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Design of Supplementary Controller for HVDC Using Memetic Algorithm

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Abstract: This paper investigates the ability of Memetic Algorithm (MA) in designing supplementary controller of High Voltage Direct Current (HVDC) link to damp the power system oscillations. A conventional lead-lag structure is considered for the supplementary controller. The aim of the proposed control strategy is to choose the best controller parameters in such a way that the dominant eigenvalues of the closed-loop system are shifted to the left-hand side of s-plane as far as possible. Also, the Real Genetic Algorithm (RGA) is used to design a supplementary controller for HVDC. The characteristic convergence and time simulation results show that both algorithms have good capability in solving the problem but MA gives better convergence characteristic.

1. INTRODUCTION

HVDC links has been widely applied in power transmission for a number of years and have provided utilities around the world with important technical solutions to a wide range of transmission needs due to their excellent and flexible control ability.

Direct Current (DC) transmission can be between independent systems or between points within a system. By DC link power flow can be controlled precisely and very rapidly. By controlling its power transfer, the DC link can help the system operator to dictate the power flows in the adjacent AC lines. Also, by rapidly changing its power transfer, it can improve AC system stability, and damp out post-disturbance swings. It can act as a voltage regulator by switching its reactive power banks or by adjusting control angles to absorb more, or less, reactive power.

Therefore, HVDC links can be effectively used for damping electromechanical oscillations, stabilizing power swings, reducing the life-fatigue effects of sub-synchronous resonance, etc. The development of voltage source converter technology can improve also the network voltage compensation and the transmission grid loadability, reducing the risks of voltage instability and collapse (Dash , *et al.*, 1994; Martin, *et al.,*1634, 1642; Sucena-Paiva and Freris, 1974; Todd, *et al.,* 1997; Jovcic, *et al.*, 1999; Choi, *et al.*, 2001; Wang, *et al.*, 2000).

Since, their contributions to the damping of system oscillations are of great importance for achieving satisfactory system performance, in this paper a supplementary controller is designed for a HVDC link. For this, intelligent control is used to design a conventional lead-lag structure. The binary version of genetic algorithm (GA) is used to design supplementary controller of HVDC in (Jiang, *et al.*, 2002; Jiang and Cao, 1999; Hu *et al.*, 2002,). Since the parameters of lead-lag controller are continuous variables to be found, in this paper a Memetic Algorithm (MA) with eigenvalue-based objective function is used. Also, a Real Genetic Algorithm (RGA) is applied to solve the problem and the obtained results are compared by MA.

The paper is organized as follows: to make a proper background, the basic concept of the MA and GA is briefly explained in Section 2. The optimization problem is formulated in Section 3. The results of the MA and RGA in a study system are given in Section 4 and some conclusions are drawn in Section 5.

2. OVERVIEW OF GENETIC ALGORITHM AND MEMETIC ALGORITHM

2.1 Genetic Algorithm

GA has desirable characteristics as an optimization tool and offers significant advantages over traditional methods. It is inherently robust and has been shown to efficiently search the large solution space containing discrete or discontinuous variables and non-linear constraints, without being trapped in local minima.

GA may be used to solve a combinatorial optimization problem. The GA searches for a solution inside a subspace of the total search space. Thus it is able to give a good solution of a certain problem in a reasonable computation time. The optimal solution is sought from a population of solutions using random process. Applying to the current population, the following three operators create a new generation: selection, crossover and mutation. The reproduction is a process dependant on an objective function to maximize or minimize, which depends on the problem.

GA can be implemented through binary GA (BGA) and real GA (RGA). The first step in the solution of an optimization problem using BGA is the encoding of the variables. The most usual approach is to represent these variables as strings of 0s and 1s. A collection of such strings is called population. Then, selection, crossover and mutation are applied on the encoded variables. On the other hand, RGA uses the real codes and the selection, crossover and mutation are applied to the variable directly (Corn, *et al.*, 1999).

2.2 Memetic Algorithm

MA is a population-based metaheuristic search method which is inspired by the conjecture of natural selection and Dawkins' notion of 'meme' (Dawkins, 1976). A GA models biological evolution while the MA models cultural evolution (Merz and Freisleben, 2000; Krasnogor and Smith, 2005), or the evolution of ideas. A population of ideas can be generated. Ideas can be recombined to form new ideas and they can be mutated. The unit of information in the Memetic approach is referred to as a meme rather than a gene. The main difference between this model and the biological model is that memes can be improved upon by their owner. This improvement is obtained by incorporating local search into the genetic algorithm.

Therefore, MA is a hybrid GA that uses a genetic search to explore the search space and a local search to exploit information in the search region. The first MA was implemented by Norman and Moscato (1991), where their MA was a hybrid of traditional GA and simulated annealing.

Local search in MA can be a hill-climbing one. Hill-climbing searches the neighbourhood of the current solution to find the next solution with more improvement in the value of objective function. The applied MA and local search in this paper can be described as follows:

In MA, the initial process can produce n ideas randomly. Each idea will be evaluated by a fitness function. Then, the first K ideas with the best fitness function will be selected. Now the local search is applied on the selected K ideas. This Local search is a hill-climbing one, where a neighbourhood is considered for each selected idea. The algorithm searches the neighbourhood of the K selected ideas to find a solution with more improvement in the value of fitness function. If such a solution exists, the old idea is replaced with the newly obtained idea. This local search can be repeated m times, where m is defined by the user.

3. STUDY SYSTEM AND PROBLEM FORMULATION

A 2-area-4-machine system is used. This test system is illustrated in Fig. 1. The sub transient model for the generators, and the IEEE-type DC1 and DC2 excitation systems are used for machines 1 and 4, respectively. The IEEE-type ST3 compound source rectifier exciter model is used for machine 2, and the first-order simplified model for the excitation systems is used for machine 3. An HVDC link is considered between two buses, 3 and 13.

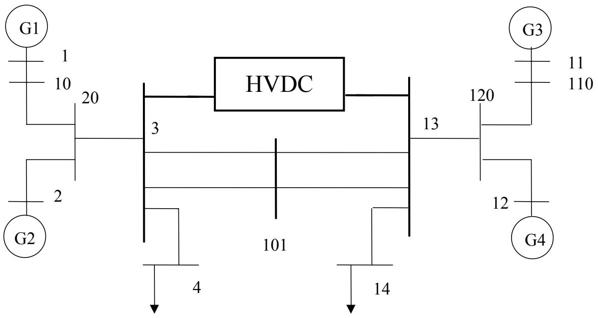

Fig. 1. Single-line diagram of a 2-area study system.

Fig. 2 shows the HVDC system with the supplementary controller, where the supplementary controller is designed using MA and RGA. The following structure shown by Fig. 3 is used for the controller, where the input to the controller could be generator speed (GS).

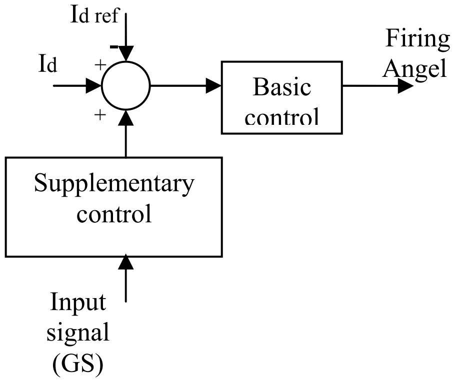

Fig. 2. HVDC system with the supplementary controller.

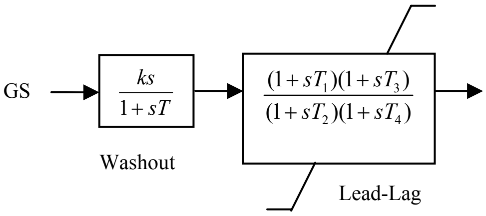

Fig. 3. A lead-lag structure model block diagram: supplementary controller for HVDC link.

The parameters of the supplementary controller, T, T_1, T_2, T_3, T_4, are determined with MA and RGA by optimizing the following objective or cost function:

$$f = \max(real(s) - \min(-\beta * abs(imag(s)), \alpha)) \qquad (1)$$

where in this study β is set to be 1. This fitness function will place the system closed-loop eigenvalues in the D-shape sector shown in Fig. 4. Having the real part of rotor mode eigenvalue (s) restricted to be less than a value, say α, guarantees a minimum decay rate α. A value α = - 0.5 is considered adequate for an acceptable settling time.

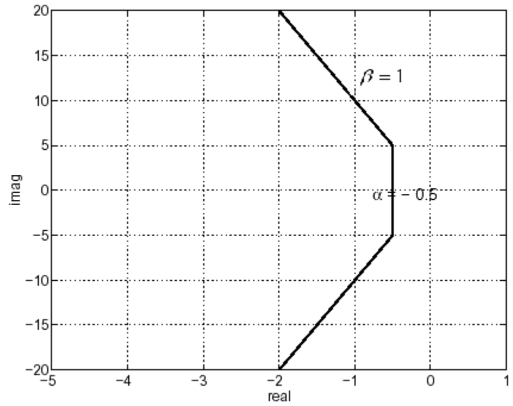

Fig. 4: A D-shape sector in the s-plane.

Furthermore, the design problem can be formulated as the following constrained optimization problem, where the constraints are the supplementary controller parameter bounds:

$$Minimize\ f\ subject\ to \quad \begin{cases} 0 \le T \le 5 \\ 0 \le T_1 \le 2 \\ 0.02 \le T_2 \le 0.05 \\ 0 \le T_3 \le 2 \\ 0.02 \le T_4 \le 0.05 \end{cases} \qquad (2)$$

MA and RGA are applied to solve this optimization problem and search for the optimal or near optimal set of supplementary controller for HVDC link.

4. DESIGN OF SUPPLEMENTARY CONTROLLER USING MA AND RGA

The implementation of MA and RGA are as follows:

The goal of the optimization is to find the best value for the five supplementary controller parameters, T, T_1, T_2, T_3, T_4 (Fig. 3). Therefore, a configuration is considered with five genes in RGA or five memes in MA.

The number of chromosomes in RGA is considered to be 50. In RGA, the chromosomes evolve through successive iterations, called generations. During each generation, the chromosomes are evaluated with some measure of fitness, which is calculated from the objective function (equation (1) subject to (2)). Moving to a new generation is done from the results obtained for the old generation. A biased roulette wheel is created from the obtained values of the objective function of the current population. To create the next generation, new chromosomes, called offspring, are formed using a crossover operator and a mutation operator.

In RGA, linear crossover and Gaussian mutation are used with the crossover probability $p_c = 0.9$ and the mutation probability is selected to be $p_m = 0.01$. The number of iteration is considered to be 100, which is the stopping criterion.

The principle of MA applied in this paper is shown in Fig. 5. For a fare comparison, the number of ideas is set to be 10 in MA. The local search is applied on the first *K* ideas with the best fitness function, where $K = 5$. The local search is repeated 8 times for each idea. With this setting, the number of evaluations of fitness function in MA is 50 ($5 \times 8 + 10 = 50$) which is the same as in RGA.

The number of iteration is considered to be 100. The crossover probability is set to be $p_c = 0.7$ and the mutation probability is selected to be $p_m = 0.3$. The reason for setting the mutation probability in MA to a higher value compared to the mutation probability in RGA is: in GA, crossover is used for both exploration and exploitation, and mutation is used for exploration or finding new promising search region. But in MA, the crossover and mutation are only used for exploration, and the local search is used for exploitation.

For the designed supplementary controller for HVDC link, the algorithm is run for 10 independent run under different random seeds. The following values for T, T_1, T_2, T_3, T_4 are found with MA as follows:

$$T = 3.5431\ ,\ T_1 = 0.16676\ ,\ T_2 = 0.026382, \quad T_3 = 0.17449, \quad T_4 = 0.032123 \qquad (3)$$

Also, the following values for T, T_1, T_2, T_3, T_4 are found with RGA as follows:

$$T = 4.4948\ ,\ T_1 = 0.15242\ ,\ T_2 = 0.047198, \quad T_3 = 0.18873\ ,\ T_4 = 0.031495 \qquad (4)$$

Equations (3)-(4) show that both algorithms find almost the same solution. The convergence characteristics of both algorithms should be illustrated to show how the algorithms are converged to these solutions.

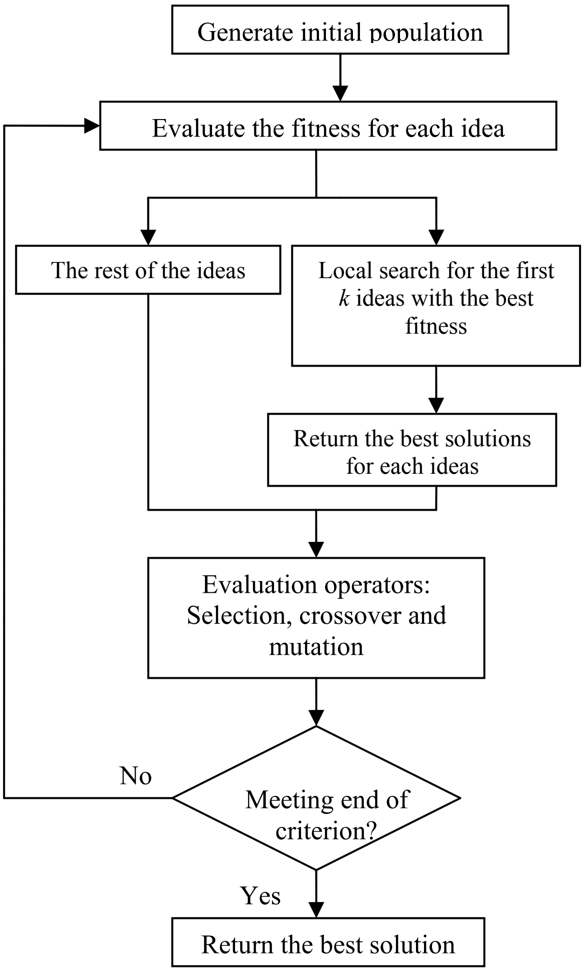

Fig. 5. The MA algorithm.

The average best-so-far of each run are recorded and averaged over 10 independent runs. To have a better clarity, the convergence characteristics in finding the best values of supplementary controller parameters are given in Fig. 6. This figure shows that MA has a better feature to find optimal solution due to the local search.

The obtained supplementary controllers for HVDC link by MA and RGA are placed in the study system (Fig. 1). To show the effectiveness of the designed supplementary controller for HVDC link, a time-domain analysis is performed for the study system. Based on the similarity of solutions (3)-(4), it is expected that both algorithms perform the same in time domain. A three-phase fault is applied in one of the tie circuits at bus 101. The fault persisted for 70.0 ms; following this, the faulted circuit was disconnected by appropriate circuit breaker. The system operated with one tie circuit connecting buses 3 and 101. The dynamic behaviour of the system was evaluated for 15 s. The voltage magnitude at fault bus is shown in Fig. 7. Also, the machine angles, δ, with respect to a particular machine, were computed over the simulation period and shown in Figs. 8-9.

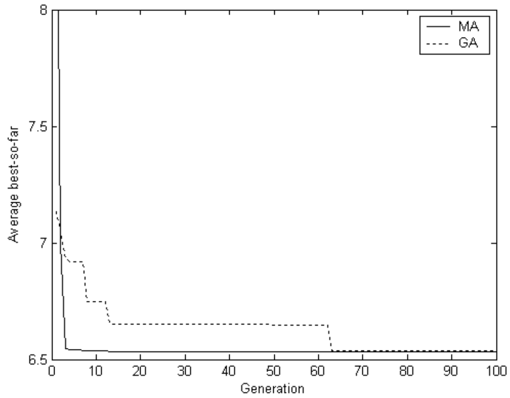

Fig. 6. Convergence characteristics of MA and RGA on the average best-so-far in finding the parameters of supplementary controller.

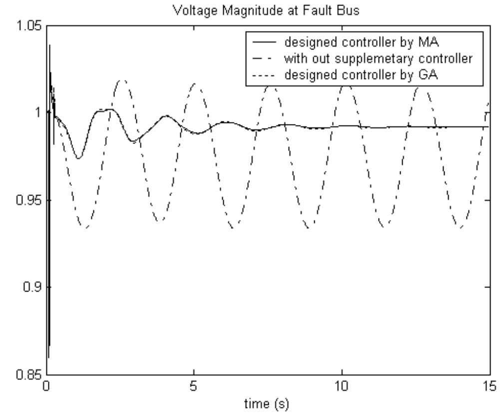

Fig. 7. Voltage magnitude at the fault bus.

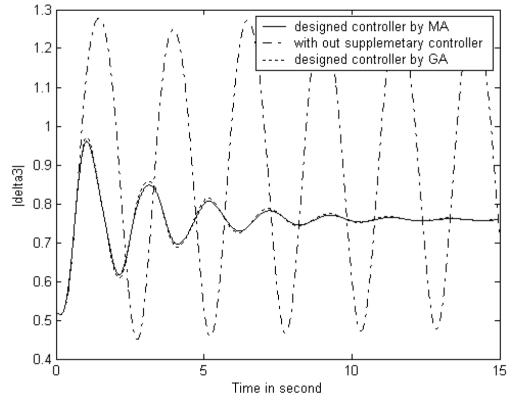

Fig. 8. The response of generator 3 to a three-phase fault.

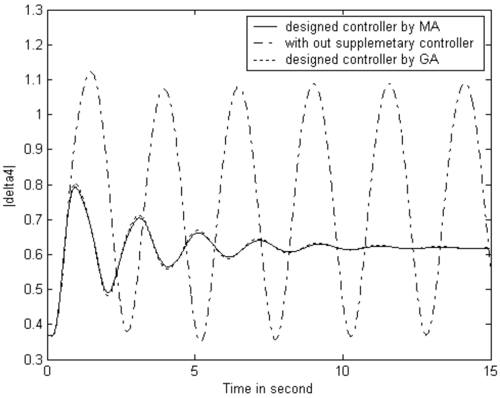

Fig. 9. The response of Generator 4 to a three-phase fault.

5.CONCLUSIONS

This paper investigated the ability of MA in designing supplementary controller for HVDC to damp the low frequency oscillations. To validate the obtained results, RGA is applied. For this the parameters of the controller are determined by MA and RGA using an eigenvalue-based objective function. To show the effectiveness of the designed controller, a three phase fault is applied at a bus. The simulation study shows that the designed controllers improve the stability of the system.

Although, both algorithms converged to the almost same solution, but the convergence characteristics show that MA finds the solution in early iterations. This may be useful for solving the problems when time is an issue.

Also, MA could be a good choice for solving unimodal functions. Unimodal functions are those functions that have a local minimum. For unimodal functions, the convergence rates of the algorithm are more interesting than the final results of optimization.

For a future work, to improve the damping, Static Var Compensators (SVC) can be used and a supplementary controller can be designed by MA and RGA for the SVC.

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