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Damping of Oscillations in Multi Machine Integrated Power Systems by SSSC Based Damping Controller Employing Modified Genetic Algorithm

Gayadhar Panda, P. K. Rautraya

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***Abstract*—**In this paper, an investigation into the use of modified Genetic Algorithm optimized SSSC based controller to aid damping of low frequency inter-area oscillations in power systems is presented. Controller design is formulated as a nonlinear constrained optimization problem and modified Genetic Algorithm (MGA) is employed to search for the optimal controller parameters. For evaluation of effectiveness and robustness of proposed controllers, the performance was tested on multi-machine system subjected to different disturbances, loading conditions and system parameter variations. Simulation results are presented to show the fine performance of the proposed SSSC controller in damping the critical modes without significantly deteriorating the damping characteristics of other modes in multi-machine power system.

***Keywords*—**SSSC, FACTS, Controller Design, Damping of Oscillations, Multi-machine system, Modified Genetic Algorithm (MGA).

I. Introduction

SYSTEM stability remains even till now a crucial issue in many power systems in the world. As power systems are continuously expanding and upgrading to cater the ever-growing power demand, the issue of maintaining system stability becomes ever more vital. Hence, controllers and the methods to effectively tune such controllers have an increasingly significant role in the power system. The damping of these modes is traditionally ensured by retuning Power System Stabilisers (PSS) installed on generators Automatic Voltage Regulators (AVR. Using a Power System Stabliser (PSS) is technically and economically appropriate for damping oscillations and increasing the stability of power system. Therefore, various methods have been proposed for tuning these stabilizers. However, the tuning of PSS is in some way not flexible and therefore sometimes they are not able to cope with changes in the power system structure. Recent development of power electronic devices introduces the use of Flexible AC Transmission Systems (FACTS) controllers in power systems. FACTS controllers are capable of controlling the network condition in a very fast manner and this unique feature of FACTS can be exploited to improve the stability of a power system. The detailed explanation about the FACTS controllers are well documented in the literature and can be found in [1]-[5].

FACTS controllers can be categorized into three major groups: shunt devices such as the Static Synchronous Compensator (STATCOM), series devices such as the Static Synchronous Series Compensator (SSSC) and series-shunt devices such as the Unified Power Flow Controller (UPFC). The static synchronous series compensator (SSSC) controller is used to prove its performance in terms of stability improvement. A Static Synchronous Series Compensator (SSSC) is an important member of F ACTS family which is connected in series with a power system. It consists of a solid state voltage source converter (VSC) which generates a controllable alternating current voltage at fundamental frequency. When the injected voltage is kept in quadrature with the line current, it can emulate as inductive or capacitive reactance so as to influence the power flow through the transmission line. While the primary purpose of a SSSC is to control power flow in steady state, it can also improve transient stability of a power system [6]-[10].

From the view point of power system dynamic stability, damping of power system oscillations with SSSC is performed through power modulations by a supplementary damping controller. A number of classical controllers such as Lead-Lag (LL), Proportional Integral (PI) and Proportional Integral Derivative (PID) have been employed in FACTS devices as supplementary damping controller. A conventional lead-lag controller structure is preferred by the power system utilities because of the ease of on-line tuning and also lack of assurance of the stability by some adaptive or variable structure techniques. The problem of FACTS controller parameter tuning is a complex exercise. A number of conventional techniques have been reported in the literature pertaining to design problems of conventional power system stabilizers namely; the eigen value assignment, mathematical programming, gradient procedure for optimization and also the modern control theory. Unfortunately, the conventional techniques are time consuming as they are iterative and require heavy computation burden and slow convergence. In addition, the search process is susceptible to be trapped in local minima and the solution obtained may not be optimal.

Several authors have investigated utilizing FACTs, especially SSSCs to damp inter-area oscillations using artificial intelligence-based approaches. These approaches include particle swarm optimization [11], [12], genetic

Gayadhar Panda is with the Dept. of Electrical & Electronics Engineering, NIT Meghalaya, India (e-mail: p_gayadhar@gmail.com).

P.K. Rautraya is with the Dept. of Electrical Engineering, Government College of Engineering, Kalahandi, Odisha, India, (e-mail pkrautraya@rediffmail.com).

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algorithm [13], differential evolution [14], and multi-objective evolutionary algorithm [15].

This paper investigates the design of a SSSC based controller employing modified Genetic Algorithm (MGA) to improve the damping of multi-machine infinite-bus power systems. For controller design, modified genetic algorithm is employed to tune controller parameters. To show the robustness of the proposed design approach, simulation results are presented under various disturbance and faults for multi-machine infinite-bus power system. The effectiveness and superiority of the proposed design approach is illustrated by comparing the proposed approach with existing approach.

The rest of this paper is organized as follows. Section II presents the system investigated. In section III, the control strategy, the design of the SSSC based controller is presented. The problem formulated as a nonlinear constrained optimization problem is described in section IV. The general overview of genetic algorithm and proposed modified genetic algorithm for the tuning of the damping controller parameters are introduced in Section V and Section VI respectively. Simulation results are presented in section VII to show the effectiveness of the proposed approach. Conclusions are finally presented at the end in Section VIII.

II. System Investigated

The integrated multi-machine power system model consisting of three generators used for the simulation purpose is shown in Fig. 1 in a single line diagram. The three generators are connected to buses one, eight and five. Two SSSC based controllers are used to damp power system oscillations. One is connected between bus two and three and the other one is connected between six and nine. *T/F1 - T/F3* represent the transformers for stepping up and stepping down purposes. Transmission lines are connected between the buses three-nine-four-six.

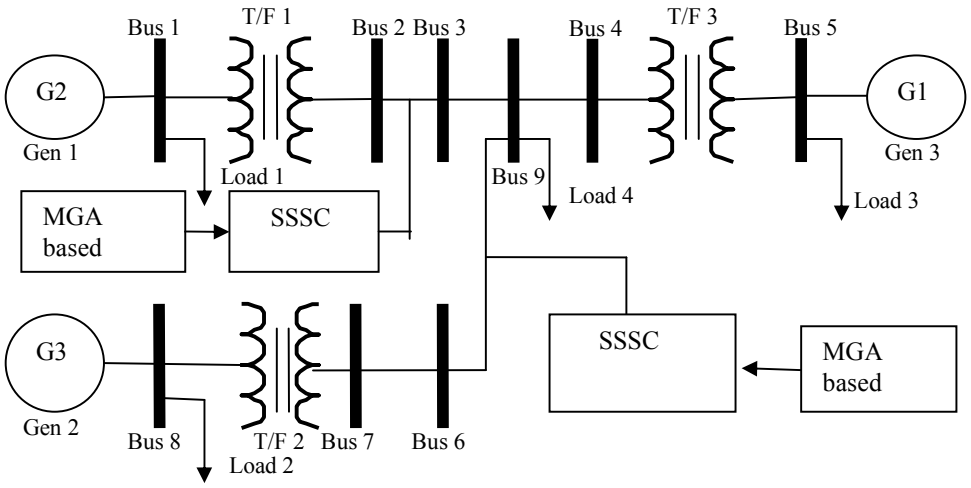


Fig. 1 Three-machine power system with SSSC

III. SSSC Based Damping Controller Design

The lead-lag structured SSSC-based controller is considered in the present study, to modulate the SSSC injected voltage V_q, is shown in Fig. 2. The input signal of the proposed controllers is the speed deviation ($\Delta\omega$), and the output signal is the injected voltage V_q. The lead-lag controller consists of a gain block with gain K_s, a signal washout block and two- stage phase compensation blocks. The signal washout block serves as a high-pass filter, with the time constant T_w, high enough to allow signals associated with oscillations in input signal to pass unchanged.

From the viewpoint of the washout function, the value of T_w is not critical and may be in the range of 1 to 20 s [16], [17]. The phase compensation block time constants (T_{1S}, T_{2S}, T_{3S} and T_{4S}) provide the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. The desired value of compensation is obtained according to the change in the SSSC injected voltage ΔV_q which is added to V_{qref}.

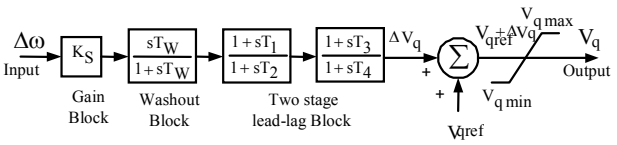


Fig. 2 Lead-Lag Structure of SSSC-Based Controller

IV. Problem Formulation

The transfer function of the SSSC-based controller is:

$$U_{SSSC} = K_S \left(\frac{ST_W}{1+ST_W}\right)\left(\frac{1+ST_{1S}}{1+ST_{2S}}\right)\left(\frac{1+ST_{3S}}{1+ST_{4S}}\right) y \quad (1)$$

where, U_{SSSC} and y are the output and input signals of the SSSC-based controller respectively,. The controller gain, K_S,

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and the time constants T_{1S}, T_{2S}, T_{3S} and T_{4S} are to be determined. During steady state conditions ΔVq and Vqref are constant. During dynamic conditions the series injected voltage Vq is modulated to damp system oscillations.

The effective Vq in dynamic conditions is given by:

$$V_q = V_{qref} + \Delta V_q. \quad (2)$$

It is worth mentioning that the SSSC-based controller is designed to minimize the power system oscillations after a large disturbance so as to improve the power system stability. These oscillations are reflected in the deviations in power angle, rotor speed and line power. Minimization of any one or all of the above deviations could be chosen as the objective. Rotor speed is taken as input signal for FACTS based controller. In view of the above, the proposed approach employs improved genetic algorithm to solve this optimization problem and search for optimal set of SSSC-based damping controller parameters. In the present study, an integral time absolute error of the speed deviations corresponding to the local and inter-area modes of oscillations is taken as the objective function J expressed as:

$$J = \int_{t=0}^{t=t_{sim}} \left(\sum \Delta\omega_L + \sum \Delta\omega_1 \right) \cdot t \cdot dt \quad (3)$$

where, $\Delta\omega_L$ and $\Delta\omega_1$ are the speed deviations of inter-area and local modes of oscillations respectively and t_{sim} is the time range of the simulation. In the present three-machine study, the local mode $\Delta\omega_L$ is $(\omega_2 - \omega_3)$, and the inter-area mode $\Delta\omega_1$ is $[(\omega_2 - \omega_1) + (\omega_3 - \omega_1)]$, where ω_1, ω_2 and $\omega_3$are the speed deviations of machines, 1, 2 and 3 respectively. With the variation of the SSSC-based damping controller parameters, these speed deviations will also be changed. For objective function calculation, the time-domain simulation of the power system model is carried out for the simulation period. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots. The problem constraints are the SSSC controller parameter bounds. Therefore, the design problem can be formulated as the following optimization problem:

Minimize J

$$\begin{aligned} K_{min} \le K \le K_{max} \\ T_{1min} \le T_1 \le T_{1max} \\ T_{2min} \le T_2 \le T_{2max} \\ T_{3min} \le T_3 \le T_{3max} \\ T_{4min} \le T_4 \le T_{4max} \end{aligned} \quad (4)$$

V. Overview of Genetic Algorithm

Genetic Algorithm (GA) has been used to solve difficult engineering problems that are complex and difficult to solve by conventional optimization methods. GA maintains and manipulates a population of solutions and implements a survival of the fittest strategy in their search for better solutions. The fittest individuals of any population tend to reproduce survive to the next generation thus improving successive generations. The inferior individuals can also survive and reproduce [17], [18].

Implementation of GA requires the determination of six fundamental issues: chromosome representation, selection function, the genetic operators, initialization, termination and evaluation function. Brief descriptions about these issues are provided in the following sections.

A. Chromosome Representation

Chromosome representation scheme determines how the problem is structured in the GA and also determines the genetic operators that are used. Each individual or chromosome is made up of a sequence of genes. Various types of representations of an individual or chromosome are: binary digits, floating point numbers, integers, real values, matrices, etc. Generally natural representations are more efficient and produce better solutions. Real-coded representation is more efficient in terms of CPU time and offers higher precision with more consistent results.

B. Selection Function

To produce successive generations, selection of individuals plays a very significant role in a genetic algorithm. The selection function determines which of the individuals will survive and move on to the next generation. A probabilistic selection is performed based upon the individual's fitness such that the superior individuals have more chance of being selected. There are several schemes for the selection process: roulette wheel selection and its extensions, scaling techniques, tournament, normal geometric, elitist models and ranking methods.

The selection approach assigns a probability of selection P_j to each individuals based on its fitness value. In the present study, normalized geometric selection function has been used. In normalized geometric ranking, the probability of selecting an Individual Pi is defined as:

$$Pi = q'(1-q)^{r-1} \quad (5)$$

$$q' = \frac{q}{1-(1-q)^P} \quad (6)$$

where,

q = probability of selecting the best individual

r = rank of the individual (with best equals 1)

P = population size

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C. Genetic Operators

Genetic operators are the stochastic transition rules applied to each chromosome during each generation procedure to generate a new improved population from an old. There are two basic types of operators: crossover and mutation. These operators are used to produce new solutions based on existing solutions in the population.

D. Crossover

It is the process of selecting a random position in the string and swapping the characters either left or right of this point with another similarly partitioned string. This random position is called the crossover point. Crossover takes two individuals to be parents and produces two new individuals while mutation alters one individual to produce a single new solution. The following genetic operators are usually employed: simple crossover, arithmetic crossover and heuristic crossover as crossover operator and uniform mutation, non-uniform mutation, multi-non-uniform mutation, boundary mutation as mutation operator. Arithmetic crossover and non-uniform mutation are employed in the present study as genetic operators. Crossover generates a random number r from a uniform distribution from 1 to m and creates two new individuals by using equations:

$$x_i' = \begin{Bmatrix} x_i, if\ i < r \\ y_i\ otherwise \end{Bmatrix} \tag{7}$$

$$y_i' = \begin{Bmatrix} y_i, if\ i < r \\ x_i\ otherwise \end{Bmatrix} \tag{8}$$

Arithmetic crossover produces two complimentary linear combinations of the parents, where r = U (0, 1):

$$\bar{X}' = r\bar{X} + (1-r)\bar{Y} \tag{9}$$

$$\bar{Y}' = r\bar{Y} + (1-r)\bar{X} \tag{10}$$

Non-uniform mutation randomly selects one variable j and sets it equal to a non-uniform random number.

$$x_i' = \begin{Bmatrix} x_i + (b_i - x_i) f(G) & if\ r_1 < 0.5, \\ x_i + (x_i + a_i) f(G) & if\ r_1 \geq 0.5, \\ x_i, \quad otherwise & \end{Bmatrix} \tag{11}$$

where

$$f(G) = (r_2 (1 - \frac{G}{G_{\max}}))^b \tag{12}$$

r_1, r_2 = uniform random nos. between 0 to 1.
G = current generation.
$G_{\max}$ = maximum no. of generations.
b = shape parameter.

E. Mutation

It is the process of random modification of a string position by changing "0" to "1" or vice versa, with a small probability. It prevents the complete loss of genetic material through reproduction and crossover by ensuring that the probability of searching any region in the problem space is never zero.

F. Initialization, Termination and Evaluation Function

An initial population is needed to start the genetic algorithm procedure. The initial population can be randomly generated or can be taken from other methods.

GA moves from generation to generation until a stopping criterion is met. The stopping criterion could be maximum number of generations, population convergence criteria, lack of improvement in the best solution over a specified number of generations or target value for the objective function.

Evaluation functions or objective functions of many forms can be used in a GA so that the function can map the population into a partially ordered set. The computational flowchart of the GA optimization process employed in the present study is given in Fig. 3.

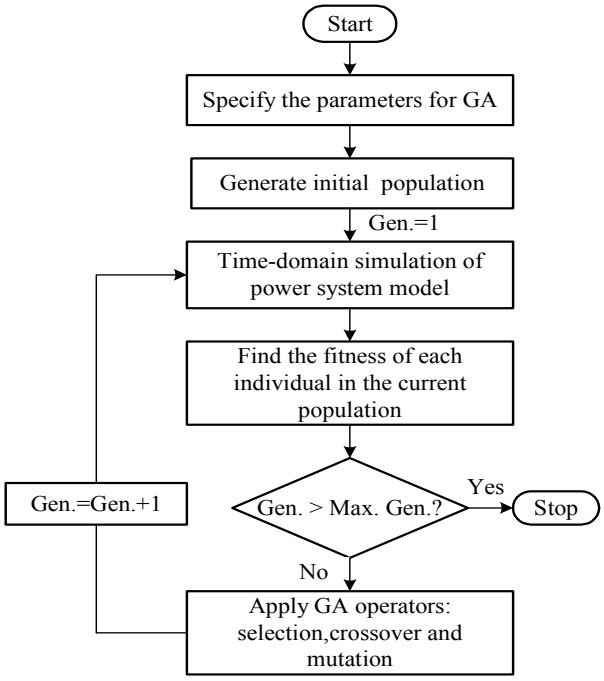


Fig. 3 Flow chart of GA

VI. Modified Genetic Algorithm (MGA)

The following two modifications have been proposed

- Modification in parent selection
- Modification in crossover mechanism

A. Parent Selection

Depending upon the values of fitness function, pairs of strings are selected from the population pool at random for forming a mating pool. In a simple GA approach this is termed as reproduction. And the strings are selected into the mating pool by simple Roulette wheel selection. In this proposed

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algorithm, the following modifications are applied for the selection of parents so that the strings with large values of fitness are copied more into the mating pool.

- The first parent in each reproduction is the string having the best fitness value. The second parent is selected from the ordered population using normal selection technique.
- At the i^{th} reproduction, first parent is the best string of the population arranged in the order of fitness values. Second parent is selected from the ordered population using normal selection technique.

B. Proposed Crossover

Crossover is an algorithm for artificial mating of two individual chromosomes with an expectation that a combination of genes of individuals of high fitness value may produce an offspring with even higher fitness. It represents a way of moving in the solution space based on the information derived from the existing solutions. This makes exploitation and exploration of information encoded in genes.

In this proposed algorithm, the following modifications have been proposed with an intuition to have better trade-off between exploration of unknown solution space and exploitation of already known knowledge of solution to find the global optimum in less number of generations. In this work, one point crossover also called Holland crossover is adopted with a probability $P_C \in [0.6, 0.95]$ with modifications in exchange of chromosomal materials.

In a binary coded chromosome, if the value of right most bits is changed [1→0,0→1], the search point in the search space shifts to a nearby point. This helps in refining the optimum point in the already known search space. As one proceeds towards the left from the right most bit of the chromosome, the shifting of search point in the search space increases and it depends on the position of the bit in the chromosome whose value is changed. The shifting is highest with the change in the left most bit. This facilitates to explore new region in the search space by shifting the search point wide apart from the current optimum position in the search space.

Therefore, it is evident that the exploitation of already known region or exploration of unknown region in the search space is relatively depending upon the position of the bit in the chromosome whose value changes. In a chromosome change in the bits towards the right from the middle position contribute more towards the exploitation of already known region. Similarly, change in the bits towards the left from the middle position contributes more towards exploration of new region in the search space. This is shown in the Fig. 4 (a).

Thus the positional dependency of crossing site in respect of middle point of the chromosome helps to maintain diversity of the search point as well as improve the value of already known optimum value.

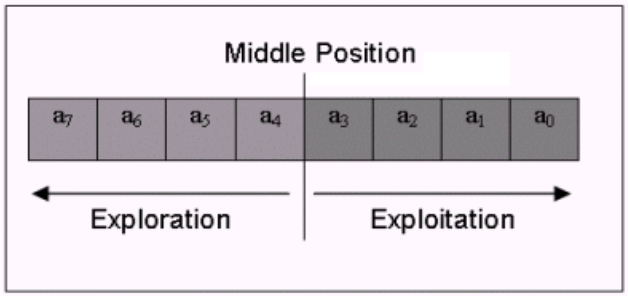


Fig. 4 (a) Example of Exploration and Exploitation in the Search Space

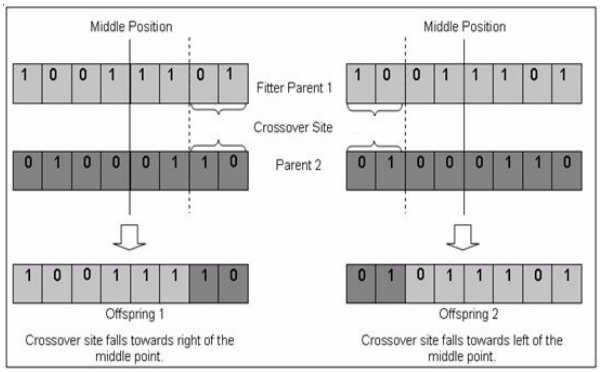


Fig. 4 (b) Example of Crossover Procedure

```
// Procedure Proposed Crossover
// n  → population size
// cs → crossover site
// l  → length of chromosome
// midl → midpoint of chromosome length

begin
   //Selection of two chromosomes
   Chromo (cn) = best chromo of pop(n)
   Chromo (cn-1) = Roulette wheel pop(n-1)
      for i=1 to 2 do
      begin
      //Selection of crossover site
      cs → rand (1,l)
      if (cs towards right midl)
         offspringm = chromo (cn) upto cs + chromo (cn-1) after cs
      else
         offspring = chromo (cn-1) upto cs +chromo (cn) after cs
      end
end
```

Fig.4 (c) the Pseudo Code for the Proposed Crossover

Here the mechanism of crossover is not same as that of one point crossover. In this proposed scheme, the exchange of chromosomal material between two parents is made considering the position of crossover site with respect to the midpoint of the chromosome. If the crossover site falls

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towards the right of the midpoint of the chromosome, the right side chromosomal material from the crossover site of the fitter parent is replaced with that of other parent to form one offspring. If the crossover site falls towards the left of the middle position of the chromosome, the left side chromosomal material from the crossover site of the fitter parent is replaced with the other parent to form one offspring.

Fig. 4 (b) shows an example of crossover procedure. Thus by generating one random number, only one offspring is produced by crossover. For each pair of parent, two random numbers are generated to produce two offspring.

Steps for Crossover

i) Two chromosomes selected for crossover.
ii) Fitter one is identified by evaluating the fitness value.
iii) An integer random number between one and length of chromosome is generated to select the crossover site.
iv) If the crossover site is towards the right of middle position of the chromosome, the right side chromosomal material from the crossover site of the fitter parent is replaced by that of other parent to form one child. Else the left side chromosomal material from the crossover site of the fitter parent is replaced by that of other parent to form one child.
v) Other child is formed from the two parents by repeating the steps (iii) and (iv)

The pseudo code for the proposed crossover is shown in Fig. 4 (c).

TABLE I
SSSC-BASED CONTROLLED PARAMETER

System	Gain	Time constants			
	Kpsssc	**Tisssc1**	**Tisssc2**	**Tdsssc1**	**Tdsssc2**
MMIB (Remote signal)	171.1314	0.4681	0.367	0.8489	0.9145
MMIB (Local signal)	$7.333e^{-004}$	0.1895	0.3654	0.7639	0.2857

VII. TIME DOMAIN SIMULATION

The SimPowerSystems (SPS) toolbox is used for all simulations and SSSC-based MGA controller design. In order to optimally tune the parameters of the SSSC based MGA controller, as well as to assess its performance, the model of example power system shown in Fig. 1 is developed using SPS block-set. The ratings of the generators are taken as 2100MVA each (G2 and G3) in one subsystem and 4200MVA (G1) in the other subsystem. The generators with output voltages of 13.8KV are connected to an inter-tie through 3-phase transformers. All of the relevant parameters are given in the Appendix. To assess the effectiveness and robustness of the proposed controller, three different operating conditions (nominal, light and heavy) are considered. Simulation studies are carried out under different fault disturbances.

Local control signals, although easy to get, may not contain the inter-area oscillation modes. So, compared to wide-area signals, they are not as highly controllable and observable for the inter-area oscillation modes. Owing to the recent advances in optical fiber communication and global positioning systems, the wide-area measurement system can realize phasor measurement synchronously and deliver it to the control center even in real time, which makes the wide-area signal a good alternative for control input. In view of the above, the speed deviation and acceleration of generators G1 and G2 are chosen as the control input of the SSSC-based MGA controller in this article.

To assess the effectiveness and robustness of the proposed MGA controller, load flow is performed with Machine 1as a swing bus and Machines 2 and 3 as PV generation buses. The initial operating conditions used are:

Machine 1 generation: Pe1 = 3480.6 MW (0.8287 p.u.),
Qe1 = 2577.2 MVAR (0.6136 p.u.)

Machine 2 generation: Pe2 = 1280 MW (0.6095 p.u.),
Qe2 = 444.27 MVAR (0.2116 p.u.)

Machine 3 generation: Pe3 = 880 MW (0.419 p.u.),
Qe3 =256.33MVAR (0.1221 p.u.)

Simulation studies are carried out for the example power system subjected to various severe disturbances as well as small disturbances. The simulation results are also compared with the result of lead-lag controller as given by [13]. The original system is restored upon the clearance of the fault.

A. Simulation Results

A 3-cycle, 3-phase fault is applied at one of the line sections between bus1 and bus 6 near bus 6 at t = 1 s. The fault is cleared by opening the faulty line and the line is reclosed after 3-cycles. Fig. 5 shows the variations of the local mode of oscillation against time and Fig. 6 shows the variations of the inter-area mode of oscillation against time. It is revealed from this figure that, inter-area modes of oscillations are highly oscillatory in the absence of SSSC-based damping controller and the controller significantly improves the power system stability by damping these oscillations. The simulation results as show with different legends demonstrate that SSSC based damping controller employing modified proposed genetic algorithm significantly damp the oscillation of multi-machine power system as compared to the SSSC based controller with simple GA optimization approach.

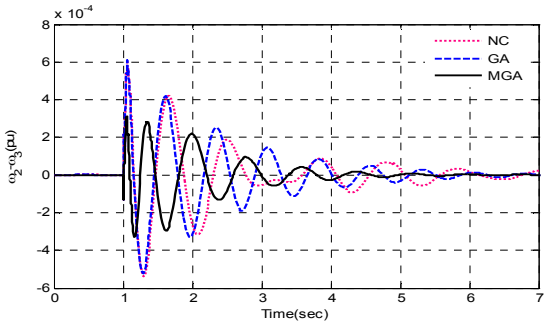


Fig. 5 Damping performance of Local mode of oscillation ($\omega_2 - \omega_3$) for 3-phase fault disturbance

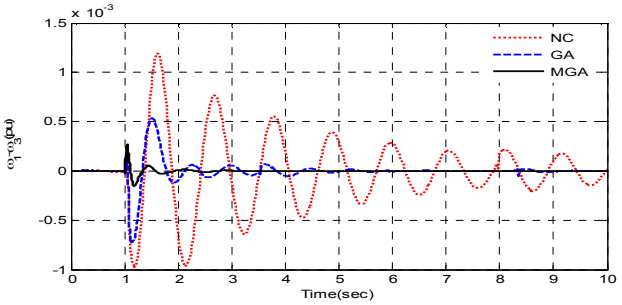


Fig. 6 Damping performance of Inter-area mode of oscillation ($\omega_1 - \omega_3$) for 3-phase Fault disturbance

In order to examine the effectiveness of the proposed controller under small disturbance, the load at Bus 4 is disconnected at t = 1sec for 100m. Fig. 7 shows the variations of the inter area of oscillations against time and Fig. 8 shows the variations of the local modes of oscillations against time from which it is clear that the modified SSSC-based damping controller damps the modal oscillations effectively, even for small disturbance.

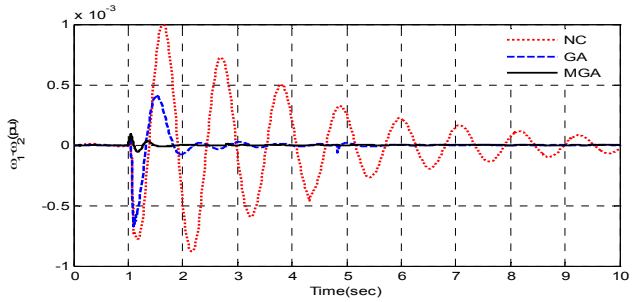


Fig. 7 Damping performance of inter-area mode of oscillation ($\omega_1 - \omega_2$) for small disturbance

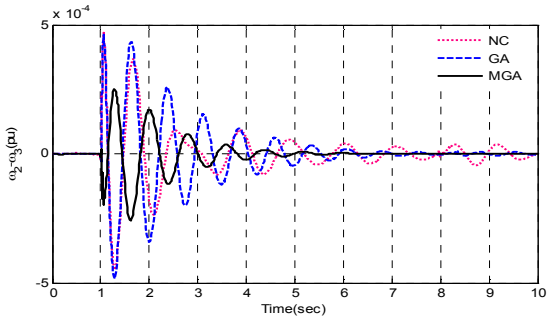


Fig. 8 Damping performance of Local mode of oscillation ($\omega_2 - \omega_3$) for small disturbance

The effectiveness of the proposed controller on unbalanced faults is also examined by applying self-clearing type unsymmetrical faults, namely L-G ,L-L-G, , and L-L faults, each of three-cycle duration at Bus 1 at t = 1 sec. The Local modes of oscillations against time are shown in Figs. 9 (a)-(c). It is clear from these figures that the power-system oscillations are poorly damped in the uncontrolled case, even for the least-severe L-G fault, and the proposed SSSC-based damping controller effectively stabilizes the power angle under various unbalanced fault conditions. It is seen that SSSC- based controller employing modified approach improves significantly as the system is stabilized quickly

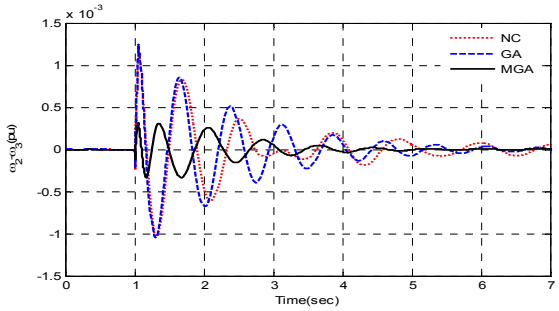


Fig. 9 (a) Variation of Local mode of oscillations against time for three cycle unbalanced faults at Bus 1 with L-G fault

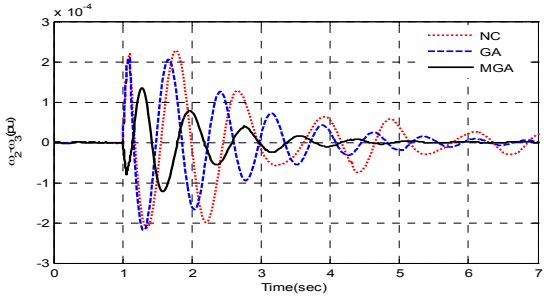


Fig. 9 (b) Variation of Local mode of oscillations against time for three cycle unbalanced faults at Bus 1 with L-L-G fault

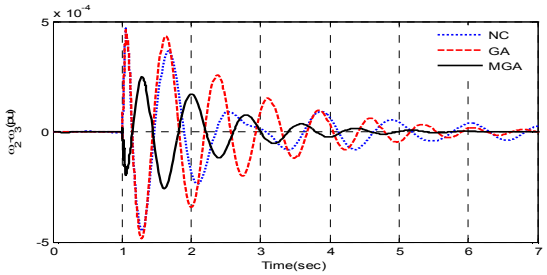


Fig. 9 (c) Variation of Local mode of oscillations against time for three cycle unbalanced faults at Bus 1 with L-L fault

B. Remote and Local

The performance of SSSC based controller is demonstrated under small disturbance condition with comparing remote signal and local signal as the input signal to the SSSC controller. A 3-cycle, 3-phase fault is applied at one of the line sections at time t = 1 s. The fault is cleared by opening the faulty line and the line is reclosed after 3-cycles. Figs. 10 (a) and (b) show the variations with comparing remote signal and local signal oscillation against time under small disturbance. The response with remote signal as input is shown in solid lines (with legend RE) and the response with local signal as input is shown in dotted lines (with legend LO). From these figures, it can be seen that local signal oscillations are highly oscillatory. It is also seen that the remote signal is the better input signal than local input signal.

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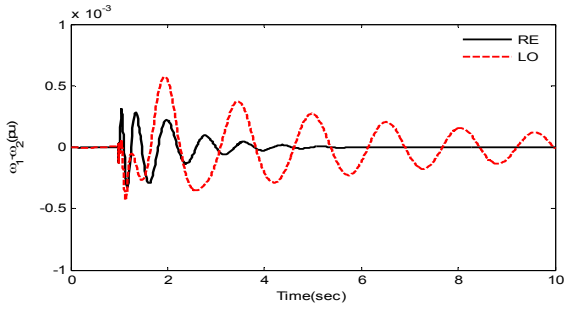


Fig. 10 (a) Inter-area mode of oscillation ($\omega_1 - \omega_2$) for small disturbance

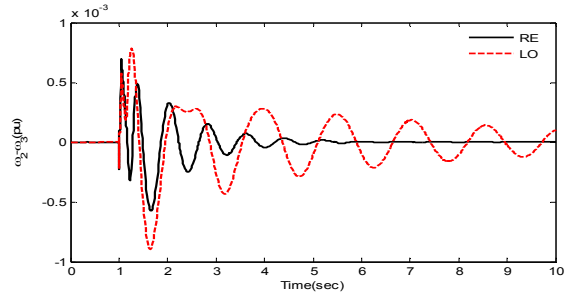


Fig. 10 (b) Local mode of oscillation ($\omega_2 - \omega_3$) for small disturbance

VIII. Conclusion

Modified Genetic Algorithm (MGA) optimised SSSC based controller for improving damping of multi-mode oscillations is proposed in this paper. The problem of optimal selection of SSSC based damping controller parameters has been formulated as a nonlinear constrained optimization problem and an improved genetic algorithm has been proposed to capture its near global solution. Investigations reveal that SSSC based controller is robust and performs satisfactorily at wide ranges of loading conditions. Optimal selection of a SSSC based damping controller parameters for a multi-machine power system using MGA is successfully performed.

Appendix

TABLE II
Data of Three Machine Nine Bus Power System with SSSC

Generators	S_{B1}= 4200 MVA, S_{B2}= S_{B3}= 2100 MVA, H=3.7s, V_B =13.8 kV, f = 60Hz, P_{eo}=0.75, V_{to}=1.0, R_S = 2.8544 e^{-3}, X_d =1.305, $X_{d'}$ =0.296, $X_{d''}$= .252, X_q = 0.474, $X_{q''}$ = 0.18, T_d =1.01 s, $T_{d'}$ =0.053s,$T_{qo''}$=0.1s
Hydraulic Turbine and Governor	K_a = 3.33, T_a = 0.07,G_{min} = 0.01, G_{max}=0.97518, V_{gmin} = -0.1 pu/s, V_{gmax} = 0.1 pu/s, R_p = 0.05, K_p = 1.163, K_i =0.105, K_d = 0, T_d=0.01s, β =0, T_w = 2.67 s
Excitation System	T_{LP} = 0.02 s, K_a =200,T_a = 0.001 s, K_e =1, T_e=0, T_b = 0,T_c=0, K_f =0.001, T_f = 0.1 s, E_{fmin}= 0, E_{fmax} = 7, K_p = 0
Transformers	S_{BT1}=4200 MVA, S_{BT2}= S_{BT3}=2100 MVA,13.8/500 kV, 60 Hz, R_1 = R_2 =0.002, L_1 = L_2=0, D_1/Y_gconnection, R_m = 500, L_m =500
Transmission Line	3-Ph,L_1 = 175 km, L_2 = 50km, L_3 =100km., R_1 =0.02546 Ω/ km,R_0= 0.3864 Ω/ km, L_1=0.9337e^{-3} H/km, L_0 = 4.1264e^{-3}H/ km, C_1 = 12.74e^{-9} F/km, C_0 = 7.751e^{-9} F/ km
SSSC	S_{nom} = 100 MVA, V_{nom} = 500 kV, f = 60 Hz,V_{qmax}= 0.2, Max rate of change of V_{qref} =3/s, ,V_{DC} = 40 kV, C_{DC} = 375e^{-6} F,K_P=0.00375, K_I=0.1875, Vq = ± 0.2 K_{P_VdcR} =0.1e^{-3},K_{I_VdcR} =20e^{-}

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Gayadhar Panda was born in Odisha,India,in 1970.He received B.E. degree in electrical engineering from the Institution of engineers (I),the M.E degree in electrical engineering from Bengal Engineering College, Shibpur, Howarh, India and the Ph.D. degree in electrical engineering from Utkal University in 1996,1998 and 2007 respectively. He is currently working as Associate Professor in the Deptt. of Electrical & Electronics Engineering, NIT, Meghalaya, India.His research interests are in the areas of stability aspects of power transmission, power electronics and development of renewable energy. Email: p_gayadhar@gmail.com

P.K. Rautraya was born in Odisha, India in 1970. He received the B.E. degree in electrical Engineering from Utkal University,Odisha,India, in 1993 and M.Tech degree from the Department of Electrical Engineering, SOA University, Odisha, India in 2009. He is currently working as a Lecturer at Govt.College of Engineering, Kalahandi, Bhawanipatna.,Odisha,India.His current area of research in power system and power electronics and drives. E-mail: pkrautraya@rediffmail.com

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