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Performance Analysis of GWO, GA and PSO Optimized FOPID and PSS for SMIB System

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Abstract: The designing of power transmission network is a difficult task due to the complexity of power system. Due to complexity in the power system there is always a loss of the stability due to the fault. Whenever a fault is intercepted in system, the whole system goes to severe transients. These transients cause oscillation in phase angle which leads poor power quality. The nature of oscillation is increasing instead being sustained, which leads system failure in form of generator damage. To reduce and eliminate the unstable oscillations one needs to use a stabilizer which can generate a perfect compensatory signal in order to minimize the harmonics generated due to instability. This paper presents a Power System stabilizer to reduce oscillations due to small signal disturbance. Additionally, a hybrid approach is proposed using FOPID stabilizer with the PSS connected SMIB. Genetic algorithm (GA), Particle swarm optimization (PSO) and Grey Wolf Optimization (GWO) are used for the parameter tuning of the stabilizer. Reason behind the use of GA, PSO and GWO instead of conventional methods is that it search the parameter heuristically, which leads better results. The efficiency of proposed approach is observed by rotor angle and power angle deviations in the SMIB system.

Keywords: Flexible AC Transmission System (FACTS), Genetically Algorithm (GA), Grey Wolf Optimization (GWO), Particle swarm optimization (PSO), Power system Stabilizer (PSS), Single Machine Infinite Bus (SMIB).

1. INTRODUCTION

A power plant contains several synchronous machines (turbo-generators) which are designed to transform the mechanical power of turbines into power (Production phase), the latter will be transmitted by means of transport distributed to potential consumers (domestic or industrial). These consumers of electrical energy always require continuity of service with system stability to satisfy electro-technicians are always looking for methods and to ensure a stable, high-quality, continuous production of electricity, and without any interruption. [1]

The problem of robustness of stability is posed in a serious way to guarantee a good operation of the Electro-Energetic Systems, and to overcome the problem of oscillations electromechanical systems by improving the damping of the system (stability), for these purposes signals stabilizers are introduced into the excitation system via its voltage [2]. These stabilizing signals will produce torques in phase with the speed variation of the generator for compensating for the phase delay introduced by the excitation system. The stabilizers[3] (Power System Stabilizers, PSSs), thanks to their advantages in terms of cost economic efficiency and efficiency, are the usual means, not only to eliminate the negative effects Voltage regulators, but also for damping electromechanical oscillations and Stability of the system. These conventional stabilizers (often made in PI or PID) have the main disadvantage [4] poor adaptation to changes in system parameters and variations of the operating conditions of the system to be controlled (uncertainties).

To ensure the stability of the electro-energy system in the presence of various variations, use advanced control techniques such as: optimal, adaptive and robust rather than the conventional ones. One of the main characteristics currently required of regulators is the robustness of stability is the ability to maintain stability in the presence of variations (Or also nonparametric) parameters, thus called uncertainties or problems uncertain. The investigation of adaptive control algorithms (Fuzzy logic, Neurons) has been widely carried out [5].Recently, optimal and robust control algorithms.

All these algorithms assume knowledge of a system model or intervals on uncertainties. For continuous power supply the stability of power system is a desirable key factor. Power system stability can be described as the attribute of a system that helps the system to maintain equilibrium under normal conditions and also retrieve the equilibrium condition under the condition of disturbance also. Various circumstances could lead to the conditions of instability in power system relying upon the mode of operation and system's configuration. Maintenance of synchronization is the major issue of concern particularly for those power systems that depend upon synchronous machines. The relationship between power and angle and the dynamics of generator angles affects the above mentioned synchronous attribute. Apart from the synchronization problem, the other issues that may be encountered are loading problems such as voltage collapse etc.

Stability can be evaluated by different methods:

A. **Stochastic Methods:** These methods use much more statistical data, different methods have been developed to carry out stochastic method to achieve the transient stability of the electrical network. A Monte Carlo approach based on probabilities and pattern recognition is developed.

B. **Evaluation of the Angular Stability to the Small Perturbations (Dynamic Stability):** The analysis of Eigen values and the modal analysis of the linearized power system are powerful tools for studying the dynamic properties of the system. These methods are techniques that are used to determine whether the system is stable or unstable. The following sections describe these techniques in detail. Which are devices based on the recent advanced in power electronics, can be modified to participate in the damping of electromechanical oscillations. FACTS systems, such as static VAR compensator (SVC), thyristor controlled series capacitor (TCSC) [6], static synchronous series compensator (SSSC) [7] are mainly placed in the power system for various reasons, Reactive power exchanges, network voltages, etc.). Additional stabilization can be added to improve stability. In addition to these main roles, FACTS can satisfy the problems of stability [8].

These systems remain very expensive to be installed solely for a reason of damping of the oscillations. Yousef et. al., [9], use LQR and LQG to design the PSS.

In the literature, several researches on heuristic techniques and artificial intelligence has been proposed and successfully implemented for dynamic stability [10, 11]. The application of genetic algorithm has also found the interest of researchers to achieve stability since last decade [12, 13]. The advantage of GAs over other optimization techniques is their independence from the complexity of the problems. In addition, it works on a population set

[14, 15]. Also, the Particle swarm optimization (PSO) technique stimulated by the movement of insects, birds and fish [16]. Particle swarms are a new class of algorithms for solving optimization problems [17].

The goal of this paper is to guarantee a maximum damping of the oscillations at low frequency by the use of the PSS, FOPID and hybrid of both. To achieve this, we propose an optimal adjustment of the parameters of the PSS and FOPID. This ensures adequate damping of the rotor oscillations and guarantees the overall stability of the system for various operating points. Based on the analysis, optimization of the parameters of the PSS and FOPID is carried out initially by means of the GA, PSO and then by the GWO. Rest of this paper is arranged as follows:

The section-two to section- four deal with the general modeling of a power system with prime focus on to the study of stability. The stability analysis is supplemented by simulation of the Heffron-Philips model in the time domain. Section five presents single machine infinite bus system (SMIB) connected with fractional order proportional-integral-derivative (FOPID) controller. Section six presents the applications of the GA, PSO and GWOto the optimization of the PSS parameters installed in the system. Section seven presents proposed hybrid approach. Section eight contains the results analysis of all the optimized approach and hybrid frame of stabilization. Finally, we conclude this paper with a conclusion and perspectives to complete this work.

2. POWER SYSTEM STABILIZER (PSS)

The electromechanical oscillations issue is resolved by accumulating to the generator a specific controller called: (Power System Stabilizer (PSS)). This controller detects the variations in rotor speed or electrical power of the generator and applies a signal adapted to the input of the voltage regulator (AVR). The generator can thus produce an additional damping torque that compensates for the negative effect of the excitation system on the oscillations.

Introduction to PSS Controllers

The additional auxiliary control of the AVR excitation system, loosely known as the PSS Stabilizer (Power System Stabilizer) has become the most common means for enhancing the damping of low frequency oscillations in power systems (i.e. improvement of dynamic and static stability).

The output power of a generator is determined by the mechanical torque. However, the latter can vary by the action of the field of excitation of the alternator. The PSS is added; it detects the variation of the electrical output power and controls the excitation so as to dampen the power oscillations rapidly [18].

A PSS incorporates the additional voltage according to the rotor speed variation in the input of the generator voltage regulator (AVR). Following are the satisfaction parameters for (AVR and PSS) [19].Initial oscillations are maintained by a huge disturbance that ensure the transient stability of the overall framework.

1. Maximize the damping of electromechanical motions related with neighborhood modes and also interregional modes without negative impacts on different modes.
2. Minimize the likelihood of adverse effects, namely:
   (a) Local instabilities in the band of desired action of the control system.
   (b) Be robust enough to enable the control system to meet its objectives for various probable operating points of the power system.

Hence, various techniques based on modern commands have been applied for the design of the PSS. It includes the optimal structure developed in [20].

Regardless of these novel control methods with various structures, power system exploiters choose the tradition al PSS advance/delay (Conventional Power System Stabilizer) because of its simple and reliable structure.

3. DIFFERENT CONFIGURATIONS OF PSS

The type of a PSS can be identified by the nature of its input signal. The most widespread are those having as input the power variation ΔP. However, recently, input signals such as Δω (variation in velocity) and/or Δ*f* (variation in frequency) have been adopted to improve the stability of the inter-zone modes in view of the ever increasing increase in interconnections in electrical networks.

The choice of the type of PSS to adopt is according to the oscillations and modes to be damped [19].

The most common type of PSS is known as the conventional PSS (or PSS advance / delay). This type has shown its great efficiency in maintaining stability at small disturbances. This PSS uses the rotor speed variation as input. It is usually composed of four blocks, Figure 1 [21]:

- An amplifier block.
- A high-pass filter block "washout filter".
- A phase compensation block.
- A limiter

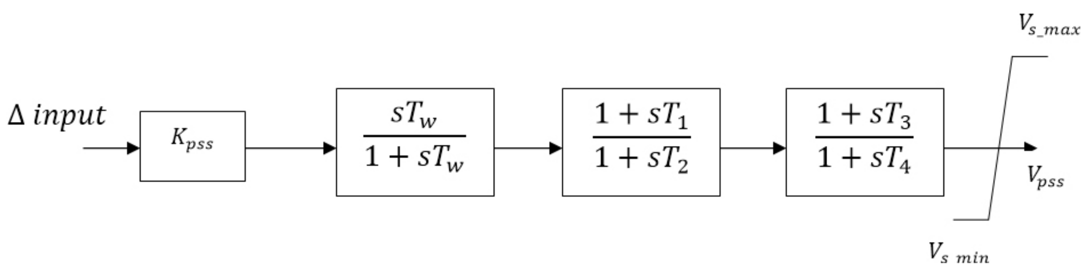

Figure 1: Conventional PSS model

Amplifier

KPSS varies from 0.01 to 50, ideally its value (KPSS) must correspond to the maximum damping. The gain should be in limit in such modes of the system degrading the stability of the other modes or the transitory stability [22].

High-Pass Filter "Washout Filter"

It eliminates very low frequency oscillations. The time constant of this filter (T_W) must be large enough to allow the signals, whose frequency is located in the useful band, to be transmitted without attenuation. However, it should not be too large to avoid leading to undesirable variations in generator voltage during the stand-by conditions.

Generally, T_W varies from 1 to 20 seconds [23]. Here it is set to 10 seconds.

Phase Compensation Block

Composed of two advance phase delays compensators as shown in Figure 1. The phase advance is used to compensate for the phase delay introduced between the electric torque of the generator and the input of the excitation system. The time constants (T_1, T_3) and delay times (T_2, T_4) are adjustable. The range of each time constant generally ranges from 0.01 to 6 seconds.

The Limiter

The PSS is a limiter to reduce its unwanted influence during transient phases. The minimum and maximum values of the limiter range from ±0.02 to 0.1 per-unit [22].

The function of the transfer of the PSS and described as follows:

$$V_{PSS} = K_{PSS} \frac{sT_w}{1+sT_w} \frac{(1+sT_1)}{(1+sT_2)} \frac{(1+sT_3)}{(1+sT_4)} \Delta\text{input} \tag{1}$$

where,

V_{PSS}: Output signal of the corrector

K_{PSS}: Gain of the corrector

T_w = Time constant of the high pass filter

T_1, T_2, T_3, T_4: Time Constant delay

Δinput: Correction input signal

4. SETTING PSS PARAMETERS

A. Phase Compensation Method

Consider a normal framework containing a generator associated to an infinite set of bars. To explain the adjustment of the PSS parameters by the phase compensation method, Figure 2.

The linear model of this system can be graphically illustrated by the Heffron-Philips representation, as shown in Figure 3.

The terms K_1, ..., K_6 are the linearization constants [24].

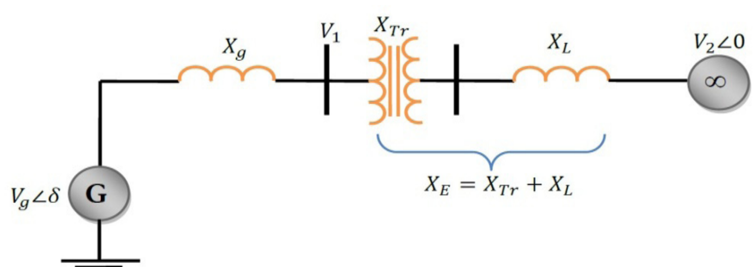

Figure 2: Synchronous Generator Connected to a Bus [24]

The transfer function PM(s) and the phase delay of the electrical loop can be derived from the Heffron-Philips model. They are given by the following two relations:

$$PM(s) = \left. \frac{K_a K_3 K_2}{(1+sT_a)(1+sT_{d_0}K_3) + K_a K_3 K_6} \right|_{s=\lambda=\sigma+j\omega} \tag{2}$$

$$phi_{PM} = PM(s)|_{s=\lambda=\sigma+j\omega} \tag{3}$$

For simplicity, we consider that the parameters to be adjusted of the PSS are the gain K_{PSS} and time constants T_1 and T_3 (where $T_1 = T_3$); the other parameters are set (where $T_2 = T_4$).

Thus, the transfer function of PSS can be rewritten as follows:

$$G_{PSS}(s) = K_{PSS} \frac{sT_w}{1+sT_w}\left(\frac{1+sT_1}{1+sT_2}\right)^2 \tag{4}$$

Since the phase advance of the PSS (phi_{PM}) is equal to the phase phi_{PM}, the time constant T_1 is given, any calculation made by the following relation:

$$T_1 = T_3 = \frac{\tan(\beta)}{\omega - \sigma\,.\tan(\beta)} \tag{5}$$

with,

$$\beta = \frac{1}{2}\left[-phi_{PM} - \tan^{-1}\left(\frac{\omega}{\sigma}\right) + \tan^{-1}\left(\frac{\omega T_\omega}{1+\sigma T_\omega}\right) + 2\tan^{-1}\left(\frac{\omega T_2}{1+\sigma T_2}\right)\right] \tag{6}$$

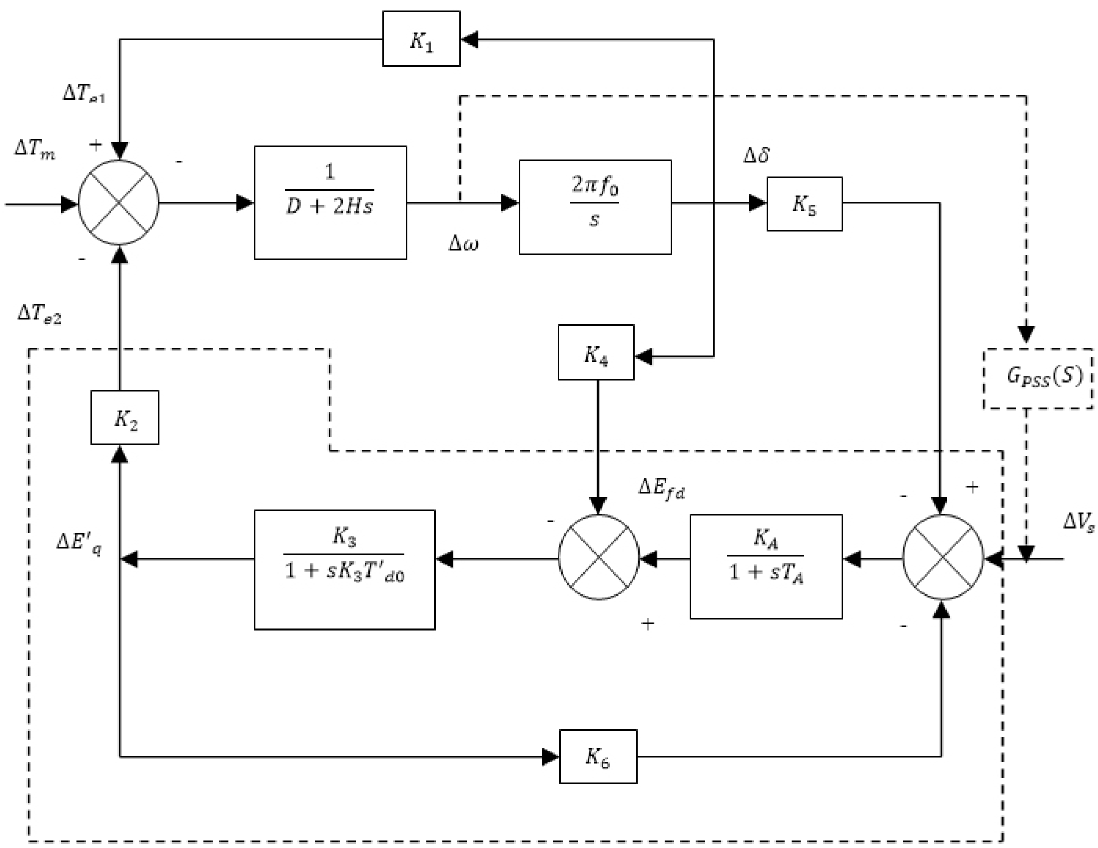

Figure 3: Heffron-Philips model of a system (Single-Machine Infinite-Bus System)

The gain of the PSS, for its part, is given by the following relation:

$$K_{PSS} = \left.\frac{4\omega_n \xi H}{K_2\,|PM(s)|\,|G_f(s)|}\right|_{s=\lambda=\sigma+j\omega} \tag{7}$$

where, ω_n is natural oscillation pulsation in rad/s given by?

$$\omega_n = \sqrt{\frac{\omega_0 K_1}{2H}} \tag{8}$$

and ω_0 is the speed of synchronism of the system, in rad/s.

The value ω_n represents the solution of the characteristic equation of the mechanical loop and is defined by the following equation (negated damping coefficient D).

$$2HS^2 + \omega_0 K_1 = 0 \tag{9}$$

where, $S = \pm j\omega_n$

B. Residue Method

The PSS advance/delay filter is used to compensate for the phase delay of the GEP transfer function (s). By determining the value of the phase delay, we can thus calculate the time constants (advance/delay) required to ensure the required compensation. To do this, the residual phase angle can be used.

Consider the following form of the PSS transfer function for an input/output system:

$$H(S) = K_{PSS} \frac{sT_w}{1 + sT_w} \left(\frac{1 + sT_1}{1 + sT_2} \right)^m \tag{10}$$

where, m is the number of compensation stages (generally $m = 2$).

C. Method of Placement of Poles

This method consists in determining the values of the parameters of a PSS so that all the poles of the closed loop system are placed at predetermined positions in the complex plane.

Considering the representation of the following system:

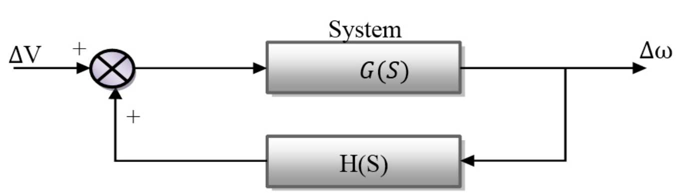

Figure 4: The Closed-Loop System (PSS)

where, G(s): transfer function of the system between the reference signal ΔV of the generator voltage regulator, where the PSS is to be installed, and the rotor speed variation Δω.

H(S): PSS transfer function.

The poles of G(S) are precisely the eigenvalues of the open-loop linearized system. The transfer function of the entire closed-loop system F(s) becomes:

$$F(S) = \frac{G(S)}{1 - G(S) \cdot H(S)} \tag{11}$$

The eigenvalues of the closed-loop system are the poles of the transfer function F(s); they must satisfy the following characteristic equation:

$$1 - G(S) \cdot H(S) = 0$$

$$\Rightarrow \qquad H(S) = \frac{1}{G(S)} \tag{12}$$

If $\lambda_i = 1, 2, ..., n$ are the eigenvalues previously specified, equation (12) can thus be rewritten as follows:

$$H(\lambda_i) = \frac{1}{G(\lambda_i)} \tag{13}$$

$$\Rightarrow \qquad K_{PSS} \cdot \frac{\lambda_i T_w}{1+\lambda_i T_w} \cdot \frac{1+\lambda_i T_1}{1+\lambda_i T_2} \cdot \frac{1+\lambda_i T_3}{1+\lambda_i T_4} = \frac{1}{G(\lambda_i)} \tag{14}$$

Consequently, we obtain a set of linear algebraic equations. By solving these equations, we can determine the values of the desired parameters of the PSS that ensure the precise placement of the Eigenvalues.

5. SMIB WITH FOPID

The PID controllers are described and named according to their nature of gains and proportional parameters. The controller output is the function of these parameters:

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau) d\tau + K_D \frac{d}{dt} e(t) \tag{15}$$

Equation (15) shows the transfer function of PID controller.

where, K_P: Proportional gain, a tuning parameter

K_I: Integral gain, a tuning parameter

K_D: Derivative gain, a tuning parameter

e: Error

t: Time or instantaneous time

τ: Variable of integration; takes on values from time 0 to t.

The FOPID controller has three parameters similar to PID controller along with the two additional parameters namely; the integral order λ, and the differential order μ. The transfer function of $PI^\lambda D^\mu$ controller is given by [20]:

$$G_c(s) = K_P + K_I s^{-\lambda} + K_D s^{\mu}, \lambda, \mu > 0 \tag{16}$$

The differential equation for the $PI^\lambda D^\mu$ controller in the time domain is given by [25]:

$$u(t) = K_P e(t) + K_I D^{-\lambda} e(t) + K_D D^{\mu} e(t) \tag{17}$$

The FOPID parameters collaborate to form the SMIB and setting up wrong values can result in undesired output. The regulation command tracking refers the wellness of controlled variables. The command tracking is determined on the proportions of rise time and settling time. Many methods were applied for controlling these parameters and here we emphasize the applications of GA, PSO and GWO for the same. All these methods (inherited from nature) compute the value of K_P, K_I and K_D based on their previous values.

Figure 5 and Figure 6 show Simulink models for proposed FOPID and SMIB-FOPID systems respectively.

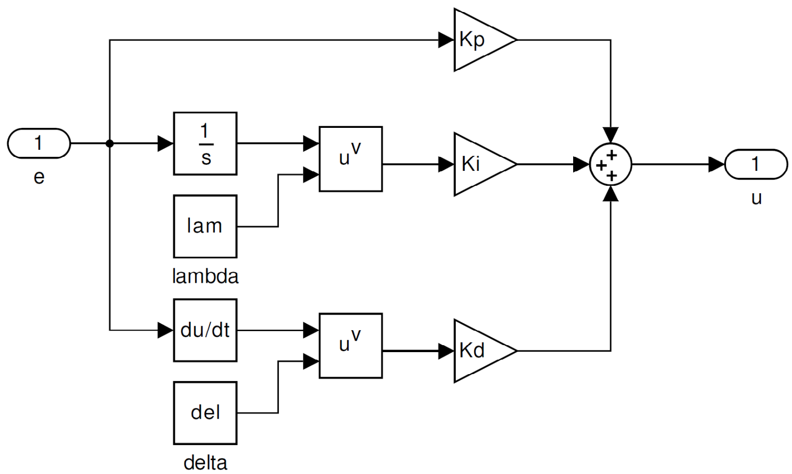

Figure 5: Simulink Model for FOPID

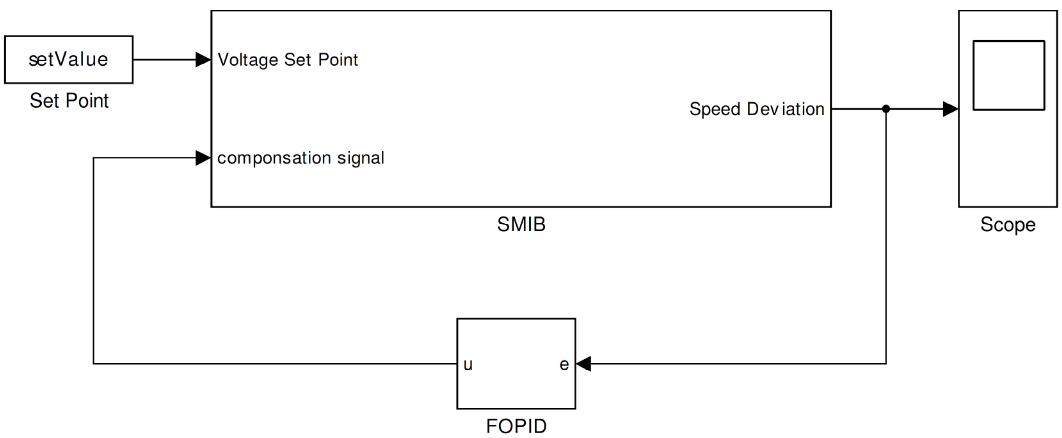

Figure 6: Simulink Model for SMIB with FOPID

6. POWER SYSTEM STABILITY ANALYSIS USING GA, PSO AND GWO

In previous section the linearized equations are derived for proposed Power System Stabilizer (PSS). This section optimizes the parameters of PSS using Genetic Algorithm, Particle Swarm Optimization and Grey Wolf Optimization.

Fitness Function for PSS

$$f(d_v) = \int_0^t \left| (d_r - d_v) \right| dt \tag{18}$$

where,

$d_r = 0$ (Reference speed deviation)

$d_v = f(v)$ (Actual speed deviation due to control variable v)

The control variable v can be given as:

$$v = \{K, T_W, T_1, T_2, T_3, T_4\}$$

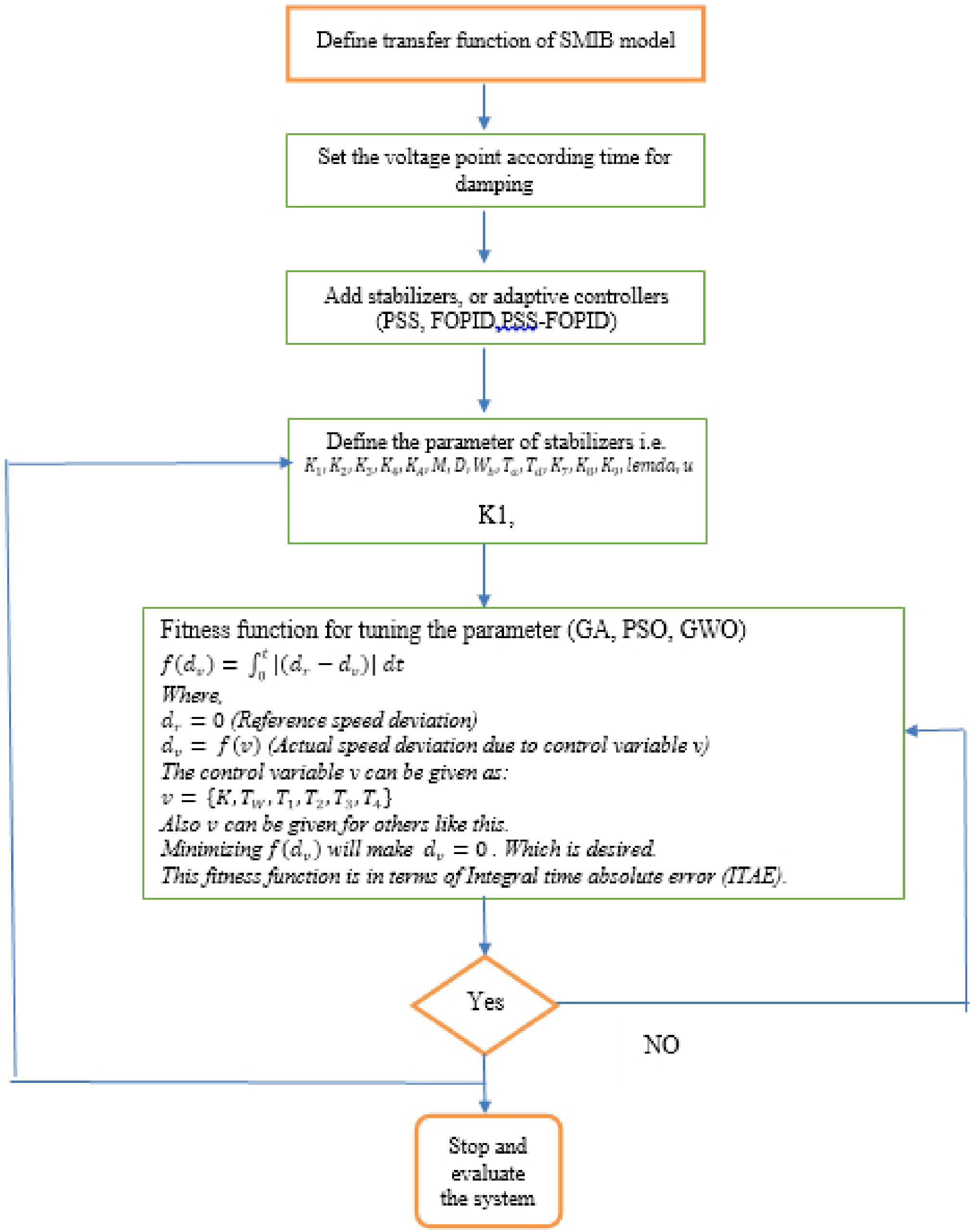

Figure 7: Flow of the Parameter Optimization of SMIB System Model

Also v can be given for others like this.

Minimizing $f(d_v)$ will make $d_v = 0$. Which is desired.

This fitness function is in terms of Integral time absolute error (ITAE).

Genetic Algorithm

Genetic Algorithm of GA is an optimization tool that lies on the platform of Heuristic Approaches. Based on the proposal of Darwin principle of fittest survival, this method was introduced to commence optimization problems in soft computing [26]. The first category of results is termed as initial population and all the individuals are candidate solution. Simultaneous study of the population including all candidates and next phase of solutions are generated following the steps of GA [27].

An iterative application of operators on the selected initial population is the initiative process of GA. Further steps are devised based on valuation of this population. The typical routing of GA is described in following pseudo code:

1. Randomly generate initial population.
2. Employ fitness function for evaluation.
3. Chromosomes with superior fitness are valued as parents.
4. New population generation by parent's crossover with probability function.
5. Chromosome mutation with probability to defend system from early trap.
6. Repeat step 2.
7. Terminate algorithm based on satisfaction criteria.

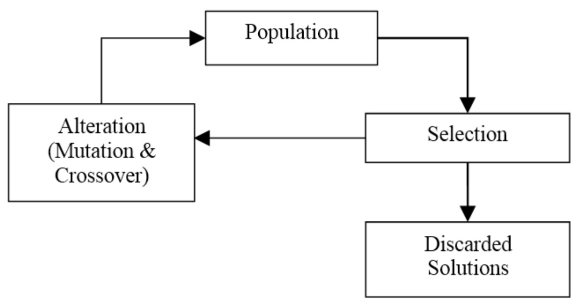

Figure 8: Genetic Algorithm Evolutionary Cycle

A. Particle Swarm Optimization (PSO)

PSO is a heuristic method [28]. The evaluation of candidate solution of current search space is done on the basis of iteration process (as shown in Figure 9). The minima and maxima of objective function is determined by the candidate's solution as it fits the task's requirements. Since PSO algorithm do not accept the objective function data as its inputs, therefore the solution is randomly away from minimum and maximum (locally/ globally) and also unknown to the user. The speed and position of candidate's solution is maintained and at each level, fitness value is also updated. The best value of fitness is recorded by PSO for an individual record. The other individuals reaching this value are taken as the individual best position and solution for given problem. The individuals reaching this value are known as global best candidate solution with global best position. The up gradation of global and individual best fitness value is carried out and if there is a requirement then global and local best fitness values are even replaced. For PSO's optimization capability, the updation of speed and position is necessary. Each particle's velocity is updated with the help of subsequent formula:

$$v_i(t+1) = wv_i(t) + c_1r_1[\hat{x}_i(t) - x_i(t)] + c_2r_2[g(t) - x_i(t)] \tag{19}$$

B. Grey Wolf Optimization

Grey Wolf Optimization (GWO) algorithm was first proposed in 2014 by Mirjalili et. al., [29]. GWO is an iterative search technique, which is based on swarm intelligence. GWO algorithm was simulated by the self-governing behaviour and the hunting mechanism of grey wolves for a prey in the forest. Grey wolves usually prefer to live in a pack. A pack of Grey wolves consists of four different categories of wolves according to their ranking, α, β, δ and Ω. In a pack, they abide themselves by the harsh social leadership hierarchical structure as shown in the Figure 9.

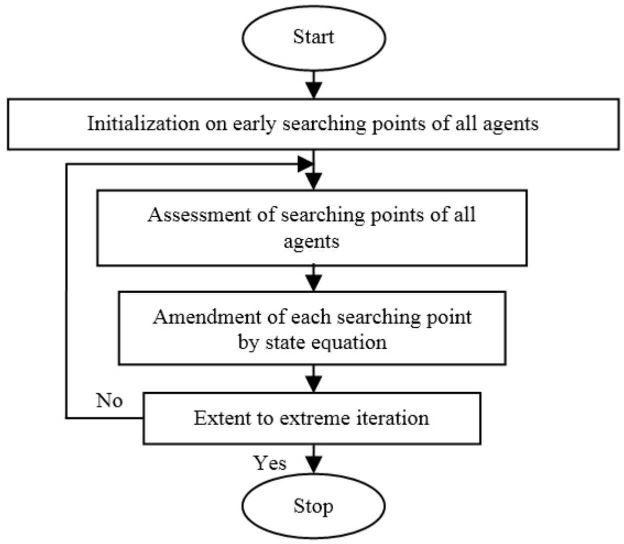

Figure 9: Flow Chart of PSO Algorithm

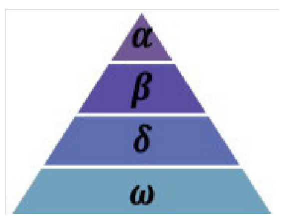

Figure 10: Grey Wolf Social Leadership Hierarchy (Superiority Increases from Bottom to Top) [29]

The leaders of a Grey wolf pack are called as alphas (α), which may be a male or female. Prominently these alphas take decision like hunting of prey, dozing place etc. Their decisions are binding to the pack. In other words alpha wolves are also called as dominant wolves amongst the pack because pack followed the decision taken by them. The advisors to the alpha wolves are designated as betas (β) (second ranking in hierarchy), which work as subordinate to the alpha and help them while making any decision. The β wolf can be a male or female, he/she should respect alphas, as well commands other low ranking wolves in a pack. The β imposes the alpha's command to the pack also provide feedback to α. The third level of grey wolves named as deltas (δ), which have to accede to α and β but they command lowest rank grey wolves named as omegas (Ω). The custodians, predators, elders and vanguards belong to δ category wolves.

Omega wolves forever have to accede to all the other superior wolves.

Mathematical Model of GWO Algorithm

Grey wolf while hunting takes certain steps which are as follows:

1. Tracking the prey
2. Encircling the prey
3. Attacking the prey

In this section social hierarchy and hunting steps are presented in mathematical models.

Social Hierarchy

While creating the hierarchy of the grey wolves in mathematical form, the alpha (α), the beta (β) and the delta (δ) is considered first ,second and third best solutions respectively. The omega (Ω) is concluded as remaining part. The alpha (α), beta (β) and delta (δ) escort the hunting (optimization) process in GWO algorithm. The omega (Ω) wolves follow them during hunting process.

Encircling Prey

While hunting (optimization) grey wolves encircle the pray until it stops moving. The modeling of encircling behaviour of the grey wolves in mathematical form is represented by following equations:

$$\vec{D} = \left| \vec{C} . \vec{X}_P t - \vec{X}(t) \right| \tag{20}$$

$$\vec{X}(t+1) = \vec{X}_P t - \vec{A} . \vec{D} \tag{21}$$

where, $\vec{X}_P$ the position vector of the prey is, $\vec{X}$ denotes the position vector of a grey wolf, t denotes the current iteration, and $\vec{A}, \vec{C}$ represent coefficient vectors.

The computation of coefficient vectors $\vec{A}$ and $\vec{C}$ is carried out as:

$$\vec{A} = 2 . \vec{a} . \vec{r}_1 - \vec{a} \tag{22}$$

$$\vec{C} = 2 . \vec{r}_2 \tag{23}$$

where, $\vec{a}$ = value decreases linearly from 2 to 0 during iteration.

$\vec{r}_1, \vec{r}_2$ are random vectors in [0, 1] and allow wolves to reach any position in the search space around the prey to obtain best solution.

Hunting (Optimization)

Grey wolves are able to identify the location of pray (optimum) to encircle them. The alphas guide the hunt amongst pack, sometimes betas and deltas also participate in hunting. As we have no idea about location of pray (optimum) in an abstract search space, we assume that the alphas, betas and deltas have better knowledge about the potential location of prey. To model hunting behaviour of grey wolves in mathematical form, we select the first three best candidate solutions obtained so far and discard the other candidate solution (including the omegas). The other candidates (search agents) update their position according to the position of the candidates (search agents).

The following equations are formulated for the candidates to update their position [29].

$$\begin{Bmatrix} \vec{D}_\alpha = \left| \vec{C}_1 . \vec{X}_\alpha - \vec{X} \right| \\ \vec{D}_\beta = \left| \vec{C}_2 . \vec{X}_\beta - \vec{X} \right| \\ \vec{D}_\delta = \left| \vec{C}_3 . \vec{X}_\delta - \vec{X} \right| \end{Bmatrix} \tag{24}$$

$$\begin{Bmatrix} \vec{X}_1 = \vec{X}_\alpha - \vec{A}_1 . \vec{D}_\alpha \\ \vec{X}_2 = \vec{X}_\beta - \vec{A}_2 . \vec{D}_\beta \\ \vec{X}_3 = \vec{X}_\delta - \vec{A}_3 . \vec{D}_\delta \end{Bmatrix} \tag{25}$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \tag{26}$$

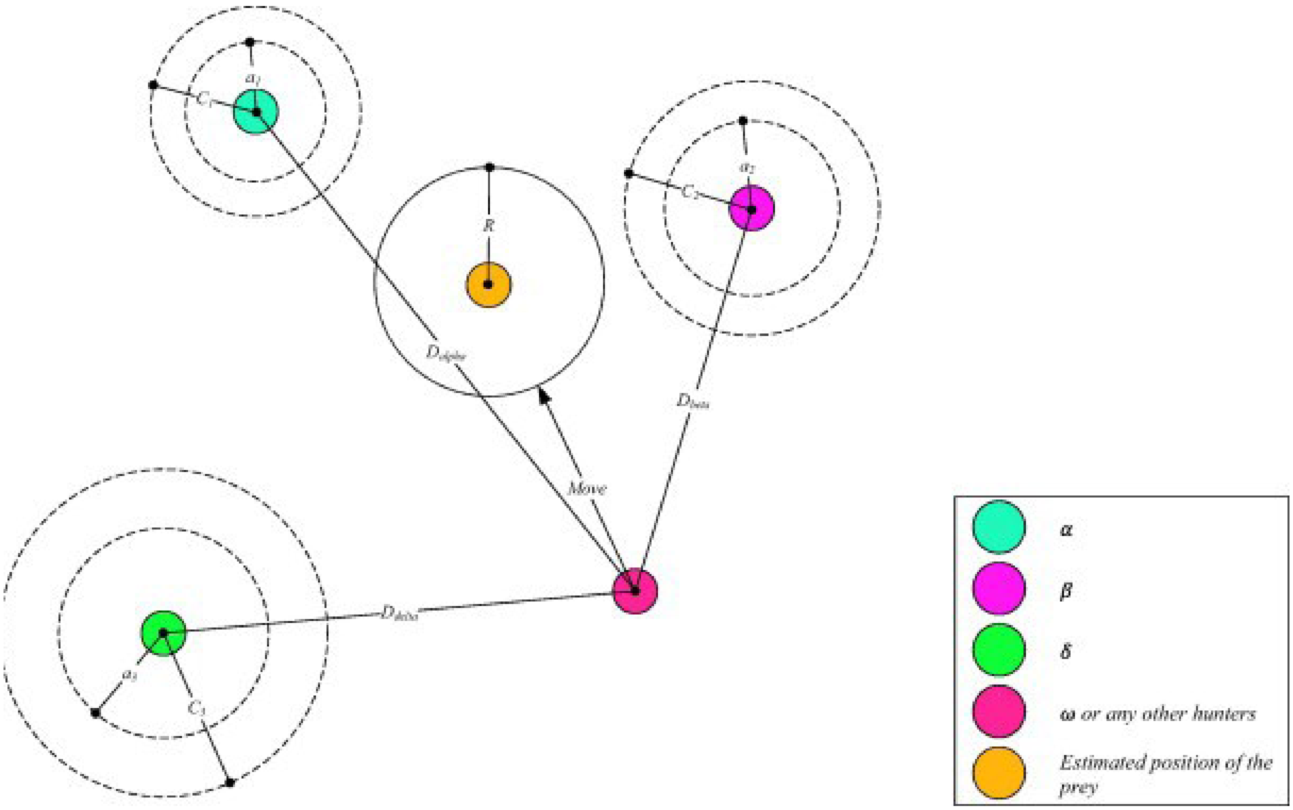

Figure 11: Grey Wolf Position Update in GWO [29]

Attacking Prey (Exploitation) and Search for Prey (Exploration)

The mathematical modelling of attacking the pray by grey wolves are carried out by linearly decreasing the value of $\vec{a}$ from 2 to 0 during iteration count, thus value of $\vec{A}$ will also be decreasing during each iteration. The '$\vec{A}$' will take any random values in between $[-2a, 2a]$. The random values '$\vec{A}$' of are utilized to force the candidate (search agent) to move towards or away from the prey. When $|A| < 1$, the wolves are forced to attack the prey and when $|A| > 1$, the grey wolves are enforced to diverge from the prey. In this way GWO algorithm search for optimum globally and locally.

GWO Algorithm

Step 1: Start

Step 2: Initialization of variables; K_P, K_I, K_D, λ, μ, $\vec{a}$, coefficient vectors $\vec{A}$ and $\vec{C}$.

Step 3: Initializing grey wolf population: Create random population of variables considering their locations.

Step 4: Evaluation of initial cost of all candidates (search agents)**:** Calculate the fitness function of all particles considering the K_P, K_I, K_D, λ, μ, and its location which is generated in previous step.

Step 5: Finding the first three best solutions $\vec{X}_\alpha$, $\vec{X}_\beta$ and $\vec{X}_\delta$ according to the obtained cost of all candidates.

Step 6: Starting iteration:

Set iteration counter, iter = 1.

Step 7: Update each candidate position: Update current search agent position according to equation

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \tag{27}$$

Step 8: Authentication of candidate: Check the validity of candidate according to the candidate's particular conditions i.e. validate the candidate's new positions according to the limitations of variables and their valid locations. If new position of any particle is not valid, then randomly regenerate that candidate according to their conditions.

Step 9: Updating the parameter $\vec{a}$, coefficient vectors $\vec{A}$ and $\vec{C}$ and calculate the fitness function.

Step 10: Update $\vec{X}_\alpha, \vec{X}_\beta$ and $\vec{X}_\delta$.

Step 11: Increment the iteration count.

Step 12: If stopping criteria is not satisfied (i.e. if iter<=maxiter && repeat<maxrepeat) then go to Step 7, otherwise continue to next step.

Step 13: Print the results and plot graphs.

Step 14: Stop.

7. PROPOSED HYBRID APPROACH

Voltage stabilizer (PSS) generates spikes during the speed deviation and the output of PSS is generally positive. To decrease those spikes, this hybrid method uses FOPID along with the PSS. This approach reduces the spikes generation. In hybrid approach, we have associated FOPID stabilizer with the PSS connected SMIB as shown in Figure 12.

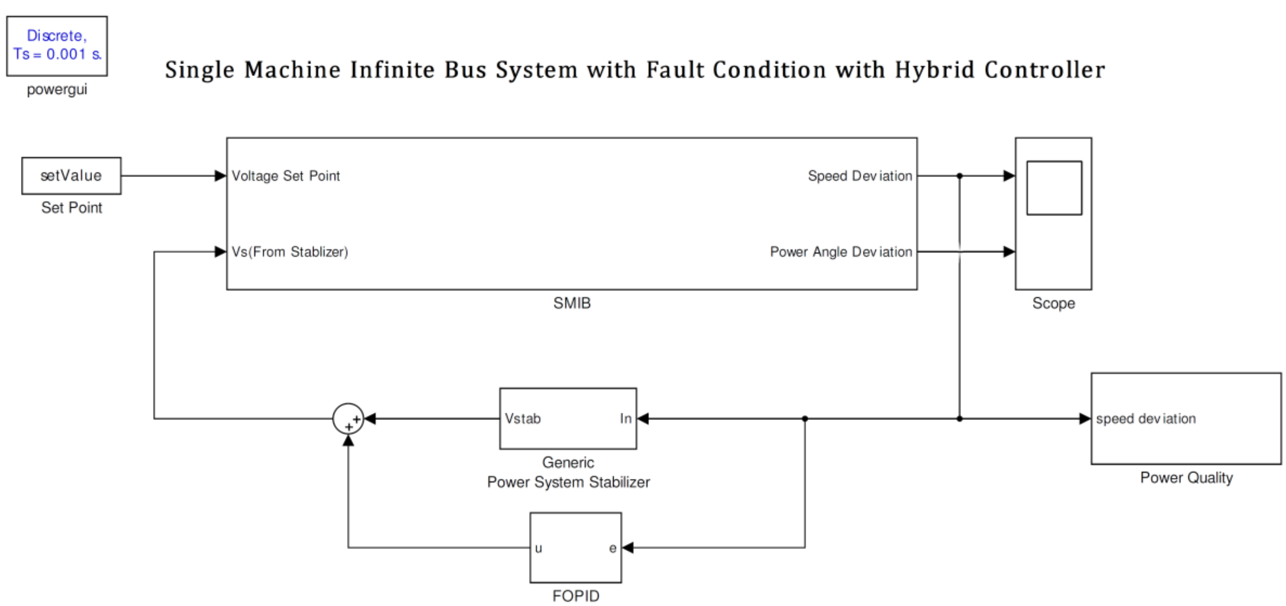

Figure 12: Simulink Model for Hybrid Approach

The mathematical model for proposed hybrid approach is given by using Equation (1) and Equation (17) as:

$$V_{Hybrid} = K_{PSS} \frac{sT_w}{1+sT_w} \frac{(1+sT_1)}{(1+sT_2)} \frac{(1+sT_3)}{(1+sT_4)} \Delta\text{input} - [u(t)\Delta\text{input}] \quad (28)$$

where,

V_{PSS}: Output signal of the corrector

K_{PSS}: Gain of the corrector

T_w = Time constant of the high pass filter

T_1, T_2, T_3, T_4: Time Constant delay

Δinput: Correction input signal

$u(t)$ = Differential equation for the FOPID

8. EXPERIMENTAL SETUP

Simulation parameters:

1. Generator: H = 3.5, M = 2H, TdO' = 7.76, D = 0, Xd = 0.973, Xd = 0.19, Xq = 0.55, Xe = 1.08.
2. Excitation system: KA = 200, TA = 0
3. Transmission line and Transformer: = 0.0 + *j*0.8(XL = *j*0.7, XT = 0.1)
4. Field circuit: K3 = 0.4494, T3 = 3.9336
5. SMIB K constants: K1 = 0.5320, K2 = 0.7858, K4 = 1.0184, K5 = –0.0597, K6 = 0.5746
6. Operating points:
   1. P = 1.0, Q = 0.6, D = 0, et. = 1.1, Frequency = 60 Hz.
   2. P = 1.1, Q = 0.8, D = 0, et. = 1.1, Frequency = 60 Hz.
   3. P = 1.2, Q = 0.9, D = 0, et. = 1.1, Frequency = 60 Hz.

The optimization was held by bounded search. Various parameters used for proposed strategy are listed in Table 1. Certain parameters are utilized for tuning purpose are; KF, KP, T1F,T2F, T3F, T4F, T1P, T2P, T3P and T4P. The parameters with subscript F shows they have a place with FOPID controller and that of P demonstrates they have a place with PSS Control. Following are the ranges on the basis of these parameters are tuned.

Table 1
Max./Min. values measured for parameters [30]

PSS		*FOPID*	
Parameter	*Range*	*Parameter*	*Range*
K*p*	30 – 80	K*p*	0.1 – 100
T1*p*	0.1 – 0.6	K*i*	0.1 – 100
T2*p*	0.02 – 0.4	K*d*	0.1 – 100
T3*p*	0.1 – 0.6	the integral order λ	0.01 – 0.99
T4*p*	0.02 – 0.4	differential order μ	0.01 – 0.99

Soft computing parameters:

Table 2
Parameter utilized in GA algorithm

GA Parameter	*Value*
Population size	10
Mutation rate	8
Number of generations	20

Table 3
Parameters utilized for PSO Algorithms

PSO Parameter	*Value*
Swarm size	10
No of iteration	10
Acceleration factor c1	0.12
Acceleration factor c2	0.8
Inertia	0.9

Table 4
Parameters used for GWO Algorithms

GWO Parameters	*Value*
Number of Wolf	10
Number of Iteration	20

9. RESULT ANALYSIS AND SIMULATION

– Perform control of the system from the controllers (PSS, FOPID and HYBRID)

– To visualize the results of the regulation and the simulation of our system - To calculate the dynamic parameters of the system.

– Test the stability of the system.

The study of the system was carried out for the following three cases:

1. Open loop system (without regulation);
2. Loop system closed with the conventional PSS controller, FOPID controller;
3. Closed Loop System with hybrid (PSS+FOPID) Controller
   - Disturbances were made by sudden variation of the turbine torque at 15% of $\Delta T m$ at time $t = 0.2$s,with variations of the parameters of the external network (variation of XL):
   - The following operating modes have been simulated (with different configurations of the external network cited at the top):
     – Rated speed
     – Returns the reactive power of the network to the machine (Q <0) under the excited state during the rest hours (at night, for example);

– The overproduction of reactive energy (very large Q) under over - excited conditions during peak hours.

Stability Study

To study the dynamic behavior of our system in perturbed regime (damping of electromechanical oscillations of synchronous machine parameters), the different models (with and without excitation control) were realized under MATLAB/SIMULINK.

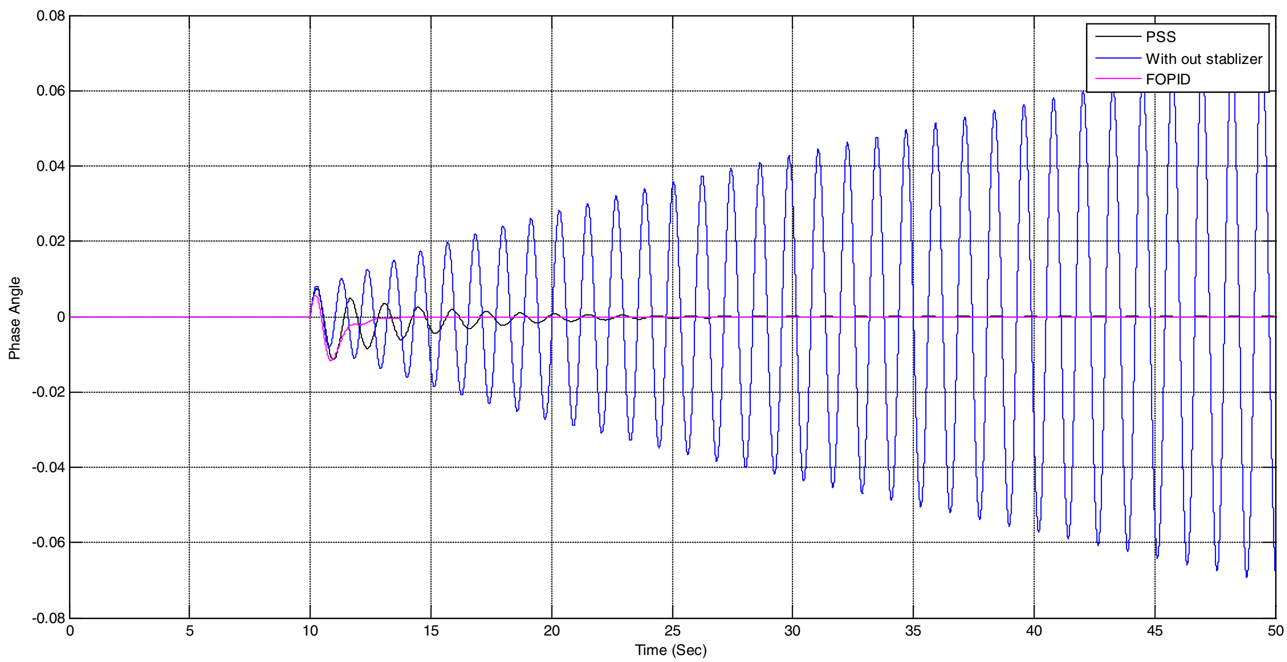

Figure 13: Comparison of Phase Angle Deviations in SMIB for PSS and FOPID

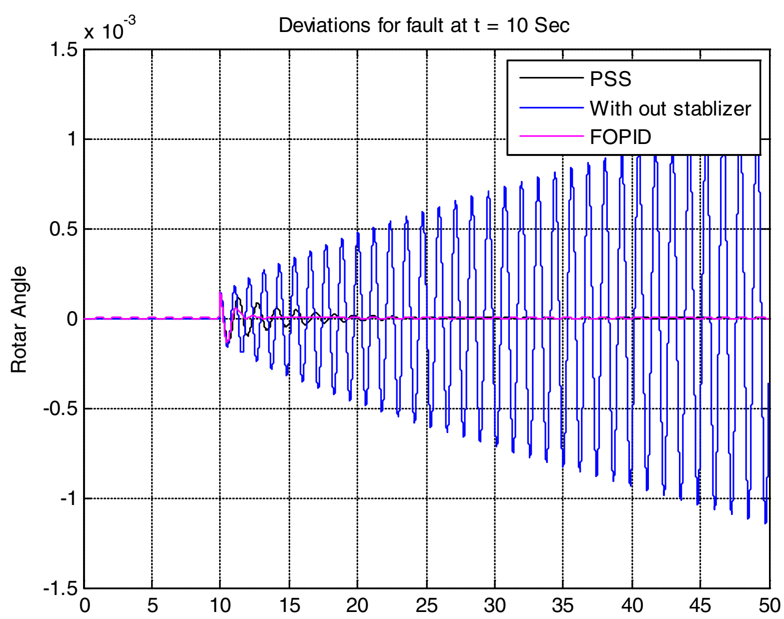

Figure 14: Comparison of Rotor Angle Deviations in SMIB for PSS and FOPID

Above Figure 13 and 14 shows the response of phase angle and rotor angle PSO-FOPID against an impulsive fault at t = 10 second. The fault duration without controller extends to 50 sec, with PSS and FOPID the fault duration is only one sample of time and then fault has been cleared. On the fault inception rotor of the generator starts deviation from a constant speed, which is shown in form of deviation. Deviation is received at FOPID on very next sample of time in form of non-zero deviation error and FOPID responses in form of compensation signal. Above figure shows that deviations settle down to zero around 13.24 seconds, for FOPID and 14.45 sec for PSS which is a fair amount of time.

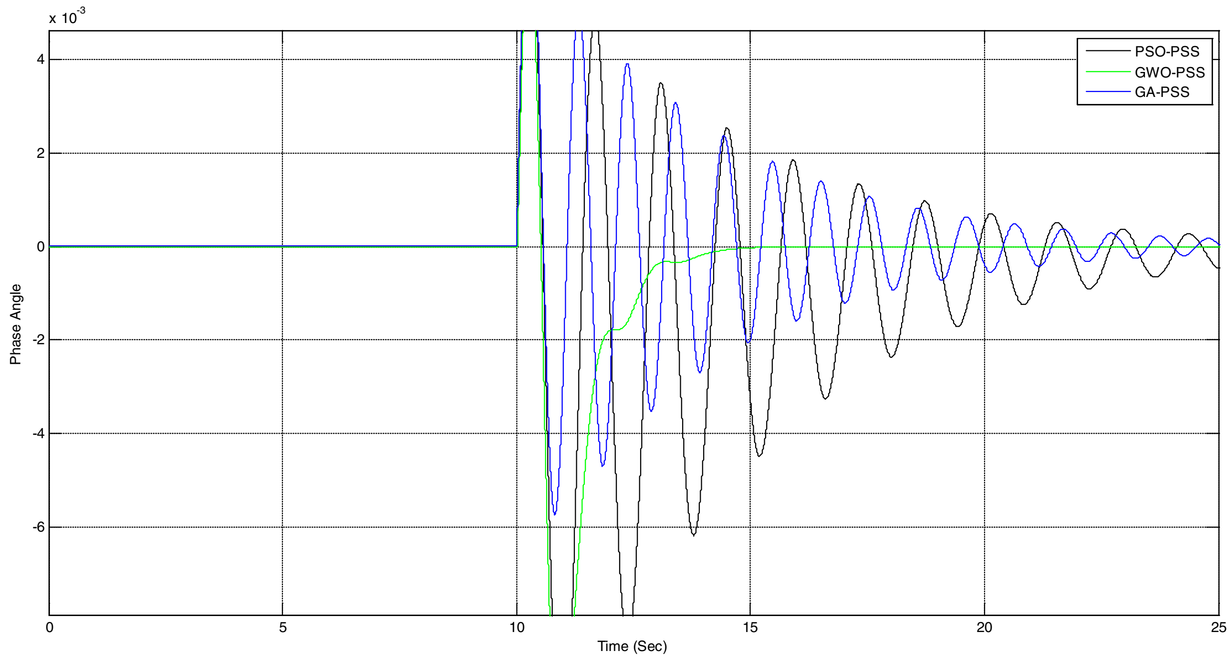

Figure 15: Comparison of Phase Angle Deviations in SMIB for GA-PSS, PSO-PSS and GWO-PSS

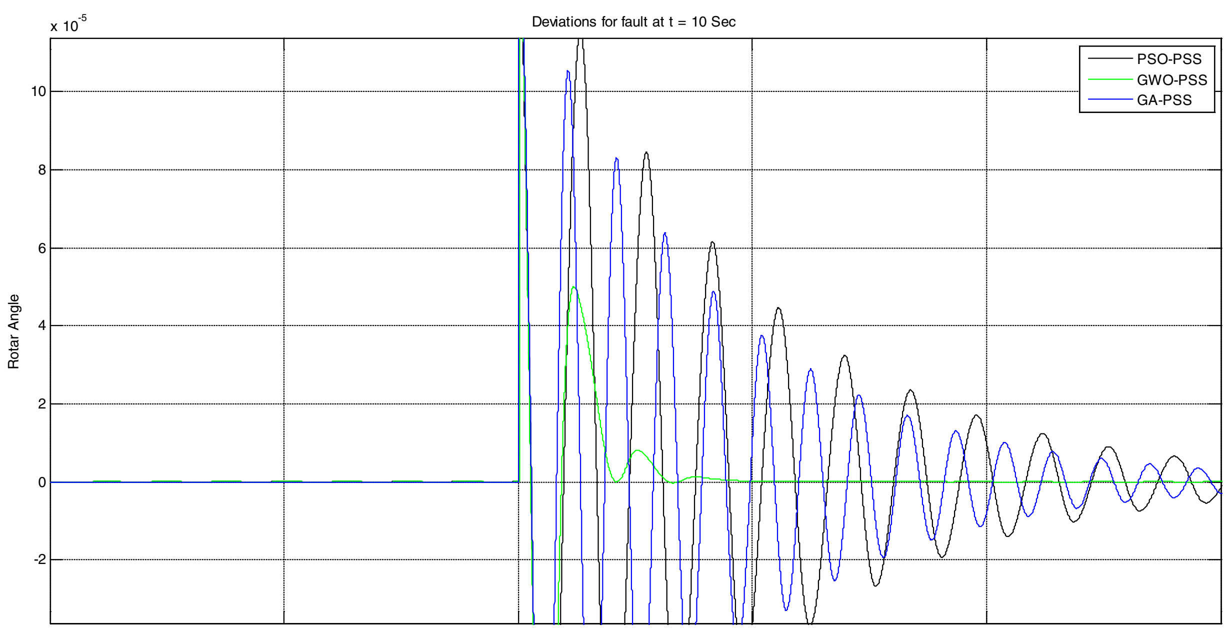

Figure 16: Comparison of Rotor Angle Deviations in SMIB for GA-PSS, PSO-PSS and GWO-PSS

Above Figure 15 and 16 shows the zoomed response of phase angle and rotor angle GA-PSS, PSO-PSS and GWO-PSS optimized parameters against an impulsive fault at $t = 10$ second. The fault duration without controller extends to 25sec, with GWO-PSS, PSO-PSS and GA-PSS the fault duration is only one sample of time and then fault has been cleared. On the fault inception rotor of the generator starts deviation from a constant speed, which is shown in form of deviation. Deviation is received at GWO-PSS on very next sample of time in form of non-zero deviation error and GWO-PSS responses in form of compensation signal. Above figure shows that deviations settle down to zero around 12.33 seconds, for GWO-PSS which is a fair amount of time.

From the results obtained it can be seen that:

With the use of the excitation controller, the system is considerably more stable and more efficient than the non-regulating system, high damping coefficients are allowed, response times are short of the system), weak static errors (accuracy). Generally, very good qualities of the transient regimes have been obtained with the better electromechanical damping of the electromechanical oscillations with this excitation controller.

The transient stability of the system is very high and especially with the FOPID and Hybrid controller, considerable improvements are obtained in the quality of the transient regimes of all the parameters of the system, even for our critical regime, which is the resting state of the station (Under excited). After small oscillations the system returns to its initial state with negligible static errors (milling precision) and very short set-up times (very fast system).

Below Figure 17 shows the response of PSO-FOPID against an impulsive fault at $t = 5$ second. The fault duration is only one sample of time and then fault has been cleared. On the fault inception rotor of the generator starts deviation from a constant speed, which is shown in form of deviation. Deviation is received at FOPID on very next sample of time in form of non-zero deviation error and PSO-FOPID responses in form of compensation signal. Above figure shows that deviations settle down to zero around 5.24 seconds, which is a fair amount of time.

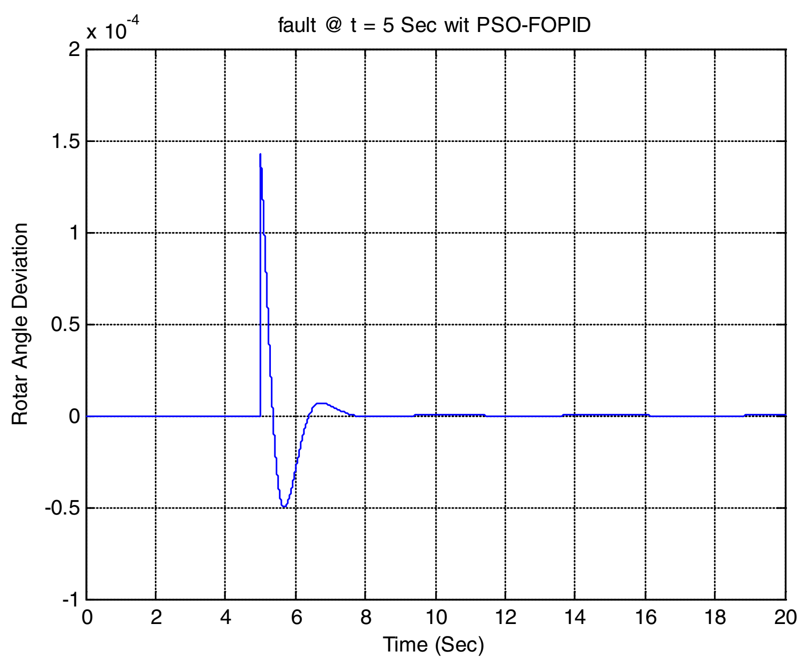

Figure 17: Rotor Angle Deviation for PSO-FOPID

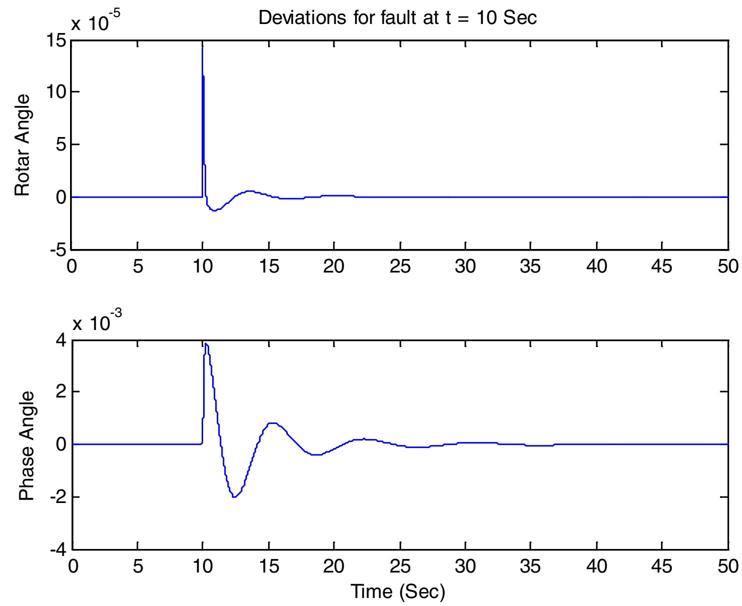

Figure 18: Rotorangle Andphase Angle Deviation Of Hybrid Model (PSS-FOPID)

Above Figure 18 the response of Hybrid model against an impulsive fault at $t = 10$ second. The fault duration is only one sample of time and then fault has been cleared. On the fault inception rotor of the generator starts deviation from a constant speed, which is shown in form of deviation. Deviation is received at hybrid on very next sample of time in form of non-zero deviation error and FOPID responses in form of compensation signal. Above figure shows that deviations settle down to zero around 14.24 seconds, which is a fair amount of time.

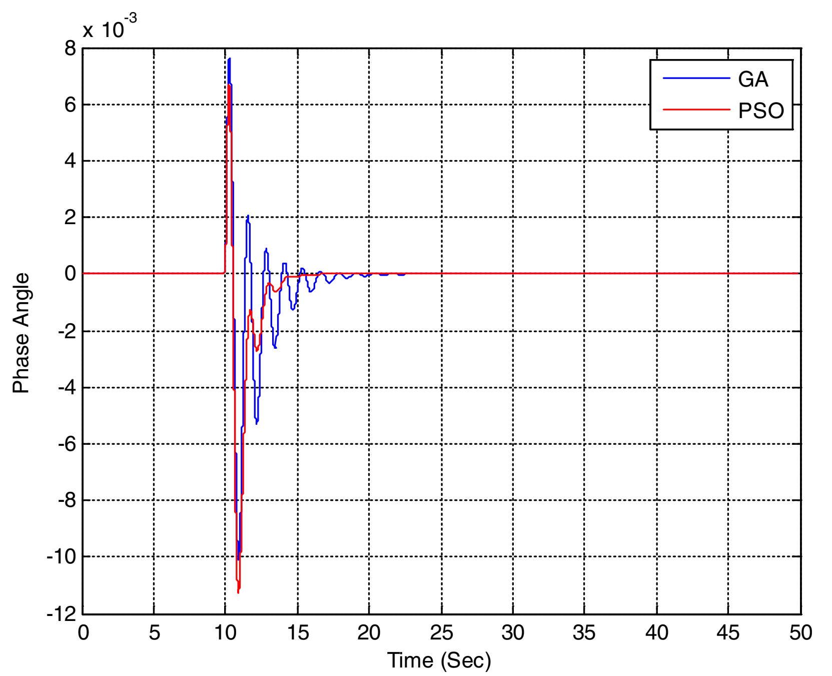

Figure 19: Comparison of Phase Angle Deviations in SMIB for GA and PSO

Above Figure 19 shows a comparative graph of phase angle deviations in SMIB for GA and PSO against an impulsive fault at $t = 10$ second. Above figure shows that PSO based approach outperforms GA approach.

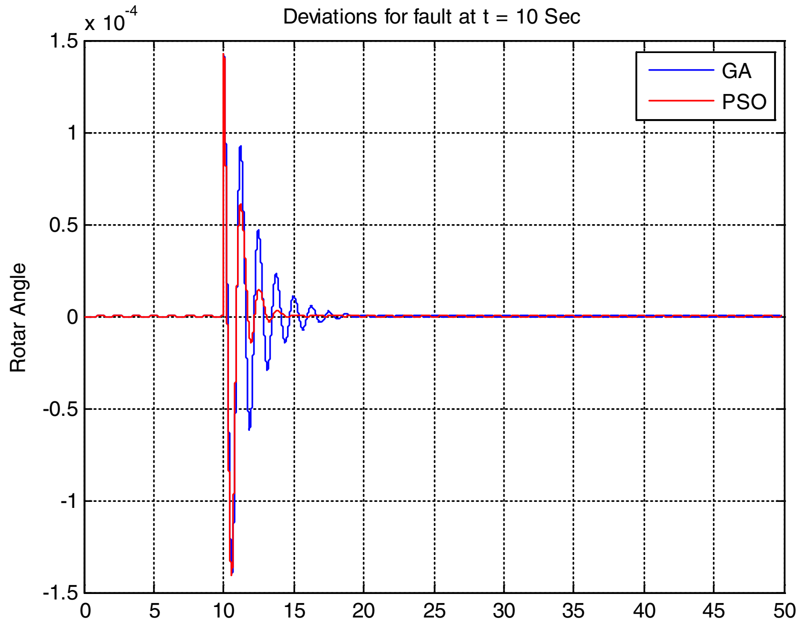

Figure 20: Comparison of Rotor Angle Deviations in SMIB for GA and PSO

Above Figure 20 shows a comparative graph of rotor angle deviations in SMIB for GA and PSO against an impulsive fault at $t = 5$ second. Above figure shows that PSO based approach outperforms GA approach.

Table 5
Comparative Analysis

Method	*Settling Time (S)*
PSO-PSS	13.94
GA-PSS	14.80
GWO-PSS	12.81
PSO-FOPID	9.24
GA-FOPID	10.10
GWO-FOPID	9.19
Hybrid method	7.26

On observing Table 5, it was found that the Hybrid method outperforms other methods on the basis of lowest settling time.

10. CONCLUSION

These excitation controllers are capable of maintaining better dynamic performances and of guaranteeing the robustness of stability of the system studied in the face of disturbances including uncertainties (system uncertainties) under different operating modes. The study presented in this paper deals with the application of GA, PSO and GWO in the optimization of the parameters of the stabilizing device of the PSS power system. The aim of the paper is to provide the necessary damping to the electromechanical oscillations of the generators, when the system undergoes perturbations around its operating point. A fitness function is derived which is aimed to minimize rotor speed deviation as a function of stabilizers parameter. It is found that with the proposed tuning method every stabilizer gives stable study state. The proposed hybrid stabilizer gives the fastest settling of system when compared to conventional controllers.

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