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Tuning of Power Oscillation Damping Controllers using Firefly Algorithm - A Comparison Study

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ABSTRACT

This paper deals with the design and tuning of an effective power oscillation damping controller for a single machine infinite bus (SMIB) and multi-machine power system model (MMPS). Two different structures of damping controllers are investigated: a lead-lag and a proportional-derivative-integral controller. A remote signal is considered as the input signal which is in this case is the speed difference of the synchronous generator at pre-fault and during fault condition. The controller parameters are optimized using a nature inspired optimization method known as Firefly Algorithm (FFA) in order to attain fast convergence to the global optima. Both the power system models are designed in a MATLAB-7.10.0 SIMULINK environment and the optimization algorithm was coded as .m file. To check the performance and efficiency of the designed damping controller in a single machine and multi-machine power system (MMPS) model following a disturbance, controller responses are compared by changing the loading.

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INTRODUCTION

In the electricity market, new challenges are introduced everyday due to the growth and deregulation. So in order to maintain the power quality, power systems are now operating near to their stability limit. The technical solution to this problem is to use the existing power systems with flexible ac transmission (FACT) controllers. Static synchronous series compensator (SSSC) is the FACTS device which is considered in this paper (Kundur, *et al*). It is a series controller which can control the overall line reactive voltage drop, in turn controlling the transmittable power along with capable of damping power oscillation.

The design of damping controller which describes in the following sub-section of this paper requires tuning of controller parameters. Several deterministic optimization techniques such as particle swarm optimization (PSO)[Panda, *et al.*, 2013], genetic algorithm (GA) [Panda, *et al.*, 2014], differential evolution (DE) [Panda, *et al.*,2010], tabu-search (TS), artificial neural networks (ANN) and many more are already been used for the optimal tuning of the controllers parameters. In this paper, fire-fly algorithm (FFA) is used for optimizing both controller parameters.

System Model:

Fig. 1 shows a single machine power system model where T/F represents the converter transformer, V_s sending end voltage, V_R is the receiving end voltage, V_1 is the voltage of bus-1, V_2 is the voltage of bus-2, V_{DC} is the DC supplied voltage to the voltage source converter (VSC) of the SSSC, V_{cnv} is the output voltage of the VSC converter, I is the current in the transmission line, P_L is the transmission line real power flow, a load is connected to bus-1 [Hingorani and N. G. Gyugyi].

A SSSC is a voltage source converter (VSC) that is connected in series at the middle of the tie line. The output voltage V_q and the line current I are in quadrature with and independent to each other. Following a disturbance SSSC operates as a compensator to restore the system as quick as possible.

The proposed controllers:

1. PID power oscillation damping controller:

Fig. 2 shows the block diagram of PID damping controller with a proportional, integral and derivative block having Kp, Ki, and Kd as their respective blocks gains which will be calculated by FFA. The speed deviation signal results from a disturbance is feed as the input signal to the controller and the output equivalent voltage signal is feed as input to

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the SSSC which act as the injected voltage to the transmission line [Hingorani and N. G. Gyugyi].

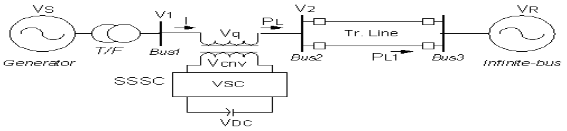

Fig. 1: SMIB power system with SSSC.

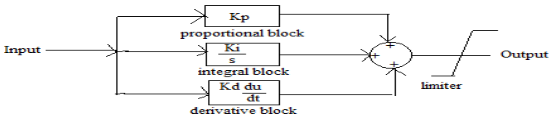

Fig. 2: Block diagram of PID controller.

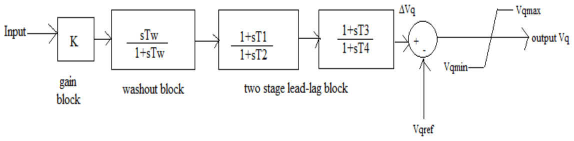

Fig. 3: Block diagram of lead-lag controller.

2. Lead-lag power oscillation damping controller:

Fig. 3 shows the block diagram of lead-lag damping controller, including a gain block, a washout block, a lead block and a lag block. As shown in the fig. 3 K is the gain of the gain block, Tw is the time constant of the washout block (1-20 sec) [Panda, S., 2009] and T_1, T_2, T_3, T_4 are the time constants of the lead-lag block.. V_{qref} is the constant voltage required at steady state conditions. During dynamic condition the effective output voltage (V_q) as given by eq. (1). In the present study Tw = 10 sec and T_1, T_2, T_3, T_4 are to be determined by FFA.

$$V_q = V_{qref} + \Delta V_q \qquad (1)$$

3. Problem formulation:

The stability of a power system, following a disturbance can be improved by damping the oscillations. The speed difference is considered as the input signal to the controller which has already been proved as a better alternative [Panda, S. and S. C. Swain, 2014]. So the objective of the controller is to provide a minimum speed difference which became the objective function J for the FFA and can be expressed as the integral time absolute error (ITAE) of the speed difference as given in equation (2):

$$J = \int_{t=0}^{t=tsim} (\Sigma|\Delta w|t\ dt) \qquad (2)$$

Where, Δw is the speed difference and tsim is the simulation time period.

The design problem is formulated as a constraints optimization problem [Panda, at el., 2014] as the parameters of different controller blocks must have a lower and upper limit as given in equation (3) and (4)

a) For L-L controller
Minimize J
Subject to
$K_{min} <= K <= K_{max}$
$T_{1min} <= T_1 <= T_{1max}$
$T_{2min} <= T_2 <= T_{2max}$
$T_{3min} <= T_3 <= T_{3max}T_{4min} <= T_4 <= T_{4max}$ (3)

b) For PID controller:
Minimize J
Subject to
$K_{Pmin} <= K_P <= K_{Pmax}$
$Ki_{min} <= K_i <= Ki_{max}$
$K_{dmin} <= K_d <= K_{dmax}$ (4)

Firefly Algorithm:

FFA is an optimization method stated in 2008 by Yang [Yang, X.S, 2009], based on the process by which the firefly attracts their mating partners and prey by producing short-rhythmic flashes known as bioluminescence process. This nature inspired technique depends on attractiveness coefficient (β), light intensity (I), absorption coefficient (γ) and distance r between any two fireflies. The attractiveness coefficient defines the light intensity at a particular distance r from the light source. Further the air absorbs light which is determined by the absorption coefficient (γ) [Mahapatra *et al*., 2014]. The following assumptions are taken into considerations:

- Every fire-fly should attract to the other fire-fly: All fireflies in a given population are unisex.
- As the distance between any two fire-fly increases the brightness should decrease.
- A fire-fly should move in a random direction if it did not find a brighter fire-fly.
- The landscape of the objective function which is to be optimized should determine the brightness.

For a basic firefly algorithm, Fig. 4 shows the process of flow.

For any two fireflies 1at x_1 and 2 at x_2, the distance at is given by:

$$r_{12} = ||x_1 - x_2||^2 \qquad (5)$$

The movement of a firefly 1 toward another brighter firefly 2 is determined by:

$$x_{1(t+1)} = x_{1t} + \beta_0 e(-\gamma r_{12}^2)(x_{1t} - x_{2t}) + \alpha\epsilon_{1t} \quad (6)$$

Where β_0 is the attractiveness at r = 0 and ϵ is a random variable drawn from a Gaussian distribution [Swain, S. C., S. Panda and P. Kar, 2014].

Implementation Of Ffa:

The power system model in this paper is developed in MATLAB 7.10.0/SIMULINK environment whereas .m file is used for writing the program for the FFA algorithm. The program for FFA was run for a given size of population (10) and generations (10) as mentioned in the program. The algorithm was run for several combinations of parameters and the best combinations are selected as α = 0.5, β0 = 0.9, γ = 1. The optimum controller parameters values are shown in Table 1and 2.

Simulation Results:

The transmission line in between bus-1 and bus-2 is subjected to a three-phase (L-L-L-G) fault at the middle of the line at t = 1sec. The fault is clear at 100 ms. Further, the loading of power system model is subject to change for the verification of the performance of both damping controller as mentioned in Table 3.

Case 1: Nominal Loading:

Fig. 5 to 9 shows the responses for no controller, PID controller and L-L controller at different loading.

Extension To Mmps:

1. System under Study:

Fig. 10 shows a two area three machine system with SSSC. Following a disturbance Speed difference of generator G1 and G3 is chosen as input signal [Panda, *et al*., 2010].

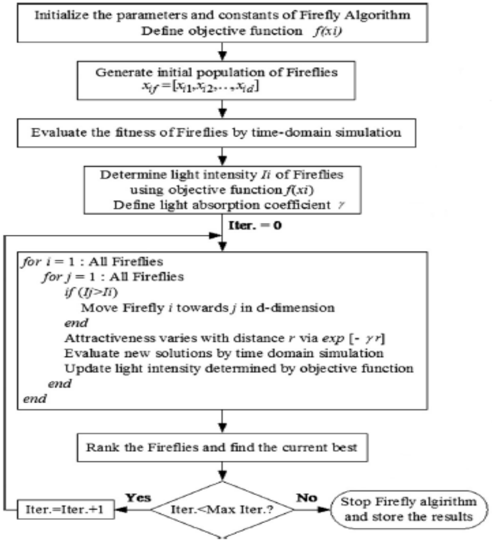

Fig. 4: Flowchart of FFA.

Table 1: Lead-lag damping controller parameters.

Method	K	T1	T2	T3	T4
FFA	69.4147	0.6459	0.5109	0.6241	0.8600

Table 2: PID damping controller parameters.

Method	Kp	Ki	Kd
FFA	93.5629	0.5630	0.9642

Table 3: Loading conditions.

Loading Conditions	Pe in per unit(pu)
Nominal	0.8
Light	0.6
Heavy	1.0

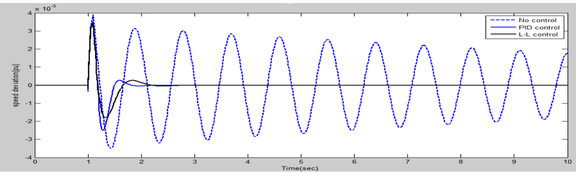

Fig. 5: Speed deviation with nominal loading.

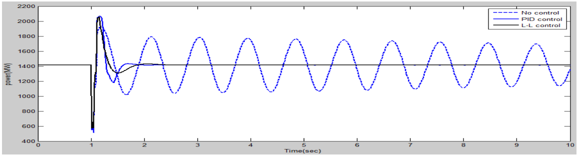

Fig. 6: Transmission line power flow with nominal loading.

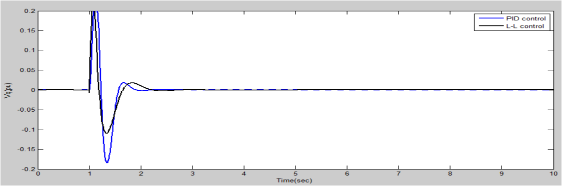

Fig. 7: SSSC injected voltage variation for nominal loading.

Case 2: Light Loading:

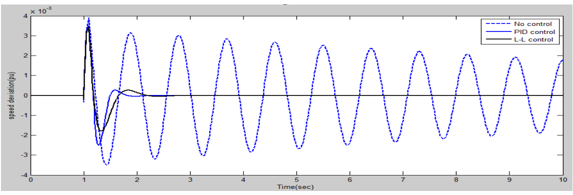

Fig. 8: Speed deviation response for light loading.

Case 3: Heavy Loading:

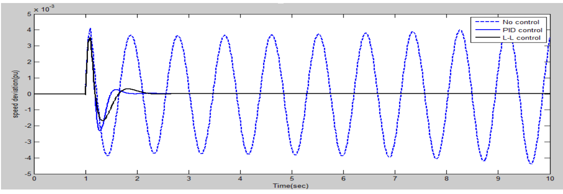

Fig. 9: Speed deviation response with heavy loading.

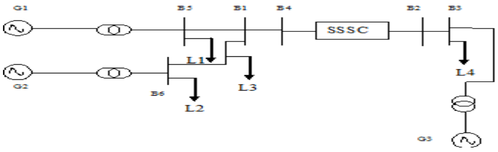

Fig. 10: A multi-machine power system with SSSC.

So the objective function J is the integral time absolute error (ITAE) of the speed difference and is expressed as:

$$J = \int_{t=0}^{t=tsim} \left(\sum|\Delta w_L| + \sum|\Delta w_I|\right) t.dt$$

(7)

Where Δw_L = speed deviation of local modes of oscillations

Δw_I= speed deviation of inter-area modes of oscillation.

tsim = simulation time period.

2. Implementation of FFA:

FFA is used to optimize the controller parameters for a population size of 10 and number of generation 10. The optimized lead-lag and PID controller parameters are listed in Table 4 and 5 respectively

3. Simulation Results:

To the tie-line between bus-2 and bus-3, a three phase fault (L-L-L-G) is applied at t = 1 sec and cleared at t = 1.1s. Fig. 11 and 15 show the response for no controller, PID controller and L-L controller. These responses prove the effectiveness and robustness of the both the controller and it is clearly evident that PID controller is more powerful then L-L controller for damping system oscillations.

Table 4: Lead-lag damping controller parameters.

Method	K	T1	T2	T3	T4
FFA	45.9146	0.3480	0.4345	0.4137	0.4455

Table 5: PID damping controller parameters.

Method	Kp	Ki	Kd
FFA	68.3595	0.4096	0.1280

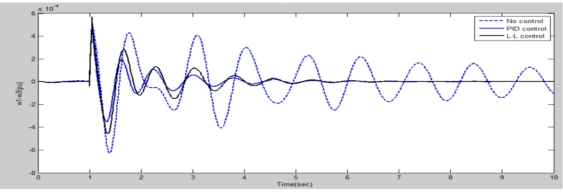

Fig. 11: Inter-area (w1-w3) mode of oscillation.

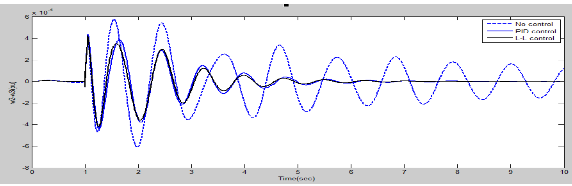

Fig. 12: Inter-area (w2-w3) mode of oscillation.

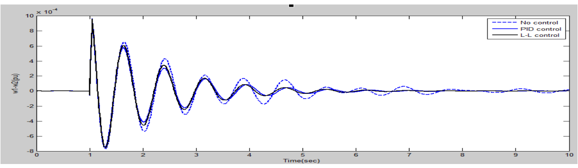

Fig. 13: Local mode (w1-w2) of oscillation.

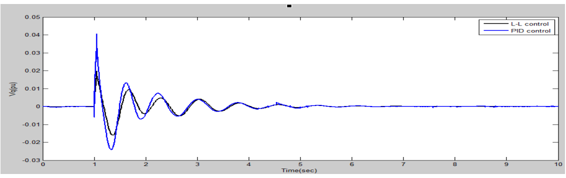

Fig. 14: SSSC injected voltage.

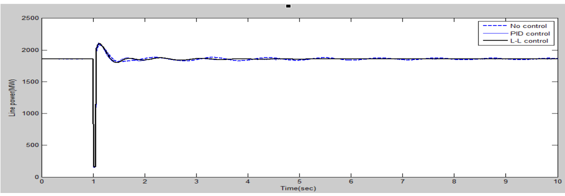

Fig. 15: Tie-line power.

Conclusion:

In this study, SSSC-based damping L-L and PID controller for both single and multi-machines are thoroughly investigated for enhancement of power system dynamic stability. For the design of the proposed controllers the integral time absolute error is used as the objective function which is need to be optimized. A non-linear optimization method known as fire-fly algorithm is used for optimal tuning of the controller parameters taking the constraints as limits of the parameters into consideration. The results showed that settling time and maximum overshoot of the PID damping controller is less in compared to that of a lead-lag damping controller. Hence it can be concluded as the PID damping controller is more effective to damp out power oscillations in compared to the lead-lag damping controller under different operating conditions.

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