Optimal Shunt Capacitor Placement In Power Distribution Systems Using A Genetic Algorithm

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Abstract

The problem of optimal placement of capacitors determines the size, type (fixed or switched), and locations of the capacitors to be installed in a radial distribution feeder that will reduce power loss while minimizing the costs of investment and installation of the capacitor banks. The present work is devoted to determine the optimal locations and sizes of capacitors in radial distribution system with different load levels using a genetic algorithm, taking in consideration the economic saving and cost of the capacitor. The optimal capacitor placement consists of problem formulations (based on the load flow equations in distribution system), genetic algorithms and sensitivity factors for a given load pattern. In the method, capacitor placement is applied to correct voltage deviation, power factor and reduce real power loss. The capacitor placement problem is a combinatorial optimization problem having an objective function composed of power losses and annual capacitor installation costs subjected to bus voltage constraints, which is commonly solved by employing mathematical programming methods in genetic algorithm to obtain the optimal solution. Two methods of load flow solution with different accuracy are employed. The first one is a simplified method, which uses the approximation of P and Q at the start of the implemented program. The second is a fast-decoupled technique, which gives an exact solution at the end of the program. The proposed algorithm has been implemented and tested on three-test systems. The first and second are theoretical samples (a 69-bus distribution system), while the third test is a practical sample taken from Baghdad distribution network of 11-bus distribution system. Tests show that GA is suitable algorithm as optimization technique with high accuracy, and avoids local minimum. Thus, the outcome of the study shows an efficient technique to solve the problem of capacitor placement in the power distribution system.

الخلاصة

تتضمن مشكلة الأمثلية لمواقع المتسعات العامة في منظومات توزيع القدرة الكهربائية إيجاد أفضل الحجوم، والأنواع (الثابتة أو المتغيرة)، والمواقع للمتسعات لخفض القدرة الكلية المرسلة عبر خطوط نقل القدرة الكهربائية إلى أدنى حد ممكن، و تحسين خواص المنظومة المتمثلة في تقليل الضياع الحقيقي، وتحسين عامل القدرة الكهربائية، بالإضافة إلى تقليل الهبوط بالجهد. يتضمن البحث صيغة جديدة لمشكلة مواقع المتسعات العامة في منظومة التوزيع الشعاعية، إذ بنيت الصيغة مع الأخذ بنظر الإعتبار الجوانب العملية للمتسعات، وكلفها، وتحديدات التشغيل، وتحديدات الأحمال في مستويات التحميل المختلفة، وذلك باستخدام الخوارزمية الجينية، إذ استخدمت طريقتان كفوءتان لسريان الحمل في الحل. كما أستخدم (عامل الحساسية) لإختيار المواقع المرشحة (المثلى) لوضع المتسعات ليتم بعدها إختزال الوقت، وتسريع الحسابات، والوصول للحل الأمثل الأوسع لمشكلة مواقع المتسعات عن طريق الخوارزمية الجينية. كما تم في هذه الدراسة تصميم أسلوب مقترح عن طريق تشغيل برامجيات ذات تقنية عالية بإستخدام برنامج الـــ (MATLAB) الذي جرى تطبيقه على ثلاثة أمثلة: الأول والثاني، نظريان ذو (٦٩–عقدة)، أما المثال الثالث، فهو عملي تم تطبيقه على شبكة التوزيع العراقية ذات (١١–عقدة). وقد أثبتت الدراسة أن الخوارزمية الجينية هي تقنية أمثلية ملائمة ولها دقة عالية، وتتجنب الوقوع في (النقطة الصغرى المحلية). كما أثبتت الدراسة كفاءة الأسلوب المقترح، وإمكانية أستخدامه كحل أمثل لمشكلة مواقع المتسعات العامة في منظومات توزيع القدرة الكهربائية.

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1- Introduction

Capacitors have been commonly employed to provide reactive power compensation in distribution systems. They are used to minimize power losses and to keep the voltages within operational limits, increase the released thermal capacities of the distribution lines and transformers, and improve power factor. Capacitors are usually installed on distribution systems in a three-phase configuration rather than single phase, a single unit or as a bank of series or shunt. Shunt capacitor modifies the characteristic of an inductive load by drawing a leading current which counteracts some or the entire lagging component of the inductive load current at the point of installation. By using a shunt capacitor to the distribution feeder, the magnitude of the source current can be reduced, the power factor is improved and the voltage drop between the sending end and the load end is reduced. R.F. Cook [1,2] presented an analysis of the application of fixed or fixed and switched capacitors on uniformly distributed feeders maximizing the total savings in terms of peak power loss and energy loss reductions, and total kVA is released. In addition, approach to treat randomly distributed feeder (actual feeder) has been developed by representing it by an equivalent uniform feeders to it. Y.C. Huang, H.T. Yang & C.L. Huang [3] used a sensitivity-analysis method to select the candidate installation locations of the capacitors to reduce the search space of this problem. T. Ghose & S.K. Goswami & S.K. Basu [4], introduced a solution technique, using combined simulated annealing and genetic algorithm to solve the problem of optimal placement of capacitor such that the reduction of energy losses become maximum considering the load variation and cost of capacitor. A. Abdul Ghani's [5] thesis was devoted to the determination of the optimum location and size of capacitor in radial distribution system with different load levels taking the cost of capacitor into consideration. The solution methodology based on simulated annealing optimization technique is a novel approach using approximate reasoning to determine suitable candidate nodes in a distribution system for capacitor placement (N. Ng & M.A. Salama & A.Y. Chikhani [6] and G. Levitin & A. Kalyuzhny & A. Shenkman & M. Chertkov [7]). A new approach to shunt capacitor placement in distribution systems has customers with different load patterns. The allocation of capacitors is considered in a system comprising a network of feeders fed from an upstream equivalent transmission system through a substation transformer. H. A. Ferreira & B. A. Souza & H. N. Alves [8], introduced a genetic algorithm for the solution of capacitor allocation and control problems in electrical distribution systems. From the daily load variation curve the proposed technique finds optimal locations for fixed and switched shunt capacitors. The objective function variables are the energy loss, the peak power loss at distribution feeders and the costs of the capacitor banks including installation. A simple iterative method is used to compute the power flow. In the work of J. S. Ra'aft.[9], artificial neural network is used to control the multi-tap capacitors installed in radial distribution system for varying the load profile so that the system losses are to be minimized. Control of the multi-tap capacitors achieves the minimization of losses due to reactive load current, reduction of kVA demand, released system capacity, improvement of voltage profile and power factor. In this paper, a solution methodology has been developed which is based on an optimization by genetic algorithm to determine: (1) the locations of installed capacitors. (2) Types and sizes of the capacitor to be installed. (3) Control settings of these capacitors at different load levels, at the same time it is necessary to obtain the most economic solution taking into account operation constraints. GA is a search mechanism based on the principle of natural choice and population genetics. The demanded design variables are encoded into string as set of genes corresponding to chromosomes in biological systems. The concept of selective adaptation and survival of the fittest is employed to search the parameter space to determine the optimal string by way of randomized information exchange. During each iterative procedure referred to as a generation, a new set of strings is produced using rules of evolution with improved performance. GA has been successfully employed to the capacitor placement problem in which design variables are the capacitor sizes at the candidate locations during finite discretized load levels. By observing the results, we may conclude that optimal global solution or solution very close to global ones has been reached.

2- Programming

The simulations of general capacitor problem solutions are performed on (IBM personal computer, Pentium IV processor) using MATLAB Version 6.1 programming language under Microsoft windows-XP operating system. The Programming is divided into four parts: solution of load flow, solution of general capacitor problem, sensitivity factor analysis, and genetic algorithm implementation.

2-1 Solution Of Power Flow

Power flow study includes the calculation of bus voltage and line power flow of a network. A single-phase representation is adequate. Associated with each bus, there are four quantities to be determined: real and reactive powers, the voltage magnitude and phase angle. We apply the load flow equations, using simplified method and fast-decoupled method that can be expressed by the following recursive set of equations.

1-A Simplified Method; The branch flow equations: It is observed, that the quadratic terms in the equations represent the power losses of the branch and are much smaller compared with the branch powers P_i,Qi . Neglecting these quadratic terms yield the following simplified branch flow equation:

$$P_{i+1} = P_i - P_{Li+1} \tag{1}$$

$$Q_{i+1} = Q_i - Q_{Li+1} + Q_{ci+1} \tag{2}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i+1}.P_i + X_{i+1}.Q_i) \tag{3}$$

Using the previous simplified branch flow equation, the power flow solution for a main feeder system (see Figure (1) is easily obtained as follows:

$$P_{i+1} = \sum_{i+1}^{n} P_{LK} \tag{4}$$

$$Q_{i+1} = \sum_{i+1}^{n} Q_{LK} \qquad K = i,\ldots..,n \tag{5}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i+1}.P_i + X_{i+1}.Q_i) \tag{6}$$

In similar way, the power flow solution for a general radial distribution system can be easily calculated from equations (4, 5, 6).

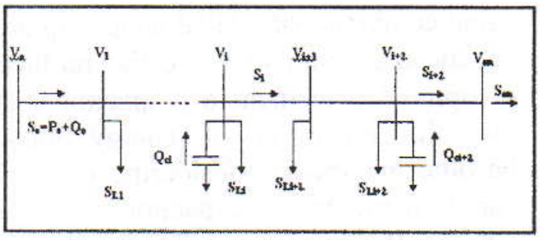


Fig. (1) One line diagram of a main distribution feeder.

2- A Fast Decoupled Method

In general, the real and reactive power flowing at the receiving end of branch i+1,P_{i+1},Q_{i+1} and the voltage magnitude at the $|V_{i+1}|$ sending end can be expressed by the following recursive set of equations:

$$P_{i+1} = P_i - R_{i,i+1}\frac{P_i^{\,2}+Q_i^{\,2}}{|V_i|^2} - P_{Li+1} \tag{7}$$

$$Q_{i+1} = Q_i - X_{i,i+1}\frac{P_i^{2}+Q_i^{2}}{|V_i|^2} - Q_{Li+1} + Q_{ci+1} \tag{8}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i+1}.P_i + X_{i+1}.Q_i) + (R^2{}_{i+1} + X^2{}_{i+1})\frac{P_i^2+Q_i^2}{|V_i|^2} \tag{9}$$

Where: Pi, Qi: real and reactive powers flowing into the sending end of branch i+1. $|V_i|$ Bus voltage magnitude at node i.

Equations (7), (8) and (9), called the branch flow equations, can be written in a compact form.

$$X_{oi+1} = f_{oi+1}(X_{oi}, U_{i+1}) \tag{10}$$

Where:$X_{oi} = \lfloor P_i, Q_i, |V_i|^2 \rfloor$ and $U_{i+1} = Q_{ci+1}$

The branch flow equations at branching node k of the main feeder are:

$$P_{ok} = \hat{P}_{ok}(X_{ok-1}) - P_{ko} \tag{11}$$

$$Q_{ok} = \hat{Q}_{ok}(X_{ok-1}) - Q_{ko} + Q_{C_{ko}} \tag{12}$$

$$|V_{ok}| = \hat{V}_{ok}(X_{ok-1}) \tag{13}$$

There are several boundary conditions to be satisfied:

(1) at the substation, the voltage magnitude $|\mathbf{V}_{oo}|$ is specified.

(2) at the end of the main feeder;

$$P_{on} = \hat{P}_{on}(X_{on-1}) = 0 \tag{14}$$

$$Q_{on} = \hat{Q}_{on}(X_{on-1}) = 0 \tag{15}$$

(3) at the end of branch k;

$$P_{Kn_k} = 0 \tag{16}$$

[illegible] (17)

Since there are N_t different load levels to be considered, the overall distribution load flow equations are:

$$F(Z^i, U^i) = 0 \qquad \text{i=1,2,}N_t \tag{18}$$

Where: Z^i, U^i, is the state and control variables at load level i.

The distribution power flow equation (18) is a set of non-linear algebraic equations. The question regarding the existence and the uniqueness of solution has been investigated in [10,11], in which it is shown that the load flow solution with feasible voltage magnitude for practical radial distribution network always exists is unique. The power loss of the line section connecting buses i and i+1 can be computed as:

$$P_{Loss}(i,i+1) = R_{i,i+1}\frac{P_i^2+Q_i^{\,2}}{|V_i|^2} \tag{19}$$

After that we determine total power loss of the feeder, $P_{T,loss}$ by summing up the losses of all sections in the feeder. The total power loss is given by:

$$P_{T,Loss} = \sum_{i=0}^{n-1} P_{Loss}(i,i+1) \tag{20}$$

where n = the total no. of buses in the feeder.

The purpose of placing compensating capacitors along distribution feeder is to lower the total power loss and bring the bus voltage within their specified limits while minimizing the total cost considering shunt capacitor.

After calculation of the total power loss, we transfer to the next step to calculate the total system cost of general capacitor problem.

2-2 Solution Algorithm For General Capacitor Placement

In summary, a radial distribution system has been considered with N_c possible locations to place capacitors and

N_t different load levels. Let C_1, C_2 represent the set of switched capacitors and the set of fixed capacitor respectively.

Let $n_t=[1,2,\ldots\ldots N_t]$ and $n_c=[1,2,\ldots N_c]$

Then the general capacitor placement problem is formulated as follows:

Minimize $(U^0,U^1)\sum_{k=1}^{N_c} C_k(U_k^0)+K_e\sum_{i=1}^{Nt} T_i.P_{loss,i}(x^i,U^i)$ (21)

Subject to:

$C_k(U_k^0)=(K_c.(U_k^0/U_s)+C_k^f(U_i^0))/10$

Where $C_k(U_k^0)$ is the annual cost of capacitor at location i with size U_i.

In this work, we developed the equation formulated of the general capacitor placement to find the annual cost by dividing the cost of capacitor on 10 assuming that the capacitors ages 10 years at least, after that we must replace it [8]. These assumptions assisted in minimizing the energy cost and the total cost of the system by the ability of adding many of capacitors to the system.

$U_k^0=I_k.U_S$, I_k is a non-negative integer, $k\in N_C$

U_k^i = Discrete variable $i\in N_t, k\in N_C$

$F(z^i,U^i)=0,\qquad i\in N_t$

$H(x^i)\le 0,\qquad i\in N_t$

For = $k\in C_1$ (fixed capacitor),

$U_k^i=U_k^j\le U_k^0\qquad for\ i,j\in N_t$

For = $k\in C_2$ (switched capacitor),

$0\le U_k^i\le U_k^0\qquad for\ i\in N_t$

Where U^0 is the sizing vector whose components are multiples of the standards sized of on bank. U^i is the control setting vector at load level i whose components are discrete variables because in practice capacitor are tuned in discrete steps.

Operational Constraints

The voltage magnitude of each node at each load level must lie in a permissible range as expressed below

$V_j^{\min}\le|V^i{}_j|\le V_j^{\max}$

j=1,2,……n and i=1,2,……N_t

Or in compact form

$G^i(X_j)\le 0$ j=1,2,….n and i=1,2,…..N_t

And

$$\sum_{i=1}^{n} Q_{ci}\le\sum_{i=1}^{n} Q_{Li}+\sum_{i=0}^{n-1} Q_{loss}(i,i+1)$$

Where V_{min} and V_{max} are the permissible minimum and maximum bus voltages, respectively. Q_{ci} is the reactive power compensation at bus i.

2-3 Sensitivity Factor Analysis

A sensitivity analysis is employed to select the candidate locations for placing capacitors in the distribution system. The evaluation of these candidate locations basically helps in reducing the search space during optimization procedures. In earlier works, heuristics and engineering judgment have been employed to select the locations. The sensitivity analysis is a systematic procedure to select locations, which reduce system real power losses the most when we place capacitors at those locations [3].

The sensitivity factor associated with a node is defined as:

$$\delta=\frac{\partial P_{LOSS}}{\partial Q_{ci}}\qquad(22)$$

where δ is the sensitivity factor which is estimated at each node every time a configuration change occurred in the feeder such as the addition of a capacitor bank. The nodes are ranked in the order of the values of sensitivity factors for these nodes. That is, the top-ranked node in the priority list has the greatest sensitivity factor and is the one to be first considered for capacitor addition in the optimization process.

The bus, which has the greatest sensitivity factor is tentatively added capacitors to it. The total cost and bus voltages are then calculated. If both the total cost is reduced and voltage limits of the nodes are satisfied, the capacitor addition is accepted; otherwise, this capacitor addition is discarded, and a similar tentative capacitor addition to the node with next greatest sensitivity factor is taken. Once a capacitor addition is accepted, the sensitivity factors of the nodes are re-evaluated. A new priority list is then established. Similar procedures for capacitor addition are repeated. The final results obtained from this sensitivity factor method are taken to be the initial strings for the subsequent GA application.

2-4 Genetic Algorithm Implementations

Genetic Algorithm (GA) is an original search mechanism based on Darwinian principle of natural evolution [8]. They are the results of search done to incorporate the adaptable process of natural systems into design of artificial systems. GA is calculating simple and providing robust search in complex problem spaces. GA is basically unconstrained seek procedures in the given problem domain. Any constraints associated with the problem could be combined into the objective function as penalty functions. GA operates with a set of strings instead of one string. This set or populations of strings go through the process of evolution to generate new individual strings. During each iterative step referred to as generation, the representative strings in the current population are estimated for their fitness as optimal domain solutions. The estimation function is a procedure to determine the fitness of each string in the population and is very much application oriented. Since the GA progresses in direction of evolving better fit strings and fitness value is the only information available to the GA, the performance of the algorithm is highly sensitive to fitness values. On a comparative basis of these fitness values, a new population of solution strings is established using the genetic operators. Genetic operators are the stochastic transition rules applied by GA. These operators are applied on each string during each generation to produce a new and improved population from the old one. A simple GA consists of five basic operators, which are (representation or coding), evaluation string, reproduction (selection), crossover and mutation.

2-4.1 Representation or Coding

Genetic algorithms determine the optimal size, number, and type of capacitors. To apply genetic algorithms, we produce an initial population composed of k chromosomes. Each chromosome represents a possible solution, and has a fitness function or objective function. In the case of fixed capacitor placement problem, we can encode the bus number and the total number of available capacitor sizes in decimal representation according to the previous sensitive buses selection and GA operations. A string (or chromosome) is composed of substrings. The number of substrings is equal to the number of candidate locations (or bus) for capacitor installation. Each substring is composed of bits numerous enough for carrying information on capacitor sizes. (Fig 2) represents an example of decimal chromosomes for fixed capacitors. In the case of general capacitor problem, the chromosome would be divided into three parts, each part represents one of three load level, and each of substrings is divided into parts representing the total numbers of buses for general capacitor installation. Each chromosome is composed of a certain number of genes, each one representing a capacitance value associated with a bus of the distribution system in different load levels and according to the previous sensitive buses selection. (Fig 3) represents an example of decimal chromosome for general capacitors (fixed and switch capacitor) problem representation. Each chromosome represents a possible solution of general capacitor problem. At the end of the program, the capacitor, which its size is still constant in different load levels, will be the fixed capacitor, otherwise when the size of capacitor changes in the load levels, the capacitor will be switched capacitor. The objective is to minimize the annual total cost of the system, minimize the cost of purchase, installation and maintenance of the capacitors and the overall cost of energy loss. To achieve this goal, the evaluation functions assess each chromosome of population to obtain its fitness (associated cost).

BUS No.	1	2	3	....	N_c
Chromosome	20	45	60		30
Decode Capacitor Size=10 Kvar/unit	20	45	60		30
Total capacitance For bus i (Kvar)	200	450	600		300

Figure (2) Example of Fixed Capacitors decimal Codification In a Chromosome.

Load level	Level 1			Level 2			Level 3		
BUS No.	1	2...	N_c	1	2 ..	N_c	1	2....	N_c
Chromosome Bits per	0	0	30	5	0	40	10	0	20
Decode Capacitor Size=10 Kvar/unit	0	......	30	5	....	40	10		20
Total capacitance For bus i (Kvar)	0	......	300	50		400	100		200

Figure(3) Example of General Capacitors Decimal Codification In a Chromosome.

2-4.2 Evaluation the string (Fitness function)

The objective function combines the energy losses with the cost associated with the capacitors placement. The input variables are capacitors of continuous or discrete sizes. Capacitor sizes are represented as (binary or decimal) strings to form chromosomes, which represent solutions.

The best chromosomes are giving a greater chance of survival and reproduction. At the end of several generations, the genetic algorithm converges to the minimum seeked cost. A typical evaluation function in such application may have the following form:

$$F_A(I)=(U^0,U^1)\sum_{k=1}^{N_C} C_k(U_k^0)+K_e\sum_{i=1}^{Nt} T_i.P_{loss,i}(x^i,U^i) \qquad \ldots(23)$$

Where $F_A(I)$: is the annual total cost of the system.

$C_k(U_k^0)=(K_c.(U_k^0/U_s)+C_k^f(U_i^0))/10$

If we want to obtain the optimum solution to the capacitor problem, we should obtain the minimum total cost or objective function $F_A(I)$. Genetic algorithm, however, deals with the fitness function and generally tries to maximize it. Moreover, constraint violations must also be represented in the fitness value because GA search is controlled by the strings having higher fitness value. The strings with large fitness values offer better solutions to the problem and have a higher probability of being selected. Therefore, the string evaluation "fitness function" of the GA methodology for the capacitor placement problem can be obtained using the fitness described by the following equations:

$$FF=\frac{1}{F_A(I)} \quad \text{Or} \quad FF=\frac{1}{1+F_A(I)} \qquad (24)$$

Where FF is the fitness function, According to the above equations, the less is the loss in the distribution system, the higher is the fitness value. Thus, we can take P_{Loss} as the fitness function in the GA.

2-4.3 Reproduction (selection)

Reproduction is a probabilistic selection process in which strings are selected to generate offspring based on their fitness values. This ensures that the expected number of times in which a string is selected is proportional to the string's fitness relative to the rest of the population. Strings with higher fitness values have a higher probability donating offspring and are simply copied on into the next generation. Competition or elitism principle [12-13] will be employed in this proposed method. That is each individual p_i in the combined population must compete with some other individuals to get its chance to be transcribed to the next generation. A weight value Wi is assigned to the individual according to the contest as follows:

$$W_i = \sum_{t=1}^{q} W_t \qquad \text{........ (25)}$$

where q is the contest number, W_t is a number of {0,1}, which represents win, 1 or loss, 0, as p_i competes with a randomly chosen individual p_r in the combined population. Here, W_t is given as follows:

$$W_t = \begin{cases} 1, & if\ u_i \rangle \dfrac{f_r}{f_r + f_i} \\ 0, & otherwise \end{cases} \qquad \text{........(26)}$$

where f_r is the fitness of randomly chosen individual p_r and f_i is the fitness of individual p_i, u_i is randomly chosen from a uniform distribution set, U(0,1). When all individual p_i, i=1,2,...,m, get their contest weights, they will be ranked in descending order of their corresponding value W_i. The first m individuals are copied along with their corresponding fitness f_i to be the basis of the next generation.

2-4.4 Crossover

Crossover is the process of selecting a random position in the string and swapping the characters either left or right of this point with another similarly partitioned string. This random position is called the crossover point. For example:

Father = 01111: 01011
Mother = 01010: 10001

and suppose the crossover point has been selected as shown and if swapping is executed to the right of this point, the resulting structures would be

offspring 1 = 01111 : 10001
offspring 2 = 01010 : 01011

2-4.5 Mutation

Mutation is the process of random variation of the value of a string position with a small probability. It is not a main operator but it ensures that the probability of searching any region in the problem space is never zero and prevents complete loss of genetic material through reproduction and crossover.

3-Flowchart Of The Computational Procedures

The solution procedures start off with performing a simplified power flow study to calculate bus voltages and line losses. Then determination of location and sizes for capacitors sitting are performed by the sensitivity factor method. The results obtained from the sensitivity factor serve as the initial strings for the subsequent GA application. GA employs its five operators to find the optimal solutions. Since voltages along the feeders are required to be maintained between their upper and lower limits, if a solution having any bus whose voltage is not kept within its limits, the solution is discarded, otherwise the solution is accepted. The solution procedures of the proposed method which combine sensitivity factor method and genetic algorithms may be stated using a flowchart as shown in Fig. (4).

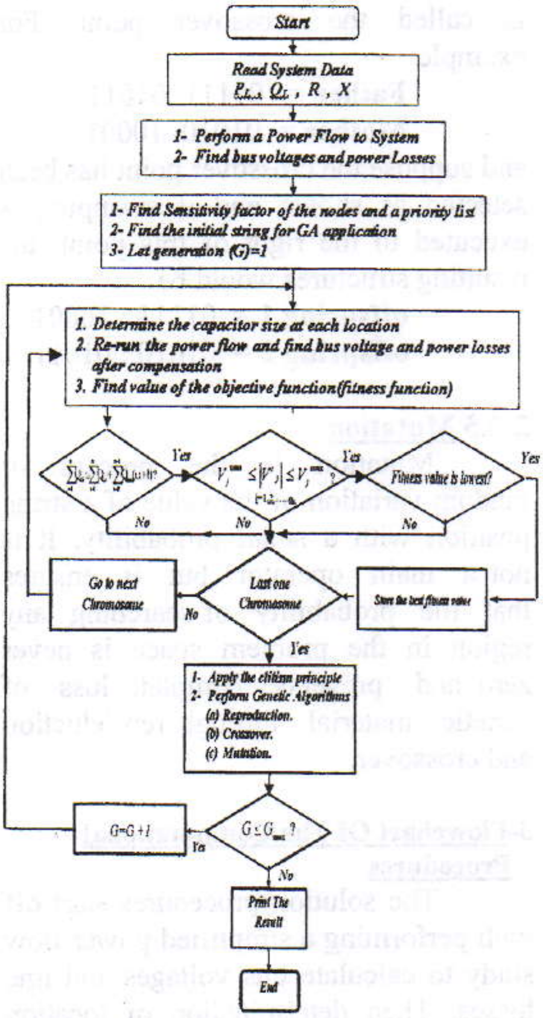


FIG (4) Flowchart for proposed method

4- Numerical Test Systems

The proposed solution methodology has been implemented into a software program in (MATLAB 6.1) technical language. The program can find the global optimal solution for general capacitor placement problem. To illustrate the application and demonstrate the effectiveness of the proposed method, three sample systems with different levels of complexity are tested. The two examples are hypothetical taken from ref [5, 14] respectively (each one with 69 buses and 7 laterals, 12.66 KV system), shown in Figure (5) with load duration data given in table (1). The result of (test2) compare with other method results ref [15]. While the third example is practical example taken from Baghdad distribution network (with 11 buses, 11 KV system). Shown in Figure (6) with load duration data given in table (1).

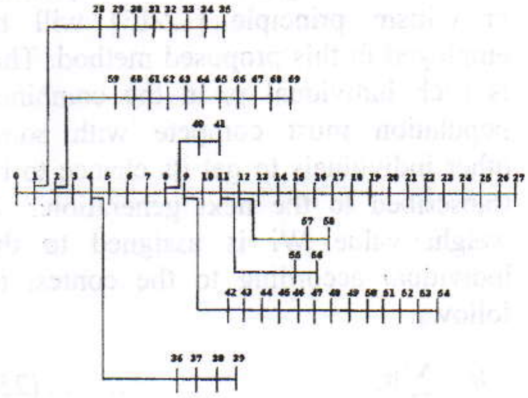


Figure (5) the schematic of a 69-bus distribution system

Fig. (6) One –Line Diagram of Distribution actual feeder.

System	Load level (p.u)			Time intervals(hr)		
	S_0	S_1	S_2	T_0	T_1	T_2
	1.8	1.0	0.5	1000	6760	1000

Table (1) Load Duration data for the theoretical test system

Sensitivity Factor Results

A sensitivity analysis is employed to select the candidate locations for placing capacitors in the distribution system. After employing sensitivity factor at each node of the test system [system (1, 2 & 3)] every time a configuration change occurred in the feeder, such as the addition of a capacitor bank, the nodes are ranked in the order of the values of sensitivity factors for these nodes. The top-ranked node in the priority list has the greatest sensitivity factor and is to be first considered for capacitor addition in the optimization process. From the results obtained from sensitivity factor method, we selected ten candidate locations for placing capacitors in the (system1 & system2), and we selected five candidate locations in the system3, as examples for the results of sensitivity factors (for the three systems) in heavy load level table (2, 3&4) and in Figures (7, 8 & 9) respectively, the results are taken to be the initial strings for the subsequent GA application. After running the program of implementation genetic algorithms for fixed and general capacitor placement problem, the power losses and the voltage profile of the systems with/without fixed and general capacitor placement in different load level is tabulated in tables, as well as the annual cost energy losses and annual systems cost with/without capacitor placement is outlined in tables such as the tables (5,6,7,8,9&10) below for systems (1, 2&3) respectively.

Candidate Bus No.	Best Sensitivity factors
50	23.3589
51	23.0697
52	22.6167
49	21.7627
48	20.5506
53	20.3991
47	19.4486
46	16.6156
54	16.0182
45	10.8977

Table (2) optimum ten-sensitivity factor in heavy load level

Candidate Bus No.	Best Sensitivity factors
50	311.45
51	307.16
52	300.44
49	289.81
48	273.37
53	267.53
47	258.41
46	219.92
54	203.47
45	142.39

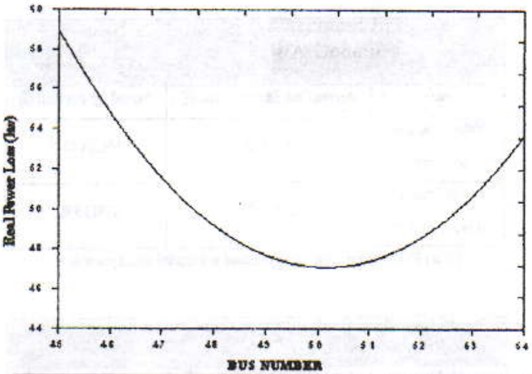
Table (3) optimum ten-sensitivity factor in heavy load level

Candidate Bus No.	Best Sensitivity factors
8	33.6928
7	33.6370
6	32.6276
9	31.5503
5	31.4246

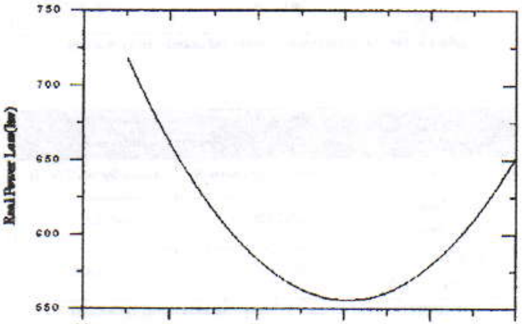
Table (4) optimum five-sensitivity factor in heavy load level

Annual System Cost with/without Fixed Capacitor Placement Annual System Cost=Annual Cost Energy Losses+Annual Capacitor cost		
Systems	Annual Cost Energy Losses ($)	Annual System Cost($)
Without Capacitor placement	12998.3371	12998.3371
With Fixed Capacitor placement	8799.9055	9164.9055

Table (5) The annual cost energy Losses and annual total system cost



Fig(7) the minimum total real power loss after injected 790kvar in the buses(45,46,47,48,49,50,51,52,53,54) at the heavy load level.



Fig(8) the minimum total real power loss after injected 2460kvar in the buses(45,46,47,48,49,50,51,52,53,54) at the heavy load level.

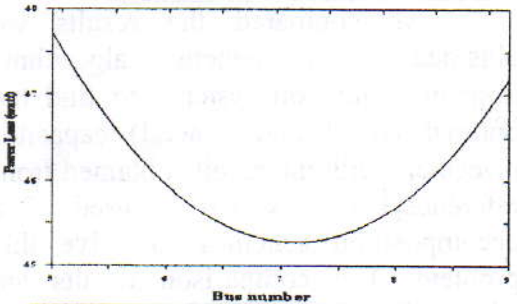


Fig (9) the minimum total real power loss after injected 3850kvar in the buses (5,6,7,8,9) at the heavy load level.

Annual System Cost with/without General Capacitor Placement Annual System Cost = Annual Cost Energy Losses + Annual Capacitor cost		
Systems	Annual Cost Energy Losses ($)	Annual System Cost ($)
Without Capacitor placement	12998.3371	12998.3371
With General Capacitor placement	8417.9467	8872.9467

Table (6) The annual cost energy Losses and annual total system cost

Annual System Cost with/without Fixed Capacitor Placement Annual System Cost = Annual Cost Energy Losses + Annual Capacitor cost		
Systems	Annual Cost Energy Losses ($)	Annual System Cost ($)
Without Capacitor placement	146384.6733	146384.6733
With Fixed Capacitor placement	97071.9267	98300.9267

Table (7) The annual cost energy Losses and annual total system cost

Annual System Cost with/without General Capacitor Placement Annual System Cost = Annual Cost Energy Losses + Annual Capacitor cost		
Systems	Annual Cost Energy Losses ($)	Annual System Cost ($)
Without Capacitor placement	146384.4435	146384.4435
With General Capacitor placement	92281.9583	93915.9583

Table (8) The annual cost energy Losses and annual total system cost

Annual System Cost with/without Fixed Capacitor Placement Annual System Cost = Annual Cost Energy Losses + Annual Capacitor cost		
Systems	Annual Cost Energy Losses ($)	Annual System Cost ($)
Without Capacitor placement	14822.7571	14822.7571
With Fixed Capacitor placement	8621.5893	9388.5893

Table (9) The annual cost energy Losses and annual total system cost

Annual System Cost with/without General Capacitor Placement Annual System Cost = Annual Cost Energy Losses + Annual Capacitor cost		
Systems	Annual Cost Energy Losses ($)	Annual System Cost ($)
Without Capacitor placement	14822.7571	14822.7571
With General Capacitor placement	8151.4071	9122.4071

Table (10) The annual cost energy Losses and annual total system cost

5- Comparison Of The Results

we compared the results we obtained from genetic algorithms implementation on system2 to find the optimal (fixed and general) capacitor placement with the results obtained from reference[14] which used a decomposition schemes to solve this problem. The comparison results are tabulated as shown in tables (11, 12).

Table (11) The Result Comparison Using Fixed Capacitors

Technique	Total Number	Locations	Size of the Capacitors	Energy loss reduction in (KWh)	Economic Savings($)
Decomposition schemes	2	19 52	300 1200	734000	37500
Genetic Algorithms	5	10 17 39 50 53	380 280 440 1180 150	821879.11	48083.747

Table (12) The Result Comparison Using General Capacitors

Technique	Total Number	Locations	Size of the Capacitors	Energy loss reduction in(KWh)	Economic Savings($)
Decomposition schemes	2	19 52	330 1700	785000	39180
Genetic Algorithms	5	10 17 39 50 51	630 470 440 1270 970	901708.09	52468.49

After comparing the results of the two methods (genetic algorithms and decomposition schemes), we considered even to use more capacitor banks than the decomposition scheme technique. We obtained a significant increase in economic saving by the proposed genetic algorithm approach and more energy loss reduction. Therefore, the genetic algorithms method is the best and efficient method compared with other methods, and the solution algorithm can achieve global optimal solution rather than just local optimal solution.

Finally, we consider capacitor types; two types of capacitor have the same purchase cost of 30$/bank, one bank=10KVAR (fixed and switched capacitors banks). The fixed banks are operating on the feeder all the time, while switched capacitor is turned on or off depending on the load level. Therefore, at any location, the minimum capacitor size demanded for any level can be considered as the type of fixed capacitor that could be placed in that location. The remaining capacitance compensation required other than the fixed compensation is designed as the switched type. The schedule of capacitor type and size is shown in Table

(13, 14 &15) for systems (1, 2 &3) respectively.

Table (13) Type and Size of capacitor added

[illegible]	[illegible]		[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	0	60	60	60	100	60
50	0	210	210	210	480	210

Table (14) Type and Size of capacitor added

	At Light Load		At Medium Load		At Heavy Load	
Bus No.	Switch	Fixed	Switch	Fixed	Switch	Fixed
10	0	210	180	210	420	210
17	0	100	170	100	370	100
39	0	240	200	240	200	240
50	0	280	950	280	990	280
51	320	0	0	0	970	0

Table (15) Type and Size of capacitor added

Bus No.	At Light Load		At Medium Load		At Heavy Load	
	Switch	Fixed	Switch	Fixed	Switch	Fixed
5	0	520	580	520	580	520
9	0	430	430	430	1040	430

6- Conclusions

A new capacitor placement method, which employs sensitivity factors and genetic algorithms as well as (simplified & fast-decoupled) power flow formulations to reduce power losses and enhance voltage profile for primary distribution systems, is presented. The method seeks the most effective buses to install the compensation capacitors with optimum reactive power, such that a maximum annual cost saving is attained. The employed sensitivity factors to the nodes are effective in reducing the total number of alternatives examined for finding the optimal solution. The results obtained theoretically for the system2 were compared with the solution given by a Decomposition Scheme method. By observing the results, we note that even when using more capacitor banks than the Decomposition Scheme, there is a significant increase in economic saving when using the proposed Genetic algorithm approach. Therefore, the Genetic algorithm is the best and efficient method, especially when using in large distribution systems.

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