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Genetic Algorithm Based Proportional- Integral Controller for Synchronous VAR Compensator

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Abstract. Proportional- Integral (PI) controllers are one of the most popular controllers in industry. In this paper, this controller is applied to control the fire angle of synchronous VAR compensator (SVC). The SVC is member of FACTS device that have excellent properties in reactive power control and real power loss reduction. In synchronous VAR compensator, the fire angle controls the level of injected reactive power to power network. Therefore the value of the fire angle must be controlled based on power network condition. In this paper the usage of PI controller is proposed for this purpose. In PI controller, the parameters of this controller have vital role in performance of controller. If these parameters don't tuned properly, the controller will has poor performance. Therefore in this study, a novel method is proposed for selecting of these free parameters. In the proposed, genetic algorithm is used to tune the free parameters of PI controller. The proposed method is tested on power network and the computer simulation results show that the proposed method has good accuracy.

Keywords: Controller, SVC, GA, Reactive power, Tuning

1. INTRODUCTION

In last decades, new control techniques, such as adaptive control, predictive control, fuzzy control, and neural network based controller have been emerged. These controllers have good performance and have high accuracy. But the application of these nonlinear and complicated controllers in industry is very difficult and is not practical (Xiangnan, 2015). Contrarily these developments, Proportional- Integral controller is the most popular and efficient controller in industry. This type of controller is very effective and has simple structure. The PI controller has many applications in industry (Sergei, 2015).

The Proportional- Integral controllers date to 1891 governor design. In that time, PID controllers were used for ship steering. In 1910s, Elmer Sperry introduced application of PID controllers in industry and releases the results of experiments in a paper. But the first theoretical investigations of PID controllers were performed by Nicolas Minorsky in 1922. Nicolas Minorsky was American researcher. The PID controller consists of three independent and free gains. These three gains called control terms. These gains are proportional gain, integral gain and derivative gain. Each of these gains denotes special criteria in control goal.

With development in computer capability in computing and solving nonlinear problem, the solution of this problem is come easier. In last decades the nature based optimization algorithms are emerged such as genetic algorithm (GA), particle swarm optimization (PSO) algorithm, bee's algorithm (BA), imperialist competitive algorithm (ICA) and cuckoo optimization algorithm (COA) (Mernic, et.al.2015). One of the

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most efficient and powerful of these algorithms is genetic algorithm. This optimization algorithm has many applications in many areas of industrials and sciences (Cheng, 2015). In this paper an intelligent technique is proposed for PI controller gains setting. In each optimization algorithm two features are essential: exploration and extraction. The exploration feature is the capability of finding the global solution's vicinity. The extraction feature is capability of optimization algorithm to find the global solution from this vicinity. The genetic algorithm has good exploration and extraction capability. Therefore in this study GA is selected as optimization algorithm. The proposed intelligent control system is applied in power network system to enhance its performance.

Electrical power network is the biggest system that made by man. This system have many sections such as big generators, big transformers, breakers, loads, transmission lines, compensators and many other parts and instruments. With increasing the demand of electrical by humans and factories and as sequence increasing the scale of this big network, some difficulties and complicated problems have been emerged. In this large scale power network the level of voltage is low, power factor is weak and the stability margins are very weak. For overcome to these problems numerous techniques and technologies have been proposed by researchers. One of the most efficient and powerful of these technologies is Flexible AC Transmission Systems or FACTS devices (Wei, et.al., 2015). This new technology first presented in 1980s. In next years and decades some modifications and improvements on FACTS devices have been performed. Also some new devices added to this technology. Some of the FACTS devices are SVC, STATCOM, UPFC (Chen, 2015).

The SVC is one of the most effective of FACTS devices. In synchronous VAR compensator, the fire angle controls the level of injected reactive power to power network. Therefore the value of the fire angle must be controlled based on power network condition. In this paper, the proposed intelligent controller is applied for SVC control. The more details regarding the optimization algorithm and PI controller are presented in next sections.

2. GENETIC ALGORITHM

In soft computing science, genetic algorithm is an optimization algorithm that models the process of natural selection in animals and human. The genetic algorithm is used for many optimization problems that are very complicated and nonlinear. Also genetic algorithm can be used for discrete optimization problem. The genetic algorithm is one of the evolutionary algorithms (EA) that generate random solutions to optimization problems that this procedure is based on natural events in human or animal's life. The genetic algorithm has several main operators: elitism, crossover, mutation and roulette wheel. The flowchart of genetic algorithm is depicted in figure 1.

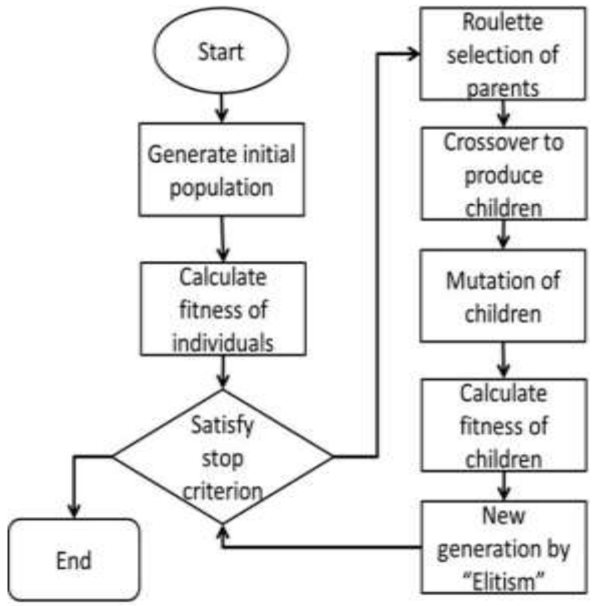

Figure 1. GA flowchart.

In the genetic algorithm like other nature based optimization algorithms, initial random population is generated. The each candidate in initial random population is called chromosome. These chromosomes are like particle in particle swarm optimization algorithm, bee in bee's algorithm or countries in imperialist competitive algorithm. The chromosomes must be generated in predetermined search space. The low boundary and maximum boundary of each problem is unique. The optimization process starts with initial random population, and in each iteration or generation, the fitness function is calculated. Based on the evaluated fitness function for each chromosome, the elitism and crossover is performed. The chromosomes with high level of fitness are randomly chosen from the existing population, and each chromosome is modified by crossover operator. The new generated population is used in following iteration. The same procedure is performed iteratively. In any iteration the stopping criteria must be checked. If the stopping criteria are satisfied, the algorithm will stop the searching procedure. Figure 2 shows the crossover operation. Also figure 3 shows the mutation operation. Figure 4shows the pseudo code of GA.

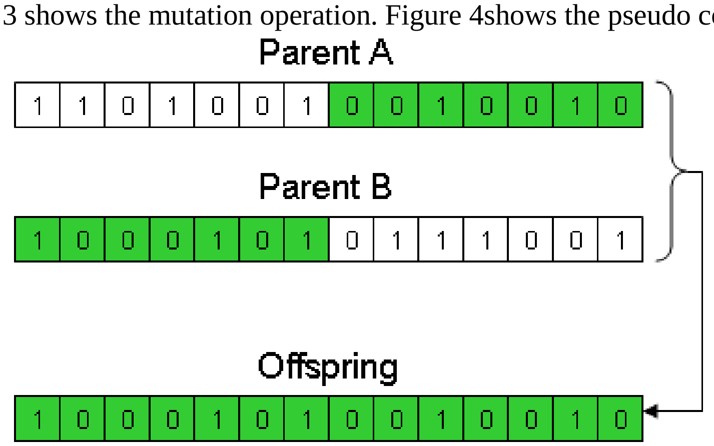

Figure 2. Crossover operation.

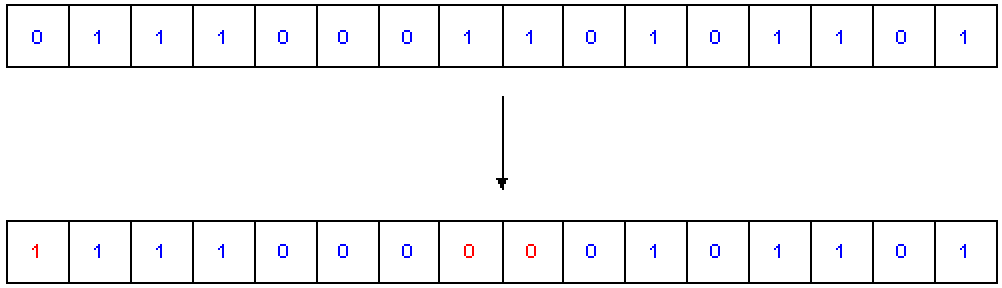

Figure 3. .Mutation operation.

```
0. GENERATE POPULATION P[0]
1. DO{
     1.1 EVALUATE FITNESS OF INDIVIDUALS IN P[k]
     1.2 DO{
              SELECTION (ROULETTE WHEEL)
              APPLY GENETIC OPERATORS:
                    PMX CROSSOVER (PROBABILITY p_c)
                    MUTATION (PROBABILITY p_m)
             }
           WHILE NEW GENERATION NOT COMPLETED
     1.3 EXECUTE CREATE-ELITE
     }
     WHILE {TERMINATION CRITERIA = NO}
2. PRINT BEST ASSIGNMENT SOLUTION u_i

FUNCTION CREATE-ELITE:
{
     SELECTION OF BEST INDIVIDUALS
     MUTATION (PROBABILITY p_m)
     ELITE = MUTATED ELITE + NOT-MUTATED ELITE
     INSERT ELITE INTO POPULATION:
          P[k+1]=INSERT(ELITE,P[k])
}
```

Figure 4. The pseudo code of GA algorithm.

3. CONTROLLER

A proportional- Integral- Derivative controller or PID controller is the close loop control system. This type of controller has numerous applications in industry. The PID controller has simple structure and therefore can be applied in most industries. This controller has three free parameters that determine the behavior of controller. If these parameters set by accuracy, the PID controller will has good output. The basic strategy of PID is based on fault magnitude between the output of the system and desired input. The PID controller changes its parameters to reduce this difference between the real output and desired input.

In control science, the three free parameters of PID controller called control gains and indexed P, I, and D. PID controller is very simple and inexpensive. In contrast other controllers such as fuzzy controllers and adaptive controllers are very complicated and costly. Therefore it is not economical selection to apply fuzzy controllers and adaptive controllers. Based on the mentioned reasons, selection of PID controller is economic and smart selection. In this controller the input signal to controller called control signal and defined as follow:

$$u(t) = K_p e(t) + K_i \int_0^\infty e(t)dt + K_d e(t) \quad (1)$$

Here K_p indicates the proportional gain, K_i indicates the integral gain, K_d indicates the derivative gain, e shows the error signal and finally t represents the time or instantaneous time.

4. SVC- CONTROL CONCEPT OF SVC

A static VAR compensator (var is defined as volt ampere reactive) is a set of electrical devices for supplying fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, and harmonics and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.

An SVC is a controlled parallel susceptance (B) which infuse reactive power (Q_{net}) into thereby increasing the bus voltage back to its net favor voltage value. If bus voltage enhance, the SVC will infuse low (or TCR will absorb more) reactive power, and the final will be to gain the favor bus voltage magnitude [Fig.5]. Where, $+Q_{cap}$ is a set to capacitance value, therefore the amplitude of reactive power infused into the power system, Qnet, is governed by the amplitude of $-Q_{ind}$ reactive power suctioned using the TCR. The basis of the thyristor-controlled reactor (TCR) which conducts on alternate semi-cycles of the supply frequency. If the thyristors are gated into conduction precisely at the tops of the supply voltage, perfect conduction results in the reactor, and the current magnitude is the same as though the thyristor controller were short circuited or SC. Fig.5 shows the SVC based control system and its structure.

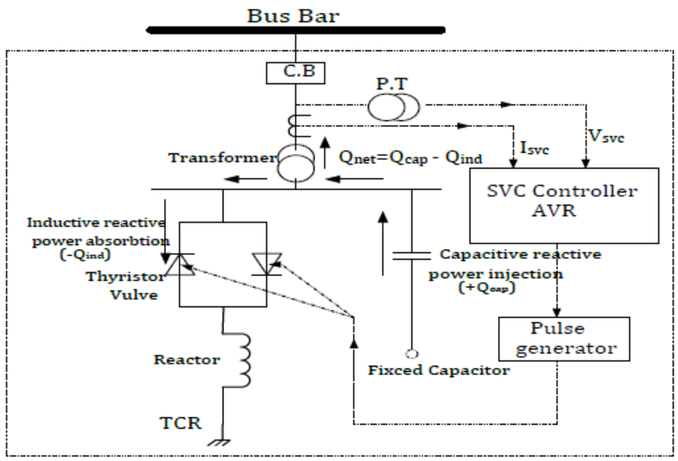

Figure 5. SVC based control system structure.

The SVC can be operated in two different states:
a) In voltage regulation state (the voltage is governed within boundaries as described below).
b) In VAR control state (the SVC susceptance is kept fix).
From V-I curve of SVC, and then we will have from Fig.6.

$V = V_{ref} + X_s.I$: In regulation bound ($-B_{c,\max} < B < +B_{c,\max}$)

$V = I/B_{c,\max}$: SVC is fully capacitive or ($B = B_{c,\max}$)

$V = 1/B_{c,\max}$: SVC is fully inductive or ($B = B_{l,\max}$)

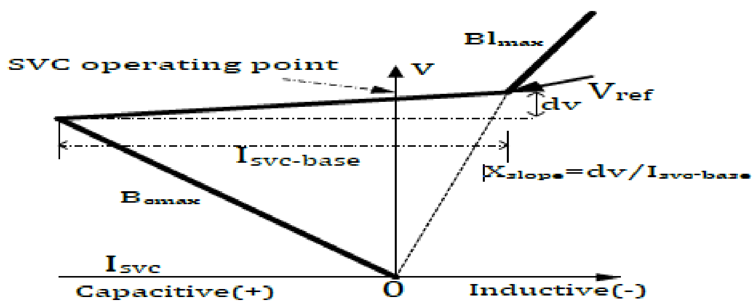

Figure 6. Steady state(V-I) characteristic of a SVC.

5. PROPOSED METHOD AND SIMULATION RESULTS

5.1. Proposed method

In this article, a PI controller is modeled by GA based on the simple structure (that is GA-PI controller). To evaluate the ability of the introduced technique the system shown in Fig. 7 will be investigated. The proposed method include of a big generator providing bulk power to an infinite bus through a transmission line in power system, with an SVC fixed at its special bus. SVC is connected by a step down power transformer that shown in figure. The mentioned SVC has govern features identical to synchronous condensor as continuous control action in contrast with existing switched parallel capacitor banks that mentioned before in sections three and four. As illustrated in Fig. 4, the SVC include of a Fixed Capacitor (FC) and Thyristor Controlled Reactor (TCR) in parallel position which can be seen in figure. By governing thyristor, firing angle a variable susceptance is gained.To test the effectiveness of proposed technique, some simulations of two cases were done and investigated. In next lines the details of proposed method and obtained results is presented.

- Case 1: System with SVC device and GA based PI controller or the proposed method.
- Case 2: System with SVC and Conventional or classical PI controller or without optimization.

The way of finding the controller variables to meet given function features is called PI tuning. GA is used to gain the optimum of K_p, K_i values to the PI controller. In the single machine-infinite bus system that shown in figure with SVC, the method combining PI controller with GA algorithm is as follow. The variables of PI controller are made as one string and the solution population is composed as N strings. And the fitness function used for the each string evaluation of solution population uses the absolute magnitude summation of speed deviation.

$$Fitness = \sum_{m=1}^{M} |\omega_{\Delta}| \qquad (2)$$

Here m is a sampling in case of system application voltage as is combined a string with PI controller variables and M is total sampling number.

The main scheme of optimum GA-PI controller of SVC system is given as Fig. 8 or the proposed method. The starting operating situation and SVC variables are mentioned in Table 1.

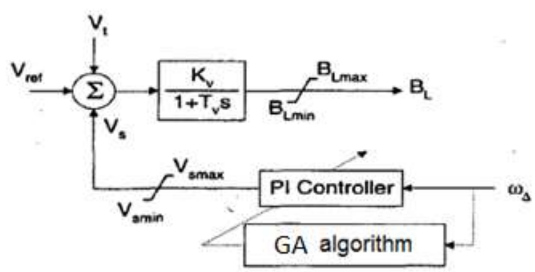

Figure 8. GA-PI controller of SVC system.

Table 1. SVC parameters and initial conditions.

$K_v[p.u]$	T_v[sec]	$B_c[p.u]$	$X_T[p.u]$	$B_{L0}[p.u]$	$B_{Lmax}[p.u]$	$B_{Lmin}[p.u]$	$V_{smax}[p.u]$	$V_{smin}[p.u]$
10	0.15	0.6	0.08	-0.45	-0.3	-0.9	0.12	-0.12

5.2. Obtained results

The starting state applied to achieve the variables optimization of GA-PI controller is in case of the load growth to the nominal output 3% oscillation of power during 100 millisecond in rated load $(P_e = 1.0\ ,\ \mathrm{Q_e} = 0.595)$. To test the operation of introduced GA-PI controller, it is used in single machine infinite bus system with SVC device. The simulations and tests are done in cases of heavy (Study Case one), normal or nominal (Study Case two) and light loads or not heavy load (Study Case three). Each generator reply is collated in cases of the power system with SVC device and GA-PI controller system that mentioned before (Case one) and system with SVC device and classical PI controller system (Case two).

The chromosomes number applied was 100, crossover rate is 0.75, mutation rate is 0.25 and max iteration is hundred. The optimized PI variables by GA algorithm are $K_p = 43.76$ and $K_I = 4.15$. The fitness function is shown in Fig. 9. The variation of PI parameters had shown in figures 10 and 11.

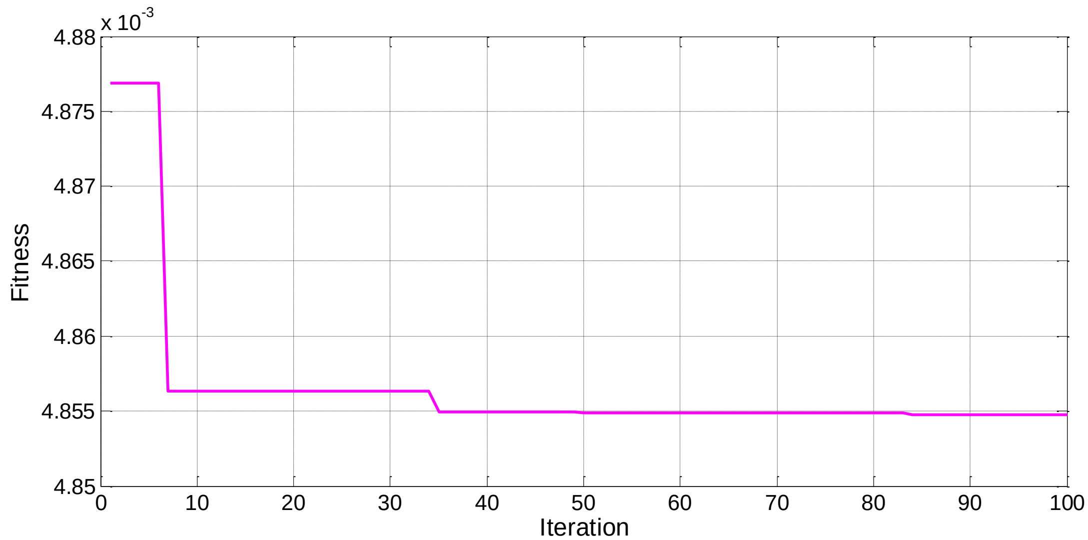

Figure 9. Fitness

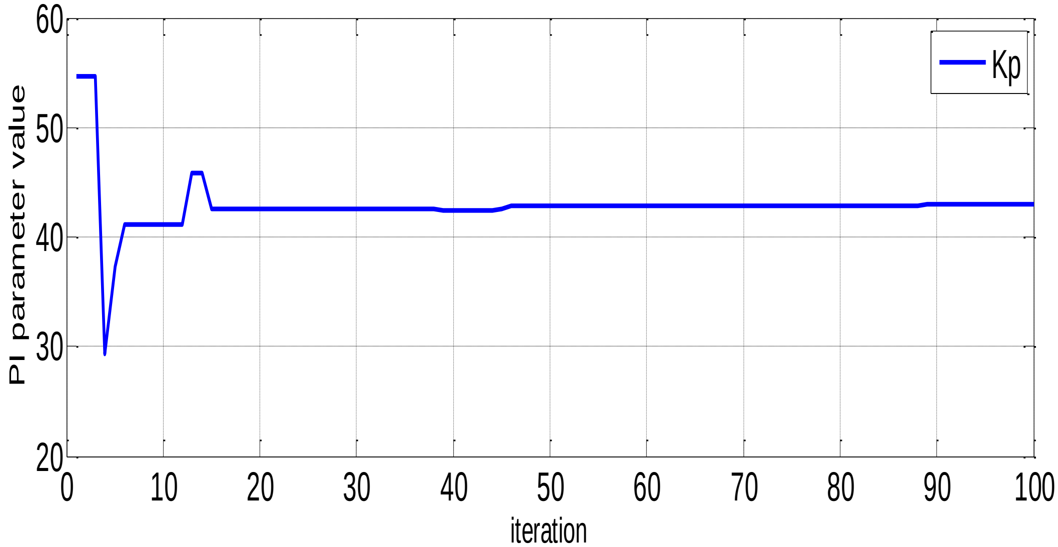

Figure 10. K_p variation during the GA search.

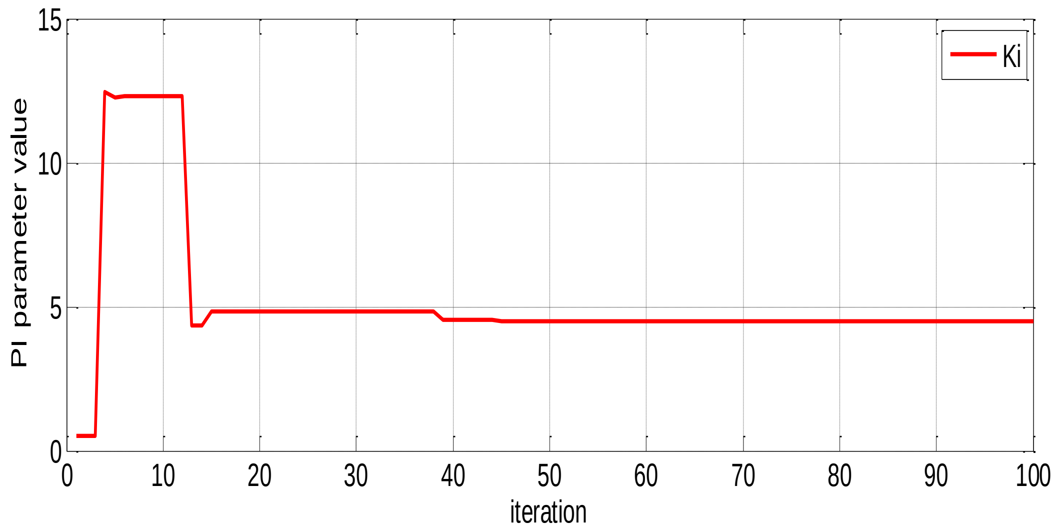

Figure 11. K_I variation during the GA search.

The study case situation is the 3% oscillation of starting power during 100 milliseconds shown in Figs. 8 through 10. From Fig. 12, the reply feature of the bus voltage of heavy load $(P_e = 1.3\ , Q_e = 0.595)$ is most best to those of Case two or normal loading that mentioned before. The setting time of Case one or heavy load is better response features as setting time is 0.4 seconds. Figs. 13 and 14 shows the output features of generator bus voltage for normal load or case two $(P_e = 1\ , Q_e = 0.595)$ and light load or case one $(P_e = 0.7\ , Q_e = 0.595)$ respectively. Case 1 or heavy load shows very intelligent response performance as setting time is 1.8 and 1 seconds.

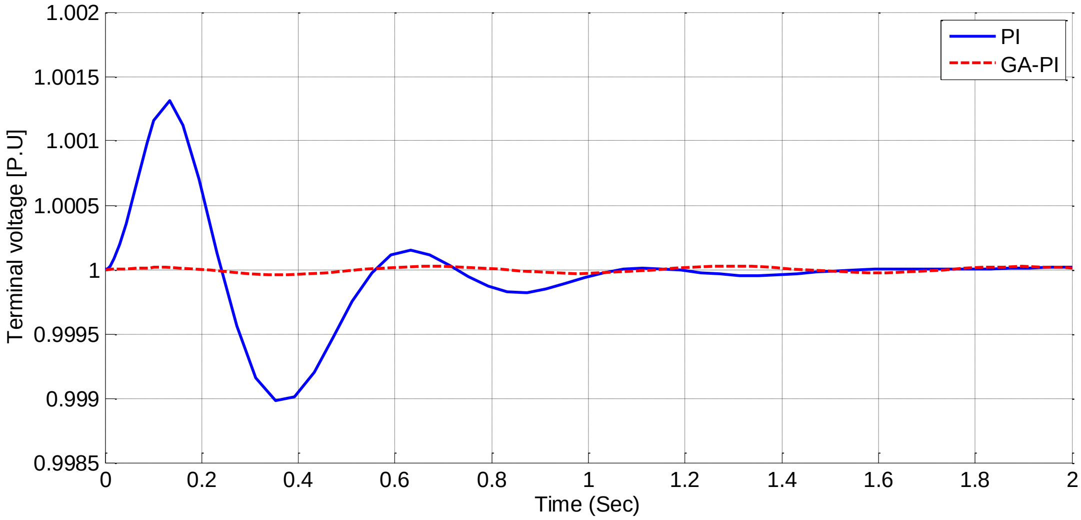

Figure 12. Terminal voltage for Heavy load.

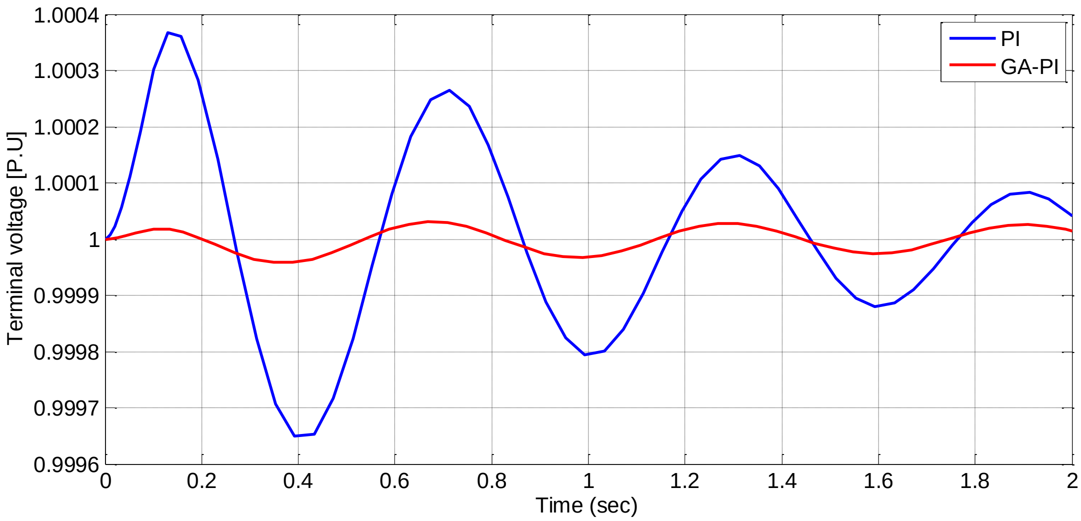

Figure 13. Terminal voltage for normal load.

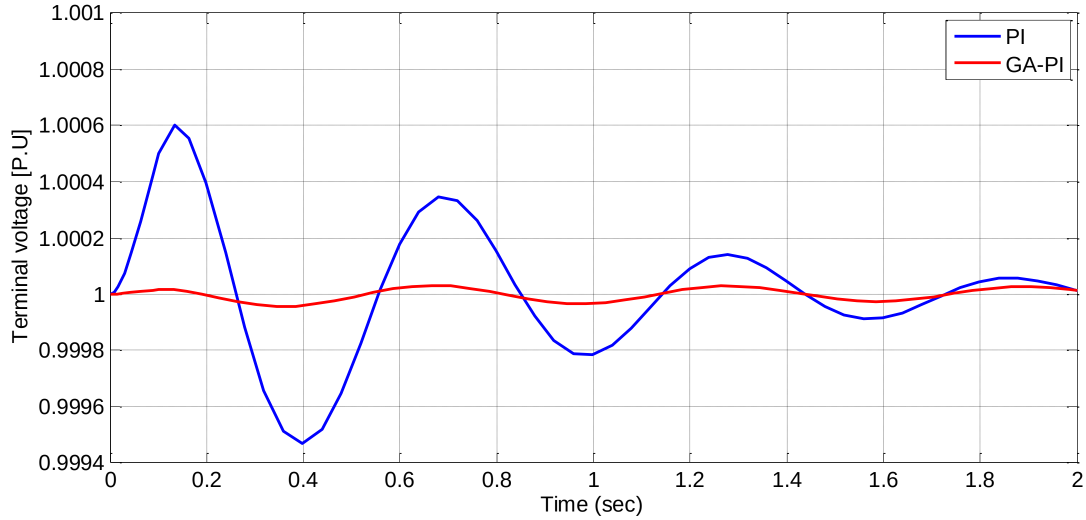

Figure 14. Terminal voltage for light load.

5.3. Operation test with optimization algorithm in several execution

In this section, for testing the operation of the optimization algorithm, several independent runs have been done. Fig. 11 shows a rate of decrease of the fitness (speed deviation) of the best chromosomes fitness of the generation achieved from introduced system for several runs. As illustrated in this figure, its fitness curves normally enhanced from iteration 0 to 100, and exhibited no notable improvements after iteration 20 for the several independent runs. The optimal stopping iteration to get the best validation accuracy for the several independent runs was about iteration 20–30.

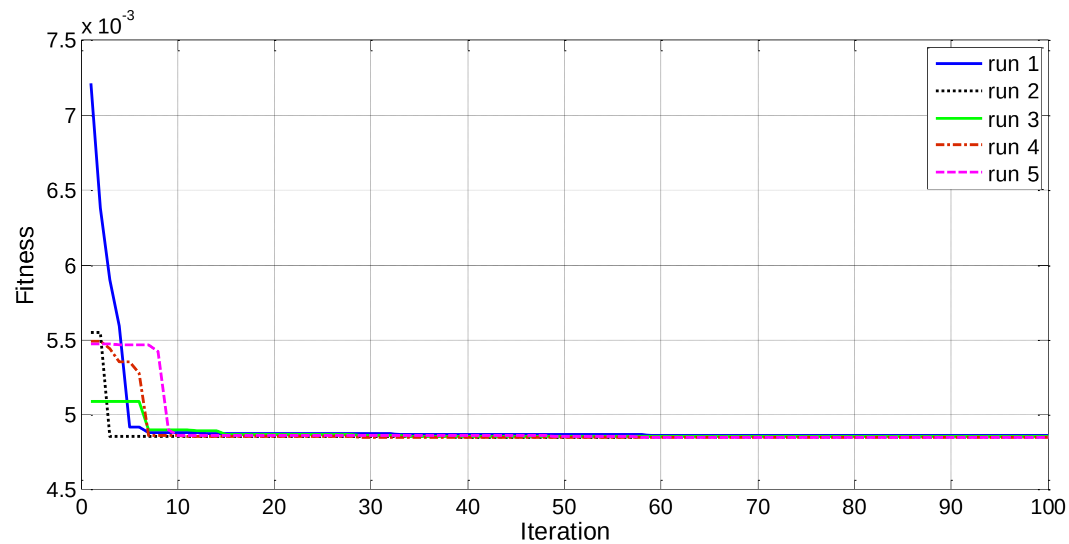

Figure 11. Evolution of proposed method for different runs.

6. CONCLUSION AND DISCUSSION

In this article the application of genetic algorithm to optimize the variables of a SVC's PI controller system has been investigated. The powerfulness of the introduced approach for the system dynamic stability margin has been shown computer simulation by two different cases.

- Case one: System with SVC device and GA-PI controller system.
- Case two: System with SVC device and classical PI controller system.

The dynamic output of generator bus voltage oscillation was investigated. From the simulation results, the notable results were as next:

(1) The power distribution system with SVC device has better transient operation stability profile.
(2) The variables finding of PI controller using GA was very powerful.
(3) Appling GA-PI controller to power system with SVC might result in operation.
Future research for multi-machine system and high voltage direct current transmission with SVC should be done to evaluate the powerfulness of this system on other systems.

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