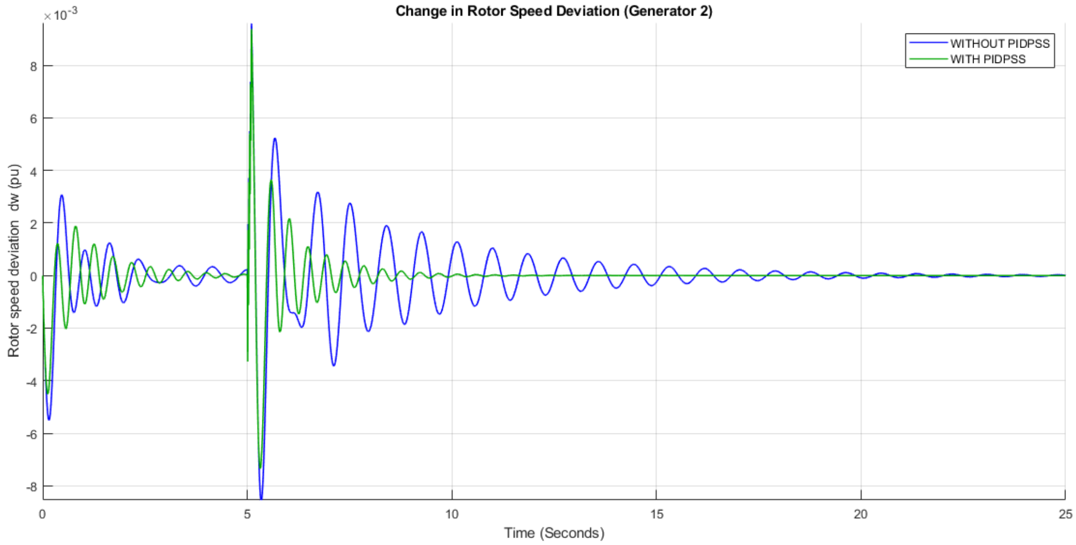
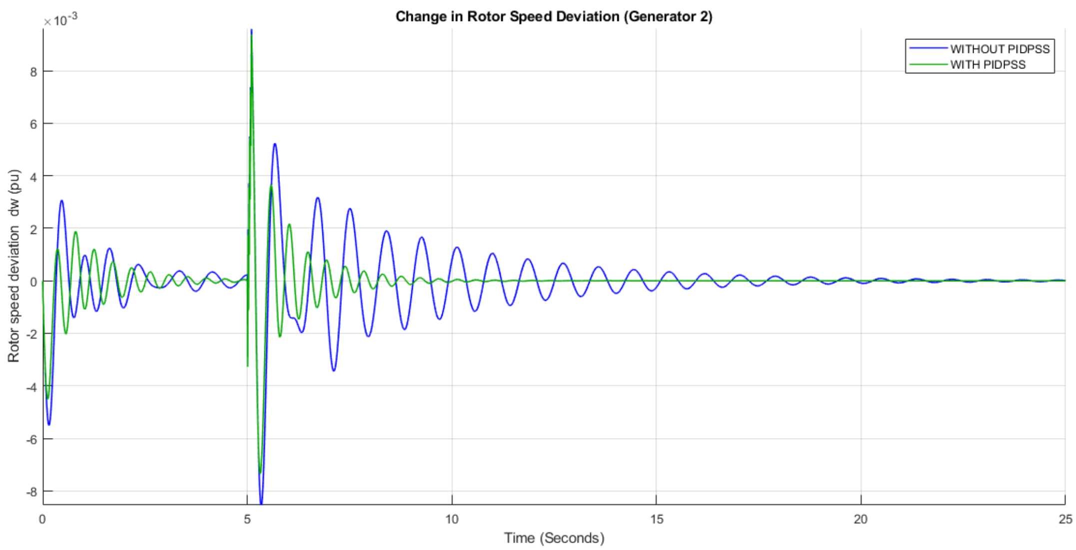


Figure 9. Generator 1 IEEE 14 Bus System Electrical Power vs Time graph

Generator 2





. Generator 2 IEEE 14 Bus System Speed Deviation vs Time graph

Figure 10 is the graph of speed deviation versus time for generator 2. The result shows that the oscillation of the system with PIDPSS was attenuated within 4s after the fault was cleared while without PIDPSS the system settled within 15s. Furthermore, the application of PIDPSS reduces the overshoot time by 24% without the PIDPSS.

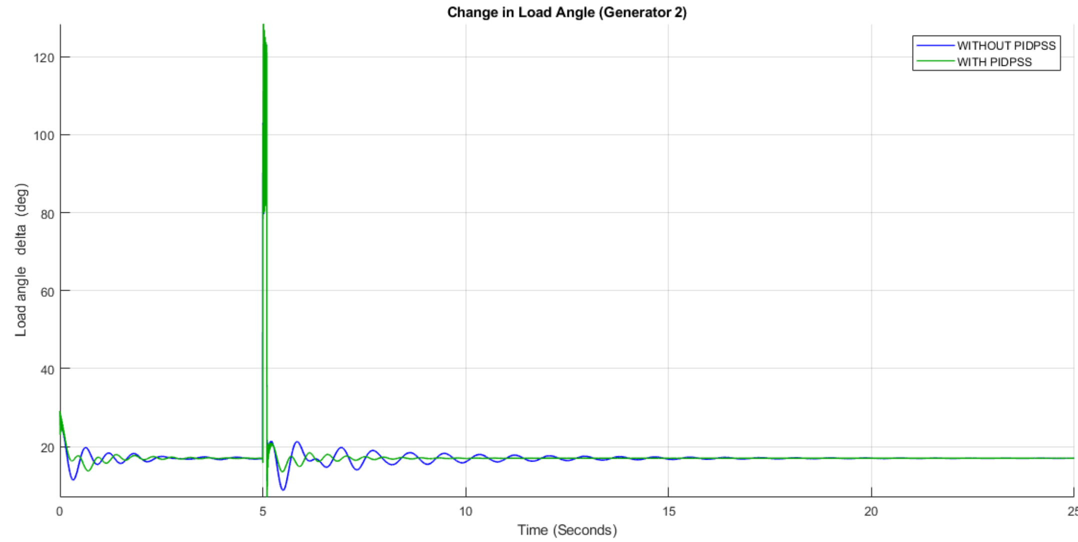


Figure 10. Generator 2 IEEE 14 Bus System Load Angle vs Time graph

Figure 10 shows the Load Angle vs Time graph of generator 2. The result shows that the damping time in the presence of PIDPSS is within 2.5s with overshoot reduction of 19%.

The Electrical Power vs Time graph of Generator 2 is shown in Figure 11 with the PIDPSS. The settling time of PIDPSS is 4s with overshoot reduction of 6%.

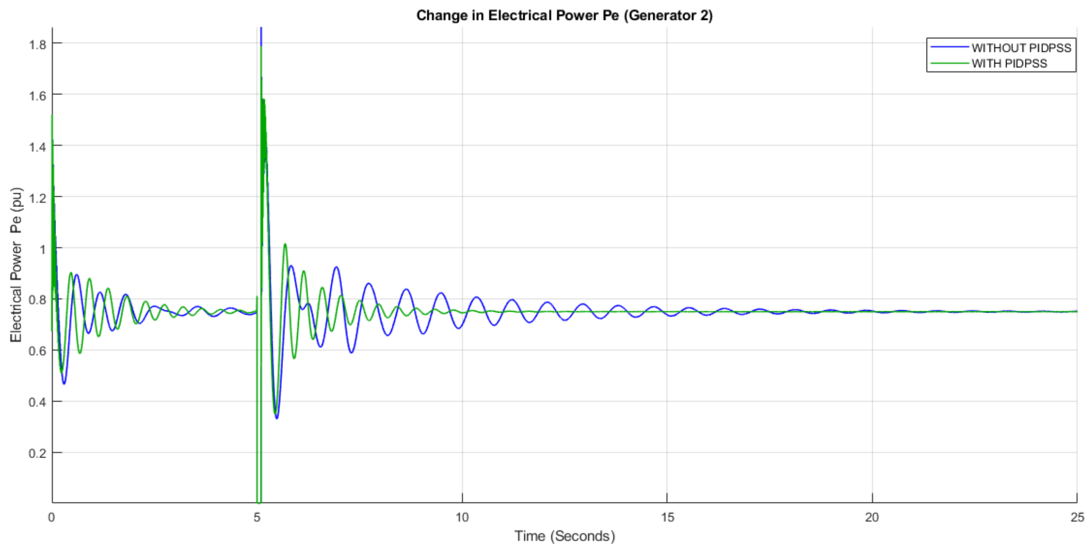


Figure 11. Generator 2 IEEE 14 Bus System Electrical Power vs Time graph

4.2 Simulation Results for SMIB

Figure 12is the graph for the Speed Deviation versus time of SMIB. The results show that with the introduction of PIDPSS, the system settles within 4s with overshoot reduction of

25%.

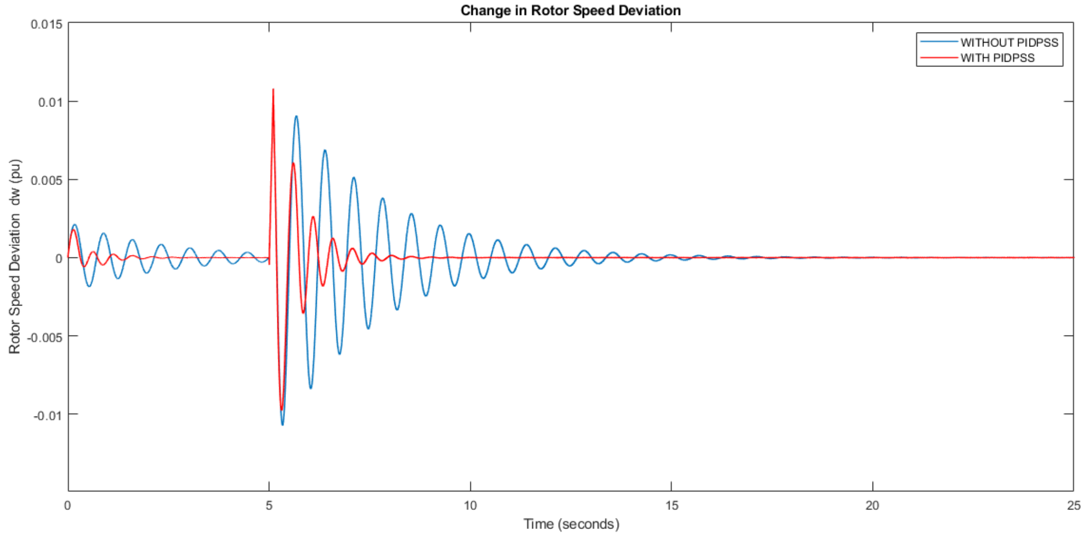


Figure 12. Speed Deviation of SMIB

Figure 13 shows the Load Angle vs Time graph of SMIB. The result shows that with PIDPSS integrated, the system had an overshoot reduction of 13% and a settling time of 2s.

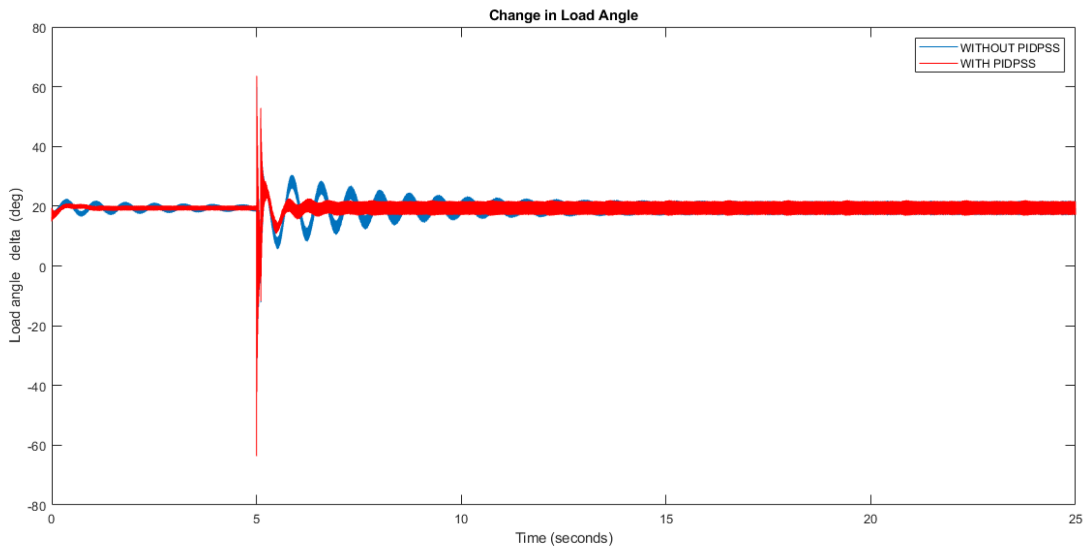


Figure 13. Load Angle of SMIB

The graph of Electrical Power vs Time of the SMIB is shown in Figure 14. Here, the presence of PIDPSS has an overshoot reduction of 15% and settling time of 2s.

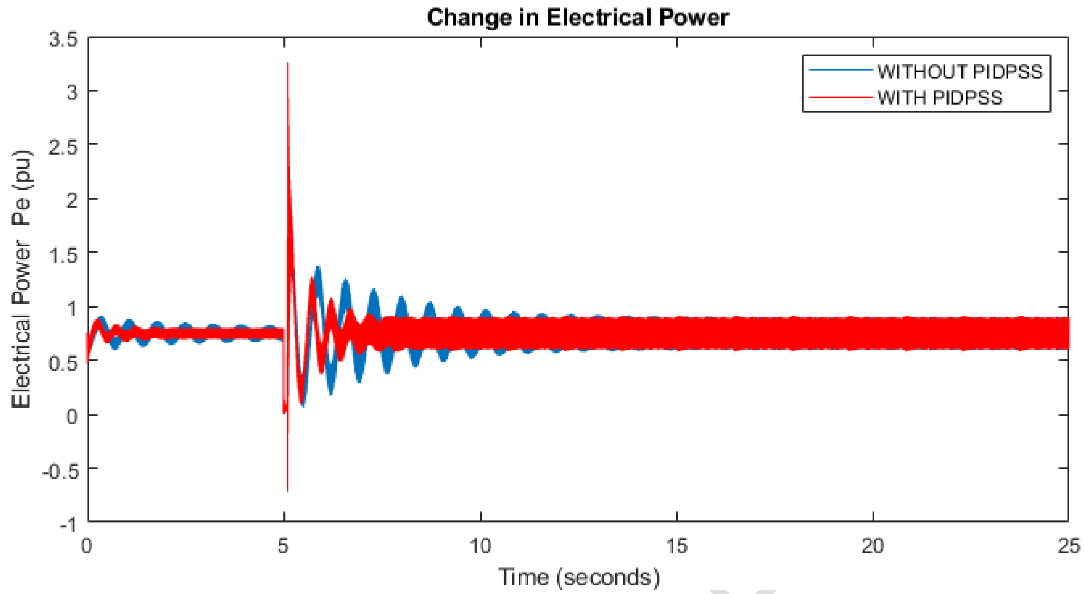


Figure 14. Electrical Power vs Time graph of SMIB

5. CONCLUSION

This paper presented an optimized Jaya Algorithm-based Proportional Integral Derivative Power System Stabilizer (PIDPSS) for improving angular stability. An IEEE14-bus system and a Single Machine Infinite Bus (SMIB) were adopted to test the algorithm's performance in MATLAB/Simulink. A three-phase fault designed into the system was initialized at 5 seconds runtime, and a fault clearing time of 0.1 seconds was introduced into the network. Results showed that in terms of overshoot and settling time for electrical power, speed deviation, and load angle, Jaya algorithm-optimized PIDPSS had an appreciable percentage improvement in the SMIB and IEEE14 Bus Systems. These findings demonstrated that the PIDPSS increased overall system stability.

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APPENDIX

BUS DATA – IEEE 14 BUS SYSTEM

BUS NUMBER	BUS VOLTAGE		GENERATION		LOAD	
	MAGNITUDE (P.U)	PHASE ANGLE (DEGREE)	REAL POWER (MW)	REACTIVE POWER (MVAR)	REAL POWER (MW)	REACTIVE POWER (MVAR)
1	1.060	0	114.17	-16.9	0	0
2	1.045	0	40.00	0	21.7	12.7
3	1.010	0	0	0	94.2	19.1
4	1	0	0	0	47.8	-3.9
5	1	0	0	0	7.6	1.6
6	1	0	0	0	11.2	7.5
7	1	0	0	0	0	0
8	1	0	0	0	0	0
9	1	0	0	0	29.5	16.6
10	1	0	0	0	9.0	5.8
11	1	0	0	0	3.5	1.8
12	1	0	0	0	6.1	1.6
13	1	0	0	0	13.8	5.8
14	1	0	0	0	14.9	5.0

LINE DATA – IEEE 14 BUS SYSTEM

BUS NUMBER	FROM BUS	TO BUS	LINE IMPEDANCE (P.U)		HALF-LINE CHARGING SUSCEPTANCE (P.U)	MVA RATING
			RESISTANCE	REACTANCE		
1	1	2	0.01938	0.05917	0.02640	120
2	1	5	0.05403	0.22304	0.02190	65
3	2	3	0.04699	0.19797	0.01870	36
4	2	4	0.05811	0.17632	0.02460	65
5	2	5	0.05695	0.17388	0..1700	50
6	3	4	0.06701	0.17103	0.01730	65
7	4	5	0.01335	0.04211	0.00640	45
8	4	7	0	0.20912	0	55
9	4	9	0	0.55618	0	32
10	5	6	0	0.25202	0	45
11	6	11	0.09498	0.1989	0	18
12	6	12	0.12291	0.25581	0	32
13	6	13	0.06615	0.13027	0	32
14	7	8	0	0.17615	0	32
15	7	9	0	0.11001	0	32
16	9	10	0.03181	0.0845	0	32
17	9	14	0.12711	0.27038	0	32
18	10	11	0.08205	0.19207	0	12
19	12	13	0.22092	0.19988	0	12
20	13	14	0.17093	0.34802	0	12

DATA FOR SMIB MODEL

PARAMETER	VALUE
DEADBAND VALUE	0.0
PERMANENT DROOP (R_P)	0.04
MAXIMUM GATE POSITION (G_{MAX})	1.5PU
MINIMUM GATE POSITION (G_{MIN})	0.0PU
MAXIMUM GATE OPENING RATE (MXGTOP)	0.8/MIN
MAXIMUM GATE CLOSING RATE (MXGTCG)	-0.6/MIN
PILOT VALVE SERVOMOTOR TIME CONSTANT (T_P)	0.03S
SERVO GAIN (Q)	1.0
MAIN SERVO TIME CONSTANT (T_G)	0.2S
TEMPORARY DROOP (Δ)	0.6
RESET DASHPOT TIME CONSTANT (T_R)	8.0S
WATER STARTING TIME CONSTANT (T_W)	1.6S
TURBINE DAMPING COEFFICIENT	0.25

SYNCHRONOUS GENERATOR PARAMETERS IN PU

MVA	NO OF UNITS*	H	x_d	x'_d	x''_d	x_q	x'_q	x''_q	T'_{do}	T''_{do}	T'_{qo}	T''_{qo}	x_l	R
700	4	3.24	0.8	0.3	0.2	0.49	-	0.24	5.57	0.05	-	0.34	0.16	0.004