# Analysis of Power System Stability in Infinite Bus System using Firefly Algorithm

Vinod Thakur[1], Prof. Sourabh Gupta[2]
[1]*Mtech scholar, Technocrats Institute of Technology & Science, Bhopal (M.P.)*
[2]*Associate professor, Technocrats Institute of Technology & Science, Bhopal (M.P.)*

***Abstract*—A significant challenge in power system operation is addressing small signal instability caused by inadequate damping. To mitigate this issue, Power System Stabilizers (PSS) are employed as auxiliary controllers to introduce additional damping into the system. Historically, stability concerns arose from transmitting power from remote generating stations to load centers via extended transmission lines. The use of slow exciters and non-continuous voltage regulators often limited power transfer capacity due to steady-state and transient rotor angle variability, resulting from insufficient synchronizing torque.**

***Index Terms*—simplified single machine infinite (SMIB), MATLAB/SIMULINK, PID controller, power system stabilizer (PSS), Power stability, Power quality**

## I. INTRODUCTION

Power System Stabilizers (PSS) play a crucial role in mitigating electromechanical oscillations, thereby enhancing power system stability through their supplementary excitation mechanism. As the demand for efficient and reliable electricity transmission and generation continues to grow, power systems have expanded to cover vast areas, incorporating numerous transmission lines, synchronous generators, loads, and various controllers. The stability of a power system is defined by its ability to counteract disturbing forces with equal or greater restoring forces, maintaining equilibrium.

The power industry has undergone significant upgrades to provide affordable, efficient, and reliable electricity to an increasing number of consumers. However, this growth has led to increased complexity in power systems, particularly as they become more interconnected. Rising load demands, driven by a growing user base, have further exacerbated the need for stability and reliability in power systems. Since stability issues can limit the system's transfer capability, ensuring the stability and reliability of power systems has become an economic imperative.

In response, researchers and authorities have been working tirelessly to develop simple, effective, and economical strategies for stabilizing power systems, which remains a top priority.

## II. PROBLEM IDENTIFICATION & THEORETICAL ANALYSIS

### A. Problem Identification

Maintaining power system stability is crucial for ensuring uninterrupted power supply. It refers to the ability of a power system to operate in a state of equilibrium under normal conditions and recover to an acceptable state after experiencing a disturbance. Power system instability can manifest in various situations, depending on the system's configuration and operating mode.

One critical stability concern is maintaining synchronism, particularly since power systems rely heavily on synchronous machines. This aspect is influenced by the dynamics of generator rotor angles and power-angle relationships. Another uncertainty issue that may arise is voltage collapse, which is primarily related to load behavior rather than the synchronous speed of generators.

### B. Operating Principle of PSS

The primary function of a Power System Stabilizer (PSS) is to provide damping to generator rotor oscillations by modulating its excitation through auxiliary stabilizing signals. Building upon the Automatic Voltage Regulator (AVR), PSS utilizes power deviation, frequency deviation, or speed deviation as supplementary control signals. By introducing an additional torque aligned with the rotational speed deviation, PSS enhances low-frequency oscillation damping, thereby improving the dynamic stability of the power system. A detailed torque analysis illustrating the interaction between AVR and PSS is presented in Figure 1 below.

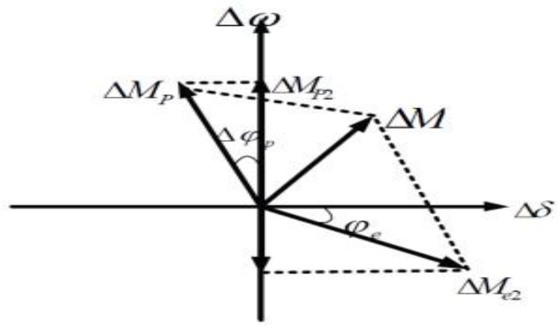

Figure 1: Torque analysis between AVR and PSS

Under specific conditions, such as high impedance or heavy load, the additional torque ΔMe2 provided by the Automatic Voltage Regulator (AVR) can lag the negative feedback voltage (-ΔVt) by an angle φx. This phase shift generates a positive synchronizing torque component, but unfortunately, also introduces a negative damping torque component that can reduce low-frequency oscillation damping.

To counteract this effect, a Power System Stabilizer (PSS) utilizes the speed signal (Δω) as an input, producing a positive damping torque element, ΔMp2. By combining the synchronizing torque with the damping torque, the PSS enhances the system's ability to dampen oscillations.

A detailed structure diagram of the Power System Stabilizer (PSS) is presented in Figure 2, illustrating its role in improving power system stability.

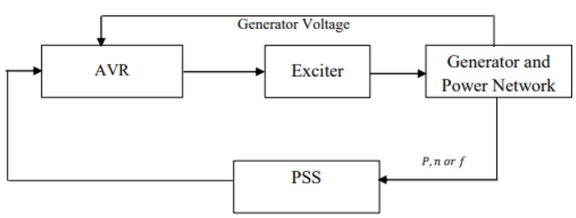


Figure 2: The structure diagram of power system stabilizer (PSS)

## III. PROPOSED METHODOLOGY

### A. Single Machine Infinite Bus System

The simplicity of analyzing power system dynamics can be achieved by focusing on a single machine or system. This is where the Single Machine Infinite Bus (SMIB) system offers a distinct advantage, simplifying the complexities associated with multimachine power systems.

As illustrated in Figure 3: the SMIB system consists of a single machine connected to an infinite bus through a transmission line. This line is characterized by its inductive reactance (xe) and resistance (re). By representing a larger power grid as an infinite bus, the SMIB model provides a straightforward approach to analyzing the dynamic behavior of a single machine within the context of a broader power system.

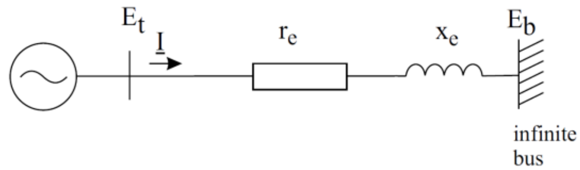


Figure 3: Single machine infinite bus system

### B. Firefly Algorithm

Fireflies, also known as lightning bugs, are bioluminescent insects that emit short, rhythmic flashes of light. This unique ability is used for various purposes, including attracting mates through communication, luring potential prey, and serving as a warning signal to deter predators. Interestingly, the intensity of the flash plays a crucial role in guiding other fireflies to move towards the source of the light, facilitating social interactions and mating behaviors.

The Firefly Algorithm is based on three idealized rules that mimic the behavior of fireflies:

1. Fireflies are unisex and attracted to each other, regardless of their sex.
2. The attractiveness of a firefly is directly proportional to its brightness. Consequently, a less bright firefly will be drawn to a brighter one.
3. The brightness of a firefly is determined by its objective function value, which serves as a measure of its fitness or quality.

These simple yet intuitive rules form the foundation of the Firefly Algorithm, enabling it to efficiently search for optimal solutions in complex problem spaces.

### C. Structure of Firefly Algorithm

In the Firefly Algorithm, two key variables are light intensity and attractiveness. Fireflies are drawn to those with brighter flashes. Attractiveness is directly tied to light intensity, which decreases with distance (r) from the source. As distance increases, light intensity and attractiveness dwindle.

$I(r) = I0e - \gamma r$ 2

I = light intensity,

$I0$ = light intensity at initial or original light intensity,

$\gamma$ = the light absorption coefficient
r = distance between firefly i and j
Attractiveness is proportionally to the light intensity seen by another fireflies, thus attractiveness is β
$\beta = \beta 0e - \gamma r$ 2
$\beta 0$= Attractiveness at r is 0

```
Objective function f(x),        x = (x_1,...,x_d)^T
Generate initial population of fireflies x_i (i = 1,2,...,n)
Light intensity I_i at x_i is determined by f(x_i)
Define light absorption coefficient γ
while (t < MaxGeneration)
for i = 1:n all n fireflies
   for j = 1:i all n fireflies
      if (Ij > Ii), Move firefly i towards j in d-dimension; end if
      Attractiveness varies with distance r via exp[−γr]
      Evaluate new solutions and update light intensity
   end for j
end for i
Rank the fireflies and find the current best
end while
Postprocess results and visualization
```

Figure 4: Pseudo code for Firefly Algorithm

The distance between two fireflies can define using Cartesian distance
$rij = |xi - xj| = \sqrt{\sum} (xi, k - xj, k)\ d\ 2\ k{=}1$
Firefly i is attracted toward the more attractive firefly j, the movement is defined as:
$\Delta xi = \beta 0e - \gamma rij\ 2\ (xj\ t - xi\ t) + \alpha\varepsilon i, xi\ t{+}1 + \Delta xi$
the first term is for attraction, $\gamma$ is the limitation when the value is tended to zero or too large. If $\gamma$ approaching zero ($\gamma \rightarrow 0$), the attractiveness and brightness become constant, $\beta = \beta 0$
PID controllers have proven to be effective in numerous control applications, thanks to their straightforward design and versatility. As a result, PID controllers have become a ubiquitous solution for regulating a wide range of industrial processes. However, the performance of control systems can be compromised by numerator dynamics, specifically the presence of a zero in the process transfer function. Many industrial processes exhibit complex dynamics, often modeled as second-order systems with time delays and zeros, which can pose challenges for traditional PID control strategies.

## IV. SIMULATION AND RESULTS

The Simulink model for PSS consists two lead-leg compensators preceded by washout controller. The five-time constants are optimized Particle Swarm Optimization and Genetic Algorithm for performance improvement.


Figure 5: Simulink model of PSS

The model above is the Philip Heffron model of single machine infinite bus system. All electrical and mechanical parts are modelled here as standard transfer functions.

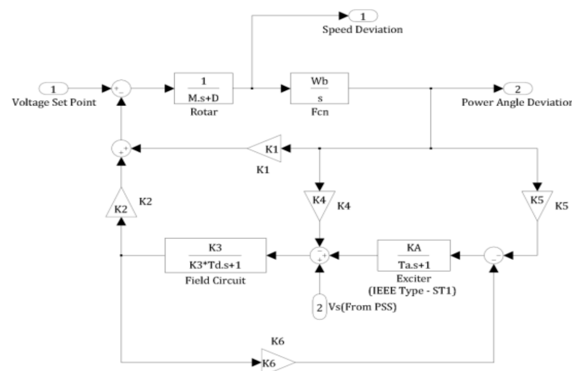


Figure 6: Simulink model of SMIB

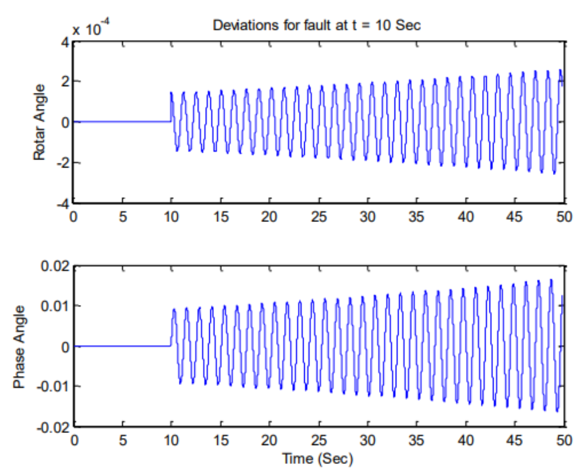


Figure 7: Speed deviation in SMIB for rotor angle and phase angle without any controller

When a fault occurs in the SMIB system at t = 10 Sec, Rotor start deviation and if no control is there than oscillation become higher as shown above. Following are the graphs for the rotor angle and phase angle deviations for PID and PSS controllers.

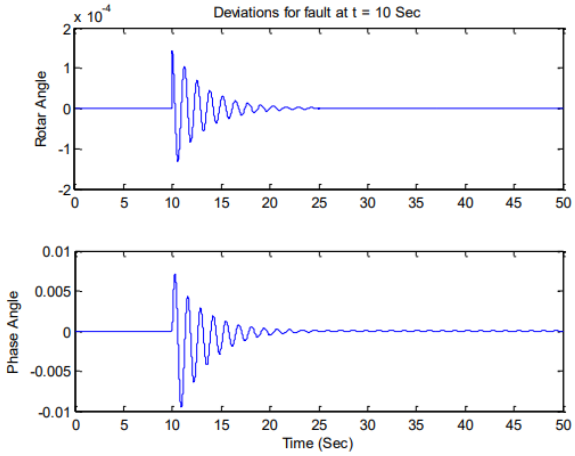


Figure 8: Speed deviation in SMIB-PID for rotor angle and phase angle

## V. CONCLUSION

The robust tuning of Power System Stabilizer (PSS) parameters is formulated as an optimization problem, leveraging a time-domain based objective function. This optimization problem is effectively solved using the Firefly Algorithm technique. The proposed Firefly-based PSS is tested on a Single Machine Infinite Bus (SMIB) power system, demonstrating superior performance compared to the conventional SMIB-PSS system.

Notably, the design process can be performed offline or online, catering to time-varying or time-dependent systems. The efficiency of the Firefly Algorithm in achieving global optimization within a single run is crucial, as it minimizes computational time.

The application of this developed method to a representative problem showcases its effectiveness in meeting the desired design objectives, particularly when compared to traditional implementation methods.

## REFERENCES

[1] Rashmi Vikal, Balwinder Singh Surjan, “Variable Structure Control Based Power System Stabilizer for Single Machine Infinite Bus System Using Particle Swarm Optimization”, International Journal of Computer and Electrical Engineering, Vol. 5, No. 5, October 2013.

[2] Goodarz Ghanavati, Paul D. H. Hines, Taras Lakoba, Eduardo Cotilla-Sanchez, “Calculation of the Autocorrelation Function of the Stochastic Single Machine Infinite Bus System”, Proc. of the North American Power Symposium, August 2013.

[3] S. Jalilzadeh, M. Darabian, M. Azari, “Power System Stability Improvement via TCSC Controller Employing a Multi-objective Strength Pareto Evolutionary Algorithm Approach”, Journal of Operation and Automation in Power Engineering, Vol. 1, No. 1, March 2013.

[4] D. K. Sambariya, Rajendra Prasad, “Differentiation method based Stable Reduced Model of Single Machine Infinite Bus System with Power System Stabilizer”, International Journal of Applied Engineering Research, ISSN 0973- 4562, Vol. 7, No. 11, November 2012.

[5] M. A. Mahmud, H. R. Pota, M.J. Hossain, “Full-order nonlinear observer-based excitation controller design for interconnected power systems via exact linearization approach”, ELSEVIER, Volume 41, Issue 1, Pages 54–62, October 2012.

[6] Balwinder Singh Surjan, Ruchira Garg, “Power System Stabilizer Controller Design for SMIB Stability Study”, International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249–8958, Volume-2, Issue-1, October 2012.

[7] Venkatesh Gudla, P. Kanta Rao, “Improvement of Dynamic Stability of a Single Machine Infinite-Bus Power System using Fuzzy Logic based Power System Stabilizer”, International Journal of Engineering Research and Development ISSN: 2278-800X, Volume 4, Issue 5, PP. 60-70, October 2012.

[8] M. Suguna, “Damping of Low- frequency Oscillations Using Swarm Optimized Controller for SMIB System”, International Journal of Engineering and Innovative Technology (IJEIT), Volume 1, Issue 4, April 2012