A Modified Approach for Reactive Power Compensation in Power System Using Intelligent Control

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ABSTRACT:

This paper presents an attempt to introduce a modified approach for an optimization technique, where the automatic and controlling problems will be analyzing and formulated aiming to improve voltage regulation and reducing power losses. An optimal control of capacitor banks in distribution power systems will be discussed also, using intelligent control. The focus will be on the capacitor placement problem to determine the locations and sizes of the capacitors so that the power loss is minimized and annual economic savings are maximized to achieve the reactive power compensation, in addition to the power factor enhancement.

الخلاصة

يستعرض هذا البحث محاولة لإيجاد مقاربة معدلة في التقنية المثلى ، حيث ان مشاكل السيطرة سيتم استعراضها و تحليلها لغرض تحسين تنظيم الفولتية و لتقليل خسائر القدرة. سيتم مناقشة السيطرة المثلى باستخدام مخازن المكثفات في أنظمة التوزيع الكهربائية و ذلك باستخدام السيطرة الذكية. سيتم التركيز على مشكلة اختيار قيم و أماكن المكثفات المراد نصبها في الشبكة الكهربائية من اجل الحصول على اقل خسائر للقدرة و كسب اكبر مردود اقتصادي من خلال تعديل و موائمة القدرة الغير فعالة إضافة إلى تحسين معامل القدرة.

Introduction

The main goal in the electric power analysis is the reactive power compensation in the electric power system, this can be down in many methods and techniques and the main method and technique is to use capacitors with specific values at a specific locations. The objective of the capacitor placement problem is to determine the locations and sizes of the capacitors so that the power loss is minimized and annual savings are maximized. Electrical power losses in distribution systems correspond to about 70% of total losses in electric power systems [Pissara 2005]. Even though considerable amount of research work was done in the area of optimal capacitor placement [Salama, 2000],[Prakash, 2007]. Reduction of total power loss in distribution system is very essential to improve the overall efficiency of power delivery. This can be achieved by placing the optimal value of capacitors at proper locations in radial distribution systems. Capacitors are installed at strategic locations to reduce the losses and to maintain the voltages within the acceptable limits. Application of shunt capacitors to the primary distribution feeders is a common practice in most of the countries. The advantages anticipated include boosting the load level of the feeder so that additional loads can be carried by the feeder for the same maximum voltage drop, releasing a certain kVA at the substation that can be used to feed additional loads along other feeders and reducing power and energy losses in the feeder.

Total Real Power Loss In A Distribution System

The total *I*2R loss (PL) in a distribution system having *n* number of branches is given by:

$$P_L = \sum_{i=1}^{n} I_i^2 R_i \quad \text{----------(1)}$$

Here Ii is the magnitude of the branch current and Ri is the resistance of the *ith* branch respectively. The branch current can be obtained from the load flow solution. The branch current has two components, active component (*Ia*) and reactive component (*Ir*). The loss associated with the active and reactive components of branch currents can be written as

$$P_{La} = \sum_{i=1}^{n} I_{ai}^2 R_i \quad \text{------------(2)}$$

$$P_{Lr} = \sum_{i=1}^{n} I_{ri}^2 R_i \quad \text{-----------(3)}$$

Note that for a given configuration of a single source radial network, the loss PLa associated with the active component of branch currents cannot be minimized because all active power must be supplied by the source at the root bus. However, supplying part of the reactive power demand locally can minimize the loss PLr associated with the reactive component of branch currents. So the goal of this paper is to reduce the reactive power demand in order to reduce the power losses by installing the specific capacitors in values and locations, as a consequence, this will be enhance the load power factor and reducing the apparent power also.

The Principles of Power Factor Correction

Under normal operating conditions certain electrical loads (e.g. induction motors, welding equipment, arc furnaces and fluorescent lighting (draw not only active power from the supply (kilowatts, kW) but also reactive power (reactive kVA, kVAr). This reactive power is necessary for the equipment to operate correctly but could be interpreted as an undesirable burden on the supply. The demand made by such a load on the supply is outlined in Figure 1.

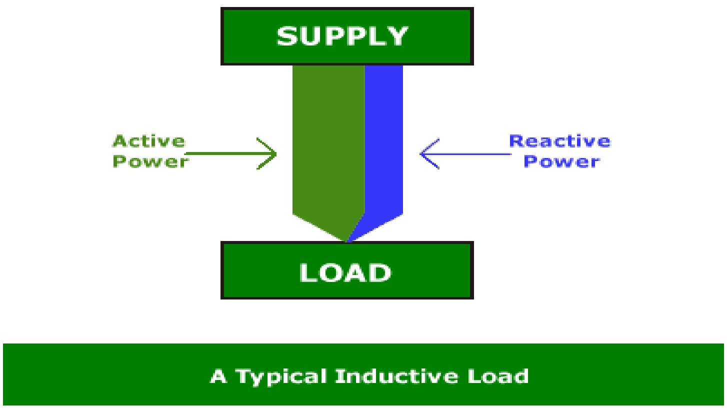

Figure 1: reactive load demand

Opposing reactive power resulting from the correction of a correctly sized capacitor can compensate for the reactive power required by the load. This ensures a reduction in the reactive power drawn from the supply. Power Factor Correction is the connection of a capacitor to an inductive load . This achieves a reduction in the total current drawn from the supply and is known as 'PFC' or 'Correction'. A load with an associated capacitor is said to be 'Corrected'. Figure 2 illustrate this case.

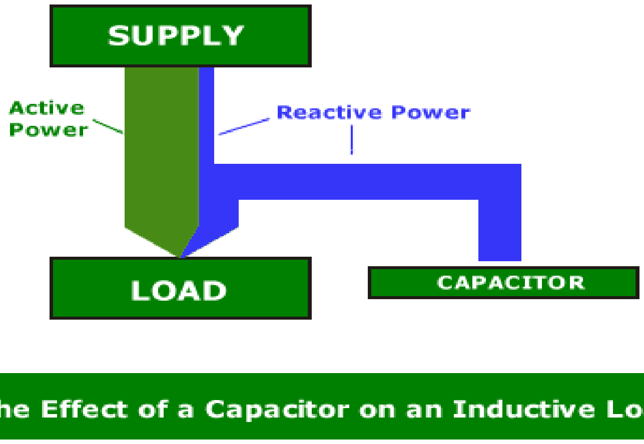

Figure 2: The effect of a capacitor on an inductive load

The Power Factor of a load is defined as the ratio of active power to apparent power i.e. kW : kVA and is referred to as cos θ. In the figure below the uncorrected power factor of the load is cos θ1 and the corrected power factor is cos θ2. The closer cos θ is to unity,the less reactive power is drawn from the supply. As illustrated in Figure 3.

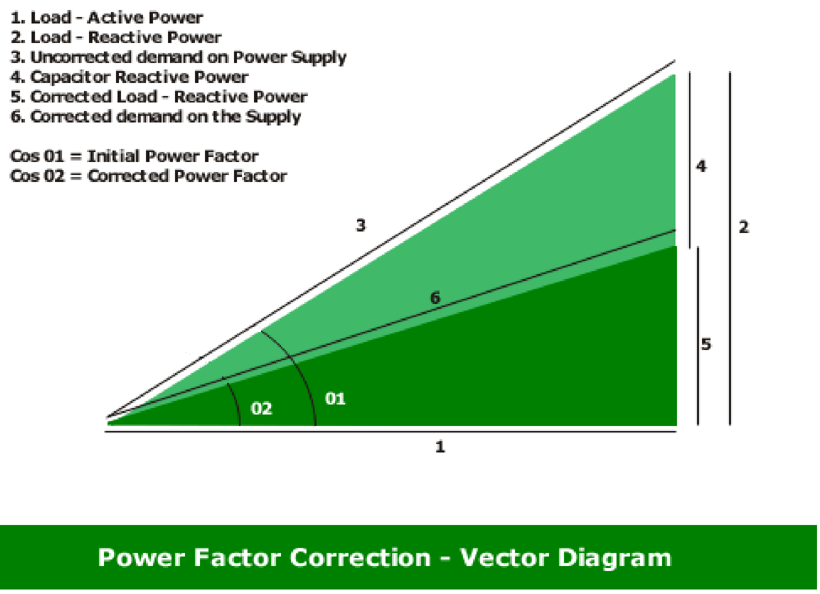

Figure 3: Power Factor Correction – Vector Diagram

Common reasons for the provision of Power Factor Correction Capacitors include:

1. The reduction in the load on cables and switchgear

2. The ability of the supply to support additional load

3. The likely reduction in the charges levied by the Electricity Supply Company

Reducing the load on distribution network components can result in an extension of their useful life. This would improve the integrity of the system.

PROBLEM FORMULATION

The determination of Capacitor bank size, location and control are based on reactive load curve, that is to say, on reactive demand versus time plot. In practice, demand is the mean power (or current) during a specific time interval denominated as demand interval. Therefore, demand varies with time and depends on the point on the feeder where measurements are taken. In ordinary situations, only load curves taken at substation bus (known as feeder load curves) are available and, eventually, curves taken at some special load buses are available too. Thus, individual load curves are considered, almost always, identical to the feeder load curve in order to define the operation control program of switched capacitor banks. This hypothesis simplifies the problem excessively, however it does not affect the final result in a significant way, especially when many loads, all of same type, like residential, commercial or industrial, are supplied [Gönen, 1986]. The load curve can be substituted, advantageously, by the corresponding load duration curve, as in Figure 4. The convenience of using the load duration curve is due to the fact of it is monotonically decreasing, once it is defined by the points (t, p) such that t is the integral of all the infinitesimal times during which the demand is higher or equal to p. For instance, it is shown how long the demand is higher than 1.2 Mvar in Fig. 4a (times t1 and t2). In Fig. 4b, the time associated with 1.2 Mvar in the original curve is exactly the sum of t1 and t2. The load duration function is usually approximated by a two steps ladder function corresponding to the schedules of pick and out of pick. Using more steps can yield better approximation, although this implies larger effort. In this work, three steps functions were used. Thus, calculation of energy losses requires calculation of
power losses in pick, intermediate and light load levels. Segmented load

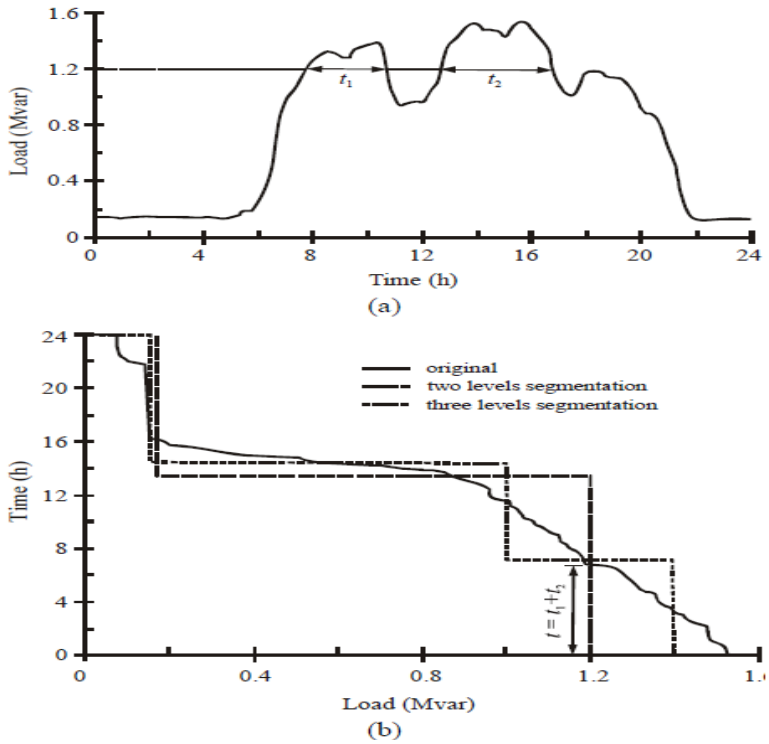

Figure 4- Demand in function of time: (a) load curve, (b) load duration curves.

duration curves are superposed on the original ones as shown in Figure 4b.In the reactive compensation problem, the objective function, to be maximized, represents the economic savings obtained with capacitor banks installation in the distribution network. The capacitor banks usually have nominal capacities that are multiple integers of a standard unit (50, 150 or 300 kvar, for example). The purpose of the reactive power dispatch in power system is to identify the control variables which minimize the system real power loss while satisfying the unit and system constraints. This goal is achieved by proper adjustment of reactive power variables like generator voltage magnitude (Vgi), reactive power generation of capacitor bank (Qci) and transformer tap-setting (tk). This is mathematically stated as [S Durairaj, 2006],

$$\text{Minimize } P_{\text{loss}} = \sum_{\substack{k \in N_l \\ k=(i,j)}} g_k \left(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right) \quad (4)$$

The real power loss given by equation (4) is a non-linear function of bus voltages and phase angles which are a function of control variables. The minimization problem is subjected to the following equality and inequality constraints:

(i) Load flow constraints

$$Q_i - V_i \sum_{j=1}^{N_B} V_j (G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) = 0; \quad (5)$$

$$i = 1, 2, \ldots\ldots, N_{PQ} \quad (6)$$

(ii) Voltage constrains

$$V_i^{\min} \leq V_i \leq V_i^{\max}; \; i \in N_B \quad (7)$$

(iii) Generator reactive power capability limit

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max}; \; i \in N_g \quad (8)$$

(iv) Reactive power generation limit of capacitor banks

$$Q_{Ci}^{\min} < Q_{Ci} \leq Q_{Ci}^{\max}; \; i \in N_C \quad (9)$$

(v) Transformer tap-setting limit

$$t_k^{\min} \leq t_k \leq t_k^{\max}; \; k \in N_T \quad (10)$$

(vi) Transmission line flow limit

$$S_l \leq S_l^{\max}; \; l \in N_l \quad (11)$$

(vii) Voltage stability constraint

$$L_j \leq L^{\max}; \; j \in N_{PQ} \quad (12)$$

The equality constraints are satisfied by running the power flow program. The active power generation (P_{gi}) (except the generator at the slack bus), generator terminal bus voltages (V_{gi}) and transformer tap-settings (t_k) are the optimization variables and they are self-restricted by the optimization algorithm. The active power generation at the slack bus (P_{gs}), load bus voltages (V_{load}) and reactive power generation (Q_{gi}) and voltage stability level (L_j) are state variables which are restricted through penalty function approach.

SOLUTION METHOD

The proposed solution method to find the optimal solution of reactive compensation problem as formulated in the previous section, Initially, using Genetic Algorithms which represent the best optimizing technique tool, all distribution system buses are appraised to determine the ones which are more adequate to have banks installed on them. Thus, the application of GAs here to find the size and locations of the capacitor banks used in reactive power compensation and enhancing the power factor value as a consequence. The genetic algorithms which applied in this optimizing problem solution use the binary code to represent solutions.

GENETIC ALGORITHM SOLUTION TECHNIQUE:

Genetic algorithm (GA) is a generalized search and optimization technique inspired by the theory of biological evolution[Deb, 2002], [Gold Berg, 1989]. GA maintains a population of individuals that represent candidate solutions. Each individual is evaluated to give some measure of its fitness to the problem from the objective function. In each generation, a new population is formed by selecting the more fit individuals based on a particular selection strategy. Some members of the new population undergo genetic operations to form new solutions. The two commonly used genetic operations are crossover and mutation. Crossover is a mixing operator that combines genetic material from selected parents. Mutation acts as a background operator and is used to search the unexplored search space by randomly changing the values at one or more positions of the selected chromosome. Figure 5 shows the various components of the proposed algorithm.

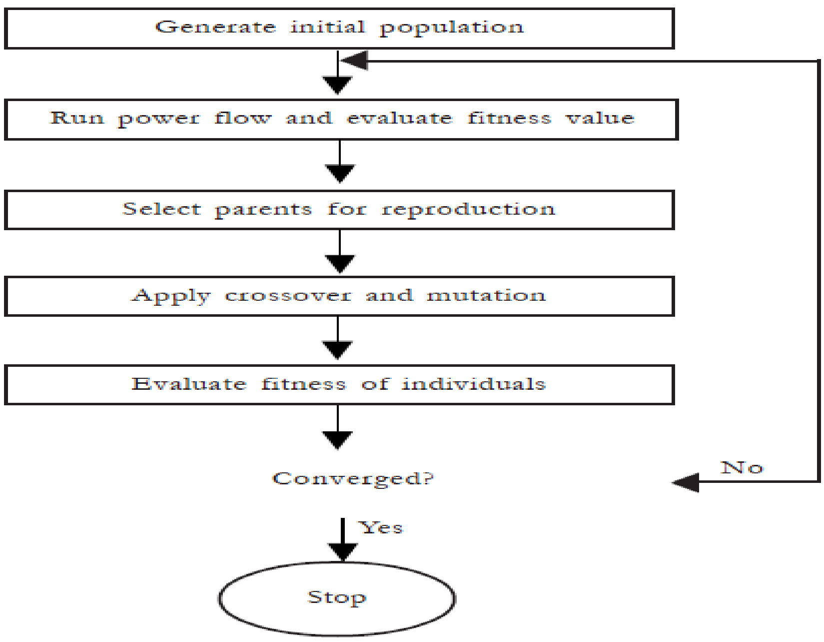

Figure 5: The flow chart for the GAs operations

Representation

Each individual in the genetic population represents a candidate solution. In the binary-coded GA, the solution variables are represented by a string of binary alphabets. The size of the string depends on the precision of the solution required. For problems with more than one decision variables, each variable is usually represented by a sub-string. All the sub-strings are concatenated together to form a bigger string. In this optimizing problem, the elements of the solution consist of all the control variables, namely, generator bus voltages (Vgi), the transformer tap-setting (tk), and the reactive power generation (Qci). These variables are represented as binary strings in the GA population. With binary representation, an individual in the GA population for the reactive power optimization problem will look like the following:

Fitness Function

In this optimizing problem under consideration the objective is to minimize the total power loss satisfying the constraints given by equations (4) to (11). For each individual, the equality constraints given by equations (4) and (5) are satisfied by running Newton-Raphson algorithm and the constraints on the state variables are taken into consideration by adding a quadratic penalty function to the objective function. With the inclusion of penalty function, the new objective function then becomes [S Durairaj, 2006],

$$\operatorname{Min} F = P_{\text{loss}} + K_v \sum_{i=1}^{N_{PQ}} \left(V_i - V_i^{\lim}\right)^2 + K_q \sum_{i=1}^{N_g} \left(Q_{gi} - Q_{gi}^{\lim}\right)^2 + K_f \sum_{l=1}^{N_l} \left(S_l - S_l^{\lim}\right)^2 + K_l \sum_{j=1}^{N_{PQ}} \left(L_j - L^{\lim}\right)^2 \tag{13}$$

where Kv , Kq , Kf and Kl are the penalty factors for the bus voltage limit violation, generator reactive power limit violation, line flow violation and voltage stability limit violation, respectively. In the above objective function Vi lim and Qgi lim are defined as;

$$V_i^{\lim} = \begin{cases} V_i^{\min}; \text{if } V_i < V_i^{\min} \\ V_i^{\max}; \text{if } V_i > V_i^{\max} \end{cases} \tag{14}$$

$$Q_{gi}^{\lim} = \begin{cases} Q_{gi}^{\min}; \text{ if } Q_{gi} < Q_{gi}^{\min} \\ Q_{gi}^{\max}; \text{ if } Q_{gi} > Q_{gi}^{\max} \end{cases}$$

The minimization objective function given by equation (13) is transformed to a fitness function (f) to be maximized, where This is used to amplify the value of [1/ F] which is usually small, so that the fitness value of the chromosome will be in a wider range.

Selection Strategy

The selection of parents to produce successive generations plays an important role in the GA. The goal is to allow the 'fittest' individuals to be selected more often to reproduce. There are a number of selection methods proposed in [Goldberg, 1989]; fitness proportionate selection, ranking and tournament selection. Tournament selection is used in this work. In tournament selection, n individuals are selected randomly from the population, and the best of the n is inserted into the new population for further genetic processing. This procedure is repeated until the mating pool is filled. Tournaments are often held between pairs of individuals, although larger tournaments can be used.

Crossover Operation

For binary-coded GA, there exist a number of crossover operators. The crossover operator is mainly responsible for the global search property of the GA. The operator basically combines substructures of two parent chromosomes to produce new structures, with the chosen probability (PC). Crossover can occur at a single position (single crossover), or at number of different positions (multiple crossover). In this paper two point crossovers is employed in which two crossover sites are chosen and offspring are created by swapping the bits between the chosen crossover sites.

Mutation

The final genetic operator in the algorithm is mutation. The mutation operator is used to inject new genetic material into the population. Mutation changes randomly the new offspring. For binary encoding bit-wise mutation is preferred which switches a few randomly chosen bits from 1 to 0 or from 0 to 1 with a small mutation probability (Pm). After mutation, the new generation is complete and the procedure begins again with the fitness evaluation of the population.

Case Study and Results

The details of the simulation study carried out on IEEE 30-bus system using the proposed GA-based method is presented here. IEEE 30-bus system consists of 6 generator buses, 24 load buses and 41 transmission lines of which 4 branches (6-9), (6-10), (4-12) and (28-27) are with the tap-setting transformer. The transmission line parameters of this system and the base loads are given in [Alsak, 1974].

For this problem, the candidate buses for reactive power compensation are 10, 12, 15, 17, 20, 21, 23, 24 and 29. The GA- based optimizing algorithm was implemented using MATLAB code and was executed on a PC (P4). One case had been taken in this paper to illustrate the effect of using GAs as an optimizing techniques for reactive power optimization. In this case the system is optimized using the optimal reactive power Optimizing method under base load condition for 100% load level. The real power settings of the generator are taken from [Lee, 1985]. To obtain the optimal values of the control variables the GA-based algorithm was run with different control settings. The optimal settings of the GA control parameters are given below:

Population size : 40
Maximum number of generations : 50
Crossover probability : 0.9
Mutation probability : 0.01
Tournament size : 2

The optimal values of the control variables and power loss obtained are presented in Table 1. which illustrate also, the locations of the capacitors banks and the needed specific value at this point.

Table – 1 : Locations and Values of the Capacitors and Generator Bus Voltage Magnitude

Table -1 a

Capacitors Values (MVAR) & Locations
C15 = 2.7985
C17 = 2.7985
C20 = 2.8435
C21 = 8.4691
C23 = 2.8435
C29 = 5.6998

Table -1 b

Buses Voltage Magnitude (p.u)
V1 =1.0368
V2 =1.0305
V5 =1.0112
V8 =1.0132
V11 =1.0058
V13 =1.0235

Table -1 c

Transformer Tap Setting X 100%
T11 = 1.0500
T12 = 1.0750
T15 = 1.1000
T36= 1.9250

Table -2 illustrates the obtained results of the optimizing techniques using GAs in controlling the optimal control variables and its setting as shown below:

Table -2 : Obtained Results Using GAs for Reactive Power Compensation Illustrating the Optimal Control Variables at specific locations

Reactive Power Variable Elements	**Control Variable Setting (MVARS)**
Q10	19.9553
Q12	16.9884
Q15	8.4998
Q17	16.9884
Q20	8.4998
Q21	19.9553
Q23	2.9311
Q24	16.9884
Q29	5.6957

Voltage Variable Elements	**Control Variable Setting (p.u)**
V1	**1.0338**
V2	**1.0018**
V5	**0.9811**
V8	**0.9799**
V11	**1.0397**
V13	**1.0496**

Transformer Tap Setting	**Control Variable Setting (x 100 %)**
t11	1.0411
t12	1.0411
t15	1.0139
t36	0.9732

Note: Voltage in per unit (p.u) values, Reactive power in MVARS, Transformer setting in percentage values.

To illustrate the convergence of the algorithm, the relationship between the best fitness value of the optimizing results and the average fitness are plotted against the number of generations in Figure 6. From this Fig., it can be seen that the proposed algorithm converges rapidly towards the optimal solution. This shows the powerfulness of the proposed method for the optimizing problem.

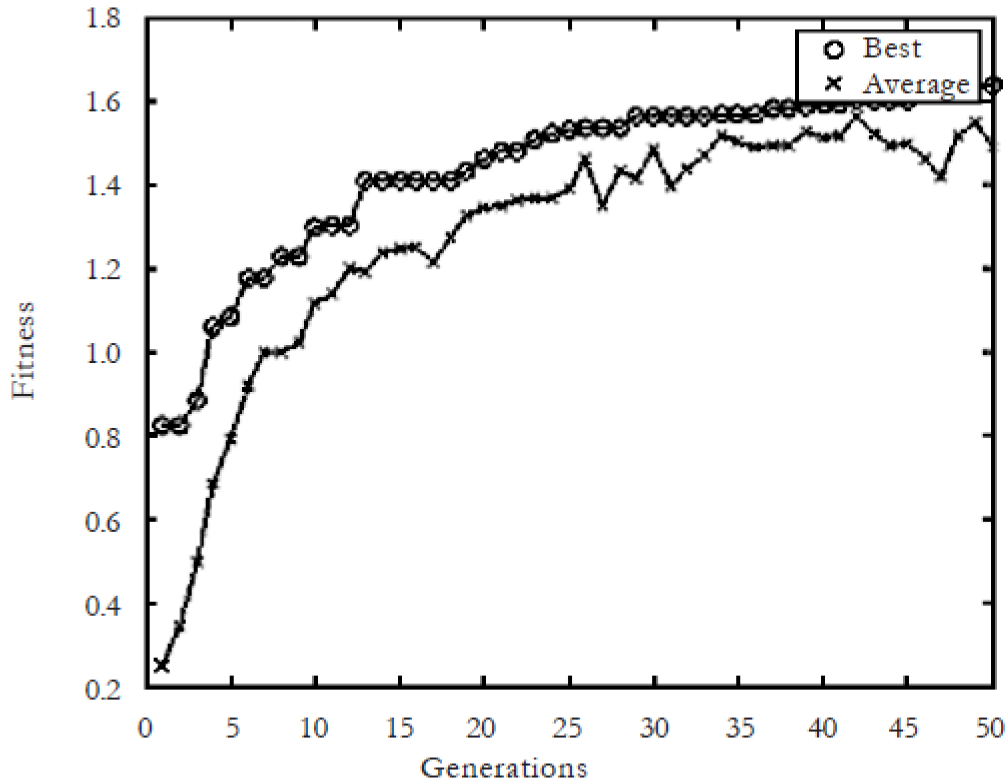

Figure 6: Convergence Characteristics

CONCLUSION

This paper present and illustrate the effectiveness of using the GAs as an optimizing tool to optimize the location and the values of the capacitors banks that needed in reactive power compensation. The continuous demand in electric power system network has caused the system to be heavily loaded leading to high power losses, and lower power factor in spite of voltage instability. Voltage instability condition in a stressed power system could be improved by having an effective reactive power compensation in optimizing procedures. Genetic algorithm (GA), a stochastic optimization technique was employed as the optimization approach in determining the optimum values for the reactive power to be dispatched to establish voltage stability during contingency condition and enhancing power factor and optimizing the power losses to the minimum value taking the best capacitors banks locations and values which is illustrated in Table 1 and Table 2, where the var sources define the locations and the values of the needed capacitors at different buses. Simulation results shows that the GA-based reactive power optimizing algorithm is able to improving power factor, and voltage stability condition along with loss minimization in the system in spite of defining the values and locations of the capacitor banks in the distributed electrical power system. Also, it is found that the results of the GA-based algorithm are always better than that obtained using conventional methods.

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