Optimal Compensation Using Genetic Algorithm for Voltage Stability Enhancement of a Multi-Machine Power System

Dinh-Nhon Truong, Huu-Phuoc Duong, Tan-Hung Nguyen, Minh-Truong Le Dang

Abstract - ***This paper presents the comparative simulation results of applying Genetic Algorithm (GA) for finding the position of the node and the value of the reactive power for compensation that is the best optimization for the stability of voltage to all nodes in a standard IEEE 14-bus power system. For improving the stability of the studied system in normal and short-circuit working conditions, a GA which is useful for optimization is applied to this system by MATLAB software. It can be concluded from the simulation results of a case study based on the power system that the GA can figure out the bus position and optimal value that meet the qualifications of the studied system under severe operating.***

Keywords: ***Genetic Algorithm (GA); Optimization; Multi-machine Power System; Voltage Stability.***

I. INTRODUCTION

In recent years, with the growth of the industry, the use of electricity is increasing daily and the high demand for electric use is also increasing rapidly. In addition, with the high use of electricity, the requirements about power quality of customers and the stability of the power system is extremely important for power engineers to maintain smooth operation of factories that use electricity from the supplier. Recently, having many projects researched about enhancing the stability of the power system using Distributed Static Synchronous Compensator (D-STATCOM) devices and it also gave the better results and made the power system more stable as shown in [1]. But to identify the optimal reactive power value and also the appropriate position is much better and it can save time, money and can enhance the stability of the system, there also were many projects about identifying position and also identifying the reactive power of capacity and position by traditional optimization method as showed in [2] and [3]. However, the disadvantages of these methods are restricted when the amount of calculation is immense. In addition to that, Particle Swarm Optimization (PSO) is proposed to solve this problem with high efficiency and it can give a better result, applying of PSO for many projects to find the position for Flexible AC Transmission System (FACTS) devices as shown in [4-5], but when using PSO, its convergence is a bit slow. In contrast to the restriction of PSO, Genetic Algorithm (GA) is also used as a recent trend, it can solve the math of both non-linear and linear math with a much more optimal result. With these advantages of GA, it is also applied to solve many problems like giving the best timetable, find the shortest way. In this paper, we present an effective method with GA with crossover, mutate, elite rate and population of swarm size to give solution of optimizing the position and also the reactive power using for compensation to enhance the stability and quality of the power system, these matters are very hot in operating and managing the power system to meet the qualifications that are agreed with their customers. The voltage of each bus and reactive power for each iteration are used for evaluating the best fitness value and if the fitness value is under a set value, the iteration will stop and the best solution will be chosen.

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II. CONFIGURATION OF THE STUDIED SYSTEM

A. Introduction to IEEE 14-bus power system

Fig. 1 shows the configuration of the equivalent 14-bus power system which included 2 generators and these are connected to bus 1, 2. There are 3 synchronous generators which are connected to bus 3, 6 and 8. The system has 14 buses which are connected to the generators, synchronous generators, loads (with high load buses from 10 to 14) and bus number one is also selected as the slack bus to compare to other nodes in angle [6].

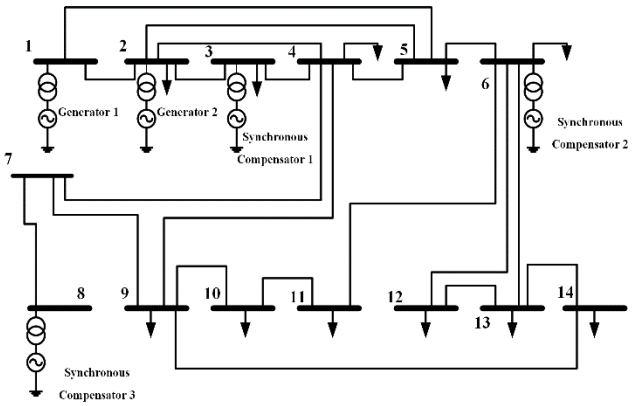


Figure 1. *Single line diagram of the studied system.*

B. Genetic Algorithm

GA is a procedure for solving both linear and nonlinear problems depended on a natural selection process that mimics biological evolution as a computational method and it is developed for optimization. The GA is based on the biological selection of all wild animals. The algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm will randomly select individuals from the current population and use them as

parents to produce the children for the next generation. Over many successive generations, the population "evolves" toward an optimal solution that is best for the swarm.

III. APPLICATION OF GA TO STUDIED SYSTEM

The application of GA to IEEE 14-bus power system will be presented in this part and the steps for applying is showed in Fig. 2 [7].

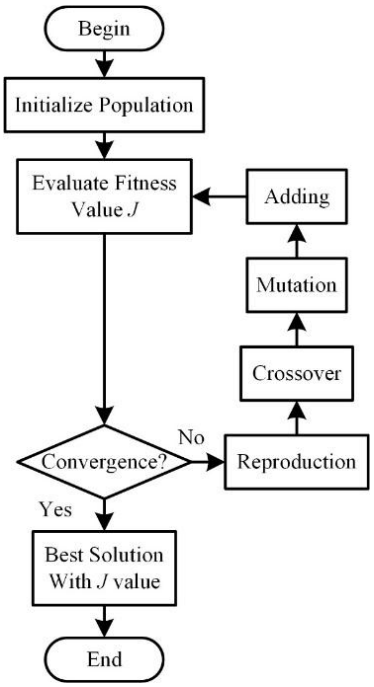


Figure 2. *The flowchart of GA*

Step 1: Produce an initial population of individuals

Start with a population of *n* random values. In each individual will have *i* solution for which buses are essential for compensation (at here, we choose the high load buses from 10 to 14) in the power system. The value of each *l* solution is limited in (4).

Solution: [limit*i*1, limit*i*2] (1)

In that:

Limit*i*1: The minimum reactive power value for compensation at bus number *i*.

Limit*i*2: The maximum reactive power value for compensation at bus number *i*.

Step 2: Fitness function

Fitness function *J* of GA is used to evaluate the efficiency of each individual of the swarm in function (2) and the value of *J* is repeatedly evaluated after a new generation is created. It is the summary of all the differences in voltages and the capacity of the capacitor used for compensation. The capacity of the capacitor will be calculated so that the value in the fitness function can be compared and identified by simulation and calculation. Voltage differences are calculated by per unit (p.u.) system and capacity of the compensation capacitor is calculated in p.u.

$$J = \sqrt{(\sum_{i=10}^{14}(V_i - 1)^2)} \quad (2)$$

With condition:

$$| V_i - 1 | \leq 0.05 \text{ with } i = 10 \ldots 14. \quad (3)$$

In that:

J: Fitness function.

V_i : The voltage value at bus *i* in p.u.

$\sqrt{(\sum_{i=10}^{14}(V_i - 1)^2)}$: The voltage differences compared to the standard value.

As the power system has five high load buses from bus 10 to 14 and it's appropriate for the compensation capacitor.

Step 3: Reproduction process

Reproduction process will create a new generation with the parents that are selected based on the fitness function. It is controlled by crossover and mutation operators.

Step 4: Crossover

Crossover defines the process for generating a child from two parents by the mix of the DNA of two, and before the crossover process is performed, the parents have to be selected from the best individuals for each generation. An individual is selected based on its fitness relevant to the other individuals and the fitness value is evaluated in step 2. The probability *p* for each individual with fitness value *J* to get chosen among *n* individuals is equal to $p = \frac{S}{\sum_{i=1}^{n} S_i}$.

After individuals were chosen as parents for regeneration, the crossover process will be implemented in the next step.

Step 5: Mutation

Mutation is performed on the newly introduced off-springs (right after the crossover). It introduces new genetic material into a population by replacing one parameter in a genome with a random value within the allowed range.

Step 6: New generation

The new generation is created depending on the number of elite, crossover and mutation children, and the matrix for a new generation is as flow:

NewGen = [elite pop, crossover pop, mutation pop] (4)

Step 7: Evaluate the best solution

After definite number of iterations, the last population will be created and the best individual in the swarm will selected to evaluate the results in both position of bus and reactive power value. Position of buses need to be compensated where we selected are high load buses. So that, these 5 buses from bus number 10 to bus number 14 are appropriate for compensation.

TABLE 1. THE VALUE OF SIMULATION FOR EACH ARGUE.

Argue	Parameters of Simulation
Individuals	{10}
DAN in each individual	{5}
Iterations	{20,25,30,40,50}
Crossover percent	{50,55,60,65}
Mutation percent	{10,15,20,25}
Solution range	[0;1]

IV. NUMERICAL RESULTS

With initial parameter with loads in bus 10 to bus 14, with load power is about 0.35 p.u for each bus. Before compensation, the voltage of all nodes is shown in Fig. 3. Without compensation, the voltage of some nodes from 10 to 14 is lower than 0.95 (p.u), it is not eligible for tolerance of 5%.

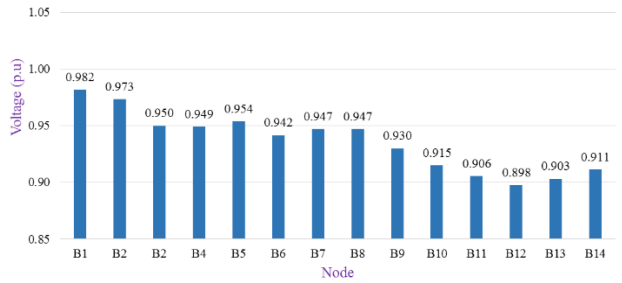


Figure 3. *The voltage of all nodes before compensation.*

After setting the optimal parameters for GA with 50% of a cross percent, 30% of mutation and also 25 times of iteration. The GA shows that with 0.7689 p.u of capacitor value at node 13, the voltage of 14 buses is between 0.95 and 1.05, it's qualified within 5% of error for the required quality of a power system. The voltage of 14 buses is shown in Fig. 4 and also the result of average voltage error for all nodes is shown in Fig. 5.

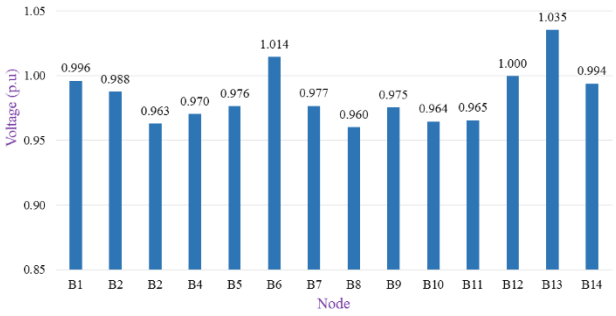


Figure 4. *The voltage of all nodes after compensation.*

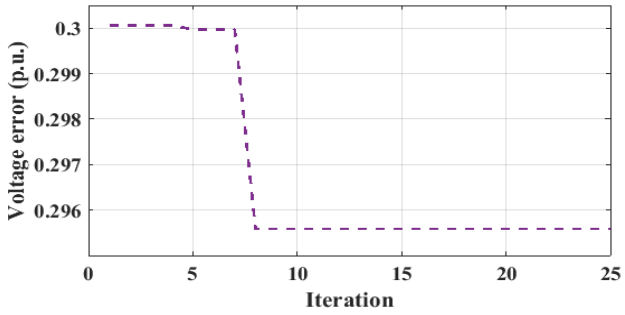
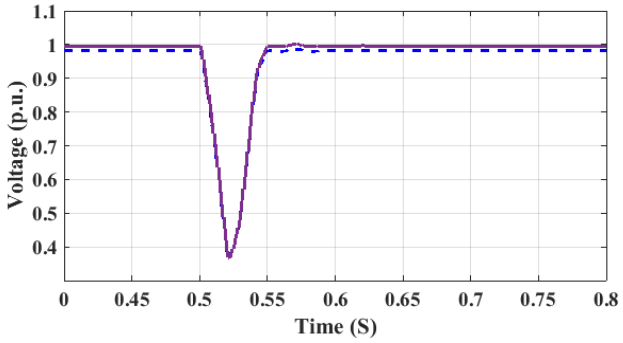
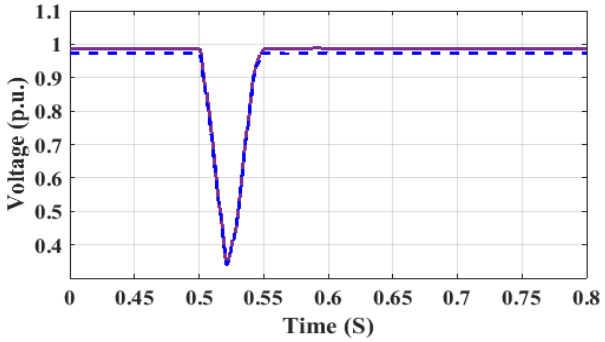


Figure 5. *The average error of all nodes for each iteration.*

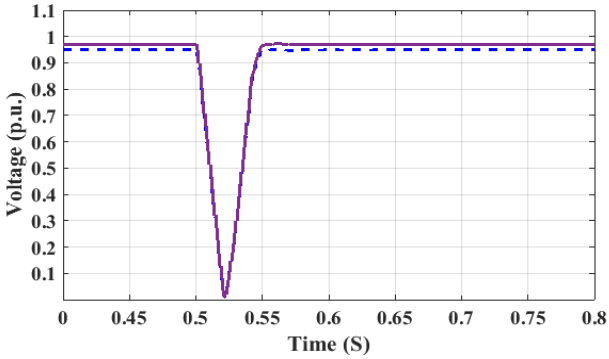
To check the stability of the system after a balanced three-phase short-circuit fault, we set a three-phase short circuit at bus 4 with the time from 0.5 to 0.52 second and the voltage curves of some nodes such as generator 1, generator 2, bus that has short-circuit and two high load buses which are shown in Fig. 6 as below.



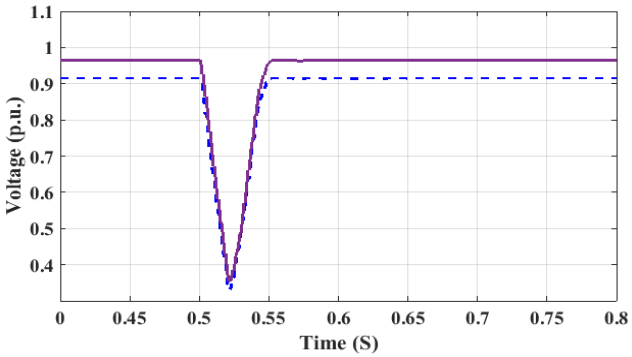
a. The voltage of bus 1.



b. The voltage of bus 2.

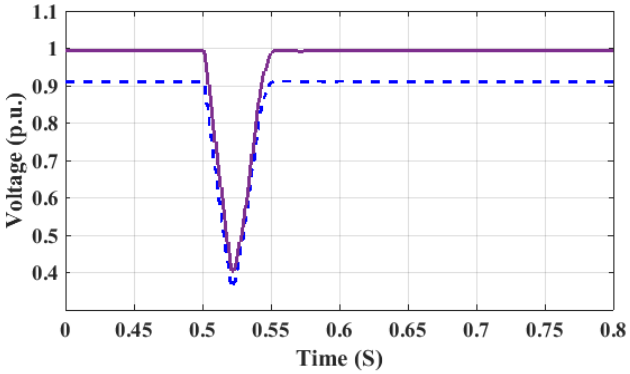


c. The voltage of bus 4.



d.

d. The voltage of bus 10.



e. The voltage of bus 14

Figure 6. *Response of the bus voltages.*
Before compensation: dash line
After compensation: solid line.

V. CONCLUSION

This paper has presented the bus and the reactive power value that are optimal for the stability improvement using GA for finding the node and the value of the reactive power that is the best optimization for the stability of voltage to all nodes in a 14-bus power system. Simulation results of the studied system indicating stability of all nodes in the system have been systematically performed to demonstrate the effectiveness of GA to the studied system. It can be concluded that the proposed GA to this benchmark power system can find the optimal solution in both position and the reactive power value for the performance of the system.

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