A Novel Algorithm for Optimal Location of FACTS Devices in Power System Planning

Iraj Kheirizad*, Amir Mohammadi†, and Mohammad Hadi Varahram**

Abstract – The particle swarm optimization (PSO) has been shown to converge rapidly during the initial stages of a global search, but around global optimum, the search process becomes very slow. On the other hand, the genetic algorithm is very sensitive to the initial population. In fact, the random nature of the GA operators makes the algorithm sensitive to initial population. This dependence to the initial population is in such a manner that the algorithm may not converge if the initial population is not well selected. In this paper, we have proposed a new algorithm which combines PSO and GA in such a way that the new algorithm is more effective and efficient and can find the optimal solution more accurately and with less computational time. Optimal location of SVC using this hybrid PSO-GA algorithm is found. We have also found the optimal place of SVC using GA and PSO separately and have compared the results. It has been shown that the new algorithm is more effective and efficient. An IEEE 68 bus test system is used for simulation.

Keywords: FACTS devices, Hybrid PSO-GA, Optimization, Placement

1. Introduction

One of the major advances in the area of power system operation and control was made by the introduction of flexible AC transmission systems (FACTS) [1]. FACTS devices are solid state converters that have the capability of controlling various electrical parameters in transmission circuits. FACTS devices include thyristor controlled series compensator (TCSC), Static VAR Compensator (SVC), Thyristor controlled phase angle regulator (TCPST), Static compensator (STATCOM), and Unified power flow controller (UPFC), etc. [2].

FACTS devices can be connected to a transmission line in various ways, such as in series, shunt, or a combination of series and shunt. The static VAR compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt, the static synchronous series compensator (SSSC) and thyristor controlled series capacitor (TCSC) [2, 3] are connected in series, and the thyristor controlled phase shifting transformer (TCPST) [6, 7] and unified power flow controller (UPFC) are connected in series and shunt combination. The terms and definitions of various FACTS devices are described in Reference [4]. It has been proved that the steady state power transfer capability of a line can be doubled when a shunt FACTS is placed at mid point of the transmission [2, 5]. Shunt compensation enhances the real power handling capacity of a line at a much lower cost than building a second transmission line of the same capacity. Shunt FACTS devices are recognized as smooth control of reactive power over a wide range to support the transmission line [5].

There are a lot of factors that can affect the performance of a power system. One of the problems which cause instability to a power system is voltage stability. Voltage stability has been defined by the System Dynamic Performance Subcommittee of the IEEE Power Engineering Committee as being the ability of a system to maintain voltage so that when load admittance is increased, load power will increase and both power and voltage can be controlled. The main cause of voltage instability is insufficient reactive power supply. Properly planned reactive reserve will provide adequate reactive power support at critical buses [6].

SVC is used for voltage control applications. SVC helps to maintain a bus voltage at a desired value during load variations. The SVC can be made to generate or absorb reactive power by means of Thyristor controlled elements. [7]

The advent of Flexible AC transmission systems (FACTS) technology has also coincided with the major restructuring of the electrical power industry. The electric supply industry is undergoing a deep change worldwide. Market forces, scarce natural resources, and an ever increasing demand for electricity are some of the drives responsible for such an unprecedented change. Particularly

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in the case of transmission systems, fair open access to transmission resources is required. Therefore sufficient transmission capacity for supporting transmission services is of great demand to a transmission network's requirement. FACTS can provide benefits in increasing system transmission capacity and power flow control flexibility and rapidity [2, 3]. The placement of FACTS devices in a power network is of great importance to ensure the utilization of the full potential of the transmission network [1].

Finding the optimal location of different types of FACTS devices in the power system has been reported using different techniques such as Genetic Algorithm (GA), hybrid Tabu approach, simulated annealing (SA), and particle swarm optimization (PSO), etc. [8, 10, 11, 12 and 13].

Population based, cooperative, and competitive stochastic search algorithms have been very popular in recent years in the research arena of computational intelligence. Some well-established search algorithms such as (GA) [10] and Evolutionary Programming (EP) [11] have been successfully implemented to solve simple and complex problems efficiently and effectively. Most of the population based search approaches are motivated by evolution as seen in nature. Particle swarm optimization (PSO), on the other hand, is motivated from the simulation of social behavior. Nevertheless, they all work in the same way, that is, updating the position of individuals by applying some kinds of operators according to the fitness information obtained from the environment, so that the individuals of the population can be expected to move towards better solution areas. The PSO algorithm was first introduced by Eberhart and Kennedy [14, 15]. Instead of using evolutionary operators to manipulate the individuals, like in other evolutionary computational algorithms, each individual in PSO flies in the search space with a velocity which is dynamically adjusted according to its own flying experience and its companions' flying experience. Unlike in genetic algorithms, evolutionary programming, and evolution strategies, in PSO, the selection operation is not performed. All particles in PSO are kept as members of the population through the course of the run (a run is defined as the total number of generations of the evolutionary algorithms prior to termination). It is the velocity of the particle which is updated according to its own previous best position and the previous best position of its companions. The particles fly with the updated velocities. PSO is the only evolutionary algorithm that does not implement survival of the fittest.

Although PSO has shown to be very effective and efficient in many optimization problems, it still suffers from some deficiencies. One of the drawbacks of the PSO is its slow convergence in the vicinity of the global optima [16].

In this paper, by applying a combination of PSO technique and genetic algorithm, the optimal location of SVC devices for power system planning is found. We have employed the best features of PSO and GA in a single algorithm and thus introduced a better algorithm for optimization problems in power system planning. In future research works we intend to focus on how to apply this novel approach for other practical optimization problems.

2. SVC Model and the Fitness Function

Revolutionary developments in the areas of high power electronic devices and their sophisticated electronic control methods result in a great deal of opportunities for the implementation of fast FACTS devices such as Static Compensator (STATCOM), Series Power Flow Controller (SPFC), and Unified Power flow Controller (UPFC). However, Static VAR Compensator (SVC) is the pioneer device proposed in this area [17]. The SVC is a shunt connected FACTS device. It has the ability to generate or absorb reactive power at the point of connection. Basically an SVC consists of a combination of fixed capacitors or reactors, Thyristor switched capacitors, and Thyristor controlled reactors connected in parallel with the electrical system. In this study, SVC is modeled as a variable susceptance [9].

Figure 1 below shows the steady state model of the SVC.

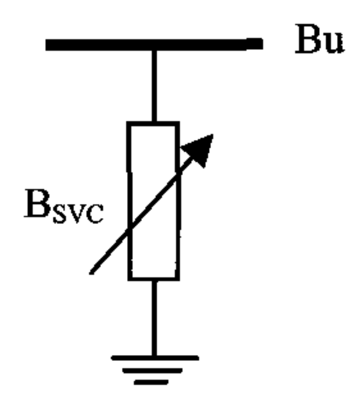

Fig. 1. SVC in steady state [9]

$$Q_{SVC} = -V_K^2 \times B_{SVC} \quad (1)$$

$$\underline{B}_{SVC} \le B_{SVC} \le \overline{B}_{SVC} \quad (2)$$

$\underline{B}_{SVC}$ is the susceptance of the SVC.

The main objective of this paper is finding the optimal location of the SVC in such a way that the total power losses of the system and the cost of installation are minimized and at the same time system constrains are met. In this condition, the voltages at different buses are kept within acceptable levels.

The fitness function of this problem according to the above mentioned statements is as follows [6]:

$$FF : F(x) = W_1 \times V_K + W_2 \times CO \quad (3)$$

In which

W_1 and W_2 are the weight factors ($W_1 + W_2 = 1$)
CO : cost of installation and operation
V_K : voltage contribution at bus K
The constraints of the problem are as follows:

$$V_{K,Min} \leq V_K \leq V_{K,Max} \quad (4)$$

$$B_{SVC,Min} \leq B_{SVC} \leq B_{SVC,Max} \quad (5)$$

3. Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a kind of algorithm employed to search for the best solution by simulating the movement and flocking of birds. The algorithm works by initializing a flock of birds randomly over the searching space, where every bird is called a "particle". These "particles" fly with a certain velocity and find the best global position after some iteration. At every iteration, each particle can adjust its velocity vector based on its momentum and the influence of its best position (Pb) as well as the best position of its neighbors (Pg), and then compute a new position that the "particle" is to fly to. Supposing the dimension for a searching space is D, the total number of particles is n and the position of the ith particle is expressed as vector Xi =(xi1,xi2, . . .,xiD); the best position of the ith particle being searched until now is denoted as Pib = (pi1,pi2, . . .,piD), the best position of the total particle swarm being searched until now is denoted as vector Pg = (pg1,pg2, . . .,pgD), and the velocity of the ith particle is represented as vector Vi = (vi1, vi2, . . ., viD). Then the original PSOA is described as [14]:

$$\begin{aligned} & v_{id}(t+1) = v_{id}(t) + c_1 * rand() * [p_{id}(t) - x_{id}(t)] + c_2 * rand() * \\ & [P_{gd}(t) - x_{id}(t)] \\ & x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \qquad 1 \leq i \leq n \quad 1 \leq d \leq D \end{aligned} \quad (7)$$

Where c_1 and c_2 are the acceleration constants with positive values; $rand()$ is a random number between 0 and 1; w is the inertia weight. In addition to the parameters c_1, and c_2, the implementation of the original algorithm also requires placing a limit on the velocity (Vmax). After adjusting the parameters w and Vmax, the PSO can achieve the best search ability.

The adaptive particle swarm optimization (APSO) algorithm is based on the original PSO algorithm firstly proposed by Shi and Eberhart in 1998 [15]. The APSO can be described as follows:

$$\begin{aligned} & v_{id}(t+1) = w * v_{id}(t) + c_1 * rand() * [p_{id}(t) - x_{id}(t)] + \\ & c_2 * rand() * [P_{gd}(t) - x_{id}(t)] \\ & x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \qquad 1 \leq i \leq n \quad 1 \leq d \leq D \end{aligned} \quad (8)$$

where w is a new inertial weight. By adjusting the parameter w, these algorithms can make w reduce gradually as the generation increases. In the searching process of the PSO algorithm, the searching space will reduce gradually as the generation increases. So the APSO algorithm is more effective, because the searching space reduces step by step nonlinearly, so the searching step length for the parameter w here also reduces correspondingly. Similar to GA, after each generation, the best particle of all the particles in the last generation will replace the worst particle of all the particles in the current generation, thus a better result can be achieved.

Generally, in the beginning stages of the algorithm, the inertial weight w should be reduced rapidly, when around optimum, the inertial weight w should be reduced slowly [15].

The step by step algorithm for the proposed optimal placement of SVC devices using PSO is given below:

Step 1. The number of devices to be placed is declared. The load flow is performed.

Step 2. The initial population of individuals is created satisfying the SVC device's constraints given by (4) and (5) and also it is verified that only one device is placed in each line.

Step 3. For each individual in the population, the fitness function given by (3) is evaluated after running load flow.

Step 4. The velocity and new population is updated by (8).

Step 5. If maximum iteration number is reached, then go to the next step or else go to step 3.

Step 6. Print the previous best individual's cost of installation and its settings.

Step 7. Stop.

4. Genetic Algorithm (GA)

The GA is a search algorithm based on the mechanism of natural selection and natural genetics. In a simple GA, individuals are simplified to a chromosome that codes for the variables of the problem. The strength of an individual is the objective function that must be optimized. The population of candidates evolves by the genetic operators of mutation, crossover, and selection. The characteristics of good candidates have more chances to be inherited, because good candidates live longer. So the average strength of the population rises through the generations. Finally, the population stabilizes, because no better individual can be found. At that stage, the algorithm has converged, and most of the individuals in the population are generally identical, and represent a suboptimal solution to the problem. A GA is governed by three factors: the mutation rate, the crossover rate, and the population size. The implementation of the GA is detailed in [18]. GAs are one of the effective methods for optimization problems especially in non-differential objective functions with discrete or continuous decision variables [20].

Figure 2 shows the way that the genetic algorithm works [6]. A brief description of the components of Figure 2 is as below:

1. Initialize a population of chromosomes.
2. Evaluate each chromosome in the population.
3. Create new chromosomes by mating current chromosomes.
4. Apply mutation and recombination as the parent chromosomes mate.
5. Delete a member of the population to accommodate room for new chromosomes.
6. Evaluate the new chromosomes and insert them into the population.
7. If time is up, stop and return the best chromosomes; if not, go to 3.

As with any search algorithm, the optimum solution is obtained only after much iteration. The speed of the iterations is determined by the length of the chromosome and the size of the populations. There are two main methods for the GA to generate itself, namely generational or steady state. In the case of generational, an entire population is replaced after iteration (generation), whereas in steady state, only a few members of the population are discarded at each generation and the population size remains constant [6].

One of the drawbacks of the GA is its possibility to converge prematurely to a suboptimal solution [10]. Another drawback of this algorithm is it's high sensitivity to the initial population [6, 19].

There are a few main limitations of a GA when being applied to problems [6]

8. The fitness function must be well-written.
9. It is a blind and undirected search.

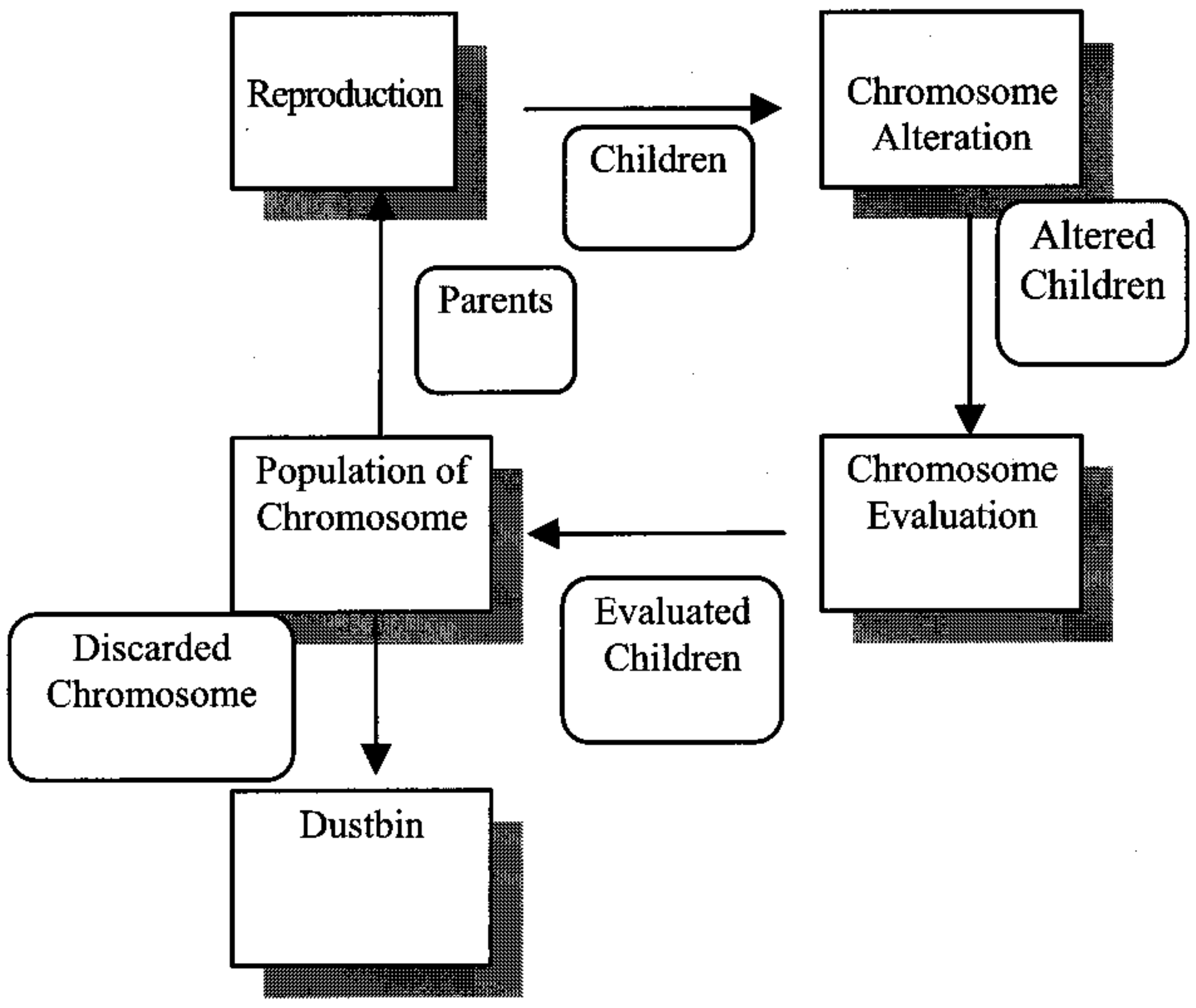

Fig. 2. Different procedures of GA [6]

10. It is a stochastic search.
11. It is sensitive to initial parameters.
12. It is computationally expensive.
13. What is the stopping criterion?

5. The PSO-GA Algorithm for Finding the Optimal Placement of SVC

We will use three kinds of algorithm, namely PSO, GA and PSO-GA, for finding the optimal placement of SVC. An IEEE 68 bus test system is used in this simulation. A comparison is made to show the effectiveness of the newly proposed algorithm.

The genetic algorithm is very sensitive to the initial population. In fact, the random nature of the GA operators makes the algorithm sensitive to the initial population [19]. This dependence to the initial population is in such a manner that the algorithm may not converge if the initial population is not well selected. However, if the initial population is well selected, the performance of the algorithm may be enhanced.

PSO, on the other hand, is not as sensitive as GA to the initial population. One of the characteristics of PSO is its fast convergence towards global optima in the early stage of the search and its slow convergence near the global optima.

The idea behind this paper is the combination of the PSO and GA algorithm in such a way that the performance of the newly established algorithm is better than the PSO or GA algorithm. This new algorithm could be used for many optimization problems.

In the fist stage of solving the problem of optimization the PSO algorithm will create an initial population near the global optima. After that the algorithm switches to the GA and the GA takes this initial population and continues to solve the optimization problem.

The step by step algorithm for the proposed optimal placement of SVC devices using PSO-GA is given below:

Step 1. The number of devices to be placed is declared and the load flow is performed.

Step 2. The initial population of individuals is created satisfying the SVC device's constraints given by (4) and (5) and also it is verified that only one device is placed in each line.

Step 3. For each individual in the population, the fitness function given by (3) is evaluated after running load flow.

Step 4. The velocity and new population is updated by (8).

Step 5. If maximum iteration number is reached, then go to the next step or else go to step 3.

Step 6. Get the last population as the initial population and using the GA update the population.

Step 7. For each individual in the population, the fitness function given by (3) is evaluated after running load flow.

Step 8. If the stop criterion is met, go to step 9 or else go to step 6.

Step 9. Output the results

6. Numerical Results and Discussion

The goal of optimization is to perform the best utilization of the existing transmission lines. In this respect, the SVC devices are located in order to minimize the power losses and maximize the system loadability while considering voltage constrains and cost of installation.

In the following section, optimal placement of SVC in the IEEE 68 bus test system is found using three kinds of algorithms. These algorithms are PSO, GA, and PSO-GA. The results obtained from these algorithms are considered and compared with each other.

The simulation studies were carried out on a Pentium IV, 2 GHz system in Matlab environment.

6.1 GA:

The parameters of the GA algorithm are set as below:
Population size = 50
Crossover probability = 1
Mutation probability = 0.7
Maximum number of generations = 100

The problem has three variables, namely Bus Number, SVC susceptance, and Voltage.

For every generation the GA will return a maximum, minimum, mean, and standard deviation value from the population size. Twenty runs have been performed for this case and the best result obtained is as follows:

Table 1. Output of the GA Algorithm

Bus Number	SVC Susceptance (per unit)	Total Power Loss Reduction (pu)
34	1.4654	0.3559

As shown in Table 1, in this case total power loss is reduced by 0.3559.

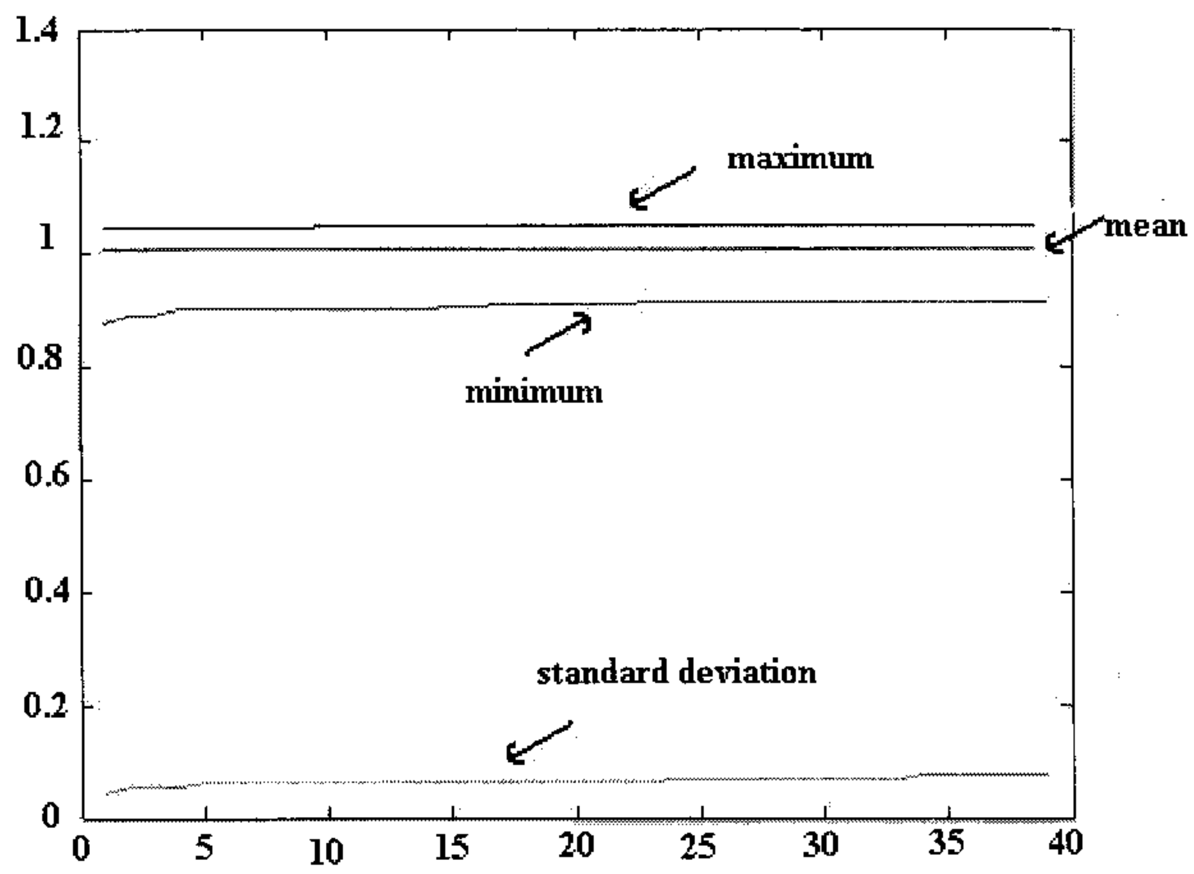

Fig. 4. Results for GA algorithm

As can be seen from Figure 4 the program has converged in 40 iterations. This program took 89.4688 seconds to converge.

6.2 PSO:

The parameters of the PSO algorithm are as follows:
Number of iterations = 100
Inertia = 0.8
Correction factor = 0.2
Swarm size = 50

Only one run has been performed for this case and the result obtained is as follows:

Table 2. Output of the PSO Algorithm

Bus Number	SVC Susceptance (per unit)	Total Power Loss Reduction (pu)
31	1.9754	0.4608

As indicated in Table 2, in this case total power loss is reduced by 0.4608

This program took 150.1671 seconds to converge.

6.3 PSO-GA

The parameters of the PSO-GA algorithm are as follows:

For the PSO
- Iteration = 20
- Inertia = 0.2
- Correction factor = 0.2
- Swarm size = 50

For the GA
- Population size = 50
- Crossover probability = 1
- Mutation probability = 0.1
- Maximum number of generations = 40

Only one run has been performed for this case and the result obtained is as follows:

Table 3. Output of the PSO-GA algorithm

Bus Number	SVC Susceptance (per unit)	Total Power Loss Reduction (pu)
50	2	0.8823

As shown in Table 3, in this case total power loss is reduced by 0.8823 which is much better than PSO and GA separately.

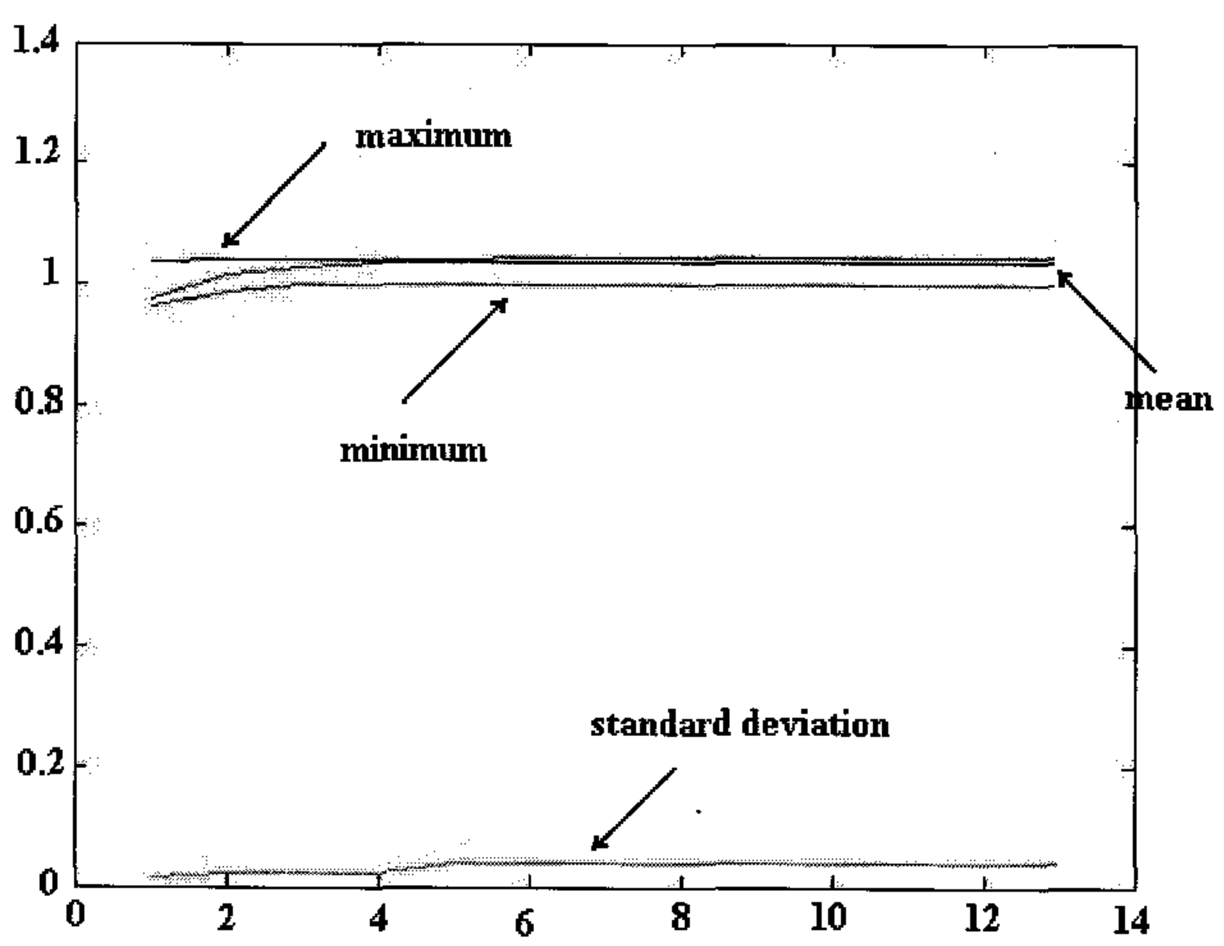

Fig. 5. Results for hybrid PSO-GA Algorithm

As can be seen from Figure 5 the program has converged in 13 iterations. This program took 32.4375 seconds to converge. Figure 5 also shows that the average fitness of the population is very close to the maximum fitness of the population. And thus it is confirmed that the performance of this algorithm is much better than the PSO or GA.

7. Conclusion

In this paper we have proposed a new algorithm which is a combination of PSO and GA. In this new algorithm we have tried to exploit the best features of both algorithms while obviating the drawbacks of PSO and GA in this new algorithm and thus form a superior algorithm. This algorithm is suitable for solving any optimization problem. With this algorithm we have optimally located the SVC devices in an IEEE 68 bus test system.

We have also found the optimal location of SVC using PSO and GA separately and compared the results. By comparing the results we have demonstrated that the new algorithm is more effective and more efficient. In the future research works we intend to focus on how to apply this novel approach for other practical optimization problems.

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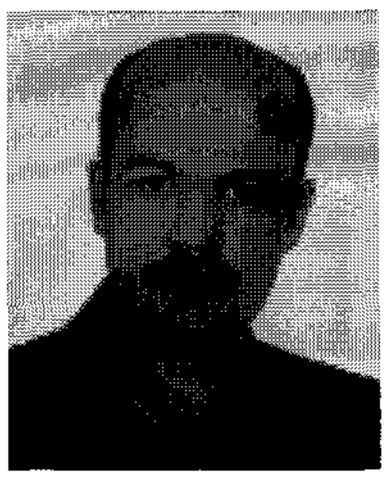

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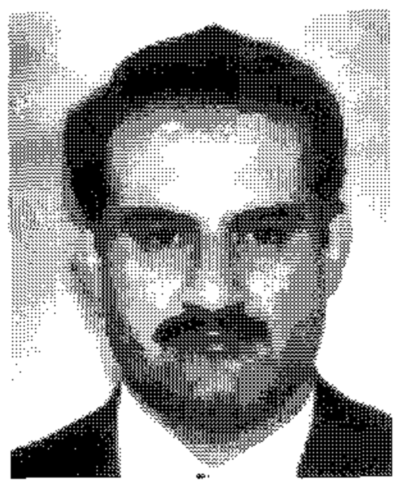

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