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Optimal Placement of Static VAR Compensator Using Genetic Algorithms

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Abstract: The management of power systems has become more difficult than earlier because power systems are operated closer to security limits, environmental constraints restrict the expansion of transmission network and the need for long distance power transfers has increased. The loading of a transmission network can be increased by maintaining proper voltage profile through injecting appropriate reactive power into the system. The existence of the multiple solutions in the optimal placement of reactive power in the power system typically often get stuck at the local optimum rather than at the global optimum. Genetic Algorithms (GAs) are stochastic searching algorithms that make the searching process jumps randomly from point to point, thus allowing escape from the local optimum, and search for many sub-optimum points in parallel. This paper presents an evolutionary computation algorithm for enhancing voltage stability. GAs will determine the most vulnerable bus in the power system, where the Static VAR Compensator (SVC) is needed to be installed at that bus as well as considering installation cost of SVC. The developed algorithms have successfully obtained the best solution for optimal placement of SVC in the IEEE 9 buses system and TNB northern area 275kV 14-bus system.

Keywords: Genetic Algorithms, Optimization, Static VAR Compensator.

1. INTRODUCTION

One of the major problems that may associate with a stressed system is the voltage instability or collapse. Instability of the voltage can affect the performance of a power system. The main cause of voltage instability is insufficient reactive power supply [1]. Reactive power can be dispatched effectively to maintain acceptable voltage levels. Maintaining viable voltage levels are very important to avoid voltage collapse.

Static VAR Compensator (SVC) as the reactive resource uses power electronics to control its reactive power output to regulate bus voltage. It has the capability of supplying dynamically adjustable reactive power within the upper and lower limits and can be modeled by a variable shunt susceptance [2]. The increase of susceptance requirement is proportional to the higher cost of SVC installation. Thus, the optimum cost of sizing and locating SVC can be represented by using minimum susceptance of SVC.

This paper presents a new technique of enhancing voltage stability with consideration of economic issues such as the installation cost of a SVC in MATLAB environment. The developed algorithms are applied to IEEE 9 buses system and TNB Northern Area 275kV Network. Literature review of conventional and recently optimization methods are presented in Section 2. Section 3 shows the basic concepts, definitions and framework of GAs. The development of algorithms of optimal placement of SVC is described in Section 4. In Section 5, the validation and application of the developed GAs are presented.

2. LITERATURE REVIEW

The existence of the multiple solutions in the optimal placement of reactive power in the power system has been investigated long time ago. There had been many attempts to solve for these multi objective solutions. Different problem solution methods have been employed to solve the problem such as linear programming, nonlinear programming and decomposition methods to obtain optimal solutions, then the only optimal solution is found, and dispatch selection is limited [3]. Furthermore, some of these conventional optimal methods, such as the Newton method, Broyden's method, and the gradient descent method, are classified as greedy search techniques and often get stuck at the local optimum rather than at the global optimum [4].

GAs are stochastic searching algorithms that make the searching process jumps randomly from point to point, thus allowing escapes from the local optimum, in which other conventional optimization algorithms might land, and these search for many sub-optimum points in parallel. Since GAs can provide many sub-optimal dispatch solutions, they enable the operator to enhance voltage stability in a flexible and practical manner.

The issue of optimal SVC placement was studied by Martins et. al. [5] and Mansour et. al. [6] to achieve the maximum damping on electromechanical oscillations and improve the voltage stability. Martins [5] used the transfer function residue-related algorithm and Mansour [6] used participation factors (which are related to the identified critical mode) to determine the most suitable place for the SVC placement. However, the optimal location of SVC to achieve minimum cost of installation of SVC and to improve system stability, while satisfying the power system constraints can not be studied using existing analysis tools. This shows the urgency to develop a new algorithm which can satisfy multi objectives optimization.

Power flow is used in determining the magnitude and phase angle of voltage at each buses and active and reactive power flow in each lines. The system is assumed to be operating under balanced conditions and a single-phase model is used [7]. Newton-Raphson power flow is applied to calculate voltage magnitude.

3. GENETIC ALGORITHMS

Genetic Algorithms (GAs) are a stochastic global search method that mimics the metaphor of natural biological evolution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation.

The process of GAs is presented in Figure 1. Individuals, or current approximations, are encoded as strings, chromosomes so that the genotypes (chromosome values) are uniquely mapped onto the decision variable (phenotypic) domain. Having decoded the chromosome representation into the decision variable domain, it is possible to assess the performance, or fitness, of individual members of a population. This is done through an objective function that characterizes an individual's performance in the problem domain. Thus, the objective function establishes the basis for selection of pairs of individuals that will be mated together during reproduction.

During the reproduction phase, each individual is assigned a fitness value derived from its raw performance measure given by the objective function. This value is used in the selection to bias towards more fit individuals. Genetic operators manipulate the characters (genes) of the chromosomes directly, using the assumption that certain individual's gene codes, on an average, produce fitter individuals.

The recombination operator is used to exchange genetic information between pairs, or larger groups, of individuals. After recombination, the objective function evaluated, a fitness value assigned to each individual and individuals selected for mating according to their fitness, and so the process continues through subsequent generations. In this way, the average performance of individuals in a population is expected to increase, as good individuals are preserved and bred with one another and the less fit individuals die out. The development of optimal placement of SVC using GAs is presented in Section IV.

4. ALGORITHMS FOR OPTIMAL PLACEMENT OF SVC

Before proceeding with GA's application, the data preparation for low voltage profile power systems and formation of the admittance matrix, Y, is necessary for the algorithms.

SVC would be installed in potential bus as shown in Figure 2 with different susceptance value. Thus, the susceptance value is the potential solution to the optimal placement of SVC problem. It's encoded as a chromosome and comprising in an initial population as shown in Figure 3 and Figure 4 respectively.

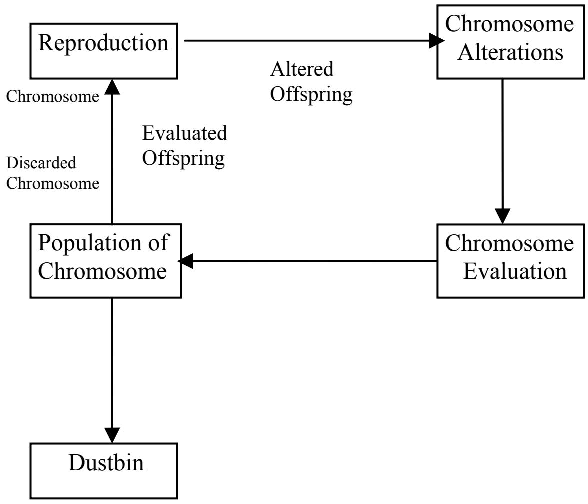

Figure 1. Flowchart of a GAs

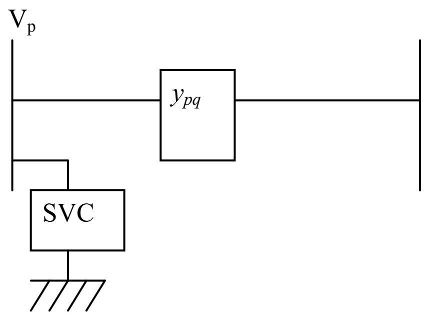

Figure 2. Simple power system diagram

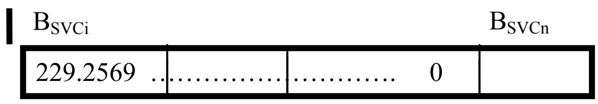

Figure 3. GAs chromosome structure

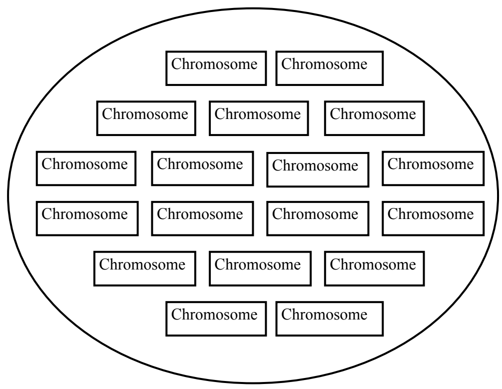

Figure 4. A population structure

Each chromosome would be put into bus matrix, undergo power flow solution to calculate the new voltage.

$$P_p - jQ_p = \sum_{q=1}^{n} |V_p||V_q||Y_{pq}| e^{-j(\theta_{pq}+\delta_p-\delta_q)} \quad (1)$$

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 \, J_2 \\ J_3 \, J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta |V| \end{bmatrix} \quad (2)$$

$$|V_i^{(k+1)}| = |V_i^{(k)}| + \Delta |V_i^{(k)}| \quad (3)$$

Finally, the new bus voltage with injected value of SVC will be obtained. The bus voltage would be applied in objective function.

$$f(x) = W_1 * k * V_c + W_2 * Co \quad (4)$$

where W_1 and W_2 are weighting factors, k as a constant variable, V_c and Co as a voltage differential and cost of setting up a SVC at any bus i respectively. If the generation counter is less than the maximum generation, GAs operations will take place with the execution of the algorithms to compute the fitness values by evaluating the objective function. The selection operator drives the optimization process towards better regions of the search space. After recombination operation, the generation counter is incremented. The GAs iterates around the loop until reach maximum generation. The GAs approach for SVC optimal placement problem can be illustrated in Figure 5. In general, the best individual in the final generation represent the solutions of the optimal placement of SVC.

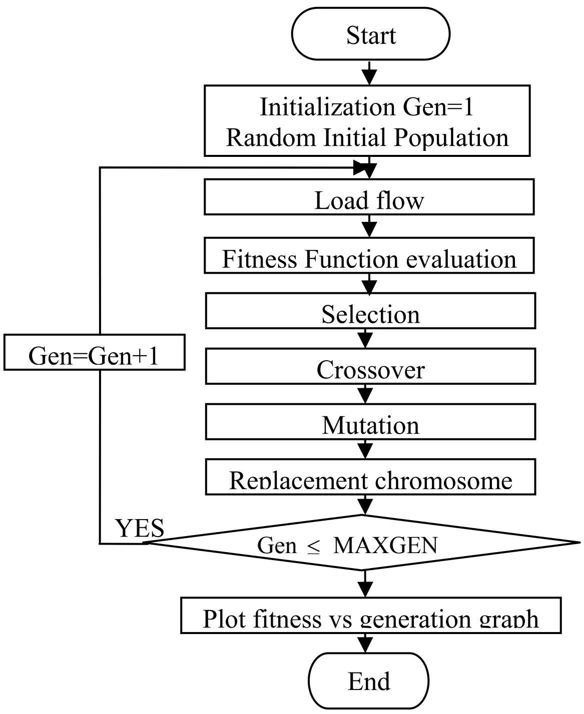

Figure 5. Flow of developed GAs optimization algorithms

5. RESULTS AND DISCUSSIONS

Results are shown in this section consists of three main parts, which are validation system, case study and practical system.

a) Validation system

For validation purpose, Klos Kerner 3-bus system shown in Figure 6 will be applied to the developed algorithms. The system bus data can be found in [8]. The results obtained with the algorithms have been compared to those calculated by power flow solution. Without SVC injection, both of the load buses voltage is out of the limit. V2 is 0.944 p.u and V3 is 0.949 p.u. which produced 1.8574 as the fitness value. Based on the genetic algorithms, the optimal placement of SVC is at bus 2 and the size of susceptance is 213.9862 which carrying the fitness value of 0.9593256. The best fitness value of 100 generations are plotted on Figure 7. From the graph, the normalized fitness values are moved toward minimum along the generations. The best value of fitness function is 0.9593 respectively.

Compare with power flow solution, whenever 210 Var (the nearest to the optimal size of SVC) injected to bus 2, the fitness value is the lowest among the others and the different of V_2 and V_3 are 0.001624 and0.000614 respectively. It is proved that the GAs succeed find the global optimum that the lowest fitness value in the validation system. In addition, GAs is able to find the smaller fitness value of 0.9593256 compare to 0.959340 by power flow solution. Since only single susceptance value will be injected into the power flow solution each time and it will consume a lot of time and energy. Comparing with the algorithms that use only 5.78 second of processing time for 20 individuals in a population and running 100 generations. Thus, the developed algorithms save a lot of time. The GAs is shown to be a valid tool to perform the SVC optimization placement.

b) Case study

9 IEEE buses system was tested to confirm the feasibility of developed algorithms. The single line diagram of test system 2 as shown in Figure 8. Initially, the system was heavily loaded. Consequently, all the voltages of the load buses as shown in as shown in table 1 were low and voltages bus 5 and 6 even out of range of the limit, which is below 0.95p.u.. After installation of SVC with 147.6192 Var at bus 5, the voltage buses generally are increased and viable as shown in table 2. The best fitness value of 100 generations are plotted on Figure 9. The best values of fitness function is 0.8351876.

The random generated susceptance value will inject in 6 load buses for initial generation. The population will get collectively stronger individuals as generations pass and weaker individuals die out. The best susceptance value is 147.6192 MVAr which installed at bus 5. All the buses voltage are viable that they lie in a specified range about their nominal value that 0.95p.u to 1.1p.u. including the previous two out of the limit. There is no other better solutions can be found in the defined objective function in test system 2.

Table 2 presents the bus data of test system 2 with the installation 147.5253Mvar susceptance value of SVC. The voltages at bus 5 and 6 have an increment of 16.023% p.u., and 6.322% p.u. accordingly. The feasibility of GAs in solving the optimal placement of SVC in case study which consists of 9 buses power system has been proven.

c) Practical system

In order to demonstrate optimal placement of SVC using GAs on a practical system, the algorithms were run on Tenaga Nasional Berhad (TNB) northern area 275kV fourteen-bus system. The system bus data can be found in [8].

Initially, the system was heavily loaded. Consequently, all the voltages of the load buses as shown in table 3 were low and voltage bus 11,13 and 14 even out of the limit, which is below 0.95p.u.. Based on the output of GAs, the optimal placement of SVC is at bus 13 and the size of susceptance is 279.0986 which carrying the fitness value (normalized) of 0.8624656.

The best fitness values of 100 generations are plotted on Figure 10. From the graph, the normalized fitness value is 0.8624656 over 100 generations with the installation SVC on bus 13. Table 4 presented the bus data of test system 3 after applied SVC of size 279.0986. The voltages at bus 11, 13 and 14 have an increased of 5.9% p.u., 6.43% p.u. and 5.69% p.u. respectively. From the numerical results presented, the optimal placement of SVC using GAs performed very well in TNB system.

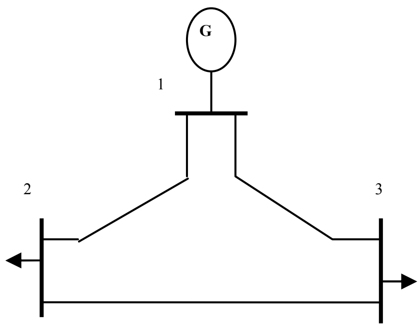

Figure 6. Klos Kerner 3-bus system

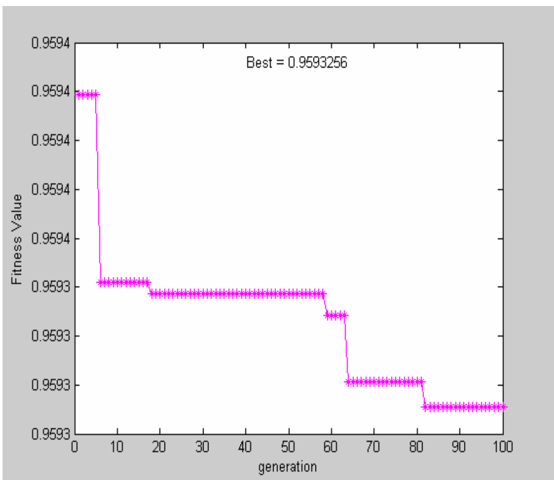

Figure 7. Convergence characteristics in obtaining the optimal placement of SVC for validation system

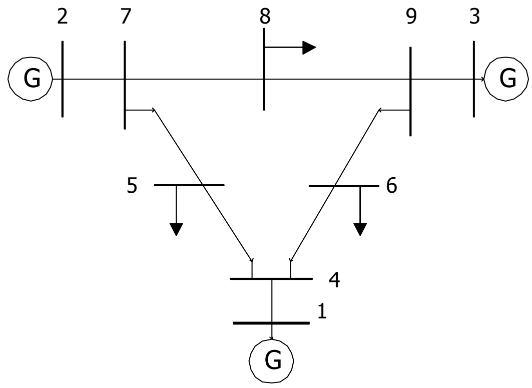

Figure 8. Test system 2

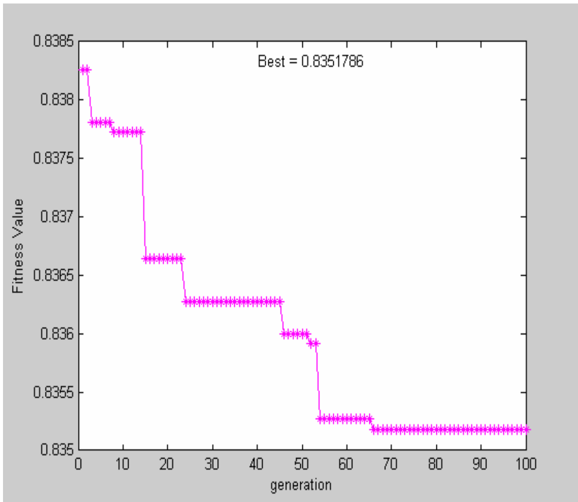

Figure 9. Convergence characteristics in obtaining the optimal placement of SVC for IEEE 9 buses system

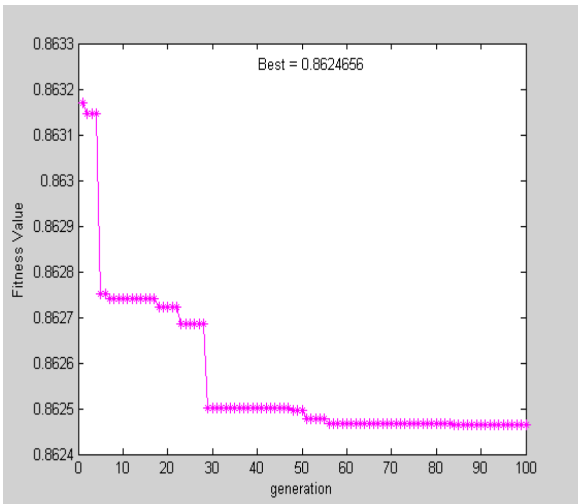

Figure 10. Convergence characteristics in obtaining the optimal placement of SVC for TNB Northen 14 buses

Table 1. Bus Data 9 IEEE buses system without SVC installation

Bus No.	Volt Mag.	Angle Degree	Load MW	Load Mvar	Injected Mvar
1	1.04	0	0	0	0
2	1.025	10.142	0	0	0
3	1.025	4.738	0	0	0
4	0.981	-2.346	0	198	0
5	0.948	-4.348	125	113	0
6	0.949	-3.768	90	130	0
7	0.969	4.253	0	123	0
8	0.982	0.77	100	10	0
9	1.008	1.974	0	10	0

Table 2. Bus Data 9 IEEE buses system with SVC installation

Bus No.	Volt Mag.	Angle Degree	Load MW	Load Mvar	Injected Mvar
1	1.04	0	0	0	0
2	1.025	9.682	0	0	0
3	1.025	4.905	0	0	0
4	1.0476	-2.233	0	198	0
5	1.0999	-4.357	125	113	147.62
6	1.0090	-3.449	90	130	0
7	1.0089	4.028	0	123	0
8	1.0146	0.9	100	10	0
9	1.0283	2.197	0	10	0

Table 3. Bus Data for TNB Northen Area 14 buses without SVC installation

Bus No.	Volt Mag.	Angle Degree	Load MW	Load Mvar	Injected Mvar
1	1.04	0	0	0	0
2	1.03	-0.339	0	0	0
3	1	-0.706	0	0	0
4	1.022	-0.986	0	0	0
5	1	-2.606	36	9	0
6	0.987	-3.422	145	73	0
7	0.989	-2.562	139	77	0
8	0.991	-2.239	0	15	0
9	0.998	-1.158	0	3	0
10	0.978	-4.452	416	5	0
11	0.949	-5.757	288	235	0
12	0.976	-4.478	133	24	0
13	0.948	-5.762	9	48	0
14	0.949	-5.709	150	225	0

Table 4. Bus Data for TNB Northen Area 14 buses after SVC installation

Bus No.	Volt Mag.	Angle Degree	Load MW	Load Mvar	Injected Mvar
1	1.04	0	0	0	0
2	1.04	-0.397	0	0	0
3	1.03	-0.972	0	0	0
4	1.036	-1.065	0	0	0
5	1.025	-2.701	36	9	0
6	1.019	-3.521	145	73	0
7	1.021	-2.718	139	77	0
8	1.022	-2.415	0	15	0
9	1.029	-1.402	0	3	0
10	1.016	-4.516	416	5	0
11	1.005	-5.803	288	235	0
12	1.016	-4.534	133	24	0
13	1.009	-5.844	9	48	279.1
14	1.003	-5.736	150	225	0

6. CONCLUSION

A genetic based optimal placement of SVC has been successfully developed. GAs have demonstrated their ability and applied to practical 14 bus system. The main advantage of the solution to this problem is its modeling flexibility. Additionally, the cost objective function and voltage contribution can be easily modeled.

In general, the developed genetic based algorithms offer a series of improvement over conventional methods. GAs have the ability to perform multiple direction searches by maintaining a population of potential solutions and these search for global optimum. The numerical results obtained for the 3 power systems clearly validate the effectiveness and robustness of the developed algorithms for finding optimal placement of SVC. The success of GAs in finding global optimum are proven with time and cost saving and, accuracy and meets the requirement of the objective defined. The developed algorithms are a promising method in solving the optimal placement of SVC. The algorithm's processing time is acceptable and it can be further improved with other high-level computer languages, for example C++ or apply hybrid methods.

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