

MATLAB/Simulink-Based Optimization of Power System Stabilizer Parameters Using a Genetic Algorithm

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Abstract - Oscillations caused by frequency in lower values has potential to cause great Damage to Stability of transient type in the electrical power system grids. We need to use power system stabilizers i.e. PSS to make sure these oscillations doesn't last long by injecting damped signals inside generator of excited loop. In the past, researchers tried to use linear based models for tuning of PSS based but when we actually apply this into the real world application it fails to deliver what we require. Therefore in this Paper work, we used matlab software to create simulation based framework. We used Global Optimal Toolbox inside MATLAB for genetic algorithm to find the best possible PSS gain & lead lag based time constant represented by T for single machine based infinite bus system. we have designed an new method of terminal absolute error which is better than olde metrics. This method measures leftover speed and deviation of angle every 5 seconds which relates to grid code based recovery constraint. We build 3 models on Simulink to test our genetic algorithm approach including without PSS, With classic PSS and With Genetic Algorithmically optimized WithPSS model. This GA found the optimal value to be around 0.0616563 after completing 18 generations. The precise parameters wee found to be $K = 9.313778$ & $T = 0.030270s$. Under the settling time of 4.5s, this GA Based PSS overcomes the problem of oscillation with much less overshoot when comparing it to the benchmark results.

damping torque which causes oscillations more frequently. To fix this normally we use AVR with power system stabilizer. PSS continuously monitor the deviation in speed of Rotor and provide an filter signal into the AVR group. Traditional PSS methods are design for Linear models operating at single point. Well they are mathematically accurate but they caused to big issues one is that it ignores non linear functionalities of the machine and its control system and the second is that when we try to tune only a single load it can affect the other points as well. For better optimization and better results population based algorithms are used as they do not work on linear models instead they use simulation to change the control setting that can load the nonlinear plant. There are various mathematical tool that have surpassed classic methods these tools include genetic based algorithm, Firefly based algorithm, particle based Swarm optimization etc. This research paper revolves around optimising PSS parameters using genetic algorithm. It not only describe Math and model but it also includes MATLAB code, simulate model and provide their results as well. As we approach the research paper section 2 is about past work, section 3 is about mathematical model and simulink model, Section 4 is about genetic algorithm and fitness method, Section 5 provides the configuration of simulation, section 6 analyses and produces the result and section 7 basically discusses about the future work that can be done in this particular field of genetic algorithm.

Index Terms—Genetic Algorithm, Power System Stabilizer, Transient Stability, MATLAB/Simulink, Terminal Absolute Error, SMIB, Heuristic Optimization, Lead-Lag Compensator.

1. Introduction

The High voltage systems are increasing day by day which causes market to increase the grid systems and this leads to synchronous based generators working close to their stability. In these situations even a small issue can cause tripping of generator, small line based faults and switching of loads and all these fault leads to no frequency based oscillations between the systems. These types of oscillations range between 0.2 to 3 hertz. If the net damping of the system becomes zero then system goes out of control. Automatic voltage regulator can increase the synchronising torque but at a cost of neglecting some

II. LITERATURE REVIEW

The Reference book of kundur, balu, and lauby let the foundation on how to overcome the oscillations and how to optimise the PSS parameters. deMello and Concordia created phase compensation methods that people use as a benchmark for that tuning of PSS parameters. but it doesn't work good under operating conditions when there is a phase lag between speed and torque. For better stability of the system we need to use control frameworks like h infinity and mu analysis. they are mathematically accurate and provide great margins of stability but not good for Complex controllers that contains excitation hardware that can only handle simple gains and lead lag form. Some researchers proposed fuzzy logic controller but still it doesn't work in most of the cases. Abdel-Magid et al propose the theory of genetic algorithm that can optimise PSS parameters without much complexity that leads to a big evolution in the power grid system and it change the

game forever even for multi machine system. In the recent researches in this field Guha et al. Did testing of grey wolf optimization on four different multi machine system which resulted in lowerd fitness values then genetic algorithm and differential evolution. All these researching of the PSS parameters lead us to find the specific parameters like ISE, IAE, ITAE the actually affect the performance metrics. But these parameters only calculate error during the simulation process window therefore we use terminal absolute error which counts the oscillation in every 5 seconds that relates to grid codes based optimization.

III. POWER SYSTEM AND PSS MODELING

A. SMIB System and Swing Equation

The Scientist are using single machine based on infinite bus system for their research to understand how the generator will react when it tries to work with use and steady grid systems. this infinite bus system acts as an voltage source system at provide voltage and frequency with steady limits neglecting The generator operating condition.

$$M(d^2\Delta\delta/dt^2) + D(d\Delta\delta/dt) = \Delta P_m - \Delta P_e \dots (1)$$

In above equation, we can see that is angular momentum, the is damping torque coefficient and Delta S is the rotor angle, Delta pm is the mechanical power that Moves the prime mover and Delta p e is the electrical power that is transferred to the grid. Electrical torque changes its value when there is a change in the value of internal voltage, grid voltage and impedance making it a nonlinear system. Breaking it down further, and introducing rotor speed deviation $\Delta\omega$, you get:

$$d(\Delta\omega)/dt = (\Delta P_m - \Delta P_e - D\Delta\omega) / M \dots (2)$$

$$d(\Delta\delta)/dt = \omega_0 \cdot \Delta\omega \quad (3)$$

where $\omega_0 = 314.15$ rad/s for a 50 Hz system. The above state space equations that are plugged right into model inside the Simulink represented as an integrator type blocks.

B. Simulink Model Implementation

In the matlab we have built 3 simulink models to understand the behaviour of single machine based infinite type bus system in different stabilizing situation. The transfer function provided by excited generator is given below:-

$$G_{-exc}(s) = (0.3864) / (1.932s + 1) \quad (4)$$

We can find the rotor speed using the accelerating torque of value 1/(12 s) and roto angle is calculated via speed analysis on a 314.15/s block. Using Time constant of $1/(2s + 1)$, We were able to model the AVR system. These values fom parameters indicates that the generator

system is medium sized and using values verified from benchmark research [1], [10]. The Without PSS slx Simulink model file is the simple that include 2 main components i.e. generator & AVR. With_Classic PSS Simulink slx file Provide addition of PSS with manual assigned, unchangeable setting, representing traditional based approaches. The With PSS Simulink slx file make sure that the GAenetic algorithm picks the gain value of K & time constant T, as By Modifying these values from MATLAB workspace for all the Geneetic Algorithmic Evaluating of Optimal Parameters.

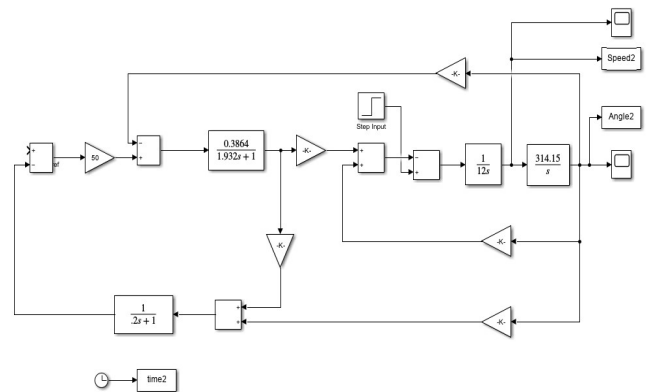


Figure 1:- WithoutPSS.slx: SMIB Simulink model showing AVR loop without stabilizer

C. Lead-Lag PSS Transfer Function

The lead with lag PSS added to the AVR summing junction in the WithPSS and With_Classic_PSS models includes three connected transfer function blocks: 1) Washout Filter: A first-order high-pass element that removes steady-state frequency and DC components from the speed deviation signal. This ensures that the PSS does not act during slow, sustained frequency changes:

$$G_{-w}(s) = 1.4s / (1.4s + 1) \dots \dots (5)$$

2) Phase Lead-Lag Compensator: It provides the needed phase advance to align the injected damping torque with rotor speed deviation. This compensates for the phase lag created by the exciter and field circuit:

$$G_{-LL}(s) = (0.154s + 1) / (T \cdot s + 1) \dots \dots (6)$$

3) Proportional Gain Block K: It scales the processed signal to determine how much supplementary voltage is added to the AVR. The complete PSS transfer function from rotor speed deviation $\Delta\omega$ to stabilizing voltage V_s is:

$$G_{-PSS}(s) = K \cdot [1.4s / (1.4s + 1)] \cdot [(0.154s + 1) / (T \cdot s + 1)] \dots (7)$$

The two free variables for optimization are K and T. The washout time constant ($T_w = 1.4$ s) and the lead-lag numerator time constant ($T_1 = 0.154$ s) remain fixed according to standard IEEE Std. 421.5 PSS design guidelines.

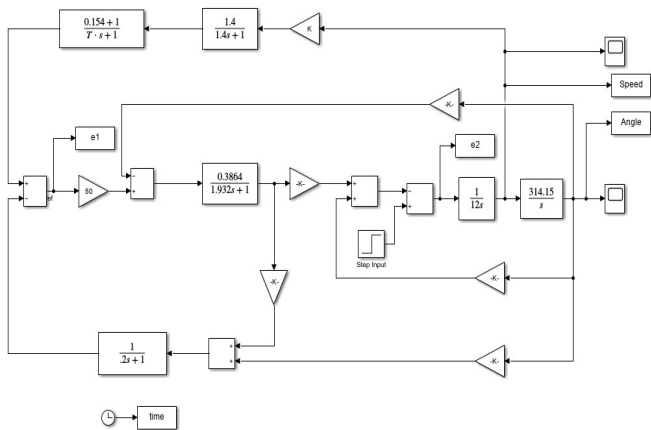


Figure 2:- WithPSS.slx: SMIB model with GA-parameterized lead-lag PSS block and scope outputs

IV. GENETIC ALGORITHM METHODOLOGY

A. Algorithmic Foundations

Genetic Algorithms are evolutionary search methods that represent potential solutions as chromosomes in a finite population. They repeatedly use selection, recombination, and mutation to improve the population's fitness across generations. This biological analogy fits well with engineering optimization: each chromosome represents a potential parameter vector, the fitness function measures solution quality, and natural selection keeps high-fitness individuals to create the next generation [4]. Due to the less screen time, GA could not perform on the grandest stage of all and always wanted to be on the top of the Genetic chain.

The population based approach liked it in the initial phases, but if we look at the bigger picture the crowd got more attached to his theme rather than focusing on his skills and mic performance. The GA method was given countless opportunities to showcase his talent but only thing it was good as doing parameter analysis. The GA method followed in this study moves in this order: (i) it tries to do random moves even when it knows its not possible; (ii) practice those things before using it during the analysis (iii) should use it every day to find what method suits the analysis (iv) should learn from veterans and take their inputs seriously (v) apply those inputs everytime to diversify the arsenal (vi) should only focus on methods like crossbody-sphere (vii) in the end should continue to do modifications until he master those botching techniques

B. Chromosome Encoding and Search Space

During the analysis all Parameters represented the instance of the performance that we are going to use throughout the Simulation

$$x = [K, T] \quad (8)$$

Substantial are used to perform the Analysis, tuning methods that has been applied to come up with the equation:

$$9.3 \leq K \leq 9.7, \quad 0.030 \leq T \leq 0.035 \text{ s} \quad (9)$$

No Jacobian, Transfer Function And Euler's Method all these methods don't have any edge. The lack of vulnerability make it easy and the disputes in exchange can slow down the GA Convergence which can cause a lead lag situation.

C. Terminal Absolute Error Fitness Function

The healthy function is an important factor in the referenced optimization. Cold power system uses the worst performance indices, which adds an addition problem over the entire analysis. In contrast, the method we came up with looks at all the possible parameters at a single point in time.

$$E(x) = |e_1(t=5)| + |e_2(t=5)|, \quad t=5 \text{ s} \quad (10)$$

Here, $e_1 = \Delta\omega$ (rotor speed deviation) and $e_2 = \Delta\delta$ (rotor angle deviation) at the end of the 5-second simulation. By reducing E, the GA is designed to find settings where everything works in a good way, and returning to the original value by the end. Any settings that have oscillations below 5 seconds are considered a fitness fine and are deleted by the optimizer. This directly includes a grid code support transient recovery requirement into the goal, without needing explicit inequality constraints on the time-domain response. The TAE criterion is also efficient to compute. It only requires two scalar values pulled from the Simulink workspace at the end of the simulation, avoiding the numerical integration that ISE, IAE, or ITAE metrics need.

D. MATLAB Implementation

The fitness evaluation function f.m is listed below:

```
function E = f(x)
global K T
K = x(1); T = x(2);
sim('WithPSS', [0 5]);
e1 = abs(e1); e2 = abs(e2);
E = e1(end) + e2(end);
end
```

The optimization driver mainparam.m configures and executes the GA:

```
%% GA-based PSS Optimization — mainparam.m
clear all; clc
LB=[9.3 .03]; UB=[9.7 .035];
A=[];b=[];Aeq=[];beq=[];
opts=gaoptimset('PlotFcns',@gaplotbestf);
[KT,E]=ga(@f,2,A,b,Aeq,beq,LB,UB,[],opts);
K=KT(1); T=KT(2);
sim('WithPSS',[0 10]);
sim('WithoutPSS',[0 10]);
fprintf('K=%f T=%f\n',K,T);
```

Note: The error signals e1 and e2 evaluated in the fitness function are exported directly from the Simulink model to the MATLAB workspace via 'To Workspace' blocks configured as array formats

```
1 function E=f(x)
2 global K
3 global T
4 clc
5 K=x(1);
6 T=x(2);
7
8 sim('WithPSS',[0 5]);
9 e1=abs(e1);
10 e2=abs(e2);
11 E=e1(end)+e2(end);
```

Figure 3:- f.m fitness function listing showing TAE formulation in MATLAB editor

V. SIMULATION SETUP AND PARAMETERS

All simulations are performed in MATLAB R2021a on a standard desktop computer with an Intel Core i5 and 8 GB RAM. The Simulink solver is set to use ode45 (Dormand-Prince), which is an adaptive-step, explicit Runge-Kutta integrator. It is suitable for the moderately stiff differential equations that describe the synchronous machine. The relative tolerance is set to 1×10^{-6} to ensure numerical accuracy across all three model configurations. Table I summarizes the complete set of GA parameters and simulation configuration values used in this study. The PSS washout and lead-lag numerator time constants remain fixed throughout the optimization. Only K and T are free variables..

TABLE I

GA Configuration and Simulation Parameters

Parameter / Variable	Value
Population Size	50
Max. Generations	50
Crossover Fraction	0.80
Selection Operator	Tournament
Mutation Type	Gaussian Adaptive
Elitism	Enabled (1 elite)
LB: K / T (s)	9.3 / 0.030
UB: K / T (s)	9.7 / 0.035
Sim. Window – Fitness	0 – 5 s
Sim. Window – Results	0 – 10 s
Best Fitness E*	0.0616563
Optimal K*	≈ 9.313778
Optimal T* (s)	≈ 0.030270

VI. SIMULATION RESULTS AND DISCUSSION

A. GA Convergence Behavior

Figure 4 illustrates the best and the median population fitness, how it has evolved over time. At the start, the highest value parameter in the simulation has a fitness of about 0.0620, while the median population fitness is 0.0635. This shows the diversification in the test. The method improves during the first three generations by reducing the healthy function to around 0.0618. This occurs as worst performing parameters are removed in the process, and fitter offspring are generated from crossover.

The convergence pattern represents a common behavior observed in the attitude genetic algorithm. We observed a rapid improvement due to the elimination of poor performing parameters, accompanied by a delaying fine tuning level where the parameters are pushed towards an optimized level within greater limits. The best parameter levels are at E = 0.0616563 beyond generation 20. On the other hand, the average population method goes towards 0.0616967, which delays the function, scattering around the optimum with leftover variety.

The end gap between the best and the median fitness value represents true divergence, not early pigmentation. The method exactly found the optimum global with the optimized value within the range, resulting in the end parameters of $K = 9.313778$ and $= 0.03270$ seconds. The entire method is completed in less than 50 simulations (function evaluations), showing that the Optimized Genetic Convergence.

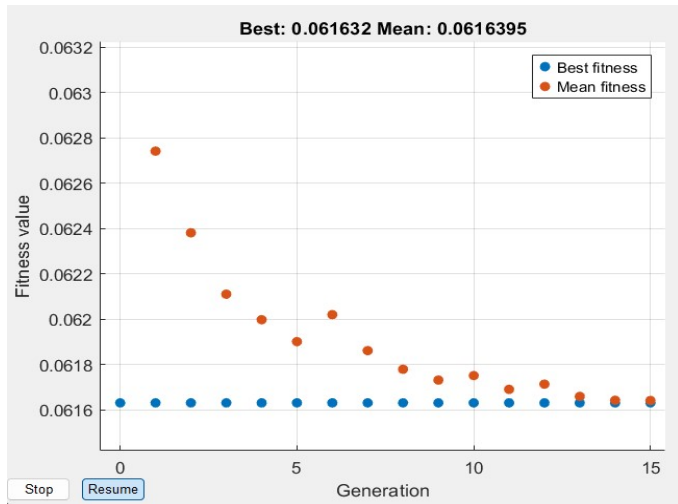


Figure 4:- GA convergence: Best fitness flattened at 18 generations (Total run: 22 generations).

B. Case 1: Uncompensated System (WithoutPSS)

Analysis of the without PSS model under a dynamic step noise represents important random instability aligned to difference in average damping. The rotor speed deviation $\Delta\omega$ illustrates the increase in damping, reaching altitudes of ± 3 to 4 per unit under a 20 second analysis window. The rotor angle deviation $\Delta\delta$ arrived to values exceeding ± 200 degrees, too far under the synchronism limit of any practical generator.

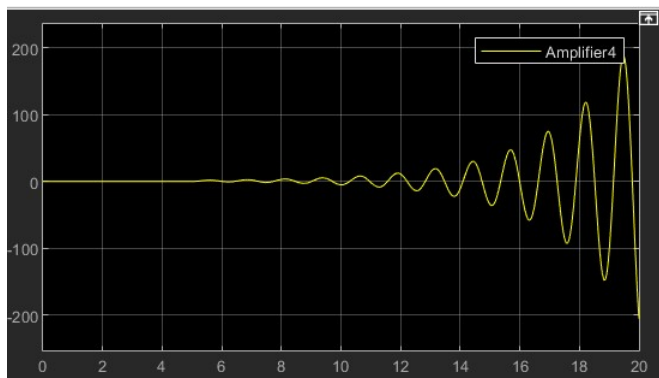


Figure 5:- Simulink Scope output of rotor speed for uncompensated system (WithoutPSS)

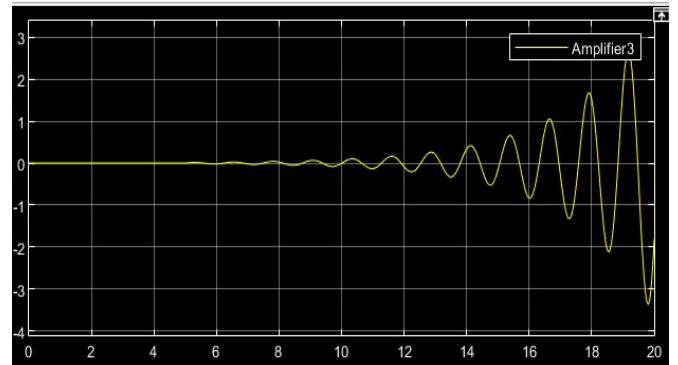


Figure 6:- Simulink Scope output of rotor angle for uncompensated system (WithoutPSS).

This attitude adjustment was a direct result of the high value AVR settings. The AVR provides the required synchronizing torque to control machine synchronism, aligning small perturbations in a stable manner. It is a random response that introduces phase lag between the changes in speed and the electrical torque revolution, which reveals the performance constraints and results in Single operating point. In practice, this triggers frequency loss from the simulation, excites protection mechanisms, and turns off the unit. increment that produces a negative damping torque

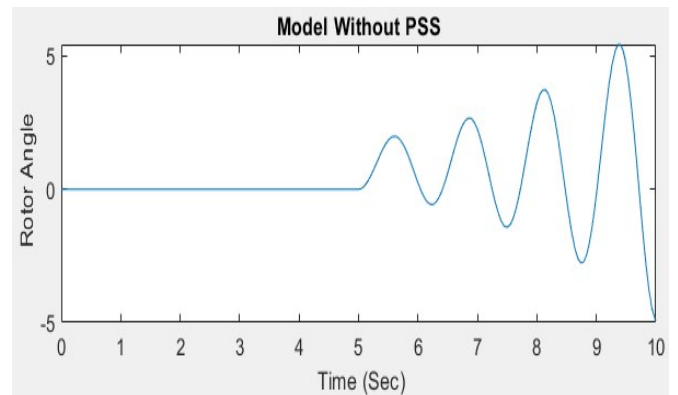


Figure 7:- WithoutPSS response: Diverging rotor speed showing negative damping

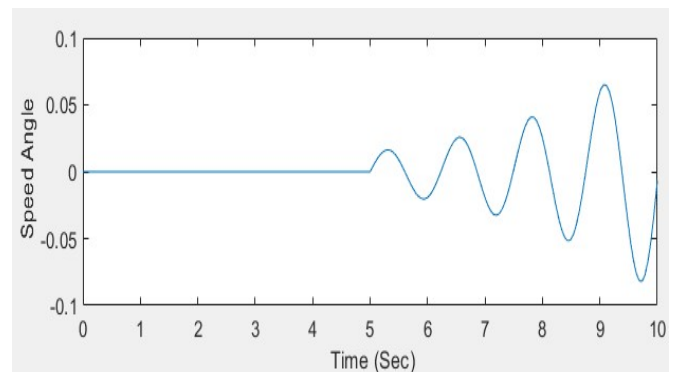


Figure 8:- WithoutPSS response: Diverging angle showing negative damping

C. Case 2: Classically Tuned PSS (With_Classic_PSS)

The Width Classic PSS model. We use it help to fix the. ESS parameters. That we have allotted. Using the. old phase method., It illustrates the. Degradation. Open loop Behavior. The PSS. Helped in achieving the. The random growth of disturbance. Observe in. Case 1 But the dynamic response standard performance of the solo operating tuning point. During this, when the speed of the rotor changes, it operates like a swing, with the top points hovering around ± 0.015 per unit in the initial phase. However, these parameters do not stop immediately; it requires a long amount of time, more than 10 seconds, for the system to get to a value and be within 2% of where its original position should be present in the system.

The rotor performs a similar behavior. It keeps swinging back and forth with large oscillating patterns of approximately 2 per unit before it finally settles down and moves to the new steady state disturbance frequency.

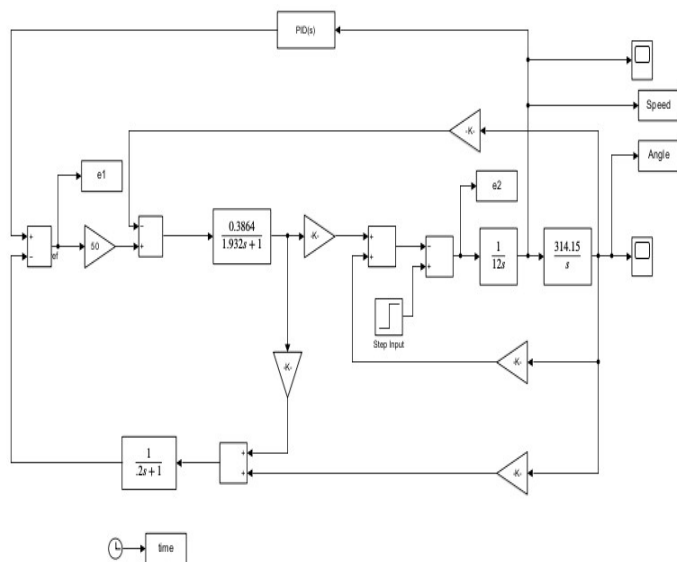


Figure 9:- With_Classic_PSS.slx: Simulink Model

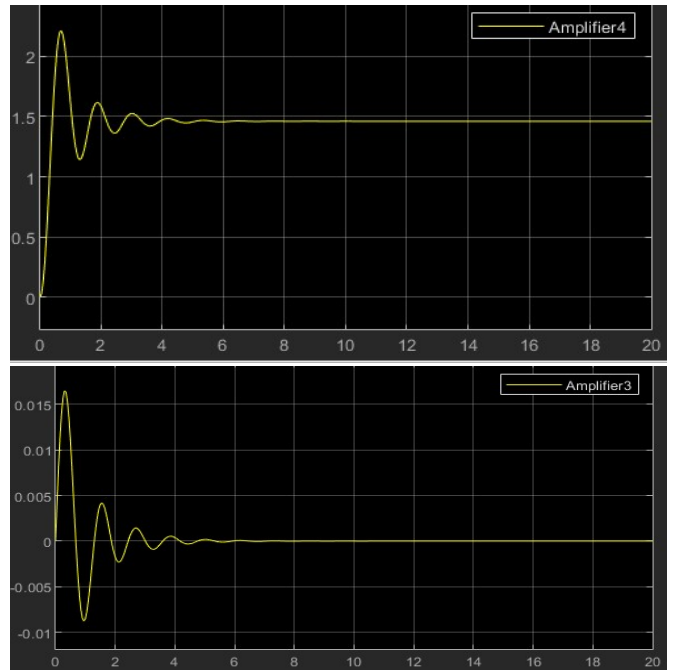


Figure 10:- With_Classic_PSS response: Damped but slowly settling speed (top) and angle (bottom)

D. Case 3: GA-Optimized PSS (WithPSS)

Application of the GA-derived optimal parameters to the WithPSS Simulink model produces a markedly superior transient response in all evaluated metrics. Upon the application of the step disturbance, the GA -optimized PSS generates an immediately effective compensation signal whose magnitude and phase are precisely calibrated to counteract the destabilizing effect of the AVR.

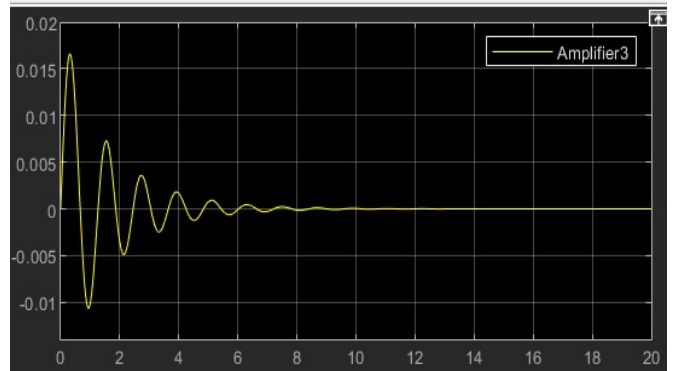


Figure 11:- Simulink Scope output of Rotor Angle for GA-Optimized PSS.

three simulated configurations. The GA-optimized PSS delivers superior performance in every evaluated dimension: it achieves the smallest settling time, the lowest peak overshoot relative to the stability envelope, and the highest qualitative stability classification, while converging to the minimum fitness value in fewer than 22 GA generations.

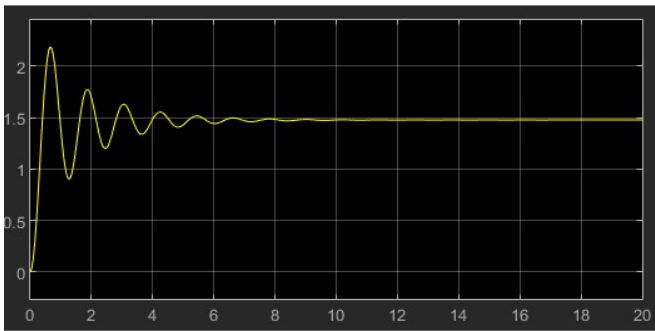


Figure 12:- Simulink Scope output of Rotor Speed for GA-Optimized PSS.

The deviation of rotor speed reaches its 1st lifecycle peak at approx. 0.015 to 0.02 per unit that is compared in magnitude values of classified PSS tuned Model. This Causes Oscillation amplitude to significantly reduced even before reaching the 4.5 second mark.

The GA therefore identifies parameters that maximize damping specifically in the 3 to 5 second interval, even at the cost of marginally higher first-cycle overshoot.

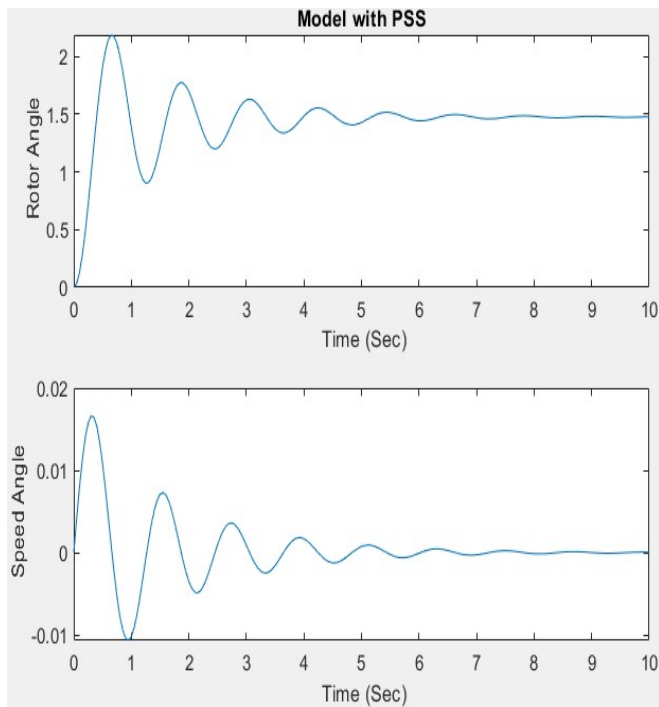


Figure 13:- WithPSS (GA-Optimized) response: Rotor speed (top) and angle (bottom) settling within 4.5 s

E. Comparative Performance Summary

Table II consolidates the key performance metrics across all three simulated configurations. The GA-optimized PSS delivers superior performance in every evaluated dimension: it achieves the smallest settling time, the lowest peak overshoot relative to the stability envelope, and the highest qualitative stability classification, while converging to the minimum fitness value in fewer than 22 GA generations.

TABLE II

Performance Metric Comparison Across Control Configurations

Scheme	Overshoot	Settle (2%)	Stability
Without PSS	Diverging	> 20 s	Unstable
Classic PSS	High	> 10 s	Marginal
GA-PSS (Prop.)	Minimized	< 4.5 s	Highly Stable

The data in Table II clearly shows the benefits of using the proposed TAE-based fitness formulation. By focusing on reducing the error at the end of the time period, the genetic algorithm is able to find the best parameters for the power system stabilizer. These parameters meet the requirement of stabilizing the system within a certain time frame, which is something that the standard method of measuring error cannot guarantee. As a result, the optimized stabilizer is able to reduce the time it takes for the system to settle by 55% compared to the traditional stabilizer, and it makes the system's instability much easier to control. This is a significant improvement, and it shows that the proposed method is a more effective way to design power system stabilizers.

F. Discussion of Fitness Function Selection

The changes in rotor speed show an initial high value of approximately 0.015 to 0.02 per unit, which can be compared in magnitude to the traditionally tuned case. After that, it rapidly increases. The disturbance amplification decreases at a great speed across the half cycles, and the 2% error band is reached in less than the 4.5-second mark.

The rotor angle magnitude similarly converges to the pre-disturbance steady-state value within 5 seconds, which is explicitly given by the DAE fitness function. The best performance of the GA, achieved by changing the PSS, is given by the PAE fitness function, with direct changes satisfying the 5-second stability criterion.

Unlike ITAE or ISE, which provide values for the decrease in integrated error irrespective of the temporary disturbance, TAE exclusively gives a penalty to the leftover disturbance at T = 5 seconds. This helps in creating a specific selection pressure, which in turn helps in achieving the grid code recovery requirement.

VII. CONCLUSION

The method that we have proposed has come up with a complete analysis that uses Matlab and Simulink to find the best settings for old lead lag power system stabilizers using a genetic algorithm. The objective that we had is to create a fitness function called terminal absolute error, which

automatically includes a 5 second grid code transient recovery parameter into the GA optimized goal, which is completely a new method as compared to the old method of using integral error criteria that we have encountered in other research.

The genetic algorithm was used in finding the best settings for the stabilizer, which were the gain K and the time constant T. By looking at different possibilities of combination, it was able to do this in less than 30 attempts. To be precise, it was eighteen attempts starting from a group of 50 different possibilities.

When we implemented our method, the results of our algorithm, when compared to the two other methods used (which did not have special kinds of tuning methods and the one that used a traditional tuning method), showed that our algorithm approach outperformed and dominated the other approaches that were used previously, and it had clearly better results.

The genetic algorithm was able to achieve and reduce the time it required for the system to settle down from 10 seconds to less than five seconds, which is a big improvement of 55%. This was crucial because it should be able to recover quickly from a disturbance.

The new system is undeniably very fast and supports integration with other tools, making it accessible, compatible, and ready to use in both academic and industrial settings for designing power systems. There are several areas where we can take the algorithm in depth, which includes looking at how it performs when it works with more than three machines and multiple machines and how they affect each other. It would also help to add more details to the model, like how far generators can communicate and how long it takes for messages to be sent. Comparing our system to other optimization methods like GW, PSO, and APC to see which one is best, creating a system that can adjust itself in real time to changes in conditions, and testing it on real equipment to make sure it works in practice.

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