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Genetic Algorithm Based Reactive Power Management by SVC

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ABSTRACT

This paper contains an approach of a generalized optimization formulation regarded as genetic algorithm with a view to determining the optimal location of distributed generators in 10-bus network offering reactive power capability. It is certainly the case that the reactive power management plays a noteworthy role, when it is required to improve not just the voltage profile but the voltage stability as well. In this paper, the requisite reactive power planning has been precisely solved by the evolutionary genetic algorithm, which is based on biological metaphor, in which best individuals are selected among parents and offspring generation. In addition, genetic algorithm does not need initial information about the system to begin the searching process since it works only with the chromosomes which will be optimized according to the objective functions and the proper constraints. As far as this paper goes, the injection of 228.5469553MVAR reactive power by Static Var Compensator (SVC) is enough to maintain voltage stability throughout the system.

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1. INTRODUCTION

Modern power system buses are generally classified into three types such as slack bus, generator bus and load bus [1]. The bus at which the magnitude and phase angle of the voltage are specified is called the reference bus or slack bus. It is connected to the generator bus and makes up the difference between the scheduled load and generated power that are caused by the losses in the network. Since, in this bus the real power is not specified, it is also called the swing bus. The bus at which the magnitude of the voltage and real power is specified and the phase angle of the voltage and reactive power have to be determined is called the generator bus or P-V bus or voltage controlled bus. The bus at which the real power and the reactive power are specified and the magnitude and phase angle of the voltage are to be determined is called the load bus. At this bus voltage and frequency remain constant and it is also called infinity bus.

It is certainly the case that voltage instability in power system is generally caused by the load change scenarios. This phenomenon easily may cause an unstable equilibrium and consequently the system would be unable to operate soundly any longer. For proper compensation, the best way is to maintain an adequate reactive power management in the network and a proper voltage level [2-3].

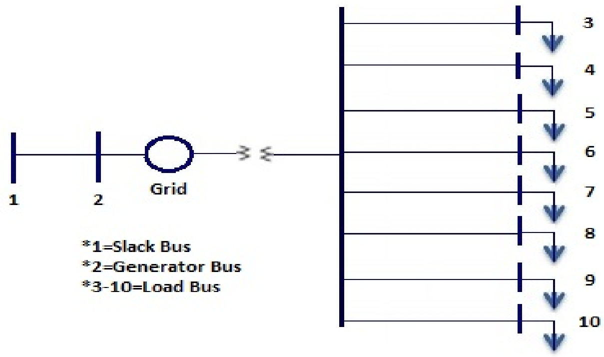

Figure 1. 10-Bus distribution network

In order to meet the changes provided by grid systems, a new perspective on network operation can be applied, in which the intelligence must be spread over Flexible AC Transmission Systems (FACTS) devices, such as Static VAR Compensator (SVC) and thus, distribution power network becomes flexible. More importantly, FACTS devices have stood out as a feasible option to improve voltage stability by influencing power flows and voltage profiles [4].

The implementation of an efficient reactive power planning is allowed by the active power networks, in which the optimum VAR sources location is chosen during the planning stage and acting this way, an efficient reactive power dispatch could be also achieved by scheduling an optimum regulation of the voltage set point at the generators connection point and at the VAR settings during the reactive power dispatch [5].

Traditionally, reactive power planning has been formulated as an optimization problem in which the determination of the instantaneous optimal steady state of an electric power system is solved by an Optimal Power Flow problem (OPF) [6]. In those situations, Genetic Algorithm (GA), a type of evolutionary optimization algorithm is defined as a single objective function expressed as a mathematical function based on some criteria [7].

An SVC is a controlled shunt susceptance (B) which injects reactive power into the system. Therefore, the bus voltage is increased to the desired level. If bus voltage increases, SVC will inject less reactive power or TCR will absorb more reactive power. The dynamic nature of the SVC lies in the use of thyristor devices such as GTO, IGBT [8]. Thyristor based SVC is shown in Figure 2,

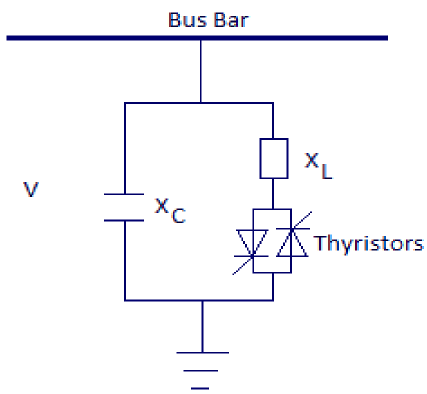

Figure 2. Static VAR compensator diagram

As is observed, V_{SVC} is the voltage at SVC connection point that is being controlled. X_L is the total inductance and X_C is the capacitance. If α_{SVC} is the firing angle of SVC then reactive power injected by SVC [9] can be expressed as:

$$Q_{SVC} = V_{SVC}^{2}[\frac{1}{X_C} - \frac{2\pi - \alpha_{SVC} + \sin 2\alpha_{SVC}}{\pi X_L}] \quad (1)$$

2. RESEARCH METHOD

Genetic Algorithm (GA) was first introduced by Holland in 1975 and it belongs to the evolutionary optimization algorithms. It is a meta-heuristic optimization method, that is, it iteratively solves a problem by improving the candidate solution based on certain criteria [10]. The major steps involved in a typical GA are initializing the population, crossover, mutation, selection and termination based on the termination criterion [11] illustrated below:

1. Population Initialization: Genetic algorithm is started with a set of solutions called population. The solution to a problem is called a chromosome. A chromosome is made up of a collection of genes which are simply the parameters to be optimized [12].
2. Fitness Evaluation and Selection: The fitness function is a representation of the quality of each solution (chromosome). According to the fitness value, the fittest chromosomes are selected and then crossover and mutation are performed on these chromosomes to generate the new chromosomes. One of the techniques is the roulette wheel selection in which, parents are selected according to their fitness. The better the chromosomes, the more chances they have to be selected [13].
3. Crossover and Mutation: Crossover and mutation are the main functions of any genetic algorithm after selection. They are the functions responsible for the creation of new chromosomes out of the existing chromosomes.
   In the crossover phase, all of the selected chromosomes are paired up, and with a probability called crossover probability, they are mixed together so that a certain part of one of the parents is replaced by a part of the same length from the other parent chromosome. The crossover is accomplished by randomly choosing a site along the length of the chromosome, and exchanging the genes of the two chromosomes for each gene past this crossover site.
   After the crossover, each of the genes of the chromosomes (except for the elite chromosome) is mutated to any one of the codes with a probability defined as the mutation probability.
   With the crossover and mutations completed, the chromosomes are once again evaluated for another round of selection and reproduction. Setting the parameters concerned with crossover and mutation is mainly dependent on the application at hand and the chromosome structure [13-14].

In this paper, the research method involves Genetic Algorithm (GA) due to the fact that the unknwn amount of reactive power has to be injected in the system with the unknown fluctuation of the bus voltages owing to the changing of load factor, which is the ratio of average load and maximum demand. With a view to applying GA, Table 1, is considered for encoding purpose where λ and Q are loading parameter and reactive power respectively. The maximum rating of the injected reactive power is assumed to be 250 MVAR.

Table 1. Initial Values

Q MVAR	239 .48	233 .82	221 .81	209 .82	202 .75	187 .46	164 .98	149 .54
Q P.U	0.9579	0.9353	0.8873	0.8393	0.8110	0.7498	0.6599	0.5982
λ P.U	0.1020	0.1320	0.1830	0.2450	0.3570	0.4860	0.6990	0.7500

Now, from Table 1, the objective function relating λ and Q is

$$f(\lambda, Q) = 0.9933 - 0.5104\lambda - Q \quad (2)$$

3. RESULTS AND ANALYSIS

In order to run Genetic algorithm using MATLAB optimization toolbox, injected reactive power, Q initially has been defined as 1 Per Unit while 0.1 Per Unit value has been chosen for loading parameter, λ. Now, Program has been started and the following data demonstrated in Table-II have been found. All these are simulated as well shown in Figure 3,

Table 2. Solutions of Genetic Algorithm (GA)

Generations	Fitness Function, f(λ,Q)	Best Fitness Function	Mean Fitness Function
1	-0.3378, -0.3378, -0.3273, -0.3378, 0.4570, 0.2109, -0.2458, -0.1228, -0.1940, -0.1345, -0.2699, 0.2904, 0.3055, 0.3450, 0.4245, -0.3378, 0.2914, 0.0311, -0.3378, -0.3378	-0.3378	-0.02682
2	-0.3378, -0.3378, -0.1228, -0.3378, -0.3378, -0.2458, -0.3378, 0.2808, 0.3055, 0.3546, -0.1839, 0.3055, -0.3378, 0.2808, 0.2808, 0.4347, -0.3378, -0.3378, 0.2914, 0.3055	-0.3378	-0.04826
3	-0.3378, -0.3378, 0.2808, -0.3378, 0.2808, -0.3378, -0.3378, -0.1839, -0.3273, -0.3378, -0.3378, -0.2458, -0.3378, 0.2808, -0.3378, -0.3378, -0.0469, 0.0074, 0.3055, -0.3378	-0.3378	-0.02075
4	-0.3378, -0.3378, -0.1839, -0.3378, -0.3378, -0.3378, 0.2808, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, 0.3055, -0.3378, -0.3378, -0.3378, -0.3378, 0.2808, 0.2808, -0.3378	-0.3378	-0.1682
5	-0.3378, -0.3378, -0.3378, -0.3378, -0.3378, 0.2808, 0.2808, -0.3378, -0.3378, -0.3378, -0.3378, 0.2808, -0.3378, 0.2808, 0.2808, -0.3378, -0.3378, -0.3378, 0.3055, -0.3378	-0.3378	-0.2052
6	-0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, 0.2808, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, 0.2808, -0.3378, -0.3378, -0.3378, -0.3918, -0.3378	-0.3378	-0.151
7	-0.3918, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, 0.2808, -0.3378, 0.2808, -0.3378, -0.3378	-0.3918	-0.2786
8	-0.3918, -0.3378, -0.3378, -0.3378, 0.2268, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3918, -0.3378, -0.3378,0.5225, -0.3378, -0.3378	-0.3918	-0.2786
9	-0.3918, -0.3918, -0.3378, -0.3378, -0.3378, -0.3378, -0.3918, -0.3378, -0.3918, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3378, -0.3918, -0.3378	-0.3918	-0.272
10	-0.3918263577319361	-0.391826	-0.351315

Final Solutions providing optimum values:
Loading Parameter, λ=0.9226852203921679
Reactive Power, Q=0.9141878212437735 *250MVAR =228.5469553 MVAR

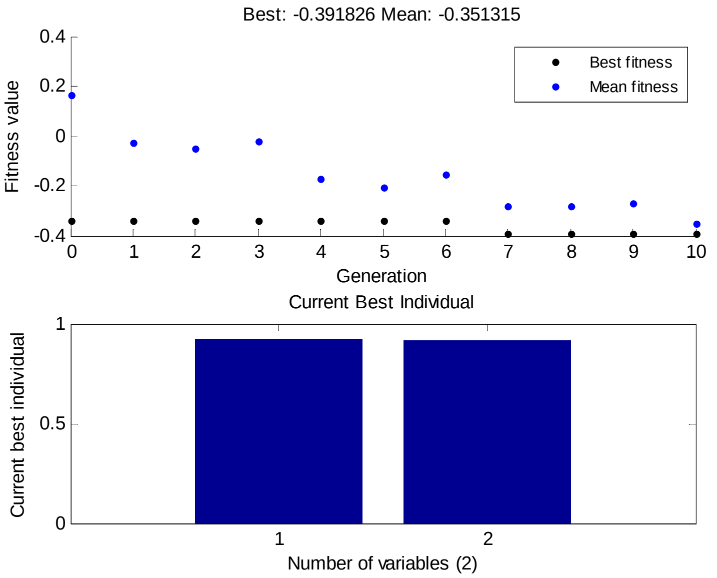

Figure 3. Solution of genetic algorithm

The local generation of reactive power reduces its import from the feeder, thus reduces the associated losses, and improves the voltage profile. As a result, the voltage security is also improved [15]. Without a hint of doubt the amount of reactive power injection largely depend on the available load bus voltage value. Normally, when the bus voltages fluctuate from expected unity per unit value owing to the variations in loading parameter as shown in "Fig.4", certain reactive powers are necessary to be supplied for the sole purpose of compensation so as to ensure the stable operation of the system.
It is considered that total inductance, X_L=5, capacitance X_c=0.65 and firing angle of SVC, $\alpha_{SVC}=5^0$. Now, from "(1)", the requirement of reactive power depending upon the availability of bus voltages can be adjusted as illustrated in Table 3,

Table 3. Reactive Power Management

Bus Locations	Loading Factors, λ (P.U)	Available Bus Voltages, V (P.U)	Voltage Variations From Unity ΔV=1-V (P.U)	Required Reactive Power Injection, Q (MVAR)
3	0.102	0.9240	0.076	239.48
4	0.132	0.9130	0.087	233.82
5	0.183	0.8890	0.111	221.81
6	0.245	0.8650	0.135	209.82
7	0.357	0.8500	0.150	202.75
8	0.486	0.8170	0.183	187.46
9	0.699	0.7699	0.233	164.98
10	0.750	0.7310	0.269	149.54

Furthermore, from final solution of genetic algorithm, if the optimum value of λ is 0.9226852203921679 Per Unit and reactive power is 228.5469553 MVAR, then the bus voltage must be 0.90265395 Per Unit which is stabilized by the proper reactive power planning.
Voltage Stability margin (VSM) after completion of GA,

$$VSM = \frac{\lambda_{Optimum} - \lambda_{Base}}{\lambda_{Optimum}} \times 100\% = 89.16174073\%$$

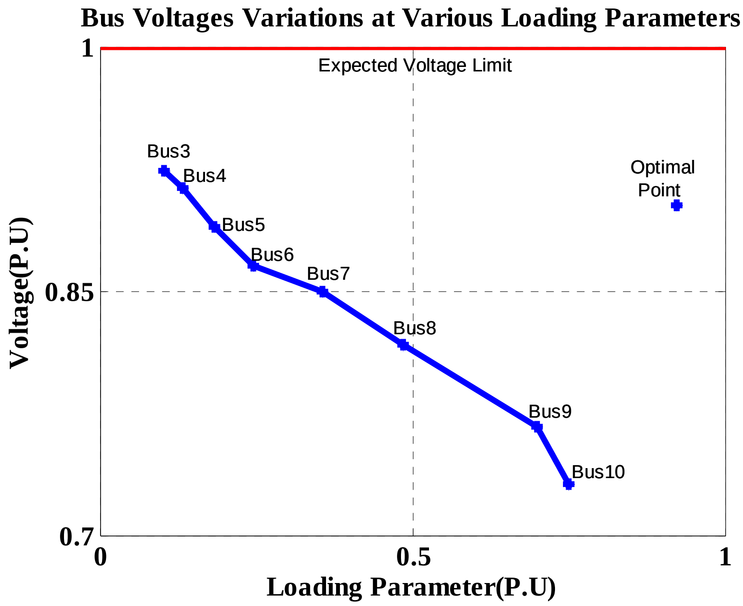

Figure 4. Available load bus voltages required to be controlled to reach the txpected limit

It has been found from the analysis of genetic algorithm that the optimal amount of reactive power that is required to be injected in four bus system is 282.95 MVAR [2], whereas the injection of 228.5469553 MVAR optimal reactive power is ascertained in this paper notifying the reduced amount of reactive power injection.

4. CONCLUSION

The proposed strategy deals with optimal reactive power injection so as to improve the voltage stability of the 10-bus power system. A step by step description of the evolutionary optimization process has been detailed in this paper for understanding the working procedure of genetic algorithm. It goes beyond disputation that genetic algorithm has been proved to be a very useful method to solve large scale, combinatorial optimization problem like reactive power planning for the sake of voltage stability. It is suffice to say that this formulation opens up several possibilities in the field of power system network containing Distributed Generators (DG) that could play an anchoring part for the utility planners and operators in the relevant field. For instance, in future, the proposed methodology can be applied to a distribution network composed by 100 buses, in which not only the optimum value of the injected reactive power but also the location of (DG) units could be determined so that both the system voltage stability and the DG penetration level could be improved. Moreover, Genetic algorithms may be utilized in solving a wide range of problems across multiple fields such as science, business, engineering, and medicine like production scheduling, call routing for call centers, routing for transportation, determining electrical circuit layouts, designing neural networks, designing and controlling robots, financial trading, credit evaluation, budget allocation, fraud detection and many more.

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