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A Novel Power System Stabilization Technique Using Non-Dominated Ranked Genetic Algorithm

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Abstract: In order to deal with wide range of operating environment and disturbance, Power System Stabilizers (PSS) should be developed with appropriate stabilization signals. Recently, stabilizing control techniques for the Multi-Machine Power System with the help of intelligent methods have been developed. The main aim for the stability analysis of the power system is because of the importance of the power systems in the present world. Moreover, industries do not encourage the controller design if power system stability is not significant. In order to handle the above mentioned problems, intelligent approaches are used. The optimal sequential design for Multi-Machine Power Systems is very vital and many techniques are widely used to deal with control signals in power system. Most widely used optimization technique is Genetic Algorithm (GA). But GA takes more time in optimization and lack in accuracy. To overcome the above mentioned issues, this study uses Non-dominated Ranked Genetic Algorithm (NRGA) for optimization. Simulation results suggest that the proposed stabilization approach is better when compared to the conventional techniques.

Key words: Power system stabilization, genetic algorithm, non-dominated ranked genetic algorithm, stability, accuracy

INTRODUCTION

Extremely complex 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 stabilization of the power systems is the foremost issue that should be taken into account.

Dynamic stability is a phenomenon that deal with the approach the system adapts with a novel state following a disturbance (Yee and Milanovic, 2008). 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 (Yagami and Tamura, 2009).

Power System Stabilizers (PSS) (Hassan *et al*., 2009; Hiyama and Hara, 2004; Hiyama *et al*., 2004; Wu and Wang, 2006; Li and Wu, 2010; Li *et al*., 2007; Lim and Elangovan, 1985; Abido, 2001; Khammash *et al*., 1994; Soliman *et al*., 2008; Arrifano *et al*., 2007; Ngamroo *et al*., 2009; Hui and Qiao, 2009; Sansawatt and Ngamroo, 2006; Sauer and Pai, 1988; Senjyu *et al*., 2007, 2005) have been used for a long time to enhance the power system damping. The methods used for tuning range from pole placement to the more recent one using the heuristic optimization algorithms like the genetic algorithms (Yagami and Tamura, 2009) and particle swarm optimization (Miyazato *et al*., 2006). 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. 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 (Haruni *et al*., 2009; Hassan *et al*., 2009; Hiyama and Hara, 2004; Hiyama *et al*., 2004; Wu and Wang, 2006; Li and Wu, 2010; Li *et al*., 2007; Lim and Elangovan, 1985; Abido, 2001; Khammash *et al*., 1994; Soliman *et al*., 2008; Arrifano *et al*., 2007; Ngamroo *et al*., 2009; Hui and Qiao, 2009; Sansawatt and Ngamroo, 2006; Sauer and Pai, 1988;

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Senjyu *et al*., 2007, 2005; Mehraeen *et al*., 2011; Yee and Milanovic, 2008; Takagi *et al*., 2009; Vournas and Papadias, 2007; Abdel-Magid *et al*., 1977; Yagami and Tamura, 2009; Miyazato *et al*., 2006; Hu and Milanovic, 2007).

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 (Hiyama *et al*., 2004; Wu and Wang, 2006; Li and Wu, 2010; Li *et al*., 2007; Lim and Elangovan, 1985; Abido, 2001; Khammash *et al*., 1994; Soliman *et al*., 2008; Arrifano *et al*., 2007; Ngamroo *et al*., 2009; Hui and Qiao, 2009; Sansawatt and Ngamroo, 2006; Sauer and Pai, 1988; Senjyu *et al*., 2007, 2005; Mehraeen *et al*., 2011; Yee and Milanovic, 2008; Takagi *et al*., 2009; Vournas and Papadias, 2007; Abdel-Magid *et al*., 1977; Yagami and Tamura, 2009). Optimization using GA techniques (Abdel-Magid *et al*., 1977) 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.

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.

Mehraeen *et al*. (2011) 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.

A robust decentralized controller based on optimal sequential design is proposed by Miyazato *et al*. (2006). 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. 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 (Arrifano *et al*., 2007; Ngamroo *et al*., 2009; Hui and Qiao, 2009; Sansawatt and Ngamroo, 2006; Sauer and Pai, 1988; Senjyu *et al*., 2007). Dynamic stability problems are usually overcome through the application of Power System Stabilizers. Vournas and Papadias (2007) proposed an alternative technique for power system stabilization (Khammash *et al*., 1994) 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 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. Yee and Milanovic (2008) proposed a Fuzzy Logic Controller (FLC) for decentralized stabilization of Multi-Machine Power Systems. The researchers 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. 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. The result of the FLC technique is compared with the classical Power System Stabilizers (PSSs) (Alcalde *et al*., 2006; Bayliss and Hardy, 2007; Demello and Corcordia, 1969; Folly and Magidimisa, 2005; Forgel, 1995) tuned by a conventional Linear Sequential tuning Method (LSM) and Optimization Based Method.

Yagami and Tamura (2009) 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.

MATERIALS AND METHODS

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 (Soliman *et al*., 2008). There were various most important collapses resulted by the instability of a power system that indicates the significance of this trend (Bayliss and Hardy, 2007). The stability maintenance in a power system is considered as one of the highly important and necessary factor of power systems quality.

Power system modeling: The model of Multi-Machine Power System considered for this proposed approach is shown in Fig. 1. The multi-machine consists of Three Machine Nine Bus System. G_1-G_3 are machine present in the multi-machine taken into consideration.

System model and PSS structure: A power system can be modeled by a set of nonlinear differential equation as:

$$W = f(X, U) \tag{1}$$

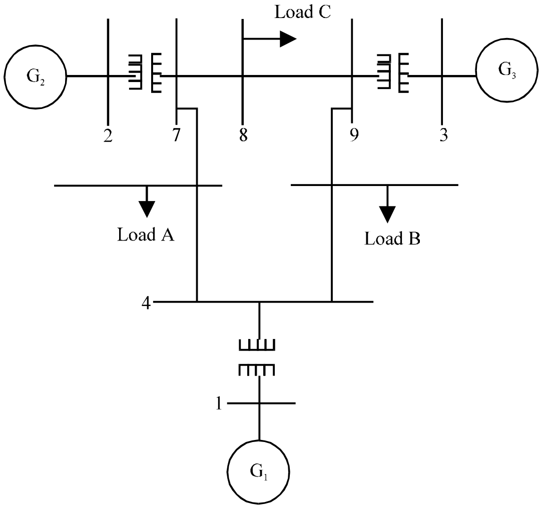

Fig. 1: Single-line diagram of Three Machine Nine Bus System

Where:
X = The vector of the state variables
U = 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 (Demello and Corcordia, 1969; Folly and Magidimisa, 2005; Forgel, 1995; Haruni *et al*., 2009; Hassan *et al*., 2009; Hiyama and Hara, 2004; Hiyama *et al*., 2004; Wu and Wang, 2006; Li and Wu, 2010; Li *et al*., 2007; Lim and Elangovan, 1985; Abido, 2001; Khammash *et al*., 1994; Soliman *et al*., 2008; Arrifano *et al*., 2007; Ngamroo *et al*., 2009; Hui and Qiao, 2009; Sansawatt and Ngamroo, 2006; Sauer and Pai, 1988). Hence, the state equation of a power system with n machines and n_{PSS} stabilizers can be written as:

$$\Delta\dot{X} = A\Delta X + BU \tag{2}$$

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

A widely used conventional lead-lag PSS is considered in this study. It can be described as (Demello and Corcordia, 1969; Folly and Magidimisa, 2005; Forgel, 1995; Haruni *et al*., 2009; Hassan *et al*., 2009; Hiyama and Hara, 2004; Hiyama *et al*., 2004; Wu and Wang, 2006; Li and Wu, 2010; Li *et al*., 2007; Lim and Elangovan, 1985):

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

Where:
T_w = The washout time is constant
U_i = The PSS output signal at the ith machine
$\Delta\omega_r$ = The speed deviation of this machine

The time constant T_w, T_2 and T_4 are usually prespecified (Lim and Elangovan, 1985). The stabilizer gain K_i and time constants T_{1i} and T_{ai} still need to be optimized.

Objective function and PSS tuning: To increase the system damping to electromechanical modes, an objective function J defined below is considered:

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

where, ζ_i is the damping factor associated with electromechanical modes. This objective function is proposed to shift these eigen values 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:

$$\begin{aligned} &K_i^{min} \leq K_i \leq K_i^{max} \\ &T_{1i}^{min} \leq T_{1i} \leq T_{1i}^{max} \\ &T_{ai}^{min} \leq T_{ai} \leq T_{aimax} \end{aligned} \qquad (4)$$

Typical ranges of these parameters are [0.01-50] for K_i and [0.01-1.0] for T_{1i} (Abdel-Magid *et al*., 1999). The time constants T_w, T_2 and T_4 are set as 5, 0.05 and 0.05 sec, respectively (Abdel-Magid *et al*., 1999; Alcalde *et al*., 2006; Bayliss and Hardy, 2007; Demello and Corcordia, 1969; Folly and Magidimisa, 2005; Forgel, 1995; Haruni *et al*., 2009; Hassan *et al*., 2009; Hiyama and Hara, 2004; Hiyama *et al*., 2004; Wu and Wang, 2006; Li and Wu, 2010; Li *et al*., 2007; Lim and Elangovan, 1985; Abido, 2001).

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

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 over the course of the 1960s and 1970s and finally popularized by one of his student, David Goldberg (Folly and Magidimisa, 2005; Forgel, 1995; Haruni *et al*., 2009; Hassan *et al*., 2009; Hiyama and Hara, 2004; Hiyama *et al*., 2004; Wu and Wang, 2006; Li and Wu, 2010). Generally in GA, there are three basic operations like reproduction, crossover and mutation.

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.

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.

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 (Forgel, 1995). Limitations of genetic algorithm in power system stabilization are slow convergence and 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 random values for K_i, T_{1i} and T_{3i} are chosen in the way that the selected random value must be within the limit specified in Eq. 4. 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 $P \cup Q$ 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 this study.

Algorithm NRGA

```
Initialize Population
  {Generate random population-size N
    Evaluate Objective Values
      Assign Rank (level) based on Pareto dominance sort
  }
  { Ranked based roulette wheel selection
    Recombination and Mutation }
for i =1 to g do
  for each member of the combined population (P∪Q) do
      Assign Rank (level) based on Pareto-sort
      Generate sets of non-dominated fronts
        Calculate the crowding distance between members of each front
        end for
    (elitist) Select the members of the combined population based on least dominated N solution make the population of the next generation. Ties are resolved by taking the less crowding distance
        Create next generation
    { Ranked based roulette wheel selection
      Recombination mulation }
  end for
```

This proposed NRGA provides significant convergence and stabilization for the Multi-Machine Power System.

RESULTS AND DISCUSSION

The evaluation for the power system stabilization is presented in this study. 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-G3 in the proposed Multi-Machine Power System. Table 2 shows the loads used in A-C for the proposed Multi-Machine Power System stabilization approach.

Table 3 shows the electromechanical mode eigen values. The Table 3 shows the comparison of the eigen values without PSS, GA and proposed NRGA Multi-Machine 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 2 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.

For evaluation, the load disturbance of 5% is induced in the considered power system at time 1 sec. 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.

$\Delta\omega_1$-$\Delta\omega_3$ deviations that occur in power system because of the introduction of 5% load disturbance are shown in Fig. 3-5, respectively. The Fig. 3-5 shows the stabilization behavior for using GA and NRGA for optimizing stability parameters. From the

Table 1: Generator loading in pu

	Case 1		Case 2		Case 3	
Gen	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: Loads in pu

	Case 1		Case 2		Case 3	
Load	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 ± 9.068^j	0.023 ± 8.921^j	0.045 ± 7.745^j	0.021 ± 8.907^j	0.034 ± 8.441^j	0.064 ± 8.042^j	0.377 ± 8.865^j	0.287 ± 7.925^j	0.201 ± 7.120^j
0.778 ± 13.86^j	0.845 ± 13.45^j	0.845 ± 13.16^j	0.519 ± 13.83^j	0.651 ± 13.01^j	0.651 ± 12.17^j	0.336 ± 13.69^j	0.636 ± 12.02^j	0.699 ± 11.22^j

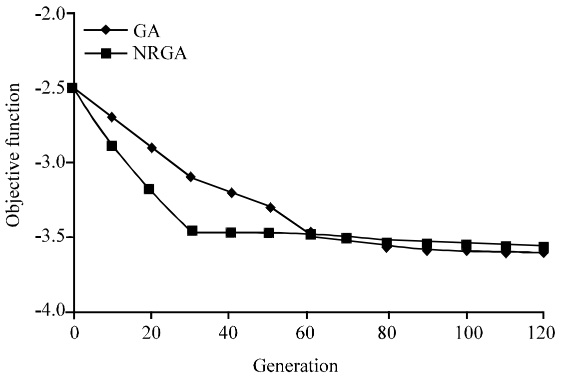

Fig. 2: Comparison of objective function

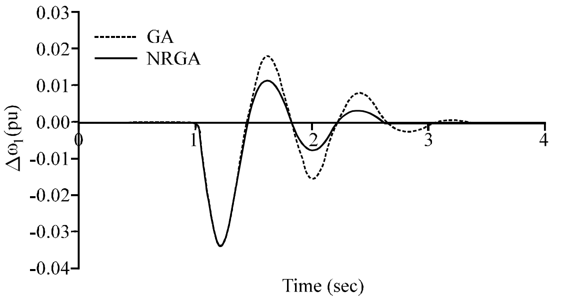

Fig. 3: System response under fault disturbance for $\Delta\omega_1$

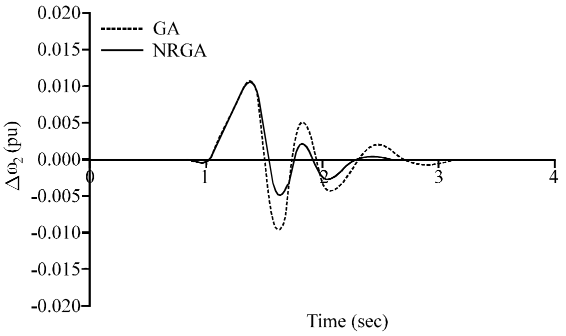

Fig. 4: System response under fault disturbance for $\Delta\omega_2$

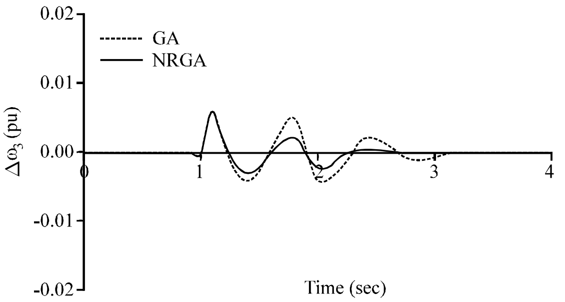

Fig. 5: System response under fault disturbance for $\Delta\omega_3$

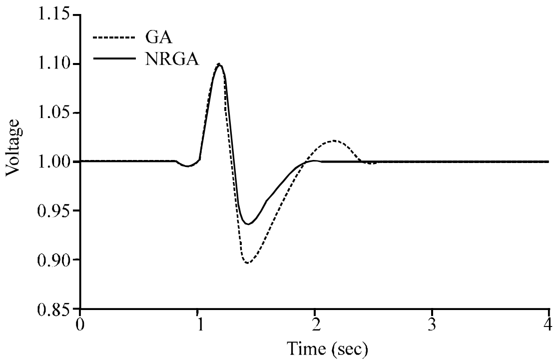

Fig. 6: Generator terminal voltage responses for Generator G1

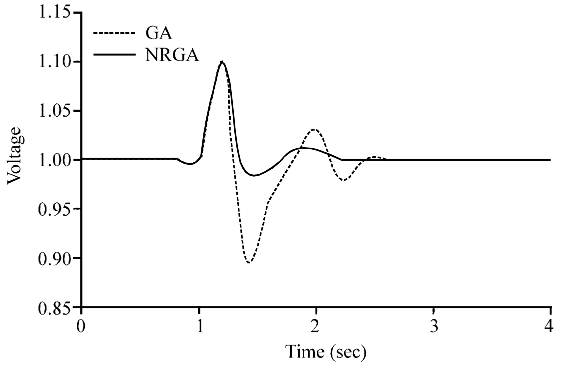

Fig. 7: Generator terminal voltage responses for Generator G2

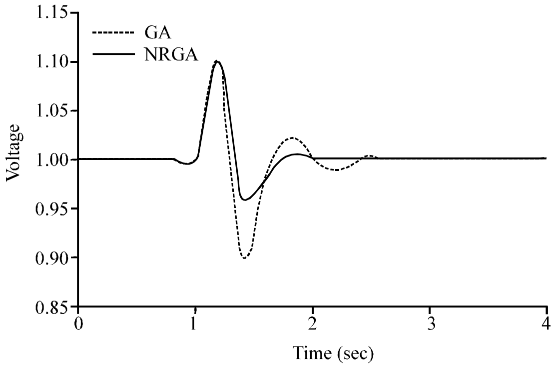

Fig. 8: Generator terminal voltage responses for Generator G3

Fig. 3-5, it can be observed that initially the system is stable until 1 sec, after that the system becomes unstable because of load disturbances. The usage of GA for stabilizing takes around 4 sec for making the system stable whereas only around 3 sec is required for the proposed technique to stabilize the system. Figure 6-8 shows the generator terminal voltage responses for Generator G1-G3, respectively. From the Fig. 6-8, it can be observed that the utilization of proposed system results in better damping of fluctuations caused in the Generators G1-G3 when compared to the usage of conventional technique.

CONCLUSION

Stabilization of the Multi-Machine Power Systems has been one of the vital problems in the research area for several years. Existing stabilization techniques for the Multi-Machine Power System have own advantages and drawbacks. One of the significant techniques used for stabilization is Genetic Algorithm. But GA lacks accuracy and takes more time for convergence. To overcome the problems of GA, this study uses non-dominated ranked genetic algorithm for solving power system stabilization control issues. NRGA has better convergence than the GA technique. The simulation results show that the proposed stabilization 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 technique would be to use better optimization techniques which can provide a better stabilization results.

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