2016 Second International Conference on Computational Intelligence & Communication Technology

A HARMONY SEARCH- FIREFLY ALGORITHM BASED CONTROLLER FOR DAMPING POWER OSCILLATIONS

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Abstract— **This paper analysed the power oscillations of a transmission system when subjected to disturbance. When a power system is followed by a fault the transmission line power as well as the rotor angle deviates from its steady state value leading to system instability. A HS-FA based damping controller used to damp out the power oscillations along with a static synchronous series compensator. The lead lag structure of the damping controller improves the stability of the system by injecting a compensating voltage through series compensator. A harmony search – firefly hybrid optimizing technique is used to tune the controller parameters. Integral of squared error (ISE) of the rotor speed deviation is considered for analysing the controller performance. Different disturbance conditions are analysed for verifying performance of the controller to damp out the power oscillations.**

***Keywords*— Static Synchronous Series Compensator (SSSC), Single Machine Infinite Bus (SMIB), Fire-Fly Algorithm (FFA), Harmony search (HS), proportional-integral-derivative controller (PID), Integral of time multiplied by Squared Error (ISE)**

I. INTRODUCTION

The transmission capability of a power system limits by a disturbance in the system leading to system instability. So a system losses its stability or attains its instability following any disturbance. Hence the stability of a power system is used to express instability [1]. Depending upon the duration of the system instability the there are different stability issues [2]. In this paper dynamic stability of a power system is analysed.

FACTS devices are the corner stone of modern technology for compensating the different stability problems. A series FACTS controller is capable of addressing the dynamic stability by operating as a series compensator [7]. Here SSSC is used to damp out the system oscillations. This series controller controls the transmission line reactive power by controlling the line reactance. It injects a compensating voltage which is independent of and in quadrature with the line current.

A damping controller is used to control the output voltage of the SSSC depending upon the system demand. There are several techniques employed by different authors for tuning of the controller parameters. From the results it is shown that the evolutionary optimizing techniques are the best techniques in compared to the conventional. Different optimization techniques already worked by different authors are: genetic algorithm (GA), particle swarm optimization (PSO), differential evolution (DE), neural network (NN), ant colony optimization (ACO), firefly algorithm (FA) and many more. Here the controller parameters are tuned by an evolutionary optimizing technique called as Harmony search- firefly algorithm (HS-FA). It is a hybrid firefly algorithm in association with harmony search which improves its performance. The following sections describe this technique in detail.

The controller design depends upon the choice of input signal which correctly damps out the power oscillations following a disturbance [10]. In this paper the damping controller takes the speed deviation of the synchronous generator when the system is subjected to a fault. Further different operating conditions are taken care of for analysing the controller performance.

II. SYSTEM UNDER STUDY

The system under study is shown in Fig. 1. It is a single machine power system connected to an infinite bus in association with SSSC.

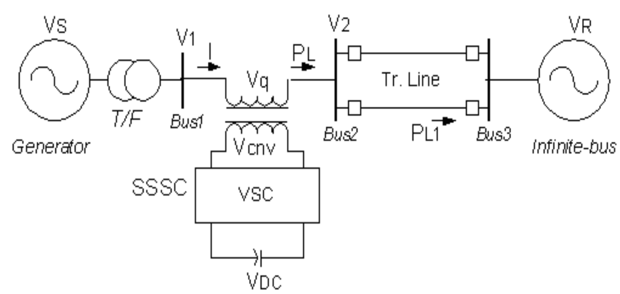

Fig.1. Single machine power system model

The system constitute of:

i) A synchronous generator

ii) A step-up transformer.

iii) A double circuited transmission line [3].

iv) A SSSC is connected in series to the transmission line. The SSSC behaves like a series capacitor or inductor which increases or decreases the line reactance according to the system requirement by injecting a compensating voltage to the transmission line in quadrature to the transmission line current. Therefore, controlling the transmission line power [8]

III. CONTROLLER STRUCTURE

978-1-5090-0210-8/16 $31.00 © 2016 IEEE
DOI 10.1109/CICT.2016.75

As shown in Fig. 2 damping controller has a PID structure. When a disturbance persists in a power system the rotor angle and the transmission line power deviates from its steady state value. Here the speed deviation is taken as the input signal to the controller, whose output is fed to the SSSC which compensates the deviations in the system bringing the system into its original steady state. The controller consists of i) a proportional block with constant (Kp) ii) an integral block with constant (Ki) iii) a derivative block with constant (Kd).

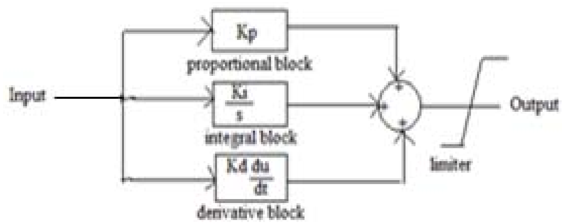

Fig.2. Lead-Lag damping controller

A. Problem formulation

The objective of the controller is to minimize the power system oscillations hence improving the power system stability [4]. So the objective function is to minimize the signal where power oscillations are observable. In this paper the Integral of squared error (ISE) of the rotor speed deviation is considered for analysing the controller performance as expressed in eq. (1).

$$J = \int_0^{tsim} |\Delta w| 2.t.dt \quad (1)$$

In order to reduce the settling time and overshoot the objective function need to be minimized [9]. Hence the optimization problem for the present study can be designed along with the constraints on the controller parameter as follows:

Minimize J
Subject to
$K_{pmin} <= K_p <= K_{pmax}$
$K_{dmin} <= K_d <= K_{dmax}$
$K_{imin} <= K_i <= K_{imax}$ (2)

IV. HS-FA ALGORITHM

This algorithm is a hybridization of Firefly (FA) and Harmony search (HS) algorithm.

A. Firefly algorithm

In 2008 Yang [5] introduced FA which is inspired by bioluminescence process of firefly to attract mating partners and potential prey. The factors by which the fireflies are attracted to each other in a given search space by producing a rhythmic light are:

a) Distance (R): Distance between two fireflies I and J

$$R = ||x_i - x_j||^2 \quad (3)$$

Where, X_I = position of I^{th} firefly
X_J = position of J^{th} firefly

b) Attractiveness coefficient (β_i): Which expressed by eq. 4

$$\beta_{IJ} = \beta_0 exp\text{-}(\gamma_{IJ}R)^2 \quad (4)$$

Where, $\beta_0 = \beta_{IJ}$ at distance R = 0.

c) Absorption coefficient (γ_{IJ}): The intensity by which the air absorbs the light produced by the fireflies.

d) Light intensity (I_I): Itensity of light produced by I^{th} firefly expressed by eq. (5)

$$I_I = I_0 \exp -(\gamma_{IJ}R) \quad (5)$$

The assumptions taken into considerations in the given problem for the system under study are:

- Each firefly in a given search space attract towards each other [6].
- The brightness (I_i) decides the attractiveness of a fire-fly directly in a given search space.
- The distance (r_i) decides the attractiveness inversely in a given search space.
- If there is no brighter firefly found in the given search space then all fire-fly attracted to each other in a random fashion.
- The intensity of light determines the objective function to be optimized [14].

In the given search space let intensity of J^{th} firefly is more than intensity of I^{th} firefly then I follows the J firefly according to the eq. (6).

$$X_I^{t+1} = X_I^t + \beta_0 exp\text{-}(\gamma_{IJ}R)^2 (x_I^t - x_J^t) + \alpha_I^t \quad (6)$$

Where, t is the iteration number and α_I^t is a random variable drawn from a Gaussian distribution.

B. Harmony search algorithm

This algorithm based on process of improvisation of music players which includes the following optimization parameters [13]:

HM: harmony memory
HMS: harmony memory size
HMCR: harmony memory consideration rate
PAR: pitch adjustment rate
BW: pitch adjustment bandwidth

For a player the feasible options are:
a) Play several pitches from HMCR
b) Play some known pitches
c) Play some improvised pitches
Pitch adjustment follows the following rules:

Rule1: If rand<HMCR
$X_{new}(d) = X_r(d)$ where r=(1,2,…….HMS) (7)

Rule2: If rand<PAR

$$X_{new}(d) = X_{old}(d)+BW*(2*rand-1) \quad (8)$$

Rule3: else

$$X_{new}(d) = X_{min}(d)+rand*(X_{max}(d)-X_{min}(d)) \quad (9)$$

C. HS-FA algorithm

In this hybrid algorithm the harmony search algorithm explore the search space and the firefly algorithm exploit the solution reducing the complexity [12]. It selects some brightest firefly to form KEEP i.e. top fireflies. If KEEP is equal to the number of fireflies then it works like standard firefly algorithm. If KEEP is very small it leads to premature convergence. So here KEEP = 2. In standard FA if intensity of I^{th} firefly is less then intensity of J^{th} firefly then it move towards J^{th} firefly and update the intensity. If not then I^{th} firefly does nothing. In this hybrid algorithm the worst firefly is improved by mutation process following the rules in harmony search algorithm. Fig. 3 shows the flowchart of a HS-FA algorithm.

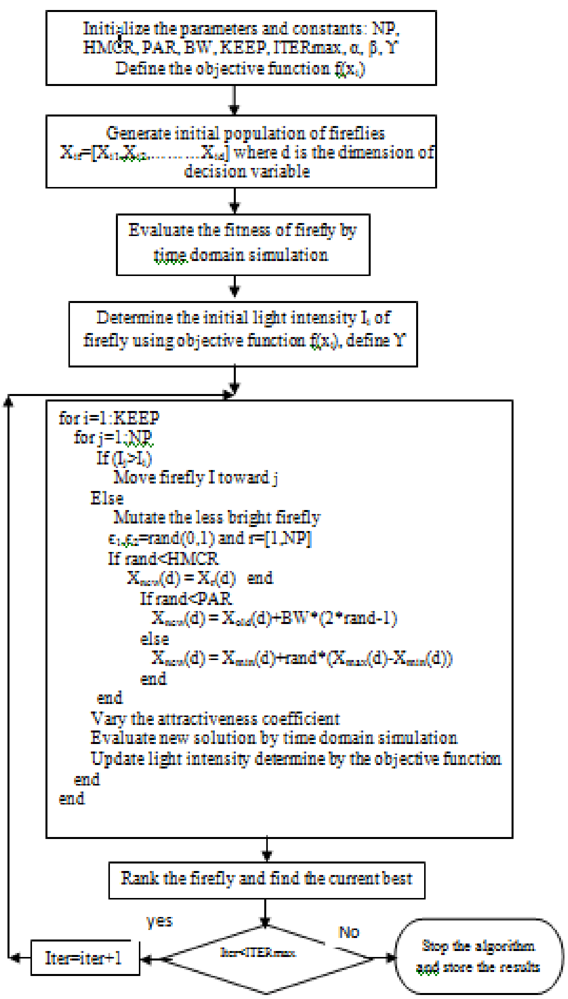

Fig.3. Flowchart of HS-FA algorithm

V. ANALYSIS OF RESULTS

The HS-FA program has been written in the MATLAB 7.10.0 .m file. The power system model under study is developed in SIMULINK environment. The simulation is done for every firefly in the search space for computing the objective function. The parameters of FFA are set as $\alpha = 0.5$, $\beta_0 = 0.9$, $\gamma_{IJ} = 1$, HMCR = 0.9, PAR = 0.1, BW = 0.2, KEEP = 2, ITERmax = 10, NP = 10. The best among the 20 runs is shown in Table 1.

Table 1. PID controller parameters

Technique	K_p	K_i	K_d
Standard FA	60.9642	0.8939	0.4203
HS-FA	95.3534	0.7043	0.2904

For the validation of the proposed controller different loading conditions are considered.

(i) Nominal loading (Pe = 0.8 p.u.)
(ii) Heavy loading (Pe = 0.97 p.u.)
(iii) Light loading (Pe = 0.57 p.u.)

The response of the controller is analysed for the following cases for validating the controller output:

- Case-1: No controller response (dashed line).
- Case-2: Standard FA optimized response of SSSC-based damping controller (blue lines) [11].
- Case-3: Hybrid HS-FA optimized response of SSSC-based damping controller (black lines).

A. L-L-L fault at nominal loading

A three phase fault is applied in between bus 2 and 3 with nominal loading, P_e = 0.8 p.u at 1 sec. The response of the system is shown for no controller, with standard FA based controller and with HS-FA based controller in Fig.5. (a) – (c). The system is regaining its original state at 1.1sec.

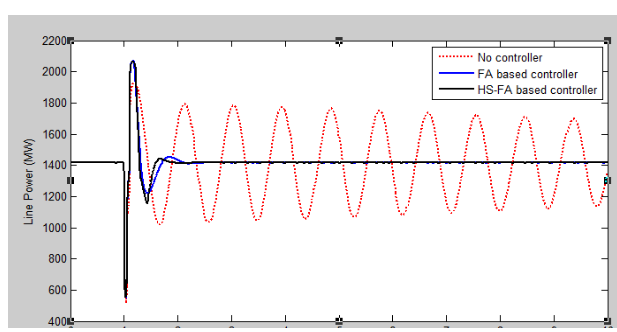

Fig.5. (a) Transmission Line power for nominal loading

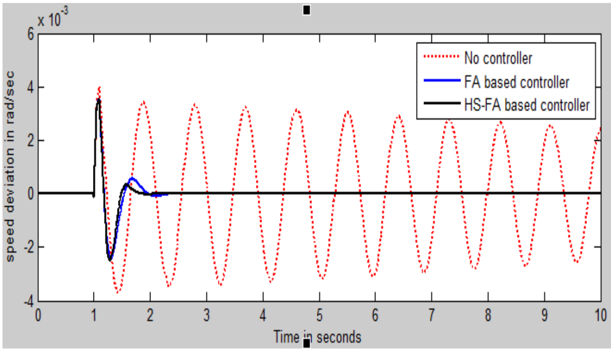

Fig.5. (b) Deviation in rotor speed for nominal loading

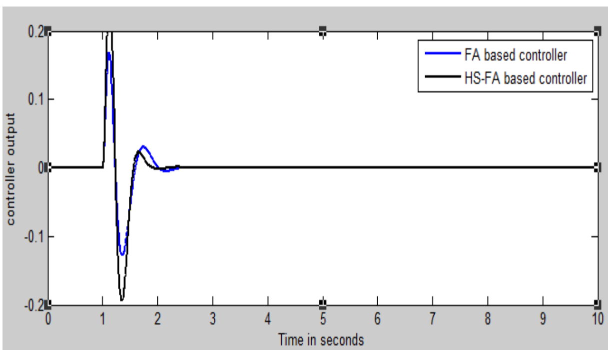

Fig.5. (c) Controller output for nominal loading

B. Three phase fault at heavy loading

A three phase fault under heavy loading, Pe = 0.97 p.u. condition is applied in between bus 2 and 3. The responses for different cases are shown in Fig.6. (a) - (c).

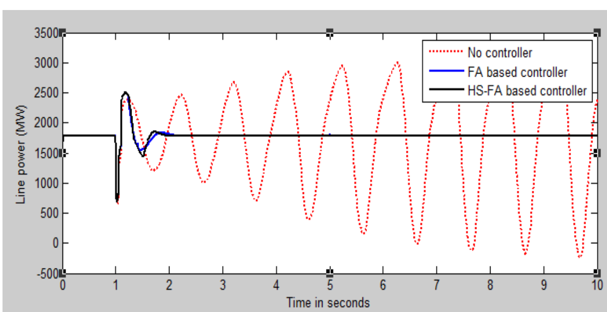

Fig.6. (a) Transmission line power for heavy loading

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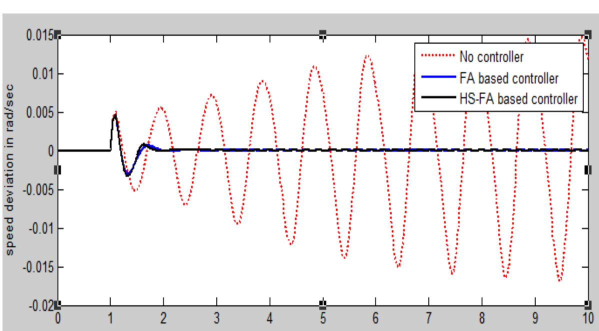

Fig.6. (b) Deviation in rotor speed for heavy loading

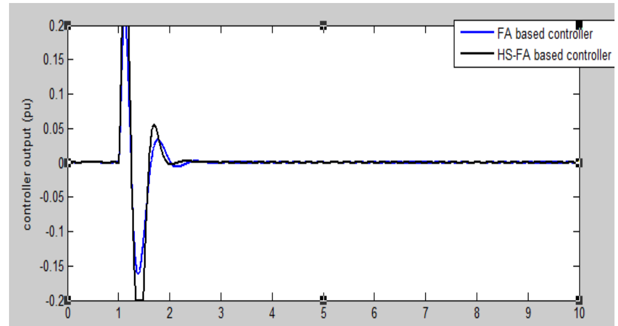

Fig.6. (c) Controller output for heavy loading

C. Three phase fault a light loading

A three phase fault under light loading condition, Pe = 0.57 p.u. is applied in between bus 2 and 3 at 1sec.the response of the system for different cases are shown in Fig.7. (a) - (c).

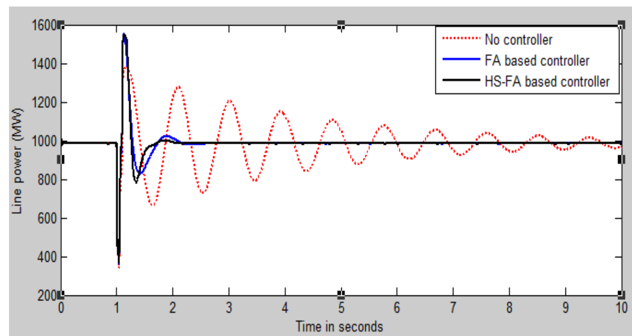

Fig.7. (a) Transmission line power for light loading

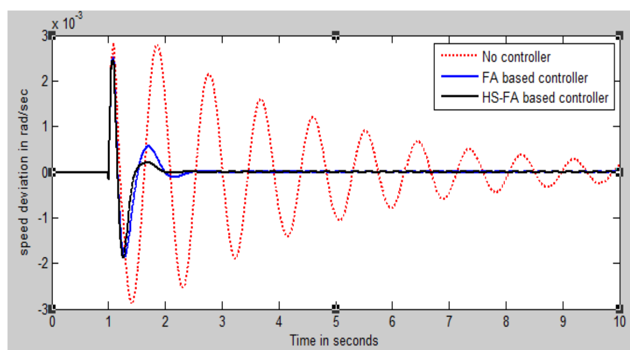

Fig.7. (b) Deviation in rotor speed for light loading

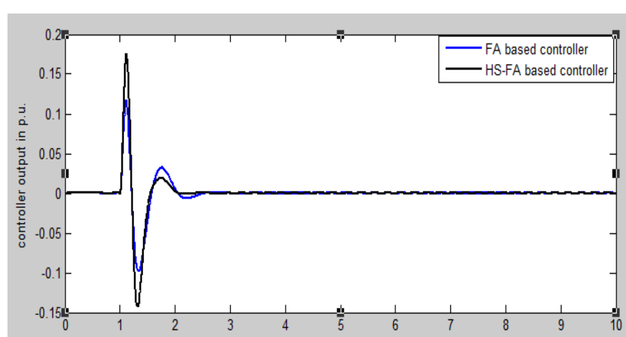

Fig.7. (c) Controller output for light loading

VI. CONCLUSIONS

A HS-FA algorithm is used to design a SSSC based damping controller. The proposed damping controller performs satisfactorily to improve the dynamic stability of the system in terms of the settling time and peak overshoot. In addition to this the controller also compensates the line power flow as well as the rotor angle deviation under severe disturbance conditions. Again the validation of the proposed controller performance is done at different disturbances. The results show that the performance of the proposed controller is better than the controller tuned by standard FA algorithm. Hence it is concluded that the HS-FA based damping controller performs effectively.

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