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Effective Power System Stabilization Using Non-Dominated Ranked Genetic Algorithm

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Abstracts - Power system stabilizers (PSS) should be accomplished with suitable stabilization signals over a wide range of operating environment and disturbances. With the enormous electric power need and requirement to function the power system in a faster and highly flexible way in the deregulated competitive situation, modern power systems can achieve stressed conditions very easily than the old systems. These make unbalanced or badly damped oscillations that have been seen more frequently in power systems across the world. In modern days, stabilizing control techniques for the multi-machine power system with the help of intelligent methods have been developed. The basis for the reduction of stability analysis is because of the complexity of the power systems. In addition, industry will be unwilling to acknowledge controller design if stability is not be assured. To deal with those problems, intelligent techniques are used. The optimal sequential design for multi-machine power systems is very essential. As a result, serious consideration is now being given on the concern of power system stabilization control. In recent times, the utilization of optimization techniques becomes possible to deal with control signals in power system. Most widely used optimization technique is Genetic Algorithm (GA). However, GA takes more time in optimization and lack in accuracy. To overcome those difficulties, this paper uses Non-Dominated Ranked Genetic Algorithm (NRGA) for optimization. Simulation results suggest that the proposed technique is better for power system stabilization when compared to the conventional techniques.

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Abstract - Power system stabilizers (PSS) should be accomplished with suitable stabilization signals over a wide range of operating environment and disturbances. With the enormous electric power need and requirement to function the power system in a faster and highly flexible way in the deregulated competitive situation, modern power systems can achieve stressed conditions very easily than the old systems. These make unbalanced or badly damped oscillations that have been seen more frequently in power systems across the world. In modern days, stabilizing control techniques for the multi-machine power system with the help of intelligent methods have been developed. The basis for the reduction of stability analysis is because of the complexity of the power systems. In addition, industry will be unwilling to acknowledge controller design if stability is not be assured. To deal with those problems, intelligent techniques are used. The optimal sequential design for multi-machine power systems is very essential. As a result, serious consideration is now being given on the concern of power system stabilization control. In recent times, the utilization of optimization techniques becomes possible to deal with control signals in power system. Most widely used optimization technique is Genetic Algorithm (GA). However, GA takes more time in optimization and lack in accuracy. To overcome those difficulties, this paper uses Non-Dominated Ranked Genetic Algorithm (NRGA) for optimization. Simulation results suggest that the proposed technique is better for power system stabilization when compared to the conventional techniques.

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I. Introduction

Highly complicated power systems have been constructed to deal with the increasing demand. The development in electric power production is focused on the interconnected network of transmission lines linking generators and loads into huge integrated systems which helps in better supply of power. This huge venture of providing electrical energy suffers various engineering difficulties that afford the engineer with a range of challenges. The systems that are developed according to this are highly complicated in its planning, construction, and operation. The stabilization of the power systems is the foremost issue that should be taken into account.

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The field of power system dynamic stability has become a wide area of research due to large scale interconnection of the power system. This research area involving the power system stability has been gaining more and more importance since 1920 because of the problems occurring due to the instability in the power systems. Moreover, requirement for consumption of energy has been amplified extensively because of the industrial revolution. The stability issue in a power system is considered as one of the most important and essential concepts of power systems quality.

Dynamic stability is a phenomenon that deal with the approach the system adapts with a novel state following a disturbance [4]. These disturbances are mainly caused due to switching-off a load or a change in the mechanical input to the system. These variations cause oscillations in the system which could ultimately become larger and makes the synchronous generators to go out of step and lose synchronism. The application of fast static excitation system, while offering a gain in stability limits, can lead to poor system damping under certain loading conditions [5].

Power system stabilizers (PSS) [17-19] have been used for a long time to enhance the power system damping. Traditionally, lead-lag structures have been used as power system stabilizers. Much has been published on the ways to tune the parameters of the lead lag controller. These controllers have previously been tuned for both single and multiple operating points of the power system [5]. The methods used for tuning range from pole placement, to the more recent one using the heuristic optimization algorithms like the genetic algorithms [5] and particle swarm optimization [2].

The highly complex, dynamic behavior and nonlinearity of power systems, together with their almost continuously time varying nature, have posed a great challenge to power system control engineers for decades. A crucial issue encountered at the generating plant level is to maintain stability or synchronism of synchronous generators when subjected to severe disturbances at various operating conditions. An effective and economical means to enhance the power system stabilization is a major concern in the present scenario. Generally, the dynamic interaction effects among various modes of the machines are found to have significant influence on the stabilizer to one machine at a time may not finally lead to an overall optimal choice of PSS parameters. Moreover, the stabilizers designed to damp one mode can create adverse effects in other modes. The optimal sequential design for multi-machine power systems available in the literature suffer from several drawbacks. This section provides better technique for stabilizing the power system. Genetic Algorithm techniques have been used to enhance the stabilization of the power systems [15, 16].

Genetic Algorithms (GAs) are global optimization techniques that utilize concurrent search from multiple-points rather than from a single-point. GA is independent of the problem complexity. The main necessity of the GA is to specify the objective function and to place finite bounds on the parameters. GA is widely used for robust Power System Stabilization [5-9]. Various approaches like self-adaptive GA operators [10-12] and parallel GAs [13-14] are present in the literature to enhance the GA performance in searching for the global optimum. Significant performance can be obtained by these techniques. But, if the searched global optimum is being existed outside the proposed search space of the problem, these techniques cannot allow Genetic Algorithm to find this optimum.

Generally, the application of GA in large scale and complex projects needs high computational effort to estimate individuals and this makes it difficult to maintain large populations. Various approaches have been proposed to calculated fitness of individuals instead of evaluating them directly [7]. It can be assumed that individuals are somehow genetically related with each other. In such case, large population size can be handled by clustering the population into groups of similar individuals [5].

Optimization using GA techniques [23] are widely applied in many real world problems such as image processing, pattern recognition, classifiers, machine learning. There are various forms of GA for different purposes. This proposed approach uses Non-Dominated Ranked Genetic Algorithm for the stabilization of power systems.

II. Literature Survey

Several researches have been done in the field of power system to provide stability. Various techniques are proposed by several researchers which have its advantages and disadvantages. Some of the techniques are discussed below.

Shahab *et al.,* [1] proposed power system stabilization using adaptive neural network-based dynamic surface control. The power system with an excitation controller is denoted as a class of large-scale, uncertain, interconnected nonlinear continuous-time system in strict-feedback form. Consequently, Dynamic Surface Control (DSC)-based adaptive Neural Network (NN) controller is intended to solve the repeated differentiation of the control input that is observed in the traditional back-stepping technique. The approximation of the unknown subsystem and the interconnection dynamics is used by the neural networks. With the help of the new online NN weight update laws with quadratic error terms, the closed-loop signals are found to be locally asymptotically stable via Lyapunov stability analysis, even in the presence of neural network approximation errors. This is in contrast with other neural network approaches where a bounded stability is normally assured. The performance efficiency of the proposed approach in damping oscillations that occur after disturbances is obtained by the simulation results on the IEEE 14-bus power system with generator excitation control. The result is a nonlinear decentralized adaptive state-feedback excitation controller for damping power systems oscillations in the presence of uncertain interconnection terms.

A robust decentralized controller based on optimal sequential design is proposed by Yoshitaka *et al.,* [2]. The inter-area oscillation mode on design phase can be directly considered by the proposed controller. Moreover, the sequential process is applied to design for robust controllers. The best design sequence of the controller is determined by using the condition number. The performance of the proposed controller is illustrated by comparing it with traditional controllers. Damping of many oscillations for a multi-machine power system is illustrated via simulations, which regard as a three line-to-ground fault for power system disturbance [20,21].

Dynamic stability problems are usually overcome through the application of Power System Stabilizers. Vournas *et al.,* [3] proposed presented an alternative technique for power system stabilization [25] based upon the tuning of the existing generator controllers, both governors and A.V.R.'s. The sensitivities of the eigenvalues to the controller parameters are estimated and an optimization approach is designed to maximize the dynamic stability. A significant approach to stabilize a number of unstable oscillatory modes by relatively small parameter variations is by the application of the parameter optimization technique on a realistic model of the Hellenic Interconnected System. The results are tested with a nonlinear simulation program and the stabilization obtained as given by the rotor angle swings is very efficient.

The acceptance of fuzzy logic within the power industry has seen very a few successes because of the requirement for prior information about an extremely complex system. Soon *et al.,* [4] proposed a Fuzzy Logic Controller (FLC) for decentralized stabilization of multi-machine power systems. The authors presented a unique, largely analytical technique for design of robust Multi-Input–Single-Output (MISO) FLC for enhancing damping and stability of an electrical power system without affecting the voltage regulation. The proposed decentralized FLC uses a systematic analytical approach based on a performance index in order to bypass the need for prior knowledge about the system. The proposed FLC tracks speed deviations to zero in order to stabilize the power output of the generator, while, at the same time, it controls and stabilizes the terminal voltage of the generator. FLC successfully stabilizes both voltage and power oscillations following small and large disturbances in a power system. A multi-machine power system, which includes a four-machine and a ten-machine (New England) system is used for the simulation of the FLC technique. The simulation results clearly showed the effectiveness of designed FLCs in stabilizing the system. The result of the FLC technique is compared with the classical Power System Stabilizers (PSSs) [22, 24] tuned by a conventional linear sequential tuning method (LSM) and optimization-based method.

Yagami *et al.,* [5] provides a power system stability improvement technique with the help of grouping of fault current limiter and thyristor controlled braking resistor. The fault current limiter functions for restriction of fault currents, improvement of the power system stability and containment of turbine shaft torsional oscillations. Next, the thyristor controlled braking resistor functions with the intention of quick managing of generator disturbances. The success of both devices has been illustrated with the help of 3LG (three-lines-to-ground) fault in a two-machine infinite bus system. Simulation results represent a better power system stability improvement and also the damping turbine shaft torsional oscillations with permitted level of temperature rise.

III. Methodology

The power system dynamic stability characteristic acts as a forever growing field of research because of the large scale interconnection of the power system. This field has been recognized as a significant problem for secure system operation from the 1920's [27]. There were various most important collapses resulted by the instability of a power system that indicates the significance of this trend [26]. The stability maintenance in a power system is considered as one of the highly important and necessary factor of power systems quality.

a) Power System Modeling

The model of multi-machine power system considered for this proposed approach is shown in figure 1. The multi-machine consists of 3 machine nine bus system. G_1, G_2 and G_3 are machine present in the multi-machine taken into consideration.

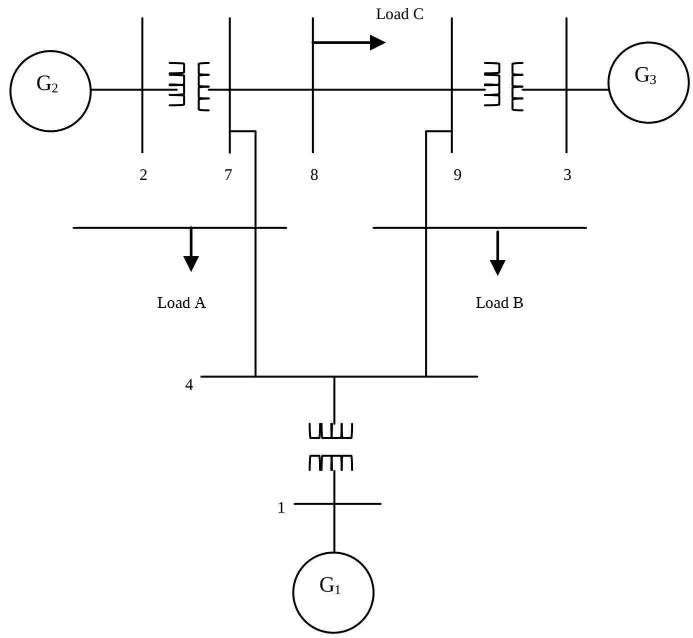

Figure 1 : Single-line diagram of three-machine nine-bus system

b) System Model and PSS Structure

A power system can be modeled by a set of nonlinear differential equation as:

$$\dot{X} = f(X, U)$$

Where X is the vector of the state variables and U is the vector of input variables. In this study, $X = [\delta, \omega, E_q^{'}, E_{fd}]^T$ and U is the PSS output signals.

In the design of PSSs, the linearized incremental models around an equilibrium point are usually employed [28, 29]. Hence, the state equation of a power system with n machines and n_{PSS} stabilizers can be written as:

$$\Delta\dot{X} = A\Delta X + BU$$

Where A is a 4n x 4n matrix equals $\partial f / \partial X$, while B is 4n x n_{PSS} matrix and equals $\partial f / \partial U$. Both A and B are evaluated at the equilibrium point. ΔX is a 4n x 1 state vector while U is n_{PSS} x 1 input vector.

A widely used conventional lead-lag PSS is considered in this study. It can be described as [29, 30].

$$U_i = K_i \frac{sT_w}{1 + sT_w} \frac{(1 + sT_{1i})}{(1 + sT_2)} \frac{(1 + sT_{3i})}{(1 + sT_4)} \Delta\omega_i$$

Where T_w the washout time is constant, U_i is the PSS output signal at the ith machine, and $\Delta\omega_r$ is the speed deviation of this machine. The time constant T_w, T_2 *and* T_4 are usually prespecified [30]. The stabilizer gain K_i and time constants T_{1i}

And T_{3i} still need to be optimized.

c) Objective function and PSS tuning

To increase the system damping to electromechanical modes, an objective function J defined below is considered.

$J = max\{\text{Re}(\lambda_i), i \in \text{set of electromechanical modes}\}$

Where $\text{Re}(\lambda_i)$ is the real part of the ith eigen value associated with electromechanical modes. This objective function is proposed to shift these eigenvalues to the left of s-plane in order to improve the system damping factor and setting time and insure some degree of relative stability.

The problem constraints are the optimized parameter bounds. Therefore, the design problem can be formulated as the following optimization problem.

Minimize J

Subject to

$$K_i^{min} \le K_i \le K_i^{max}$$

$$T_{1i}^{min} \le T_{1i} \le T_{1i}^{max}$$

$$T_{3i}^{min} \le T_{3i} \le T_{3i}^{max}$$

Typical ranges of these parameters are [0.01-50] for K_i and [0.01-1.0] for T_{1i} [1]. The time constants T_w, $T_2$and T_4 are set as 5, 0.05 and 0.05 s respectively [31].

The proposed approach employs NRGA algorithm to solve this optimization problem and search for optimal set of PSS parameters, $\{K_i, T_{1i}, T_{3i}, i = 1,2,\ldots,n_{PSS}\}$.

Genetic Algorithm

The genetic algorithm (GA) is an optimization and stochastic global search technique based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the "fitness" (i.e., minimizes the cost function). The method was developed by John Holland (1975) over the course of the 1960s and 1970s and finally popularized by one of his student, David Goldberg (1989) [7-8]. Generally in GA, there are three basic operations like reproduction, crossover and mutation.

a) Reproduction

it is a process in which a new generation of population is formed by selecting the fittest individuals in the current population. This is the survival of the fittest mechanism. Strings selected for reproduction are copied and entered to the mating pool.

b) Crossover

Mating is the creation of one or more offspring from the parents selected in the pairing process. The current members of the population limit the genetic makeup of the population. The most common form of mating involves two parents that produce two offspring. The new offspring may replace the weaker individuals in the population. With the cross over operation, GA is able to acquire more information with the generated individuals and the search space is thus extended and more complete.

c) Mutation

Random mutations alter a certain percentage of the bits in the list of chromosomes. Mutation is the second way a GA explore a cost surface. It can introduce traits not in the original population and keeps the GA from converging too fast before sampling the entire cost surface.

Recent research has identified some drawbacks in GA performance [32]. Limitations of genetic Algorithm in power system stabilization

- Slow convergence
- It lacks rank based fitness function

So the proposed approach uses the non dominated ranked genetic algorithm for the optimization purpose. The main advantages of using non dominated ranked genetic algorithm are that it converges very significantly than GA. Moreover, it is provides rank based fitness function and it is quicker than GA.

Non-Dominated Ranked Genetic Algorithm

At first, a random parent population P is formed. The sorting of the population is in accordance with the non-domination. Every solution is allocated a fitness (or rank) equivalent to its non-domination level. Non-domination level of 1 represents the best level, 2 represents the next-best level, etc.

Therefore, minimization of fitness is implicit. Initially, the normal Ranked accorded Roulette wheel choosing, recombination, and mutation operators are applied to generate an offspring population Q of size N. As elitism is initiated by contrasting present population with earlier obtained best nondominated results, the process is varied after the starting generation. Initially the ith generation of the presented algorithm as shown in below is explained.

The algorithm represents that Non-Dominated Ranked Genetic is simple and straightforward. Initially, a combined population P∪Q is created. The mixed population is of size 2N then obtained; the mixed population is sorted based on the non-domination. As every previous and present population members are incorporated in the mixed population elitism is guaranteed. This process will choose N solutions out of 2N.

The new population of size N is utilized for choosing. Next, two tiers ranked dependent roulette wheel selection is used, one tier to choose the front and the other to choose solution from the front, here the results obtained for the finest nondominated set F1 have the higher probabilities to be chosen. Therefore, results from the set F2 are selected with small probability than results from the set F1 and so on. After that crossover and mutation are used to generate a new population P of size N. The diversity between non-dominated results is established by the second tier of ranked dependent roulette wheel selection that ranks the results according to their crowding distance. The results with lesser crowding distance will have the higher probabilities.

As solutions contend with their crowding distance, no extra niching attribute is needed. Even though the crowding distance is computed in the objective function space, it can also be obtained in the parameter space, if required. The objective function space niching is utilized in this proposed approach. The NRGA algorithm is shown in figure 2.

Algorithm NRGA

```
1 : Initialize Population P
2 : { Generate random population – size N
3 :  Evaluate Objective Values
4 : Assign Rank (level) Based on Pareto dominance Sort
5 :  }
6 :  { Ranked based Roulette Wheel Selection
7 :  Recombination and Mutation }
8 :  for i=1 to g do
9 :  for
(P∪Q)  do
10 :  Assign Rank (level) based on Pareto-sort
11 :  Generate sets of non-dominated fronts
12 : Calculate the crowding distance between members of each front
13 :   end for
14 : (elitist) Select the members of the combined population based on least dominated N solution ti make the population of the next generation. Ties are resolved by taking the less crowding distance
15 : Create next generation
16 : { Ranked based Roulette Wheel Selection
17 :  Recombination Mutation}
18 : end for
```

Figure 2 : Non-Dominated Ranked Genetic Algorithm

This proposed NRGA provides significant convergence and stabilization for the multi-machine power system.

IV. Experimental Results

The evaluation for the power system stabilization is presented in this section. The power system stabilization using proposed optimization technique is evaluated by comparing with the power system stabilization using Genetic Algorithm. The controller parameters such as lower bound and upper bound are altered to 0 and 60 respectively.

Table 1 shows the loading of the generators G1, G2 and G3 in the proposed multi-machine power system.

Table 1 : Generator loading in pu

Gen	Case 1		Case 2		Case 3	
	P	Q	P	Q	P	Q
G_1	0.71	0.25	2.19	1.06	0.34	1.10
G_2	1.62	0.07	1.92	0.55	2.00	0.56
G_3	0.84	-0.10	1.28	0.36	1.51	0.38

Table 2 shows the loads used in A, B and C for the proposed multimachine power system stabilization approach.

Table 2 : Generator loading in pu

Load	Case 1		Case 2		Case 3	
	P	Q	P	Q	P	Q
A	1.24	0.51	2.01	0.80	1.50	0.91
B	0.90	0.30	1.81	0.61	1.21	0.81
C	1.00	0.34	1.51	0.60	1.00	0.52

Table 3 : Electromechanical Mode Eigen Values

Case 1			Case 2			Case 3		
Without PSS	GA	NRGA	Without PSS	GA	NRGA	Without PSS	GA	NRGA
- 0.011 ±j9.068	- 0.023± j8.921	- 0.045 ±j7.745	- 0.021± j8.907	- 0.034 ±j8.441	- 0.064 ±j8.042	0.377 ±j8.865	0.287 ±j7.925	0.201 ±j7.120
- 0.778 ±j13.86	-0.845± j13.45	- 0.845 ±j13.16	-0.519± j13.83	- 0.651 ±j13.01	- 0.651 ±j12.17	- 0.336 ±j13.69	- 0.636 ±j12.02	0.699 ±j11.22

Table 3 shows the electromechanical mode eigen values. The table shows the comparison of the eigen values without PSS, GA and proposed NRGA multimachine power system stabilization approach. It is observed from the table that the proposed NRGA approach has very less electromechanical mode eigen values in all the three cases when compared with the GA approach. Thus the proposed NRGA approach provides significant performance.

Figure 3 shows the comparison of the objective function of the GA and the proposed NRGA approach. It is observed from the figure that the convergence of the NRGA is better than GA. Thus the proposed NRGA is very significant when compared with the traditional GA approach.

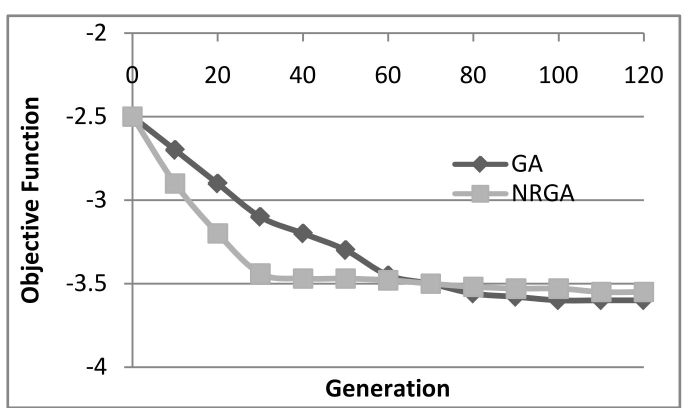

Figure 3 : Comparison of Objective Function

For evaluation, the load disturbance of 5 % is induced in the considered power system at time 1 second. Then the load disturbance induced power system undergoes stabilize using power system stabilization technique using GA and the proposed NRGA power system stabilization technique. The controller parameters are adjusted in order to stabilize the system.

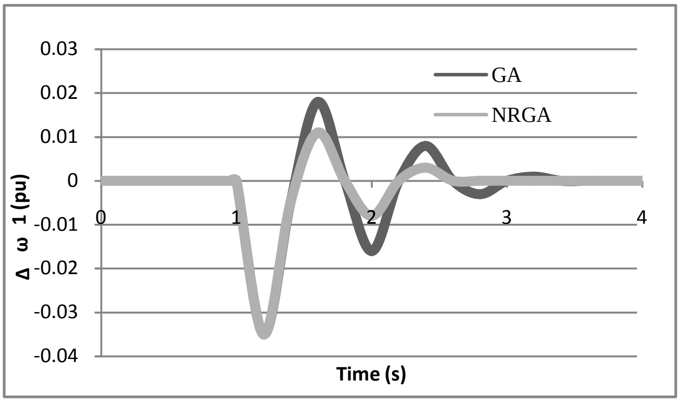

Figure 4 : System Response under fault disturbance for $\Delta\omega_1$

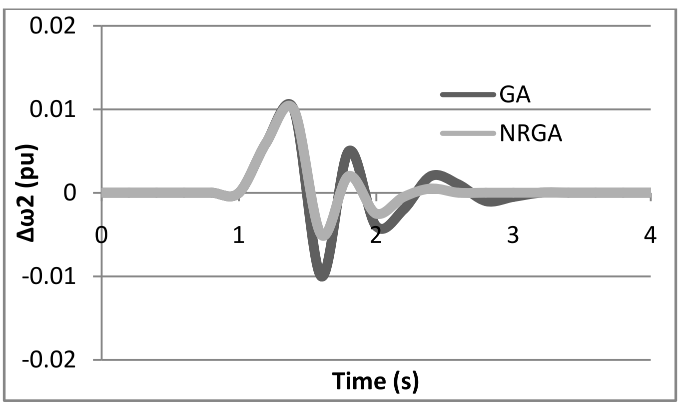

Figure 5 : System Response under fault disturbance for $\Delta\omega_2$

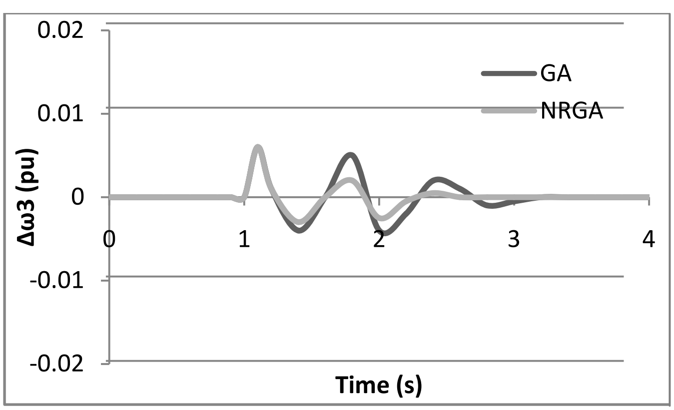

Figure 6 : System Response under fault disturbance for $\Delta\omega_3$

$\Delta\omega_1$, $\Delta\omega_2$ and $\Delta\omega_3$ deviations that occur in power system because of the introduction of 5 % load disturbance are provided in figure 4, 5 and 6 respectively. The figure depicts the stabilization behavior for using GA and NRGA for optimizing stability parameters. From the figure, it can be observed that initially the system is stable until 1 second, after that the system becomes unstable because of load disturbances. The usage of GA for stabilizing takes around 4 seconds for making the system stable, whereas, only around 3 second is required for the proposed technique to stabilize the system.

V. Conclusion

For several years Stabilization of the multi-machine power systems has been one of the most essential problems in the research area. All the existing techniques for the multi-machine power system stabilization have own advantages and disadvantages as well. The mostly used technique for stabilization is Genetic Algorithm. But, GA lacks accuracy and takes more time for convergence. To overcome those issues, this paper focuses on the use Non-Dominated Ranked Genetic Algorithm for solving power system stabilization control issues. NRGA has better convergence than the GA technique. The simulation results indicate that the proposed technique results in better stabilization than the existing techniques. The objective functions for the multi-machine power system taken into consideration shows better convergence with proposed NRGA approach. The future scope of this approach would be to use better optimization techniques which can provide a better performance.

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