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Research Paper

Tuning of PIDPSS employing Firefly Photinus Algorithm

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Abstract: *Power systems are operating at their peak transmission capacity due to increased power consumption and stable operation of such systems are of high concern. As the system complexity increases the operating points change with small disturbances itself. Low frequency rotor oscillations associated with the disturbances limit the power transfer capacity of the system. To increase these limits and to stabilise generator operations Power System Stabilizers are employed. Proportional Integral plus Derivative Type Power System Stabilizers (PIDPSS) are highly effective in attenuating rotor oscillations. Fixed parameter PIDPSS is sufficient for stabilizing the power system when its state is close to the equilibrium. But to ensure wide region of stability the parameters of the stabilizers are to be tuned tracking the changes in the operating point. Recent studies suggest Firefly Algorithm as an effective method for such tuning considering its simple implementation. But there is a serious drawback of getting trapped into local optima with conventional firefly algorithm. This paper suggests Firefly Photinus Algorithm (FPA) as a modification to firefly algorithm to rectify the above issue. Mate list mechanism and time dependent absorption parameter are the modifications incorporated in the algorithm so that a balance between exploration and exploitation is achieved. The effectiveness of this modified algorithm, FPA is tested with SMIB power systems for tuning PIDPSS. FPA was found more effective in enhancing the stability limits.*

Keywords: *Single Machine Infinite Bus, Power System Stabilizer, Firefly Algorithm, Mate list, absorption parameter.*

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I. INTRODUCTION

Power grids are compelled to operate at peak transmission capacities due to increasing consumption day by day. The system complexity is also increasing with increased power consumption. Hence stable operation of power systems is becoming more and more challenging [1,2]. The operating point of the system will change even with small disturbances causing instability to the system and hence stabilization techniques are required to be employed. Asynchronous oscillations induced into the rotor is the major reason for instability [3,4]. To ensure stability these oscillations must be damped, and Power System Stabilizers are employed for this purpose [5,6]. In the power industries PIDPSS with fixed parameters are used commonly [7].

PIDPSS with fixed parameters are sufficient in stabilising systems When state is close to the equilibrium [8]. But when the system state changes widely, stabilization become tedious. To provide wide range of stability, the stabilizer parameters are to be adjusted according to the changes in operating point. Various studies are available in this direction. Particle Swarm Algorithm (PSA) [9], fuzzy logic tuning [10-14], adaptive fuzzy [15,16], fuzzy gravitational search algorithm [17], neuro-fuzzy [18-20], Artificial Bee Colony (ABC) algorithm [21] are different methods suggested by various researchers for tuning PSS increasing stability limits of power systems. Firefly algorithm is found as a better choice in this regard as reported in [22]. It is found effective in optimizing the parameters of stabilizers for a wide range of operation but with a drawback of getting trapped in local optima biased on the selection of initial population. A modification of firefly algorithm was proposed by Waleed Alomoush et al [23] to overcome this difficulty as Firefly Photinus Algorithm (FFA).

This paper attempts to customize FPA for tuning PIDPSS. Here the firefly algorithm is modified incorporating a mate list mechanism to widen the exploration and introducing time varying absorption to enhance the exploitation. The modified algorithm is tested with Single Machine Infinite Bus (SMIB) power system undergoing symmetrical line fault. The formulation of the modified algorithm is briefly described in section 2. Details of the system under study is described in section 3. Section 4 is devoted to the results and analysis. The conclusion is given in section 5.

II. FIREFLY PHOTINUS ALGORITHM

Firefly Algorithm is a Swarm Intelligence (SI) method developed by Yang [24, 25]. The algorithm is based on the flashing patterns and behaviour of fireflies. The most distinctive features of the Firefly algorithm include discovering the mechanism, the social behaviour of fireflies and communication. Following assumptions taken for the development of the algorithm.

1. Fireflies will be attracted to other fireflies without considering their sex.
2. The attraction of each firefly to other increases based on the brightness of second one but decreases with the distance between them. The less bright firefly will move toward the brighter one. If there is no brighter one than a firefly, it will move randomly.
3. The brightness of a firefly is determined by the objective function. Then the fireflies are moved to new positions in the direction of brighter firefly via the function $exp^{-\gamma r}$

The attractiveness of fireflies is updated by following equation.

$$x_i^{t+1} = x_i^t + \beta exp^{-\gamma r_{ij}^2}\left(x_i^t - x_j^t\right) + \alpha_t \epsilon_t \qquad (1)$$

Form the Equation 1 it is evident that there are two types of movements for each firefly. One is due to attraction of the brighter firefly provided by the second term of the equation and a random move represented by the third term. The step size is controlled by the parameter α_t and ϵ_t is representing a random vector. Firefly coefficients β and γ are decided based on the implementation. The distance between any two fireflies x_i and x_j is calculated by Equation 2.

$$r_{ij} = \sqrt{\sum_{m=1}^{D}\left(x_{i,m} - x_{j,m}\right)^2} \qquad (2)$$

When $\gamma \to 0$ the firefly algorithm can be viewed as same as standard particle swarm optimisation algorithm. The pseudo code for the algorithm is given in shown in Figure 1. Various works are available in literature showing the effectiveness of firefly algorithm in optimisation in power systems [26-29]. Here the algorithm is used for optimising PID coefficients of power system stabilizer.

As described in [23] The Firefly Photinus algorithm (FPA) is proposed based on two modifications in FA. Firstly, it introduces the incorporation of a mate list mechanism to solve problems of trapping into local optima and remember history of any situation. Secondly a new absorption parameter σ, is employed to change firefly coefficient γ with the time. The mate list will store the locations of fireflies with which previous mates were occurred to a certain level back. Comparing the brightness of each firefly the locations stored in the mate list will be avoided. In each iteration this list will be updated by incorporating the presently selected location by removing the oldest one.

This can be considered as a learning process for the selection of suitable mating partner based on a storied history. The forbidden mate list compels each firefly to select a new mate other than recently mated flies thus avoiding getting trapped at any location. The number of previous states to be stored in the mate list (size of mate list *M*) is depending upon the number of populations. It cannot be too small or too big. When it is too small, trapping into local optima may not be solved. When it is too big, the choice for movement will be limited. Figure 2 shows a typical mate list with $M = 7$

The firefly coefficient γ is a constant in conventional firefly algorithm. Instead taking such a constant value throughout the process in FPA, the coefficient is getting updated during the process moves on. An absorption parameter ρ is initialized for this purpose. Equation 3 describes the updating path. According to the value of ρ, the attractiveness will be varied in each iteration. By the introduction of mate list and new absorption coefficient a balance between exploitation and exploration can be achieved. Pseudo code for FPA is given in Figure 3.

$$\gamma^{t+1} = \rho\gamma^t \qquad (3)$$

```
Objective function f(x)   where x = (x_1, x_2, .....x_d)^T
Generate initial population of fireflies x_i for i = 1, 2, ...n
Light intensity l_i at x_i is determined by f(x_i)
Define light absorption coefficient γ
while (t< max.generation)
   For i = 1 : n  all n fireflies
      For j = 1 : n  all n fireflies (inner loop)
         If (l_i < l_j), Move firefly i towards j; end if
         Vary attractiveness with distance r via exp^(-γ r_{i,j})
         Evaluate new solutions and update light intensity
      end for j
   end for i
Rank the firefly and find the best
End while
```

Figure 1. Pseudo code for firefly algorithm

M_1	x_i^1						
M_2	x_i^2	x_i^1					
M_3	x_i^3	x_i^2	x_i^1				
....							
M_7	x_i^7	x_i^6	x_i^5	x_i^4	x_i^3	x_i^2	x_i^1
M_8	x_i^8	x_i^7	x_i^6	x_i^5	x_i^4	x_i^3	x_i^2
....							
M_{t+1}	x_i^{t+1}	x_i^t	x_i^{t-1}	x_i^{t-2}	x_i^{t-3}	x_i^{t-4}	x_i^{t-5}

Figure 2. FPA mate list

Values of M and ρ are decided based on population size. In this study population size is taken as 40 like the population size taken by Waleed Alomoush et al and the values of M and ρ are taken as 7 and 0.95 respectively as reported in [23].

III. SYSTEM UNDER STUDY

A SMIB power system is taken for the study and the schematic diagram is given Figure 4. Also the SIMULINK block diagram of test system is given in Figure 5. Here R_e and X_e are in order the transmission line resistance and reactance. The V_B and V_G are infinite bus voltage and terminal voltage of generator, respectively. The system response is observed with three conditions one with PIDPSS without tuning, second tuned with conventional firefly algorithm and third tuned with FPA. The third order generator model [30] and IEEE's Type 1 exciter are used for simulation. The system can be represented by Equations 4-7.

$$\dot{\omega} = \frac{1}{M}(T_m - T_e - T_e) \quad (4)$$

$$\dot{\delta} = \omega_b(\omega - 1) \quad (5)$$

$$\dot{e_q'} = \frac{1}{T_{d0}}\left(E_{FD} - e_q' - X_d - X_d'\right) \quad (6)$$

$$\dot{E_{FD}} = \frac{1}{T_A}\left(K_A\left(V_{ref} - V_t - U_{PSS}\right) - E_{FD}\right] \quad (7)$$

where

δ	: Rotor angle in rad,
ω	: Generator speed in rad/s,
$eq^{'}$	: Generator voltage in q-axis
E_{FD}	: Output voltage of Exciter.
T_m	: Mechanical Torque
T_e	: Electrical Torque
T_d	: Damping Torque
X_d	: d axis synchronous reactance
$X_d^{'}$	: d axis transient reactance
V_t	: Terminal Voltage
V_{ref}	: Reference Voltage
U_{PSS}	: PSS output
T_A	: Exciter time constant
$T_{d0}^{'}$	: Generator time constant

```
Begin
    Define the objective function f(x);
    Initialize the firefly population X = x_1, x_2, ......, x_n;
    Define light absorption coefficient γ;
    Define multiplier ρ for varying γ;
    Initialize mate list {M}.
     While (t<MaxGeneration)
              for each firefly x_i in swarm do
               for each other firefly x_j in the swarm do
                light intensity I_i at x_i is determined by f(x_i);
                 if I_j > I_j then and (i mate j) ∉ M,
                    Attractiveness varies with distsnce r via e^{-γr}
                        Move firefly x_i toward x_j;
                        Update mate list {M}
                    end if
                 Evaluate new solutions and update light intensity
                Update γ by equation γ(t+1) = ργ(t)
               end
              end
              Rank the fireflies and find current best;
     until termination criterion reached;
    Rank the fireflies and return the best one.
End
```

Figure 3. Pseudo Code for FPA

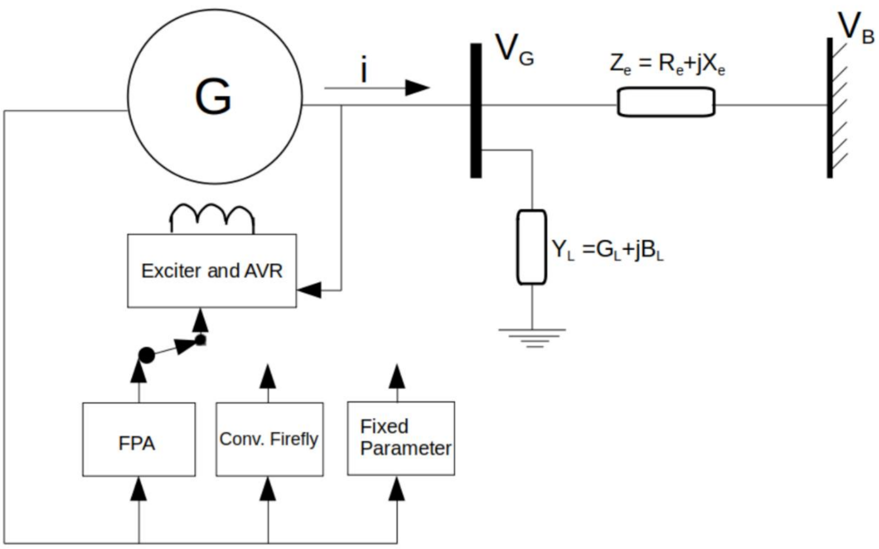

Figure 4. The block diagram of the test system

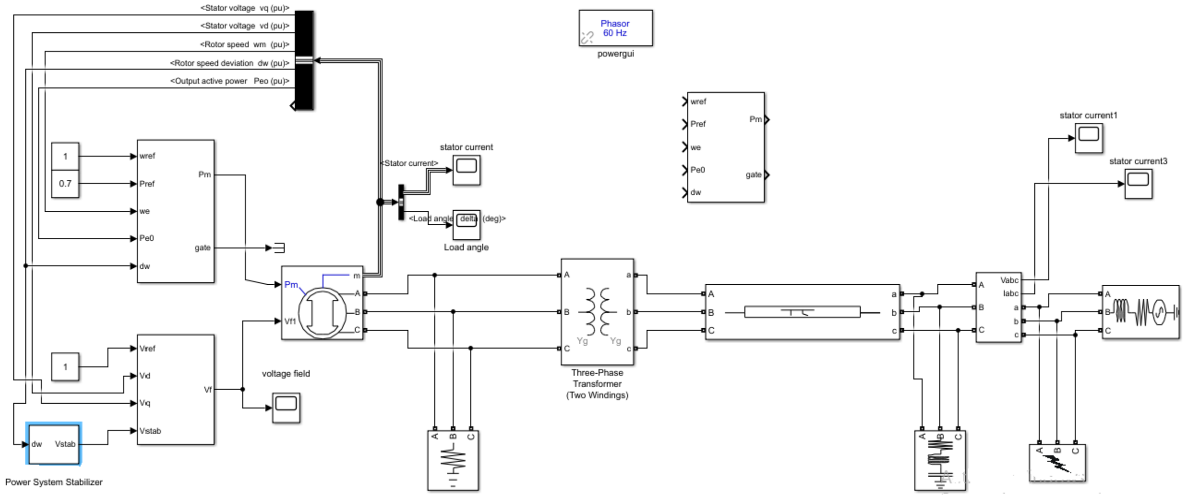

Figure 5. The SIMULINK block diagram of the SMIB system simulated for the study

A. Objective Function

The purpose of the tuning algorithm is to obtain optimum values for proportional, Integral and Derivative parameters; K_p, K_i and K_d of the PIDPSS. The power system stabilizer is used to provide an additional signal in phase with rotor oscillation so that to damp the oscillations. In order to achieve this signal normally rotor speed deviation is measured and fed back to the PSS as its input. Accelerating power, frequency deviation etc. are can be used for feeding back. A combination of these variables can also be used as input for PSS. In this study $\Delta\omega$ the speed deviation is fed back as the single input. An objective function designed with the combination of rotor angle deviation, rotor speed deviation and power deviation as given in Equation 8 is used for tuning.

$$J = \int_0^t (\Delta\delta + 100\Delta\omega + 10\Delta P)dt \qquad (8)$$

IV. RESULTS AND ANALYSIS

00 MW, 13.8 KV Synchronous machine connected to the infinite bus with 10,000MVA, 230KV capacity is simulated for the study. Symmetrical loads are connected at two points to the system. 5MW load at generator terminal and 10MVA load between transformer and infinite bus. The transformer with rating 210MVA and 13.8KV/230KV is used in the simulation. A 3phase symmetrical fault with resistance 1mΩ is simulated for testing the response. SMIB system data given in Table 1, is same as in [22]. The Resistance of the transmission link $R_e = 0$, is taken to be zero for lossless condition. The reactance of transmission link is taken as, $X_e = 0.4pu$. The power outputP_E is assumed at 0.8 per unit.

For the test, the symmetrical earth fault is applied to the system at 2m sec and cleared after 10 m sec. The parameters of PIDPSS is found out using conventional firefly algorithm as well as FPA, optimising the cost function *J* with the fault response. Optimum values of objective cost functions thus obtained with PIDPSS with fixed parameters and PIDPSS tuned with conventional and modified firefly algorithms are tabulated. Table 2 give the values of PIDPSS parameters and cost function. The time responses of rotor angle, rotor speed and power are also plotted. Figures 7, 8 and 9 show these responses, respectively. The blue, green and red plots represent time response with PIDPSS with fixed parameter, tuned with conventional firefly algorithm and tuned with FPA, respectively.

$X_d = 1.97pu$ $X_q = 1.9pu$ $X_d^{'} = 0.30pu$	$T_{d0} = 6.84pu$ $K_A = 100$ $T_A = 0.2sec$	$E_{FD}min = -5pu$ $E_{FD}max = 5pu$ $\omega_0 = 2\pi X50rad/sec$

Table 1. SMIB power system data used for simulation

	Fixed Parameter	Tuned with Firefly	Tuned with FPA
K_p	2	1.63	2.95
K_i	0.1	0.84	2.31
K_d	0.1	0.005	0.021
Objective Function	39.80	32.33	31,27

Table 2. Values of parameters of PIDPSS and objective cost function with different algorithms

From the above results the minimum value of objective cost function is minimum with FPA. Conventional firefly algorithm also reduces the cost function to a great extent. The time responses also show the same result. The responses are converging to steady state faster in conventional firefly as well as FPA for the rotor angle, rotor speed as well as the power delivered by the system. The best result is obtained with FPA. From this it can be inferred that tuning of PIDPSS with FPA is improving the stability limits of the power system.

V. CONCLUSION

This work presents a new modification of firefly algorithm employing mate list and varying absorption coefficient inspired on the behaviour of Photinus Fireflies. The modified algorithm is employed for tuning of PIDPSS with SMIB power systems. The performance of FPA in tuning of PIDPSS is compared with conventional firefly algorithm. The test system comprising of SMIB power system with IEEE's Type 1 exciter is simulated using MATLAB and SIMULINK package and time responses for rotor angle, rotor speed and power delivered for systems employed PIDPSS with fixed parameters, PIDPSS tuned with Conventional firefly algorithm and PIDPSS tuned with FPA are analysed. The stability of the system found with systems employed firefly algorithm as well as FPA. PIDPSS tuned with FPA gives better results than conventional firefly. FPA also gives a better minimum for objective cost function.

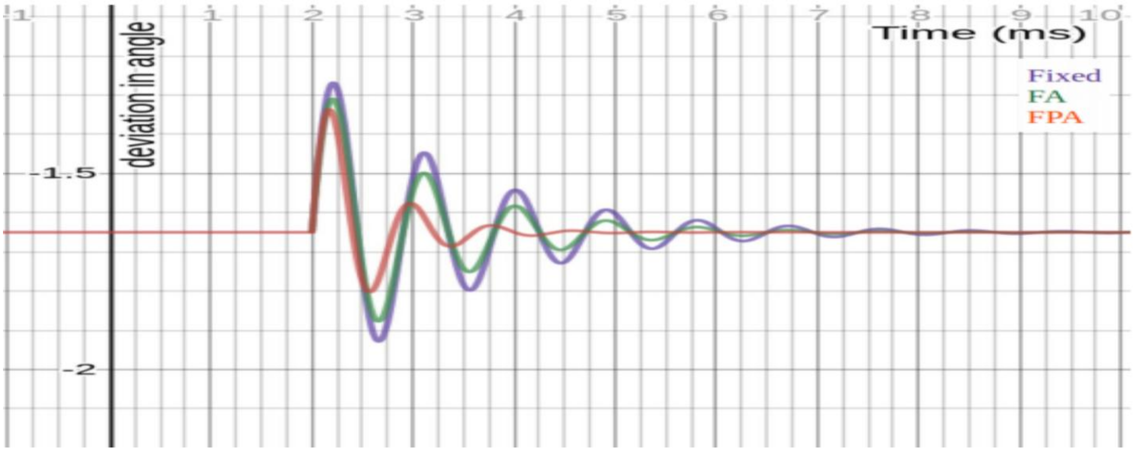

Figure 6. The time response plotted for Rotor angle with PIDPSS with fixed parameters , parameters tuned with firefly, parameters tuned with FPA .

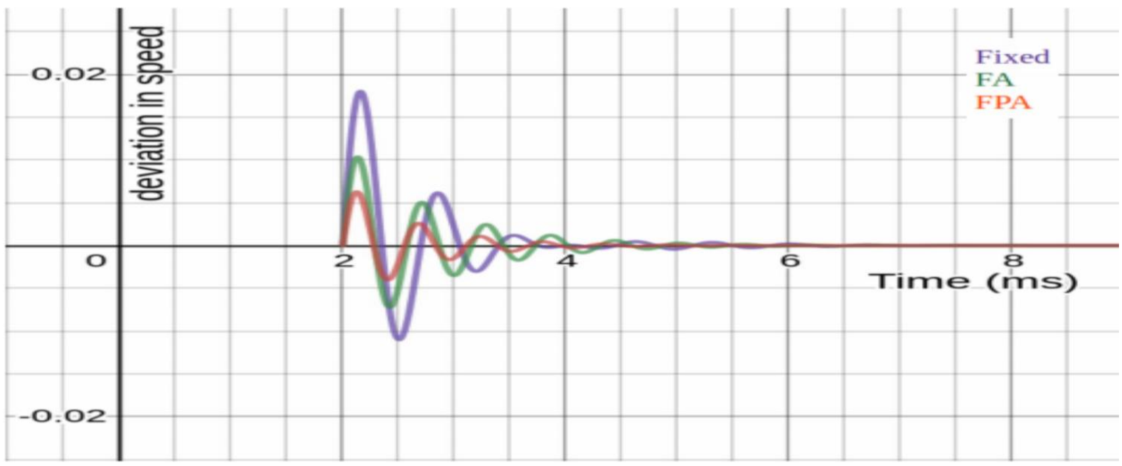

Figure 7. The time response plotted for Rotor speed with PIDPSS with fixed parameters, parameters tuned with firefly, parameters tuned with FPA.

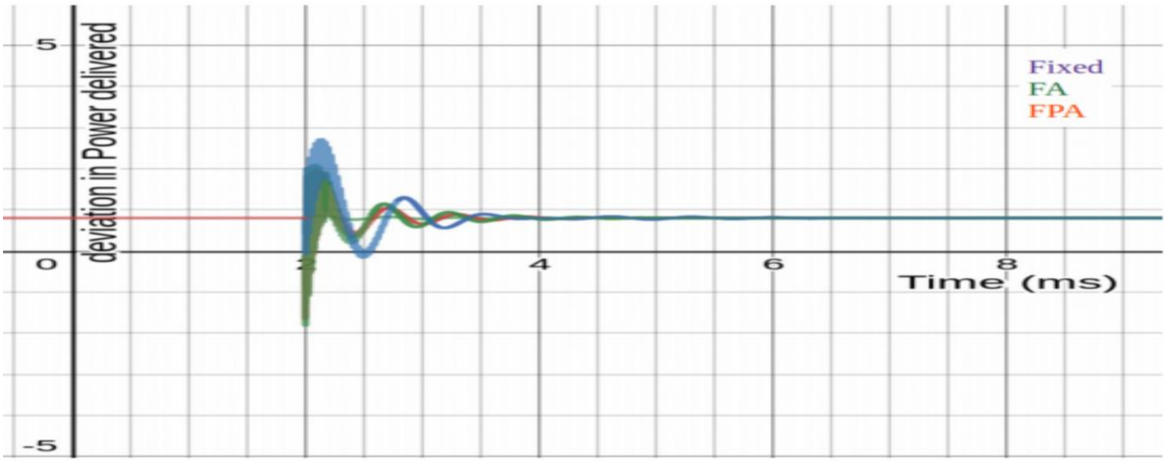

Figure 8. The time response plotted for power delivered with PIDPSS with fixed parameters parameters tuned with firefly, parameters tuned with FPA.

Conflict of interest: The Authors declare that there is no conflict of interest.

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