

Implementation of Bio Inspired Genetic Optimizer in enhancing Power System Stability

R.Shivakumar, *Member IEEE*, Dr.R.Lakshmipathi and Y.Suresh

Abstract—The phenomenon of Stability of Modern Power Systems has received a great deal of attention in recent years. With the increasing complexity of the Modern Power Systems, the system stability is affected by Low frequency oscillations produced in the system. This paper provides a systematic approach to design a damping controller to damp the oscillations based on Bio inspired Genetic Algorithm(GA).The design problem is formulated as an Multiobjective Optimization criterion comprising of Eigen value based and Time domain based objective functions to compute the optimal controller parameters. The main objective here is to shift the closed loop eigen values to better positions in s plane and also to minimize the integral squared error involving rotor speed and power angle deviations so that the system stability will be enhanced to a greater extent. To validate the effectiveness and robustness of the proposed controller, Non linear simulations has been implemented under various system operating conditions and also introduction of disturbances in the form of outage of Transmission line in the system considered. The proposed controller design is also compared with the conventional Lead lag controller design to show the importance of the proposed Bio inspired controller design.

Index Terms—Genetic Algorithm, Multiobjective function, Power System Stability, Robust Control.

I. INTRODUCTION

The application of Bio inspired Genetic Algorithms to Power system stability problems has recently attracted the attention of researchers in the field of Artificial Intelligence. Low frequency inertial oscillations, with frequencies ranging from 0.1 to 2 Hz are inherent to Electric power systems[1].Problems due to inadequate damping of such oscillations have been encountered throughout the history of Power Systems. The use of supplementary controls is generally the only practical method of mitigating the oscillations, without resorting to costly operating restrictions or transmission reinforcements. A Power System Stabilizer (PSS) is one of the most cost effective method to damp the oscillations, thus enhancing Power system stability [2].Most PSSs employ the classical linear control theory [3-4].

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Despite the potential of modern control techniques like optimal control, adaptive control, variable structure control [5-6], Power System utilities still prefer the conventional lead lag PSS structure. PSS design approach is based on a linear model in fixed configuration of the power system. This results in fixed parameters of PSS. The Power system being dynamic and Nonlinear in nature, fixed setting of the controller parameters degrades its performance. Unfortunately, the conventional techniques are time consuming, as they are iterative and require heavy computation burden and slow convergence. To have controllers provide good damping over a wide operating range, its parameters need to be fine tuned in response to the oscillations to fit the system requirements to various modes of oscillations.

Modern Bio inspired algorithms include a wide variety of population based algorithms which can be applied to different kinds of optimization problems. Recently, Bio inspired optimization techniques like Genetic algorithms, Tabu search, Evolutionary Programming, Simulated annealing, Bacteria foraging and Particle Swarm Optimization have been applied for PSS parameter optimization [7-8].

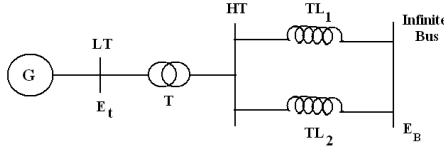
In this work, Genetic Algorithm is implemented to compute the optimal controller parameters for enhancing system stability. Genetic Algorithms are computerized search and optimization algorithms based on the principles of Natural genetics and Natural selection [9].GA mimic the survival-of-the fittest principle of nature to make a search process. Genetic algorithm differ from more traditional optimization techniques in many ways: Genetic algorithm use objective function to guide the search, not derivative or other auxiliary information. Genetic algorithm search through many points in the solution space at one time, not a single point.

The main objective here is to shift the weakly damped electromechanical mode Eigen values to stable locations in the complex s plane for system stability. The objective also involves minimization of integral squared error (Rotor speed deviation and Power angle deviation) to damp the low frequency oscillations. Non linear Time domain simulations under wide system operating conditions and system disturbances involving transmission line outage has been carried out to show the robust control property of the proposed optimal controller design.

The Complete design procedure is compared with the conventional lead lag stabilizer (CPSS) design to validate the superiority of the Bio inspired Genetic algorithm based stabilizer (GAPSS) design.

II. MODELING OF POWER SYSTEM

A. Power System model investigated



Fig(1) Single Machine Infinite Bus Power system Model

Figure (1) represents a 2220MVA, 24KV, 60 Hz Synchronous generator connected to an infinite bus through a step up Transformer (T) and double circuit transmission line. E_t and E_B being the generator terminal voltage and Infinite bus voltage respectively. All the system parameters use for simulation [10] are given in Appendix-I.

For Analysis and Simulation, the Heffron-Phillips block diagram of Single Machine Infinite bus Model was used [11].

The Dynamic model in State Space form is given by

$$\dot{x} = Ax + Bu \quad (1)$$

where $[x]$ = Vector of State variables.
 A, B = State Vector Matrix and Input Matrix respectively.

The State variables used in the modeling for open loop and closed loop system are given by,

$$[x]_{open} = [\Delta\omega \quad \Delta\delta \quad \Delta E_q' \quad \Delta E_{fd}]$$

$$[x]_{closed} = [\Delta\omega \quad \Delta\delta \quad \Delta E_q' \quad \Delta E_{fd} \quad \Delta P_1 \quad \Delta U_E] \quad (2)$$

The abbreviations for the variables are given in Appendix-II

B. Structure of Power system Stabilizer

Fig(2) Structure of Power System Stabilizer

The PSS model consists of the Gain Block, Cascaded identical Phase Compensation block and the washout block as in figure(2). The input to the controller is the Rotor speed Deviation ($\Delta\omega$) and output is the Supplementary Control signal (ΔU_E) given to Generator excitation system.

The transfer function of the PSS Model is given by

$$\left[\frac{\Delta U_E}{\Delta\omega} \right] = K_s \left[\frac{(1+sT_1)}{(1+sT_2)} \right] \left[\frac{(1+sT_3)}{(1+sT_4)} \right] \left[\frac{(sT_w)}{(1+sT_w)} \right] \quad (3)$$

Where K_s = PSS gain

T_w = Washout Time constant.

T_1, T_2, T_3, T_4 = PSS Time constants

For the identical phase compensator block, the Time Constants $T_1 = T_3$, $T_2 = T_4$. Hence K_s , T_1 , T_3 are the PSS parameters which should be computed using Conventional Lead Lag stabilizer and optimally tuned using Genetic based

stabilizer.

The washout time constant is in the range of 1 to 20 seconds and in this work, T_w is taken as 10 seconds.

III. PROPOSED OPTIMIZATION CRITERION

A. Criteria for Stability

For the System to be stable, all the system Eigen values should lie on better positions in left half of the complex s plane.

The Oscillatory mode (Electromechanical mode) is represented by an Complex Eigen value ($\sigma \pm j\omega$). The Real part (σ) of a complex Eigen value indicates whether an oscillation decays (the real part is negative), remains at a constant amplitude (the real part is zero) or grows (the real part is positive).

B. Multi objective function formulation

The Main objective of this formulation is to compute the optimal value of PSS parameters for system oscillations damping and thus enhancing system stability

1). Eigen Value Based objective function

$$[J_1] = \text{Max}[\sigma_i], \sigma_i \in \sigma_{EM} \quad (4)$$

Where σ_i = Real part of the i^{th} Electromechanical Mode Eigen value.

σ_{EM} = Set of Electromechanical Mode Eigen values.

The objective here is to *Minimize* the objective function J_1 , so that the real part of the Electromechanical mode Eigen value is shifted to left half of s plane for system stability.

The Maximum value of the real part of the electromechanical mode eigen value will be located in right half of s plane, thus making the system unstable.

2). Time Domain based Objective function.

$$[J_2] = \int_0^{T_s} [e^2(t)] dt. \quad (5)$$

Here $e(t)$ is the error involving Rotor Speed deviation $[\Delta\omega]$ and the Power angle deviation $[\Delta\delta]$.

T_s represent the Time of Simulation.

The objective here is to *Minimize* the objective function J_2 , so that the integral of the squared error deviation is minimized thus enhancing the damping of the low frequency oscillations.

The Design problem including the constraints imposed on the various PSS parameters is given as follows:

Optimize J

Subject to

$$K_s^{\min} \leq K_s \leq K_s^{\max} \quad (6)$$

$$T_1^{\min} \leq T_1 \leq T_1^{\max} \quad (7)$$

$$T_2^{\min} \leq T_2 \leq T_2^{\max} \quad (8)$$

Typical ranges selected for K_s , T_1 and T_2 are as follows:
For K_s [5 to 55], for T_1 [0.1 to 1] and for T_2 [0.1 to 1]. This Minimization criterion has been implemented in this work to compute the Optimum Value of the Parameters K_s , T_1 and T_2 .

IV. BIO INSPIRED GENETIC ALGORITHM-AN OVERVIEW

Genetic Algorithms are numerical optimization algorithms inspired by Natural selection and natural genetics [12]. GA techniques differ from more traditional search algorithms in that they work with a number of candidate solutions rather than one candidate solution. Each candidate solution of a problem is represented by a data structure known as an individual. A group of individuals collectively comprise what is known as a population. GAs are initialized with a population of random guesses.

GA includes operators such as Reproduction, Crossover, Mutation and Inversion.

Reproduction is a process in which a new generation of population is formed by selecting the fittest individuals in the current population. *Crossover* is responsible for producing new offsprings by selecting two strings and exchanging portions of their structures. The new offsprings may replace the weaker individuals in the population.

Mutation is a local operator which is applied with a very low probability of occurrence. Its function is to alter the value of a random position in a string. Finally, *Inversion* is a process which inverts the order of the elements between two randomly chosen points on the string.

The Algorithmic Steps involved in Genetic Algorithm are as follows:

- Step 1.** Specify the various parameters for GA Optimization.
- Step 2.** Create an Initial Population of individuals randomly.
- Step 3.** Evaluate the fitness of each individual (i.e) Evaluating the optimization criterion J.
- Step 4.** If value of J obtained is minimum, then optimum value of PSS parameters is equal to those obtained in current generation, otherwise Goto step 5.
- Step 5.** Based on the fitness, select the best individuals and perform recombination through a crossover process.
- Step 6.** Mutate the new generation with a given Probability.
- Step 7.** If termination condition (Maximum no of Generations) is not reached, go back to step (3).

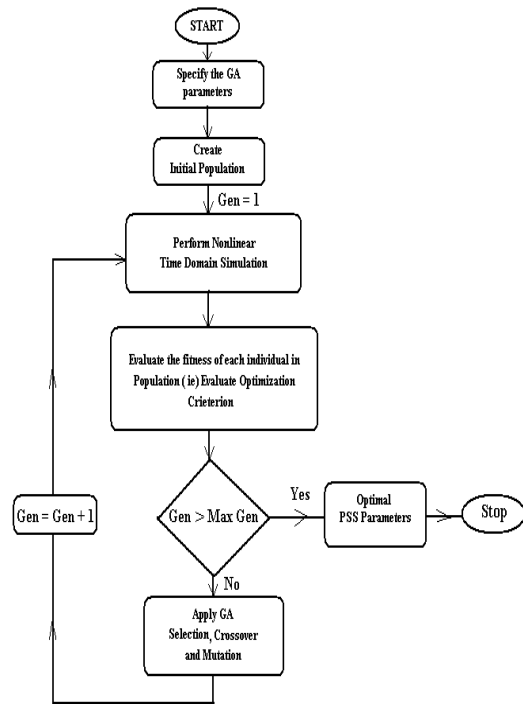


Fig (3) Computational Flow Chart for Genetic Algorithm

V. SIMULATION RESULTS

For all the Computation, Simulation and Analysis of the results in this work, MATLAB 7.0 / SIMULINK platform was used.

The Stability Analysis of the Test system is analyzed in 2 stages.

(1). Eigen Value Analysis.

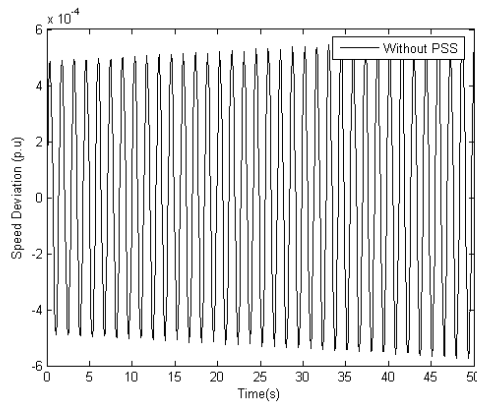
This is done for the weakly Damped Electromechanical Modes. This analysis will determine their characteristics and sources of the problem and assist in developing Damping Measures. The Eigen values located in the left half of complex s- plane will determine the stability of the system, whereas the Eigen values located in right half of complex s-plane will make the system unstable.

(2). Non Linear Time domain Simulation.

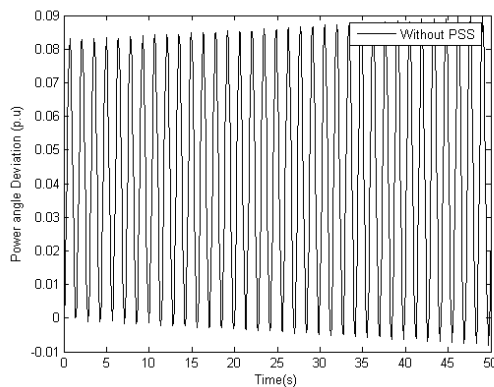
This Analysis shows how system Non linearities affect the oscillations.

The State Space Modeling of the test system was performed and the Open loop Eigen values was computed as in Table III. The Electromechanical Modes of Oscillation indicate that the test system is Unstable, having positive real part Complex Eigen values located in right side of complex s plane.

Also the time domain simulation in Figure(4) and Figure(5) indicate that the Rotor Speed deviation and Power Angle deviations respectively are oscillatory in nature having huge Overshoots and large settling time, indicating that the test system is unstable.



Fig(4) Open Loop Speed Deviation response for Operating Point (0.6, 0.03)



Fig(5) Open Loop Power angle Deviation response for Operating Point (0.6, 0.03)

The unstable system requires better damping design to mitigate the oscillations. In this work, Conventional Lead lag stabilizer (CPSS) and Genetic Based PSS (GAPSS) design is being implemented to compute the Optimal PSS parameters.

Table I gives the various parameters selected for GA implementation.

TABLE I. PARAMETERS SELECTED FOR GENETIC ALGORITHM

Genetic Algorithm Parameters	Selected Values / Type
Population Size	20
No of Generations	10
Selection Operator	Roulette Wheel Selection
Generation gap	0.9
Crossover Probability	0.95
Mutation Probability	0.10
Termination Method	Maximum Generations

Implementation of CPSS and GAPSS provide the optimal PSS parameters (K_s, T_1, T_2) as listed in Table II.

TABLE II. OPTIMAL PSS PARAMETERS COMPUTED

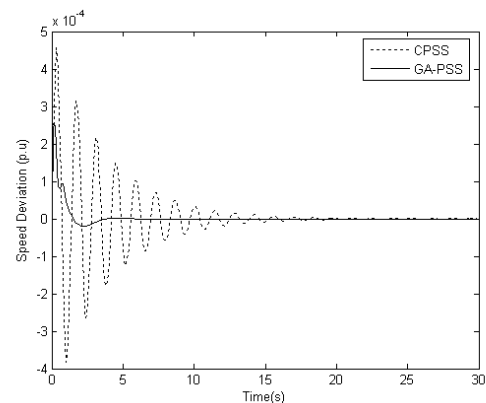
S. No	Operating Conditions	CPSS [K_s, T_1, T_2]	GAPSS [K_s, T_1, T_2]
1	P=0.6 Q=0.03	0.7951 0.6267 0.08	42.9023 0.5655 0.1463
2	P=0.5 Q=0.02	1.3449 0.4263 0.08	37.6909 0.7435 0.1004
3	P=0.6 Q=0.02+ Outage of Transmission Line TL_2	0.8933 0.6120 0.08	49.0348 0.4690 0.1494

These optimal parameters computed from CPSS and GAPSS are utilized in calculating the closed loop eigen values of the system with controllers. The closed loop eigen values are listed in Table III. The eigen values reveal that the CPSS provide damping to the system by shifting the weakly damped electromechanical mode eigen values to the left half of complex s plane, making the system stable.

Comparatively, GAPSS provide better damping to the system by shifting the closed loop weakly damped electromechanical mode eigen values to better locations in s plane than the Conventional PSS, thus enhancing system stability to a greater extent.

To validate the robustness and effectiveness of the proposed GAPSS, Non linear Time domain simulation (Based on minimizing the Integral Squared Error) has been carried out in this work under wide system loading conditions, and also introducing disturbances in the form of outage of the Transmission line (TL_2). The error refers to the Speed deviation and Power Angle deviation here.

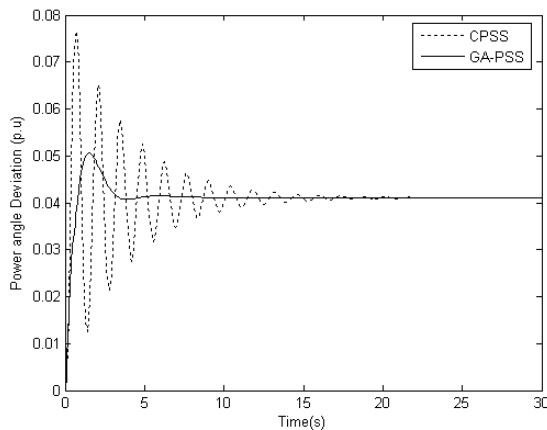
Fig(6) and Fig (7) shows the Speed deviation and Power angle deviation response of the system operating at P=0.6, Q= 0.03 respectively. From the deviation response, it is clear that the GAPSS provide better damping to the oscillations compared to the CPSS.



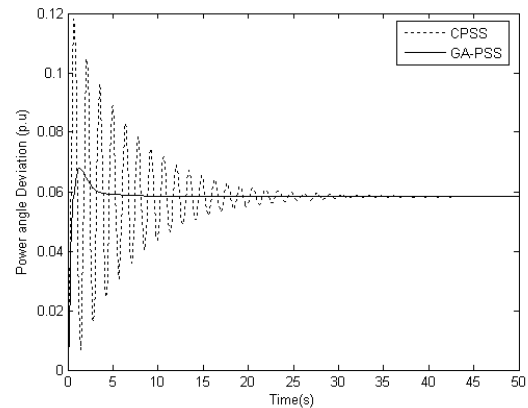
Fig(6) Speed Deviation response with CPSS & GAPSS for Operating Point (0.6, 0.03)

TABLE III . CLOSED LOOP EIGEN VALUES FOR OPEN LOOP, CPSS & GAPSS

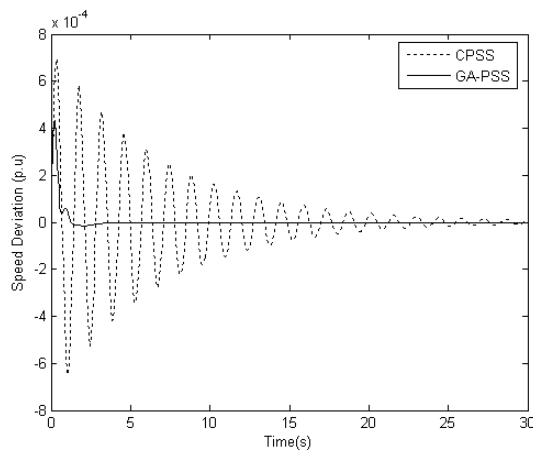
S. No	Operating Conditions	Open Loop without PSS	CPSS	GAPSS
1.	P=0.6 Q=0.03	$0.0822 \pm j8.0704$ $-5.2151 \pm j10.9396$	-11.3272 $-4.4981 \pm j11.9196$ -0.0499 $-0.2212 \pm j6.8184$	-10.4896 -0.0499 $-0.4185 \pm j7.2271$ $-4.4716 \pm j11.426$
2.	P=0.5 Q=0.02	$0.2409 \pm j7.5280$ $-4.8919 \pm j11.5012$	-11.3887 $-4.3492 \pm j12.4718$ -0.0497 $-0.3395 \pm j6.3048$	$-4.0330 \pm j12.6391$ -10.9777 -0.0498 $-0.6176 \pm j5.6568$
3.	P=0.6 Q=0.02 + Outage of Transmission Line TL ₂	$0.3953 \pm j7.6858$ $-4.7444 \pm j11.3502$	$-4.2184 \pm j12.4207$ -11.3336 $-0.5045 \pm j6.3069$ -0.0496	$-4.1813 \pm j11.8658$ -10.4353 $-0.7406 \pm j6.8499$ -0.0499



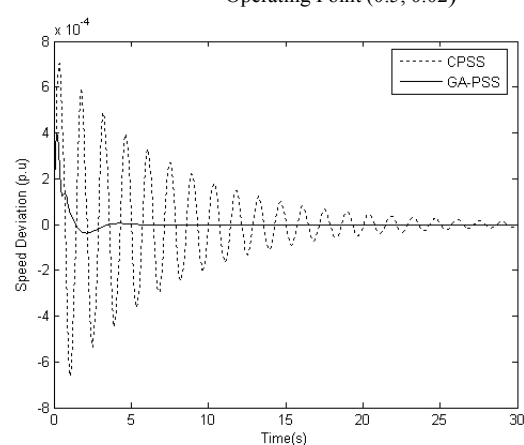
Fig(7) Power angle Deviation response with CPSS & GAPSS for Operating Point (0.6, 0.03)



Fig(9) Power angle Deviation response with CPSS & GAPSS for Operating Point (0.5, 0.02)



Fig(8) Speed Deviation response with CPSS & GAPSS for Operating Point (0.5, 0.02)



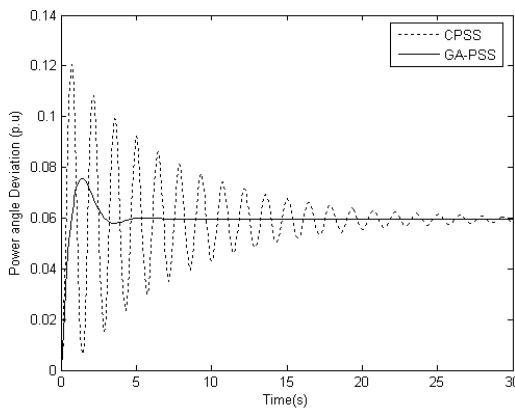
Fig(10) Speed Deviation response with CPSS & GAPSS for Outage of Transmission line(TL₂)

Fig(8) and Fig (9) shows the Speed deviation and Power angle deviation response of the system operating at P=0.5, Q= 0.02 respectively.

From the deviation response, it is clear that the overshoots are reduced and oscillations settle at a quicker stage by implementing GPSS.

Fig(10) and Fig(11) indicate the dominance of the Bio inspired stabilizer in damping the low frequency oscillations compared to the conventional controller.

For instance, in Fig(11), the initial power angle overshoot is 0.12p.u for CPSS and it is only 0.075p.u for GAPSS design.



Fig(11) Power angle Deviation response with CPSS & GAPSS for Outage of Transmission line(TL₂)

These responses clearly indicate the damping phenomenon exerted by the various controllers. In all the cases, the Bio inspired algorithm based controller (GAPSS) provide better damping to the electromechanical oscillations compared to the conventional lead lag stabilizer.

VI. CONCLUSION

In this paper, a better and efficient solution to damp the low frequency oscillations which affect Power system Stability is presented. The Eigen value analysis and Non linear Time domain analysis clearly indicate the importance of Bio inspired Algorithm applications in mitigating the electromechanical oscillations, thus enhancing system stability. The Robustness of the proposed controller is clearly tested by simulating the system model under wide operating conditions and also introducing disturbance in the form of transmission line outage. Finally, the comparative study between CPSS and GAPSS clearly indicate the superiority of the proposed Genetic Algorithm based controller.

APPENDIX I

System Parameters:

Generator : 2220MVA, 24 KV, 60 Hz
 $H = 3.5$, $T_{do}' = 8$ secs, $D = 0$
 $x_d = 1.81$, $x_d' = 0.3$, $x_q = 1.76$, $x_l = 0.16$

Excitation : IEEE ST1A type Excitation
 (For Speed input Stabilizer)
 $K_A = 190$, $T_A = 0$, $K_F = 0$,
 $T_F = 1$ Sec, $V_R \min = -6.7$, $V_R \max = 7.8$
 $K_c = 0.08$, $T_B = 10$

Line : $R = 0.003$, X (Line1) = 0.5, X (Line 2) = 0.93.
 Operating point ($P = 0.6$, $Q = 0.03$), $E_B = 0.995$.

All parameters are in p.u. unless specified otherwise.

APPENDIX II

Abbreviations:

CPSS = Conventional Lead lag Stabilizer
 GAPSS = Genetic Algorithm Based Stabilizer
 ω, δ = Rotor Speed, Angle.
 K_A = Amplifier Gain
 E_{FD} = Generator Field Voltage
 E_q' = Generator Internal Voltage.

ΔP_1 = Output State Variable of PSS Washout Block.
 ΔU_E = Supplementary Excitation Signal from PSS.
 σ = Real part of Eigen value.

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