Power System Stability Analysis of SMIB with FOPID using Cuckoo Search Optimized Differential Evaluation

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Abstract

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. Cuckoo Search (CS) Optimized Differential Evaluation (DE) approach is used for the parameter tuning of the stabilizer. The efficiency of proposed approach is observed by rotor angle and power angle deviations in the SMIB system.

Keywords:AVR, Cuckoo Search, DE, FOPID, PSS, SMIB.

1. Introduction

Nowadays, stability studies in electric power systems have taken great importance, and how they influence the different devices that compose it, such as: The topology of the network, the different types of loads, HVDC links and SVCs, the synchronous machines and the different devices associated to each of these, such as AVR (automatic voltage regulators), PSS (power system stabilizers), turbine and governor systems. With the aim of increasing the reliability and safety of the electrical system. And therefore reduce the costs and losses associated with generalized or partial blackouts throughout the network or isolation in the form of islands in different sectors of the system [1].

The instability causes financial expenses both for the users and for the companies that provide the electric service. These expenses are the result of the failure to provide electrical service, the deterioration and frequent maintenance of the equipment. Then the operating companies need to take the necessary actions to ensure the stability of the electrical system, and also be reliable and safe. For this reason, studies of the stability of an electrical power system must be carried out to determine the scope and costs of the electrical system required for the adequate provision of the service.

The main contribution of this project is to develop a tool that can be used on a recurring basis and that simulates the effects that occur in the synchronous machine when exposed to small disturbances of the electrical network.

The above is achieved using the model of the state space of the machine connected to an infinite bus, this model being linearized, since for the purpose of studying stability in small signals, the perturbations are considered small enough to allow the line to be aligned. System of equations and the models of the system components around the pre-disturbance operation point.

Under the same operating conditions (e.g. the same network topology) of the synchronous machine, but with different devices (AVR, PSS) acting on it, the machine will work at different operating points and may have a different form of instability in each case [2].

2. Power System Stability

The stability of a power system is the ability of the electric power system, for given the initial conditions of operation, to recover the state of equilibrium operation, after being subjected to a physical disturbance [3, 4].

The power system is a highly non-linear system that operates in an environment of constant change; the loads, generators and operation parameters change continuously. When subject to a disturbance, the stability of the system depends on the initial conditions of operation, as well as on the nature of the disturbance [5].

An Electrical Power System (EPS) is subject to a wide range of disturbances, small and large. Small disturbances in the form of changes in charge occur continuously; the system must have the ability to adjust to changing conditions and operate satisfactorily [6]. The system must also be able to survive numerous severe disturbances, such as a short circuit in a transmission line or loss of an important source of generation. A large disturbance can

cause structural changes due to the isolation of the failed elements as a result of the action of the protection relays.

A power system can be stable for a given physical disturbance, and be unstable for another. It is impractical and it is not economically viable to design a power system to withstand all possible faults and / or disturbances. The studies of power systems, identify the supportability of the system for a group of contingencies selected based on a reasonable probability of occurrence of them [7].

Likewise, to guarantee the safety of the EPS, it is a common practice in the electrical industry, the use of complementary protection schemes that act as backup in the system; to unlikely and / or severe contingencies.

The EPSs are constantly experiencing fluctuations of small magnitude. However, to evaluate the stability when the system is subjected to a specific disturbance, it is usually assumed that the initial condition of operation of the system is steady state. This hypothesis is valid taking into account that the variations are reasonably small. Some signal processing techniques are presented in [26-31] which can be useful in this contest.

2.1. Rotor Angle Stability

Figure 1(a) shows the steady state analysis of a system. A generator delivering power to a load through a transmission line, the load is a synchronous motor. The resistors and the capacitive effects of the network are neglected, the inductive reactance of the line is X_L, X_G and X_M are the synchronous reactances and E_G, E_M are the voltages in the excitation of the generator and the motor respectively [8, 9 10]. The power transferred from the generator to the motor is a function of the angular separation δ between the rotors of the two machines. This separation is due to three components: the internal angle of the generator δ_G (angular separation between the rotor of the generator that carries the rotating field and the stator); angular difference between voltage in terminals of the two machines (angular separation between the stator field of the generator and that of the motor); and the internal angle of the motor δ_M (angular separation between the rotor and the rotating field in the stator of the motor). From the equivalent circuit of Figure 1(b). It is solved for the current and then for the power and the function of the power is obtained in terms of the system parameters as shown in equation 1 [11]:
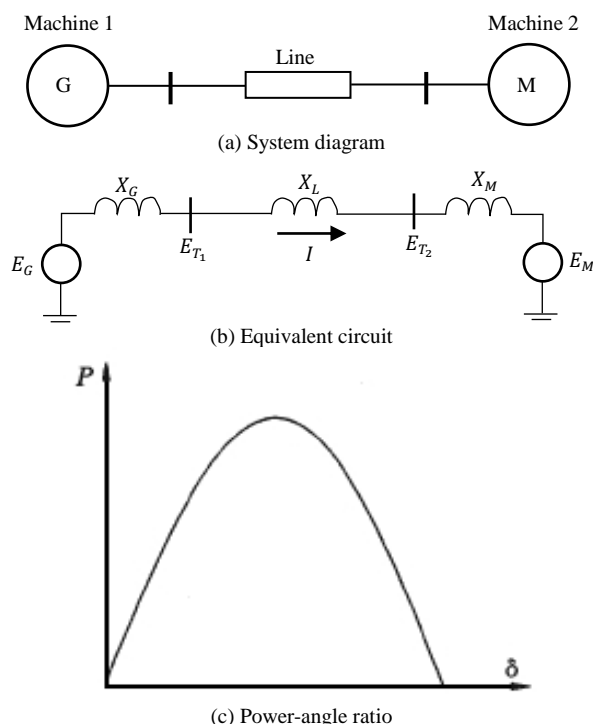
$$P = \frac{E_G E_M}{X_T} \sin \delta \qquad (1)$$

Where,

$$X_T = X_G + X_L + X_M \qquad (2)$$

2.2. Voltage Stability

It is the ability of a power system to keep the voltages in a steady state on all buses after having been subjected to a disturbance. Instability manifests as a progressive increase / decrease of the voltage in one or more buses [13].

Events that can lead to instability:

- Loss of load in an area or region.

- Shot of transmission lines or other elements leading to cascade outputs.

Loss of synchronism of some generators as a result of the output of these elements or an operation condition that violates the limits of the field current.

Main reasons for voltage instability (usually loads):

- The power consumed by the loads is re-established by:
  - Voltage regulators in distribution systems
  - Transformers with tap change
  - Loads controlled by thermostat

- Voltage instability occurs when the dynamics of the load tries to restore the power consumption beyond the capacity of the transmission network and the connected generation [14].

3. Stability Analysis of a Synchronous Machine Connected to an Infinite Bus

In this section the behaviour in small signal of a synchronous machine connected to a large electrical power system is studied. Initially, the classical model will be presented and gradually the degree of detail will be increased, including the dynamic effects of the field circuit, the excitation system and the damping [15].

In general, a synchronous machine is linked to the system through transformers and transmission lines, and it can also have loads or devices connected to it as reagent compensators. In general, the configuration that is adjacent to the machine before being connected to the electrical network can be represented by means of an equivalent Thevenin circuit. This resulting system is shown in Figure 2.
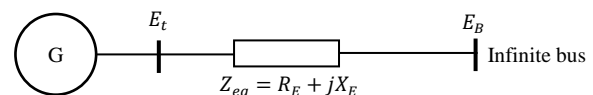

Fig. 2: Equivalent system of a machine connected to the electrical network [16]

Due to the magnitude of the system to which power is being delivered, the dynamics associated with the machine will not cause changes to the frequency and voltage of the infinite bus E_B. Such a source of voltage and constant frequency is known as an infinite bus.

For a given condition, when the machine is disturbed the magnitude of the voltage on the infinite bus E_B remains constant. However, as the steady state conditions in the system change, the mag-

(a) System diagram

(b) Equivalent circuit

(c) Power-angle ratio
Fig. 1: Power transfer characteristic of a two-machine system [12]

nitude of E_B may change, representing a change in the operating conditions of the external network.

Classic Model: When applying to the equivalent system of Figure 2 the classical model of the synchronous machine, and taking the value of the resistances as negligible, we obtain the representation of the system in the manner shown in Figure 3. In this it is assumed that the magnitude of the voltage E' remains constant at its pre-disturbance value. And we have that δ is the angle by which E' is ahead of the voltage on the infinite bus E_B, during a disturbance δ it changes by the oscillations of the rotor.
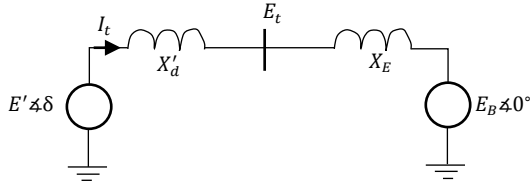

Fig. 3: System with the classic model [17]

With the phasor E' as a reference, the circuit yields:

$$I_t = \frac{(E' \angle 0°) - (E_B \angle - \delta)}{jX_T} - \frac{E' - E_B(\cos\delta - j\sin\delta)}{jX_T} \tag{3}$$

Where,

$$X_T = X'_d + X_E \tag{4}$$

The apparent power delivered by the transient excitation is:

$$S' = P + jQ' = \vec{E}'\vec{I}_t^* = \frac{E'E_B \sin\delta}{X_T} + j\frac{E'(E' - E_B\cos\delta)}{X_T} \tag{5}$$

The armature resistance must be neglected, the power delivered by the machine is equal to the power in the air gap, and that this in turn in per unit is equal to the torque in the air gap. Thus:

$$M_e = P = \frac{E'E_B}{X_T}\sin\delta \tag{6}$$

Linearizing the above equation around an initial condition of operation represented by $\delta = \delta_0$, leads to:

$$\Delta M_e = \frac{\partial M_e}{\partial \delta}\Delta\delta = \frac{E'E_B}{X_T}\cos\delta \, (\Delta\delta) \tag{7}$$

Returning to the equations of motion in per unit:

$$p\Delta\omega_r = \frac{1}{2H}(M_m - M_e - K_D\Delta\omega_r) \tag{8}$$
$$p\delta = \omega_0\Delta\omega_r \tag{9}$$

Where $\Delta\omega_r$ is the deviation of the speed in per unit, δ is the angle of the rotor in electric radians measured from the reference E_B, ω_0 is the base speed of the rotor in electric radians per second, and p is the differential operator d/dt with time t in seconds.

Linearizing equation (8) and substituting equation (7) we obtain [18]:

$$p\Delta\omega_r = \frac{1}{2H}(\Delta M_m - K_S\Delta\delta - K_D\Delta\omega_r) \tag{10}$$

Where K_S is the coefficient of the synchronization pair given by:

$$K_S = \left(\frac{E'E_B}{X_T}\right)\cos\delta_0 \tag{11}$$

Linearizing equation (9) we get:

$$p\Delta\delta = \omega_0\Delta\omega_r \tag{12}$$

The matrix form of equations (10) and (12) is:

$$\begin{bmatrix} \Delta\dot{\omega}_r \\ \Delta\dot{\delta} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & 0 \end{bmatrix}\begin{bmatrix} \Delta\omega_r \\ \Delta\delta \end{bmatrix} + \begin{bmatrix} b_1 \\ 0 \end{bmatrix}[\Delta M_m] \tag{13}$$

Where,

$$a_{11} = -\frac{K_D}{2H}; a_{12} = -\frac{K_S}{2H}; a_{21} = \omega_0; b_1 = \frac{1}{2H}$$

Equation (13) has the form of $\dot{x} = Ax + bu$. And the state matrix A depends on the system parameters K_D, H, X_T, and the initial operating conditions given by the values E' and δ in Figure 4.
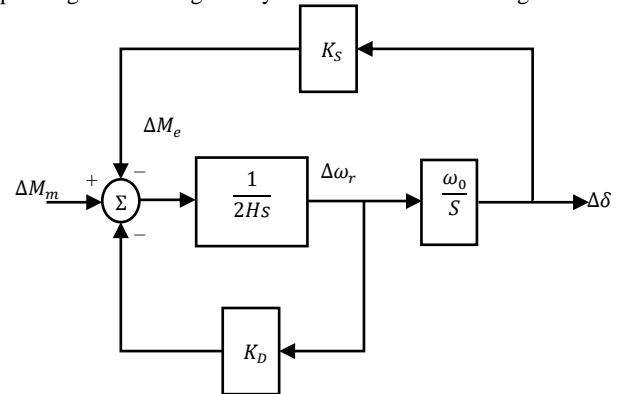

Fig. 4: Block diagram of a machine connected to an infinite bus [19]

From the block diagram we have:

$$\Delta\delta = \frac{\omega_0}{s}\left[\frac{1}{2Hs}(-K_S\Delta\delta - K_D\Delta\omega_r + \Delta M_m)\right]$$

$$= \frac{\omega_0}{s}\left[\frac{1}{2Hs}\left(-K_S\Delta\delta - K_Ds\frac{\Delta\delta}{\omega_0} + \Delta M_m\right)\right] \tag{14}$$

On ordering we get:

$$s^2(\Delta\delta) + \frac{K_D}{2H}s(\Delta\delta) + \frac{K_S}{2H}\omega_0(\Delta\delta) = \frac{\omega_0}{2H}(\Delta M_m) \tag{15}$$

So the characteristic equation is:

$$s^2 + \frac{K_D}{2H}s + \frac{K_S\omega_0}{2H} = 0 \tag{16}$$

Equation (16) is equivalent to the general characteristic equation of a second order system.

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0 \tag{17}$$

Therefore, the natural frequency is not dampened and the damping ratio is:

$$\omega_n = \sqrt{K_S\frac{\omega_0}{2H}}[rad/s] \tag{18}$$

$$\zeta = \frac{1}{2}\frac{K_D}{\sqrt{K_S 2H\omega_0}} \tag{19}$$

From equations (18) and (19) it is observed that as K_S increases it also does the natural frequency and the buffer ratio decreases. On the other hand, an increase in K_D increases the buffer ratio. And an increase in constant of inertia causes both ζ and ω_n to decrease.

4. Power System Stabilizers (PSS)

Among the problems that affect the quality of electrical energy is the oscillatory instability of synchronous machines. To maintain stability, supplementary excitation controls are used, including Power System Stabilizers (PSS). This sub-heading presents the implementation of a PSS through the use of an adaptive technique,

to overcome some of the problems of instability in the event of disturbances caused by variation in the load or the reference voltage. As a result, the tests carried out on a real prototype are described, which allow observing the good behaviour of the PSS. The applicability and efficiency of the method proposed here are shown by the experimental validation of the theoretical postulates.

Since the purpose of a PSS is to introduce a component to the damping torque, the appropriate signal to control the excitation of the generator is the deviation of the speed $\Delta\omega_r$. The above is illustrated in the block diagram of Figure 5.
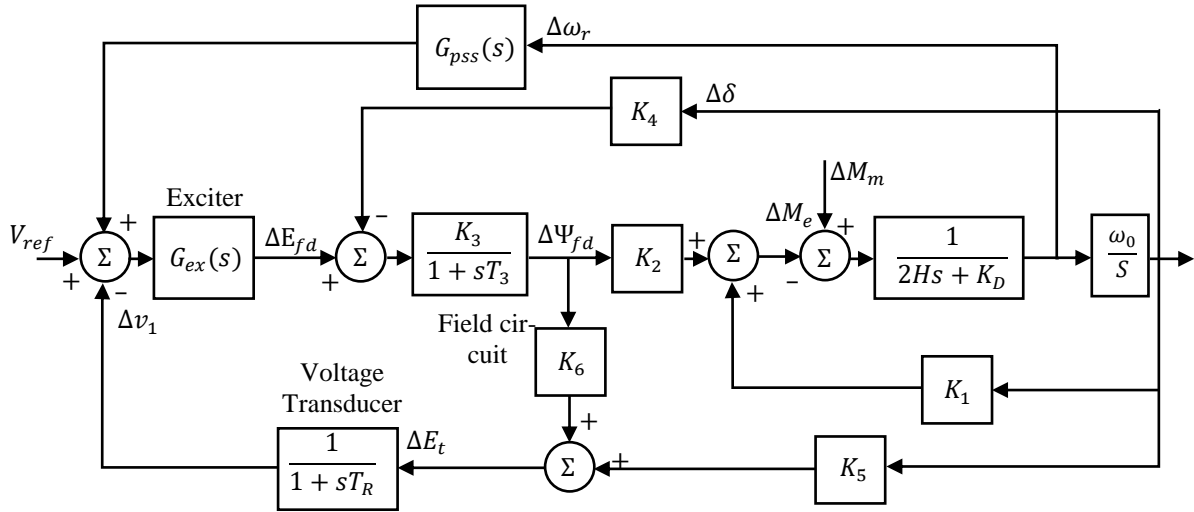

Fig. 5: Representation in block diagram of the system with AVR and PSS [18]

If the transfer function of the exciter $G_{ex}(s)$ and the transfer function between ΔE_{fd} and ΔM_e are pure gains, a direct feedback of $\Delta\omega_r$ results in a component of the damping torque. But in practice these gains are frequency dependent and have phase characteristics. Therefore, the PSS has a circuit to compensate for the phase delay between the output of the exciter and the electric torque.

Now we consider the model structure of the thyristor excitation system with AVR and PSS that is shown in figure 6, this does not show the limits to the output of the stabilizer and the exciter since it is not of interest in the behavior in small sign. Below is a brief description of the bases for the configuration of the PSS and considerations in the selection of the parameters:
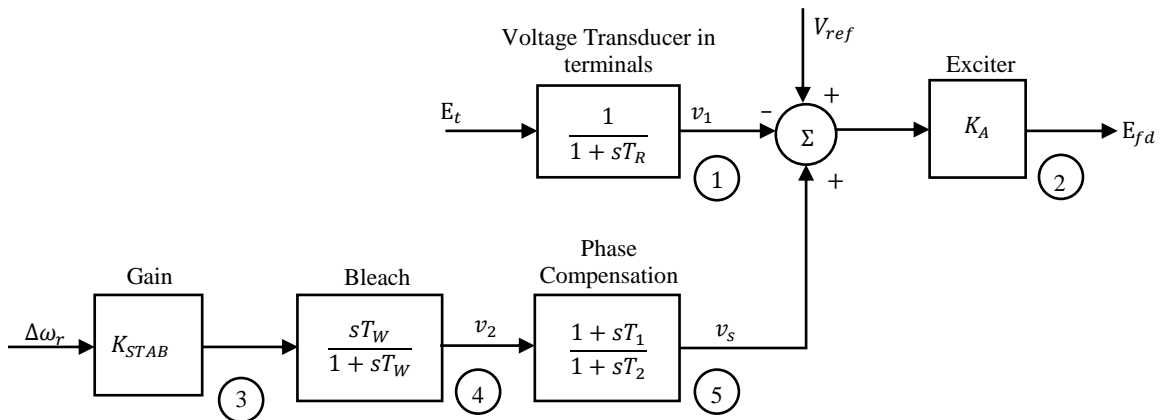

Fig. 6: Excitation system with AVR and PSS [18]

As shown in Figure 6, the PSS is composed of three blocks: a phase compensating block, a signal bleaching block, and an amplification or gain block.

The phase compensation block provides a phase advance to the signal v_2 to compensate for the delay between the input signal to the exciter and the torque in the air gap. Figure 6 shows a simple case of a single block of first order, but in practice two or more blocks of first order cascade can be used to achieve the required phase compensation. One can also use blocks of second order with complex roots.

The frequency range of interest is 0.1 to 2.0 Hz, the phase compensation circuit must provide phase advance over this entire frequency range, since the phase characteristics that must be compensated change with the system conditions. The signal bleaching block acts as a high pass filter, with the time constant T_W high enough to allow signals associated with the oscillations in ω_r go through unchanged. Without it constant changes in speed they could modify the voltage in terminals. From the point of view of the bleaching function, the value of T_W is not critical and can range from 1 to 20 seconds. The stabilizer gain K_{STAB} determines the amount of damping introduced by the PSS. Ideally the gain

could be set to a value corresponding to the maximum damping, but this is limited by other considerations in the system [19].

5. Proposed Methodology

5.1. 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:

$$u(t) == K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{d}{dt}e(t) \qquad (20)$$

Equation (20) 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 [19]:

$$G_c(s) = K_P + K_I s^{-\lambda} + K_D s^\mu, \quad \lambda, \mu > 0 \qquad (21)$$

The differential equation for the $PI^\lambda D^\mu$ controller in the time domain is given by [20]:

$$u(t) = K_P e(t) + K_I D^{-\lambda} e(t) + K_D D^\mu e(t) \qquad (22)$$

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 DE and Cuckoo Search 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 [21].
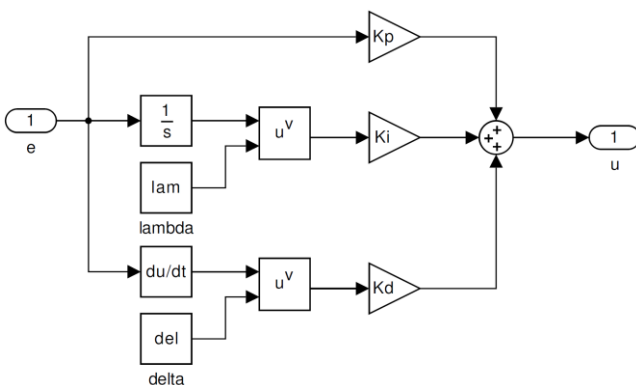Figure 7 and Figure 8 show Simulink models for proposed FOPID and SMIB-FOPID systems respectively.

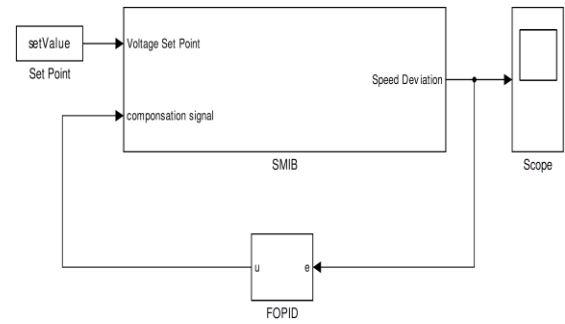**Fig. 7:** Simulink Model for FOPID

Fig. 8: Simulink Model for SMIB with FOPID

5.2. Cuckoo Search Optimized Differential Evaluation

This method was developed by Rainer Storn and Kenneth Price in 1997 [22]. The main idea of this optimization technique is to use the difference between two random vectors to generate a new solution vector. For each solution in the original population, a desired solution is generated by performing the crossover procedure. The old (parent) solutions and the new ones are compared and the best ones will appear in the next generation. So like all other evolutionary techniques, the DE algorithm will perform the following steps:
Step 1: The initial population generation which consists in creating an initial population vector of N_p individuals (solutions). The initial population is intended to give birth to successive generations. The initial population vector is randomly selected as follows [23]:

$$X_{j,i}^G = X_{jmin} + rand[0.1] \times (X_{jmax} - X_{jmin}) \qquad (23)$$
$$i = 1,2, \ldots . N_p \; ; j = 1,2, \ldots N_p$$

Where,
N_p: Number of individuals (population size); N_p: Number of parameters of the objective function; $rand$: random numbers distributed uniformly over the set [0,1].
Step 2: The mutation that is seen as the first step towards generating new solutions. A mutation vector $V_i^{(G+1)}$ is generated using the following formula:

$$V_i^{(G+1)} = X_a^G + F \times (X_b^G - X_c^G)$$
$$\qquad (24)$$

Where: x_a, x_b and x_c are vectors randomly selected with $a \neq b \neq c \neq i$. F is the scaling constant used to adjust the disturbance size in the mutation operator and is determined by the user, and its typical value is in the interval (0.4, 1) [23].
Step 3: The crossing, which is applied to the population of the vector resulting from mutation and the population of the parent vector (initial population), where a new vector called the desired vector is generated. The crossing operation is carried out according to the following criterion:

$$U_{j,i}^{G+1} = \begin{cases} V_{j,i}^{G+1} & if \; (rand, [0,1]) \leq CR \\ X_{j,i}^G & if (rand, [0,1]) > CR \end{cases} \qquad (25)$$

Where: CR is the crossover factor which at a constant value between 0 and 1 also determined by the user. If $rand_j[0,1]$ is less than or equal to CR the new solution is a combination of the three vectors chosen randomly (x_a, x_b and x_c), otherwise this new solution is only the old solution (parents), as shows the Figure 9.

$$\begin{array}{ccc} Parent \, Vector & Test \, vector & Vector \, of \, mutation \\ X_{j,i}^G & U_{j,i}^{G+1} V_{j,i}^{G+1} & \end{array}$$
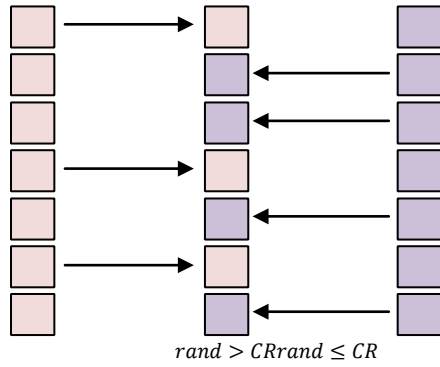
$$rand > CR \qquad rand \leq CR$$

Fig. 9: Crossing example (D = 7)

Step 4: The selection that must be applied to determine the individuals to participate in the next generation. Selection in DE is made by comparing the function of the vector of the initial population (parent vector) with the function of the test vector, and the one that gives better results must participate in the next generation. The new population must then replace the current population and a new loop will be launched.
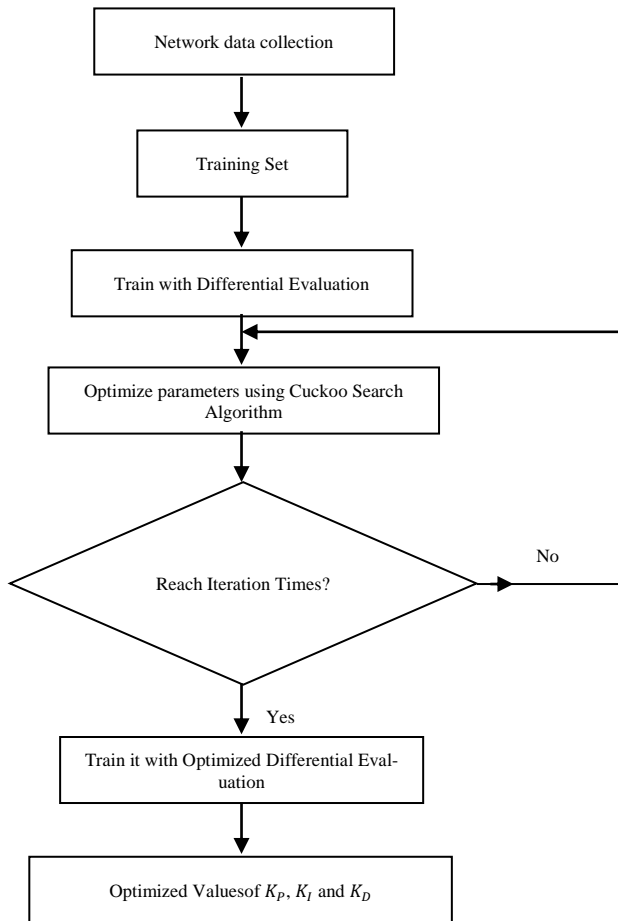
5.3 Optimization of Differential Evaluation

Fig. 10: Flow diagram for Cuckoo Search Optimized Differential Evaluation based model

5.4 Cuckoo Search (CS) Algorithm

Cuckoo Search (CS) is a recent metaheuristic [24] that is inspired by the reproduction pattern of some cuckoo species. In fact, their reproductive strategy is characterized by the fact that females lay their eggs in the nest of other species (whose eggs are similar). These eggs can then be hatched by surrogate parents. On the other

hand, when cuckoo eggs hatch in the host nest (they hatch more quickly), cuckoo chicks have the reflex to eject the host species eggs out of the nest and even mimic the cry of the host chicks for the purpose of being fed by the host species.

It may happen, however, that cuckoo eggs are discovered; in this case, the surrogate parents take them out of the nest, or abandon the nest and start their brood elsewhere. This metaheuristic is thus based on this parasitic behaviour of the species of cuckoos associated with a logic of displacement of the "Levy flight" type specific to certain birds and certain species of flies [25].

The CS algorithm is based on the following rules:

- Each cuckoo lays only one egg at a time and places it in a nest chosen randomly.
- The best nests with eggs (solutions) of high quality are kept for the next generations.
- The number of host nests is fixed and the egg laid by a cuckoo can be discovered by the host species with a probability $p_a \in [0, 1]$. In this case, the host bird either takes the egg out of the nest, or leaves the nest and builds a new one. For simplicity, this last hypothesis can be approximated by the replacement of a fraction pa of n nests by new ones.

Levy Flight is a random walk class in which jumps are distributed according to the Levy distribution which consists of a power law with infinite variance and mean of the type:

$$Levy(\beta) \sim y = x^{-\beta}, 1 < \beta \leq 3 \tag{26}$$

In the case of CS, the use of Levy Flight improves and optimizes the search: new solutions are generated by a random walk of Levy around the best solution obtained so far, which accelerates the overall search.

One of the simplest and most effective is to use Mantegna formulas to determine the pace [25]:

$$S = \frac{u}{|v|^{1/\beta}} \tag{27}$$

Where u and v are centered Gaussian distributions such as:

$$u = N(0, \sigma_u^2), \quad v = N(0, \sigma_v^2) \tag{28}$$

With,

$$\sigma_u^2 = \frac{\Gamma(1+\beta)\sin(\pi\beta/2)}{\Gamma((1+\beta)/2)\beta 2^{(\beta-1)/2}}, \quad \sigma_v^2 = 1 \tag{29}$$

Where $\Gamma(z)$ is the Gamma function.

$$\Gamma(z) = \int_0^{+\infty} t^{z-1} e^{-1} dt \tag{30}$$

Initialization of the algorithm

The initial population consists of an N_H number of host nests generated randomly in the search space. Recall that the number of host nests, cuckoos and eggs are equal.

Assuming that the ith host is represented by $X_i = (x_{i1}, \dots, x_{ij}, \dots, x_{in})$. Where n is the dimension of the problem, so each nest is generated by:

$$x_{ij} = X_{\min_j} + rnd(0,1)\left(X_{\max_j} - X_{\min_j}\right), j = 1, \dots, n, i = 1, \dots, N_H \tag{31}$$

The values of the corresponding cost functions are evaluated.

Description of the algorithm
Step 1: Global search
The first step is to do a global search. For this, we generate new cuckoo (solutions) tests from existing cuckoo (solutions) by making Levy Flight. This is to use the following evolution law for each cuckoo:

$$\left.\begin{array}{l} X_{new\,i} = X_i + \alpha \otimes Levy(\beta) \\ F_{new\,i} = f(X_{new\,i}) \end{array}\right\}, i = 1, \ldots, N_H$$

$$(32)$$

Where $\alpha > 0$ is the size of the displacement step which depends on the problem considered and such that $\alpha \approx O(L/10)$, where L is the characteristic scale of the problem considered. The $\otimes$ product is the term product term.

In order to know where / if the new i^{th} cuckoo is going to drop an egg, he chooses randomly a host nest $X_j(j \neq i)$ of cost function F_j. The new cuckoo pond if:

$$F_{new\,i} < F_j \qquad (33)$$

In this case, the solution $X_{new\,i}$ replaces the solution X_j in the population.

Step 2: Local search

New cuckoo eggs have a probability of being discovered.

If this is the case $(rnd(0,1) < p_a)$, new eggs are generated. Several methods can be envisaged for this. For CS, the following is the case where hybridization between elements of the randomly selected population is carried out:

$$\begin{array}{l} X'_{new\,ij} = x_{ij} + rnd(0,1)(x_{pj} - x_{mj}), j = 1, \ldots, n, i = 1, \ldots, N_H \\ F'_{new\,i} = f(X'_{new\,i}) \end{array}$$

$$(34)$$

Where $m \in \{1,2,3, \ldots, N_H\}$ and $p \in \{1,2,3, \ldots, N_H\}$ such that $p = m$ are randomly chosen.

A selection identical to that of the previous step is then performed.

Pseudo-code of the Algorithm

The simplified pseudo code of the algorithm is given below.

Generation of an initial population of N_H host nests X_i

As long as the stopping criterion is not satisfied, repeat:

  Generate a cuckoo by Levy Flight (32) and evaluate its cost function F_i,

  Randomly choose a nest X_j among the N_H host nests, if $F_i < F_j$

    Replace F_j with this new solution,

  End If

  A fraction p_a of the worst nests is dropped and others are generated instead (34), and make a selection.

  Identify the best X_{best} solution

End As long as

6. Experimental Setup

6.1. Simulation Parameters

a. Generator: $H = 3.5, M = 2H, TdO' = 7.76, D = 0, Xd = 0.973, Xd = 0.19, Xq = 0.55, Xe = 1.08$.

b. Excitation system: $KA = 200, TA = 0$.

c. Transmission line and Transformer: $= 0.0 + j0.8$ $(XL = j0.7, XT = 0.1)$

d. Field circuit: $K3 = 0.4494, T3 = 3.9336$.

e. SMIB K constants: $K1 = 0.5320, K2 = 0.7858, K4 = 1.0184, K5 = -0.0597, K6 = 0.5746$.

f. 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; KP, T1P, T2P, T3P and T4P. The parameters with subscript P shows they have a place with PSS Control.
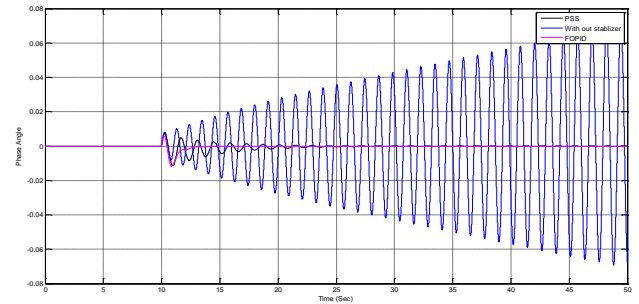
Table 1: Max. / Min. values measured for parameters

Parameter	Range
Kp	30-80
$T1p$	0.1-0.6
$T2p$	0.02-0.4
$T3p$	0.1-0.6
$T4p$	0.02-0.4

Table 2: Parameter utilized in Cuckoo Search algorithm

Parameter	Value
Population size	30
Maximum number iteration	100
Probability of discovery of alien egg	0.5
Beta	1.5
Alpha	1

6.2. Results

Fig. 11: Comparison of phase angle deviations in SMIB for PSS and CS-DE optimized FOPID
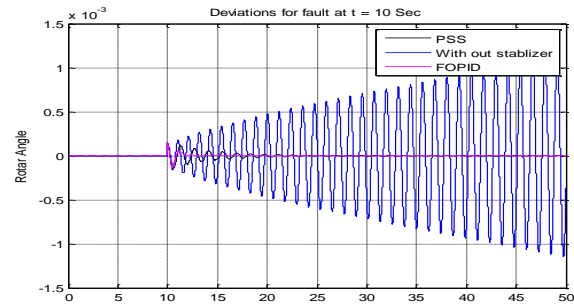
Fig. 12: Comparison of Rotor Angle Deviations in SMIB for PSS and CS-DE optimized FOPID

Above figures (11 and 12) shows the response of phase angle and rotor angle CS-DE optimized FOPID against an impulsive fault at t=10 second. The fault duration without controller extends to 50 sec, with PSS and CS-DE optimized 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.

7. Conclusion

This paper considered linearize Haffron-Philips model of single machine infinite bus system to investigate the instability generate in power system due to small signal disturbance and the elimination of this disturbance. 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 system uncertainties under different operating modes. The study presented in this paper deals with the application of Cuckoo Search optimized Differential Evaluation approach in the optimization of the FOPID parameters in the 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 the stabilizer gives stable study state.

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References

[1] Chen, Cheng-Wu. "Stability analysis and robustness design of nonlinear systems: an NN-based approach." Applied Soft Computing 11.2 (2011): 2735-2742.

[2] Díaz-González, Francisco, et al. "A review of energy storage technologies for wind power applications." Renewable and sustainable energy reviews 16.4 (2012): 2154-2171.

[3] Mostafa, Hossam E., et al. "Design and allocation of power system stabilizers using the particle swarm optimization technique for an interconnected power system." International Journal of Electrical Power & Energy Systems 34.1 (2012): 57-65.

[4] Bevrani, Hassan, Takashi Hiyama, and Hossein Bevrani. "Robust PID based power system stabiliser: design and real-time implementation." International Journal of Electrical Power & Energy Systems 33.2 (2011): 179-188.

[5] Saha, Anulekha, Priyanath Das, and Ajoy Kumar Chakraborty. "Performance analysis and comparison of various FACTS devices in power system." International Journal of Computer Applications 46.15 (2012): 9-15.

[6] de Dieu Nguimfack-Ndongmo, Jean, et al. "A simplified nonlinear controller for transient stability enhancement of multimachine power systems using SSSC device." International Journal of Electrical Power & Energy Systems 54 (2014): 650-657.

[7] Panda, Sidhartha, and Ramnarayan N. Patel., "Improving power system transient stability with an off-centre location of shunt FACTS devices", Journal of Electrical Engineering-Bratislava-57, no. 6, 2006.

[8] Ali M. Youcef, Ahmed M. Kassem "Optimal Power System Stabilizer Based Enhancement Of Synchronizing And Damping Torque Coefficient", Vol7, April 2012.

[9] Balwinder Singh Surjan, Ruchira Garg P, "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.

[10] F. S. Al-Ismail, M. A. Abido "The Impact of STATCOM Based Stabilizers on Power System Stability, Using Intelligent Computational Optimization Approach", 2011 IEEE.

[11] Sidhartha Panda and Narayana Prasad Padhy "MATLAB/SIMULINK Based Model of Single- Machine Infinite-Bus with TCSC for Stability Studies and Tuning Employing GA", International Journal of Electrical and Electronics Engineering 2007.

[12] Ali H. Ahmad, Ahmed A. Abdelqader "Power System Stabilizer Design Using Real-Coded Genetic Algorithm", 2011 2nd International Conference on Control, Instrumentation and Automation.

[13] M. A. Abido, Y. L. Abdel-Magid, "Analysis and Design of Power System Stabilizers and Fact Based Stabilizers Using Genetic Algorithms", devilla, 24-28 June 2002.

[14] A. Al-Hinai, Membre, IEEE "Dynamic Stability Enhancement Using Genetic Algorithm Power System Stabilizer", 2010 IEEE.

[15] Mahdiyeh Eslami, Hussain Shareef and Azah Mohamed, "Optimal Tuning of Power System Stabilizers Using Modified Particle Swarm Optimization", Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, Paper ID 184.

[16] M. A. Abido, "Optimal design of power–system stabilizers using particle swarm optimization", IEEE Trans, On Energy Conversion, 17(3) (2002)406-413.

[17] E.V. Larsen and D.A. Swann, Applying power system stabilizers part-II: Performance Objectives and Tuning Concepts, IEEE Trans. Power App. Sys, 100 (6) (1981) 3025-3033.

[18] Anders Hammer, "Analysis of IEEE Power System Stabilizer Models", Master of Science in Electric Power Engineering, Norwegian University of Science and Technology Department of Electric Power Engineering, June 2011.

[19] Ahmad, Ali H., and Ahmed A. Abdelqader. "Power system stabilizer design using real-coded genetic algorithm." 2nd International Conference on Control, Instrumentation and Automation (ICCIA), pp. 25-31, 2011.

[20] Pan, Indranil, and Saptarshi Das. "Frequency domain design of fractional order PID controller for AVR system using chaotic multi-objective optimization." International Journal of Electrical Power & Energy Systems 51 (2013): 106-118.

[21] Chaib, L., Choucha, A. and Arif, S., 2017. Optimal design and tuning of novel fractional order PID power system stabilizer using a new metaheuristic Bat algorithm. Ain Shams Engineering Journal, 8(2), pp.113-125.

[22] Storn, Rainer, and Kenneth Price. "Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces." Journal of global optimization 11, no. 4 (1997): 341-359.

[23] Das, Swagatam, and Ponnuthurai Nagaratnam Suganthan. "Differential evolution: A survey of the state-of-the-art." IEEE transactions on evolutionary computation 15, no. 1 (2011): 4-31.

[24] Yang, Xin-She, and Suash Deb. "Cuckoo search via Lévy flights." In Nature & Biologically Inspired Computing, 2009. NaBIC 2009. World Congress on, pp. 210-214. IEEE, 2009.

[25] Yang, Xin-She, and Suash Deb. "Cuckoo search: recent advances and applications." Neural Computing and Applications 24, no. 1 (2014): 169-174.

[26] Sowmya I, Ch. Sathi Raju, Md Zia-Ur-Rahman, D.V.R.K Reddy "Respiration Baseline wander removal from cardiac signals using an optimized Adaptive Noise canceller", Canadian Journal of Signal Processing, Vol-2, no-3, pp.27-31, 2011.

[27] Md.Zia Ur Rahman, S.R.Ahamed and D.V.R.K Reddy, "Noise Cancellation in ECG Signals using Computationally Simplified Adaptive Filtering Techniques: Application to Biotelemetry", Signal Processing: An International Journal, CSC Journals, ISSN 1985-2312, Vol. 3, Issue 5, pp. 1-12, 2009.

[28] Md. Nizamuddin Salman, P. Trinatha Rao, Md.Zia Ur Rahman, "Cardiac Signal Enhancement Using Normalised Variable Step Algorithm For Remote Healthcare Monitoring Systems," International Journal of Medical Engineering and Informatics, Inderscience Pub, Vol. 9, No. 2, 2017, pp. 145-161.

[29] Md. Zia Ur Rahman, Adaptive Noise Cancellers for Cardiac Signal Enhancement for IOT Based Health Care Systems, Journal of Theoretical and Applied Information Technology,Vol.95, no.10, 2017, pp.2206-2213.

[30] M. Nagesh, Md. Zia Ur Rahman, "A New ECG Signal Enhancement Strategy using Non-Negative Algorithms", International Journal of Control Theory and Applications Vol.10, no.35, 2017, pp.323-333.

[31] G V S Karthik, Md. Zia Ur Rahman, "ECG Signal Enhancement using Circular Leaky Adaptive Algorithm in an IOT Enabled Sensor System", International Journal of Control Theory and Applications,Vol.10, no.35, 2017, pp.271-282.