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Genetic Algorithm for Optimal Capacitor Allocation in Radial Distribution Systems

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Abstract—**Optimum location and size of capacitors for a radial distribution system is presented. In the present study capacitor sizes are assumed as discrete known variables, which are to be placed on the buses such that it reduces the losses of the distribution system to a minimum. Genetic algorithm is used as an optimization tool, which obtains the optimal values and location of capacitors and minimizes the objective function, which is the power loss in the distribution network under study. A dedicated distribution system load flow is used to calculate power loss and voltage profile of the distribution system. Implementation aspects and important results for a 33 bus, 29 Indian power distribution system and practical 34 bus system have been presented to highlight the working of the algorithm.**

***Index Terms*—Power Distribution System, Capacitor Placement, Loss Minimisation, Genetic Algorithm (GA), Optimisation, Distribution Automation (DA).**

I. Introduction

Loss minimization in distribution systems has assumed greater significance recently since the trend towards distribution automation will require the most efficient operating scenario for economic viability. Studies have indicated that as much as 13% of total power generated is consumed as I^2R losses at the distribution level. Reactive currents account for a portion of these losses. However, the losses produced by reactive currents can be reduced by the installation of shunt capacitors. In addition to the reduction of energy and peak power losses, effective capacitor installation can also release additional kVA capacity from distribution apparatus and improve the system voltage profile. Reactive power compensation plays an important role in the planning of an electrical system. Its aim is principally to provide an appropriate placement of the compensation devices to ensure a satisfactory voltage profile while minimizing the cost of compensation.

Installation of shunt capacitors on distribution networks is essential for power flow control, improving system stability, power factor correction, voltage profile management and losses minimization. Therefore it is important to find optimal location and sizes of capacitors required to minimize feeder losses. The solution techniques for loss minimization can be classified into four categories: Analytical, numerical programming, heuristics and artificial intelligence based. Capacitor allocation problem is a well researched topic and all earlier approached differ from each other either in their problem formulation or problem solution methods employed [1]. In large distribution networks it is very difficult to predict the optimum size and location of capacitor which finally results not only in reducing losses but also improves the overall voltage profile [2]. Though many conventional models and techniques are used for this purpose but it becomes a cumbersome task as the complexity of the system increases. [3,4,5] Linear and nonlinear programming methods have been proposed earlier to solve the placement problem. In most of the literature, the size of capacitor banks is handled as a continuous variable. However, a realistic formulation of the problem requires the discrete nature of capacitor banks to be accounted for.

The paper is directed towards reducing losses in the distribution system by capacitor allocation. In large distribution networks it is very difficult to predict the optimum size and location of capacitor, which finally results not only in reducing losses but also, improves the overall voltage profile. Though many conventional models and techniques are used for this purpose but it becomes a cumbersome task as the complexity of the system increases. In this research the combinatorial problem is solved using genetic algorithm, which is an artificial intelligence technique. The objective function is taken as cost function that is to be minimized. In this paper capacitor size is taken as known discrete values. The optimum location for these capacitors is determined such that it minimizes the power losses and reduces the overall cost of the distribution system under study. Genetic Algorithm is used as an optimization tool for minimizing losses [6].

II. Indian Power Distribution Scenario

In India average transmission and distribution losses have been officially indicated as 23% of the electricity generated. However as per sample studies carried out by independent agencies including TERI (Tata Energy Research Institute), these losses have been estimated to be as high as 50 % in some states. Losses have gained importance as the level of losses directly affects the sales and power purchase requirements and hence has a bearing on the determination of electricity tariff of a utility by the commission. Energy losses occur in the process of supplying electricity to consumers due to technical and commercial losses. The technical losses are

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inherent in the system and can be reduced to an optimum level whereas commercial losses are caused by pilferage, defective meters and errors in meter reading and in estimating un-metered supply of energy. At present(State Electricity Boards) SEBs lose nearly 110 paise for every unit of electricity sold. This is despite charging a very high tariff to the industrial customers whose capability to meet the challenges in globalized environment is seriously affected.

The demand for electrical energy is ever increasing. Today over 21% (theft apart!!) of the total electrical energy generated in India is lost in transmission (4-6%) and distribution (15-18%). The electrical power deficit in the country is currently about 18%. Clearly, reduction in distribution losses can reduce this deficit significantly. It is possible to bring down the distribution losses to a 6-8 % level in India with the help of newer technological options (including information technology) in the electrical power distribution sector, which will enable better monitoring and control. Hence distribution reforms at state level have, therefore, become absolutely essential. However, for the initiative to be effective, the reforms need to be implemented countrywide.

APDRP (Accelerated Power Development and Reforms Programme)

In line with the efforts of Ministry of Power (MoP) to encourage states to undertake reforms, MoP has renamed the Accelerated Power Development Program (APDP) as Accelerated Power Development Reform Program (APDRP). Under this program, the MoP will provide financial assistance to states mainly to strengthen distribution in selected circles / districts. States that agree to specific reforms related milestones would be eligible for drawing funds under this program. In the recent budget, the central government has doubled the outlay under this program to Rs. 35 billion. These funds would be available for specific projects, partly as grant and partly as loan.

Government introduced a six level intervention strategy that encompasses initiatives at national level, state level, SEB/Utility level, distribution circle level, the feeder level and the consumer level.

i. National level: Policy formulation, technical guidelines and standards, APDRP assistance.
ii. State level: Tariff fixation, corporatization, subsidies and budgetary support.
iii. SEB level: Restructuring, increased accountability, development of MIS, T&D loss reduction.
iv. Distribution circle level: Reducing outages, improving reliability.
v. Feeder level: 11 KV feeders as business units.
vi. Consumer level: Mandatory metering. Discipline of disconnection for non-payment.

Apart from that stringent penalties for theft are introduced. MOU on reforms is signed with 21 States. Its milestones are

i. 11 kV metering.
ii. Consumer metering.
iii. Energy audit, effective MIS and control of theft.
iv. Tariff determination by SERCs.
v. Timely payment of subsidies.
vi. Full metering, energy audit and MIS, control of theft.
vii. Increase in transformation capacity.
viii. Increase in HT/LT ratio. Systems analysis and reconfiguration.
ix. Reduction of technical losses.

III. PROBLEM FORMULATION

The problem of optimal capacitor allocation involves determining the locations, sizes, and number of capacitors to install in a distribution system such that the maximum benefits are achieved while all operational constraints are satisfied at a particular loading level. In this paper capacitor size is taken as known discrete values. The optimum location for these capacitors is determined such that it minimizes the power losses and reduces the overall cost of the distribution system under study. The capacitor allocation problem has been solved by Genetic algorithm and tests are done on standard 33 bus and one practical 34-bus system.

Power loss function is formulated as fitness function for genetic algorithm problem. The mathematical formulation is as below:

$$P = p_{loss} + K\sum (V - V_{\lim})^2 \qquad (1)$$

Where

p_{loss} is real power loss as obtained from the distribution load flow.

V is the voltage at the bus

$V_{\lim}$ is the max (min) voltage specified

The problem is formulated as a constrained optimization problem. In this constrained problem the constraint is the voltage limit i.e. if the voltage magnitude exceeds specified limit it increases the power loss function. Since the addition of capacitor at any bus in the distribution system results in voltage magnitude increase, therefore it becomes imperative to model voltage magnitude as a constraint in the mathematical equation which is to be optimized. Here line flow limits are taken care by the dedicated distribution load flow program that calculates the losses. The cost function (Savings function), that is minimized as a consequence of power loss reduction, is formulated as:

$$Cost = K_p \Delta P_{loss} T - \sum_{i=1}^{n} K_c C_i \qquad (2)$$

Where

K_p is cost per Kilowatt-hour (Rs/kWh)

ΔP is the total power loss reduction in the system in KW

K_c is cost per Kvar (Rs/Kvar)

C_i is the value of shunt capacitor at the ith bus in Kvar

T is the time in Hrs

The first term in cost function indicates savings due to power loss reduction i.e. Rs/Hr saved and second term stands for total capacitor cost. Optimum capacitor allocation reduces the losses but at the same time capacitor cost increases drastically as the number of capacitors are increased. But since it is assumed that capacitor cost is one time investment the payback period can be easily calculated.

Capacitor Allocation Technique Selection

The following table provides a general idea about the accuracy, practicality and complexity of the techniques used in capacitor allocation.

TABLE 1 COMPARISON OF CAPACITOR ALLOCATION TECHNIQUES

	Analytical	Numerical	Heuristic	AI
Energy loss reduction in formulation	♦	♦	♦	♦
Peak power loss reduction in formulation	♦	♦	♦	♦
Consideration of varying load	♥	♦♥♣	♦♥♣	♦♥♣
Capacity release in formulation	♣	♣		
Consideration of discrete capacitor sizes	♦	♦♥	♦♥	♦♥
Accurate feeder representation	♥	♦♥	♦♥	♦♥
Consideration of physical node selection		♦♥	♦♥	♦♥
Voltage constraints considered	♥	♥	♥	♥
Line loading constraints considered	♥	♥		
Radial feeder	♥	♦♥	♦♥	♦♥
Planning/Expansion		♣		♣
Consideration of switched capacitors	♣			♣
Regulation inclusion	♣	♦♥		
Use of load flow		♦♥	♣	♦♥

Notations:
♦ - Accuracy
♥ - Practicality
♣ - Complexity

IV. GENETIC ALGORITHMS

The idea of evolutionary computing was introduced in the 1960s by I. Rechenberg in his work "Evolution strategies" (Evolutionsstrategie in original). Genetic Algorithms (GAs) were invented by John Holland and developed by him, his students and colleagues. This lead to Holland's book "Adaptation in Natural and Artificial Systems" published in 1975. The broad guideline that Genetic Algorithm follows is that of the Theory of Evolution – the Survival of Fittest. In genetic algorithms, this procedure of survival, elimination and multiplication is done by rules more closely related to the evolution of species (survival of the fittest), the fitness of each string being determined by fitness function. Thus the operators derive their names directly from genetics – (natural) selection, crossover and mutation. Also the real world variables get coded into genetic materials, the chromosomes, so that the operations work independent of the problem being handled, resulting in one of the foremost strengths of GA – robustness. The most common genetic representation is the binary string, with values of variables coded into binary form and attached one after the other. In every generation new set of artificial creatures are created using bits and pieces of the fittest of the old; an occasional new part is tried for good measure. Thus, it is a structured, yet randomized information exchange to form a search algorithm with some of the innovative flair of human search.

Some key terms used in genetic algorithm are:

1. *Individual* - Any possible solution
2. *Population* - Group of all *individuals*
3. *Search Space* - All possible solutions to the problem
4. *Chromosome* - Blueprint for an *individual*
5. *Trait* - Possible aspect of an *individual*
6. *Allele* - Possible settings for a *trait*
7. *Locus* - The position of a *gene* on the *chromosome*
8. *Genome* - Collection of all *chromosomes* for an *individual*

Genetic Operators

The three main genetic operators are Selection Crossover and Mutation.

A. Selection

Selection is the process by which, the rules of survival are employed so that fit members survive and multiply while the unfit members die away. While there are many different types of selection like

1. Roulette Wheel Selection
2. Stochastic Remainder with Replacement Selection
3. Stochastic Remainder without Replacement Selection
4. Deterministic Selection
5. n-Member Tournament Selection
6. Part Sum Selection procedure

The most common is type - Roulette Wheel Selection. In roulette wheel selection, individuals are given a probability of being selected that is directly proportionate to their fitness. Two individuals are then chosen randomly based on these probabilities and produce offspring. The actual procedure is that, a roulette wheel having 100 slots is considered. Each individual in the population is given as many slots in the wheel as its percentage probability of selection. Then the wheel is spun and the individual on whose slot the pointer rests is chosen. This is done population size number of times. It can be seen that each individual gets its expected number of copies with this procedure based on their corresponding probabilities.

B. Crossover

Crossover is a procedure of choosing random position in a string and swapping the characters either left or right of this point with another similarly partitioned string. This random position is called crossover point. Methods used for crossover are**:** Single/multiple point crossover**,** variable-by-variable crossover and uniform crossover. For a binary coded chromosome, single/multiple point crossover is almost always used. In single point crossover, we choose a locus at which we swap the remaining alleles from one parent to the other. This is complex and is best understood visually.

Single Point Crossover Example

Parent 1	1 0 0	*1 0 0 1 0 1 0*
Parent 2	0 0 1	**0 1 1 0 1 1 1**
Child 1	1 0 0	**0 1 1 0 1 1 1**
Child 2	0 0 1	*1 0 0 1 0 1 0*

Crossover does not always occur, however. Sometimes, based on a set probability, no crossover occurs and the parents are copied directly to the new population. The probability of crossover occurring is usually 70% to 80%.

C. Mutation

After selection and crossover, a new population full of individuals is obtained. Some are directly copied, and others are produced by crossover. In order to ensure that the individuals are not all exactly the same, a small chance of mutation is allowed. It helps in restoring lost information or adds new information in the population. We loop through all the alleles of all the individuals, and if that allele is selected for mutation, we can either change it by a small amount or replace it with a new value. The probability of mutation is usually between 1 and 2 tenths of a percent i.e. it is performed infrequently. A visual for mutation is shown below.

Child 1	1 1 0 1 *0* 0 0 0 1 0 0 1 1
After mutation	1 1 0 1 **1** 0 0 0 1 0 0 1 1

In this operation, a random number is generated between 0 and 1 for each bit in the population. If for a bit, the random number falls below the probability of mutation, it value is changed. Mutation is vital to ensuring genetic diversity within the population.

Fitness determination

The fitness of a chromosome reflects its ability to survive and reproduce. In the case of maximization problems, the fitness must be directly proportional to the objective function value and in the case of minimization problems; the fitness must be inversely proportional to objective function value. If the constraints are involved, penalty methods must be used to degrade the fitness of the non-compliant individual. In the case of maximization problems, the penalty must be subtracted from objective function value and in the case of minimization problems the penalty must be added to the objective function value.

V. SOLUTION METHODOLOGY

Problem Representation

In the problem definition, size of the capacitors (decision variable) is taken as discrete known values that are generally used in 11 kV distribution system i.e. (300 Kvar, 600 Kvar and 900 Kvar). Hence the problem is reduced to finding the locations for these capacitor values such that the power loss and consequently the overall cost function are minimized. The objective function thus formulated is than minimized using genetic algorithm as an optimization tool. The value of voltage limit penalty factor constant (K) plays a major role in giving optimum results. Genetic algorithm is run number of times taking different values of K to obtain optimum results.

Capacitor Allocation Algorithm using Genetic Algorithm

i. First the initial population of randomly constructed solutions (strings) is generated i.e. capacitors of given value are placed at random nodes in the distribution system. Each string is binary coded form of capacitor size placed at each bus.
ii. Within this population new solutions (capacitor values for all the buses of the distribution system under study) are obtained during genetic cycle using crossover and mutation operator. Since the sizes of the capacitors are taken as discrete values, zero magnitude capacitor value is taken as one possibility of erecting capacitor at the bus, indicating zero reactive volt-amperes injected or no capacitor at that particular bus.
iii. Each new solution is decoded and its objective function values (power loss) are estimated. Selection procedure describes which solution is better.
iv. The better solution (i.e. a solution amongst the present population that reduces the system losses) joins the new population and worst is discarded.
v. Individuals in the initial population ranked higher in terms of fitness value are selected to replenish the shrunken population.
vi. A new genetic cycle is started till the terminating criterion is met which is the maximum number of generations.

Capacitor Allocation Problem

The flowchart in figure 1 gives the step-by-step procedure for capacitor allocation. It briefly describes the random initial selection followed by genetic operations of selection, crossover and mutation. The feedback path is shown to take care of shrunken population as a result of crossover, which has to be brought back to initial size.

Encoding Strategy

In the present study capacitor size at a particular bus location is taken as decision variable. The encoding strategy of each individual, which forms a possible solution, is as follows:

i. Each capacitor size value, when converted into binary form is of length 20.
ii. If N is the number of buses in the distribution system including the slack bus, than N-1 locations are possible for capacitor placement, hence the each individual has length equal to $20 \times (N-1)$.

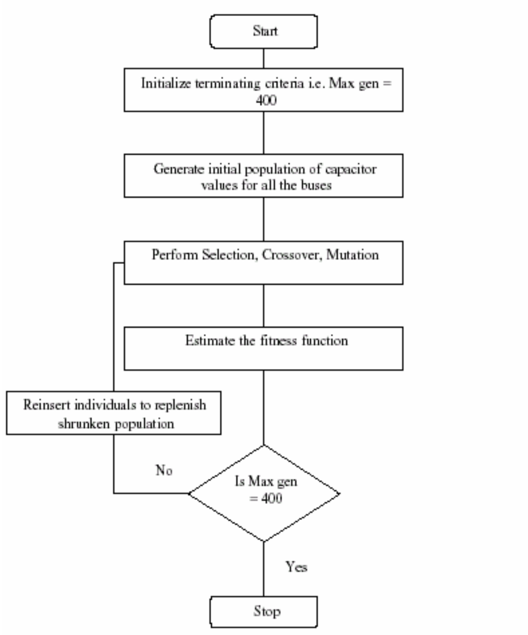

Fig.1 Capacitor Allocation using GA.

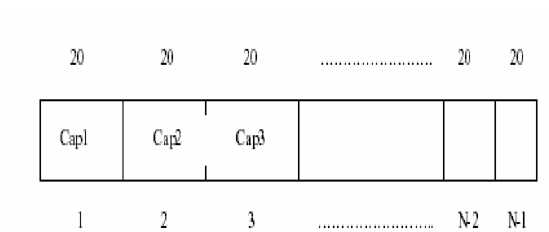

Fig.2 Encoding Strategy

In figure 2 first square box denotes a capacitor of a particular value at bus 1, second box denotes a capacitor of a particular value at bus 2 and so on. Number 20 written at the top of each box denotes the length of binary number which when decoded gives the value of the capacitor at that particular bus. Hence 20 binary digits are sufficient to encode all the capacitor values taken in the present study. Similarly twenty individuals are generated which forms the population. This population undergoes selection, crossover and mutation to find the most optimum among them. These transformations occur in the individuals in binary form, which is finally decoded into decimal form to perform other operations that are taking place outside genetic algorithm.

VI. Test Cases and Simulation Results

Case Study 1: 33 Bus Standard Radial Distribution System

The proposed method is tested on standard 33 bus system. The cost constants for this problem are Kp=3 Rs/kWh and Kc=250 Rs/Kvar.

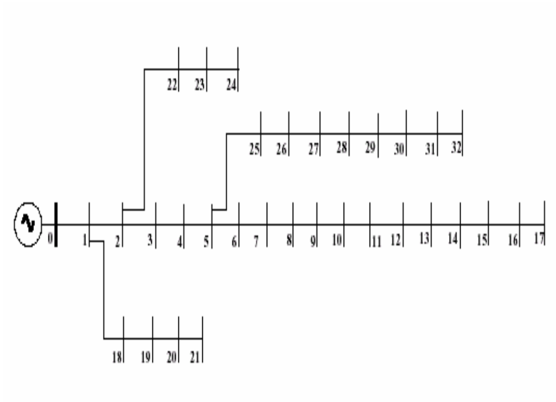

Fig. 3. Diagram of 33 Bus Distribution System

Figure 3 shows the single line diagram of a 33 bus distribution system.

Results of Standard 33 bus Distribution System

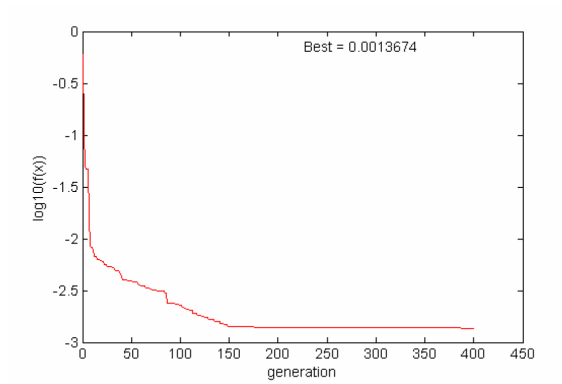

Fig.4 Objective Function for 33 Bus System

Figure 4 is a plot between logarithm of objective function and generations for standard 33-bus system. The GA parameters for the simulation are as follows: Population Size: 100; Prob. of Mutation 0.05, Prob. of Crossover 0.08. The total number of generations of study vary from 500 to 20,000. The curve is continuously decreasing as predicted. Initially the decline in the value of fitness function is sharp and further it settles down to a constant value as the number of generation increases.

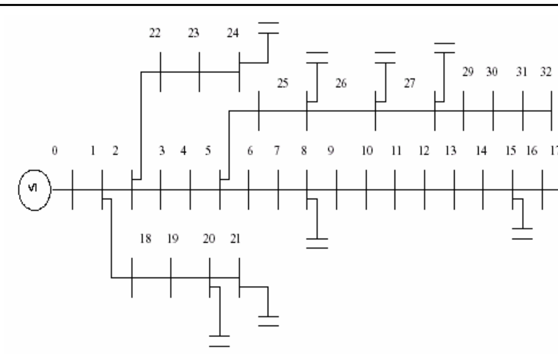

Fig. 5. 33-bus distribution system with Capacitors

TABLE 2 VOLTAGE PROFILES OF STANDARD 33 BUS DISTRIBUTION SYSTEM

Node No.	Without Capacitor		With Capacitor		
	Voltage (p.u.)	Angle (deg)	Voltage (p.u.)	Angle (deg)	Q (Kvar)
0	1	0	1	0	0
1	0.9970	0.0145	0.9980	-0.0892	0
2	0.9829	0.0960	0.9873	-0.3558	0
3	0.9755	0.1616	0.9816	-0.4753	0
4	0.9681	0.2282	0.9760	-0.6039	0
5	0.9497	0.1339	0.9643	-1.1170	0
6	0.9462	-0.0964	0.9619	-1.3586	0
7	0.9414	-0.0603	0.9576	-1.3976	0
8	0.9351	-0.1334	0.9527	-1.5757	300
9	0.9293	-0.1959	0.9483	-1.7459	0
10	0.9284	-0.1887	0.9476	-1.7598	0
11	0.9269	-0.1772	0.9464	-1.7886	0
12	0.9208	-0.2684	0.9424	-2.0328	0
13	0.9185	-0.3471	0.9402	-2.1079	0
14	0.9171	-0.3847	0.9388	-2.1438	0
15	0.9158	-0.4080	0.9375	-2.1660	300
16	0.9137	-0.4852	0.9355	-2.2397	0
17	0.9131	-0.4948	0.9349	-2.2488	0
18	0.9965	0.0037	0.9984	-0.1530	0
19	0.9929	-0.0633	0.9998	-0.5434	0
20	0.9922	-0.0827	1.0000	-0.6505	300
21	0.9916	-0.1030	1.0000	-0.7466	300
22	0.9794	0.0650	0.9848	-0.4824	0
23	0.9727	-0.0237	0.9795	-0.6654	0
24	0.9694	-0.0674	0.9775	-0.8043	300
25	0.9477	0.1733	0.9631	-1.1642	0
26	0.9452	0.2294	0.9617	-1.2297	300
27	0.9338	0.3123	0.9572	-1.5975	600
28	0.9255	0.3903	0.9530	-1.7799	300
29	0.9220	0.4954	0.9504	-1.7891	0
30	0.9178	0.4111	0.9481	-1.9726	0
31	0.9169	0.3881	0.9472	-1.9942	0
32	0.9166	0.3803	0.9470	-2.0014	0

Table 2 gives a comparison between the voltage magnitudes and angles of standard 33 bus system. It shows seven 300 Kvar capacitors (at node no. 8, 15, 20, 21, 24, 26 & 28) and one 600 Kvar capacitor (at node no. 27). Total reactive power injected into the system is 2700 Kvar.

TABLE 3. LINE FLOWS OF STANDARD 33 BUS DISTRIBUTION SYSTEM

From (i)	To (j)	Without Capacitor				With Capacitor			
		P_{ij}	Q_{ij}	P_L	Q_L	P_{ij}	Q_{ij}	P_L	Q_L
0	1	0.0392	0.0243	1.22E-04	6.23E-05	0.0385	-0.0074	8.84E-05	4.50E-05
1	2	0.0344	0.0221	5.18E-04	2.64E-04	0.0338	0.0023	3.54E-04	1.80E-04
2	3	0.0236	0.0168	1.99E-04	1.01E-04	0.0231	0.0029	1.27E-04	6.49E-05
3	4	0.0222	0.0159	1.87E-04	9.51E-05	0.0218	0.0021	1.18E-04	6.03E-05
4	5	0.0214	0.0155	3.82E-04	3.30E-04	0.0211	0.0017	2.40E-04	2.07E-04
5	6	0.0109	0.0053	1.91E-05	6.32E-05	0.0109	0.0026	1.58E-05	5.22E-05
6	7	0.0089	0.0042	4.83E-05	1.60E-05	0.0089	0.0015	3.91E-05	1.29E-05
7	8	0.0069	0.0032	4.18E-05	3.00E-05	0.0069	0.0005	3.31E-05	2.38E-05
8	9	0.0062	0.0030	3.56E-05	2.52E-05	0.0062	0.0003	2.79E-05	1.97E-05
9	10	0.0056	0.0027	5.53E-06	1.83E-06	0.0056	0.0001	4.27E-06	1.41E-06
10	11	0.0051	0.0024	8.80E-06	2.91E-06	0.0051	-0.0002	6.89E-06	2.28E-06
11	12	0.0045	0.0021	2.66E-05	2.10E-05	0.0045	-0.0006	2.14E-05	1.68E-05
12	13	0.0039	0.0017	7.28E-06	9.59E-06	0.0039	0.0017	6.95E-06	9.15E-06
13	14	0.0027	0.0009	3.57E-06	3.17E-06	0.0027	0.0009	3.40E-06	3.03E-06
14	15	0.0021	0.0008	2.81E-06	2.05E-06	0.0021	0.0008	2.68E-06	1.96E-06
15	16	0.0015	0.0006	2.51E-06	3.36E-06	0.0015	0.0006	2.40E-06	3.20E-06
16	17	0.0009	0.0004	5.31E-07	4.16E-07	0.0009	0.0004	5.06E-07	3.97E-07
1	18	0.0036	0.0016	1.61E-06	1.54E-06	0.0036	-0.0074	6.93E-06	6.61E-06
18	19	0.0027	0.0012	8.32E-06	7.50E-06	0.0027	-0.0048	2.86E-05	2.57E-05
19	20	0.0018	0.0008	1.01E-06	1.18E-06	0.0018	-0.0052	7.76E-06	9.07E-06
20	21	0.0009	0.0004	4.36E-07	5.77E-07	0.0009	-0.0026	3.36E-06	4.45E-06
2	22	0.0094	0.0046	3.18E-05	2.17E-05	0.0094	-0.0012	2.58E-05	1.77E-05
22	23	0.0085	0.0041	5.14E-05	4.06E-05	0.0085	0.0012	4.21E-05	3.32E-05
23	24	0.0042	0.0020	1.29E-05	1.01E-05	0.0042	-0.0009	1.08E-05	8.42E-06
5	25	0.0095	0.0097	2.60E-05	1.32E-05	0.0093	-0.0013	1.21E-05	6.16E-06
25	26	0.0089	0.0095	3.33E-05	1.69E-05	0.0087	-0.0015	1.50E-05	7.64E-06
26	27	0.0082	0.0092	1.13E-04	9.95E-05	0.0081	-0.0018	4.93E-05	4.34E-05
27	28	0.0075	0.0089	7.83E-05	6.82E-05	0.0075	0.0007	3.07E-05	2.68E-05
28	29	0.0063	0.0081	3.89E-05	1.98E-05	0.0062	0.0027	1.61E-05	8.19E-06
29	30	0.0042	0.0021	1.59E-05	1.57E-05	0.0042	-0.0006	1.22E-05	1.20E-05
30	31	0.0027	0.0014	2.13E-06	2.48E-06	0.0027	0.0014	2.00E-06	2.33E-06
31	32	0.0006	0.0004	1.32E-07	2.05E-07	0.0006	0.0004	1.23E-07	1.92E-07
			Total Losses =	**2.03E-03**	**1.35E-03**		**Total Losses =**	**1.35E-03**	**9.16E-04**

Table 3 gives the branch flows in standard 33 bus distribution system. It is seen that there is considerable decrease in the reactive power flows in the line which increases the overloading capacity of the line. Total real power loss in the distribution system is decreased. The savings as calculated from the cost function formulated. It comes out to be Rs 1,787,040 per year. The payback period for capacitor cost is just 138 days. The results show the effect on the line flows of standard 33-bus system due to the addition of shunt capacitors. Reactive line flows are considerably decreased. Table 4 shows the summary of capacitor allocation and loss reduction.

TABLE 4: CAPACITOR ALLOCATION AND LOSS REDUCTION :33 BUS SYSTEM

	Without Capacitor		With Capacitor		
Node No.	Voltage (p.u)	Angle (deg)	Voltage (p.u)	Angle (deg)	Q-Cap (kVAR)
8	0.9351	-0.1334	0.9527	-1.5757	300
15	0.9158	-0.4080	0.9375	-2.1660	300
20	0.9922	-0.0827	1.0000	-0.6505	300
21	0.9916	-0.1030	1.0000	-0.7466	300
24	0.9694	-0.0674	0.9775	-0.8043	300
26	0.9452	0.2294	0.9617	-1.2297	300
27	0.9338	0.3123	0.9572	-1.5975	600
28	0.9255	0.3903	0.9530	-1.7799	300
				Total Capacitors	2,700
Without Capacitor		**With Capacitor**		**Improvement**	
P Loss	Q Loss	P Loss	Q Loss	P Loss	Q Loss
2.03E-03	**1.35E-03**	**1.35E-03**	**9.16E-04**	**0.68E-03**	**1.258 E-03**

Case Study 2 : 29 Bus Distribution System, North Delhi.

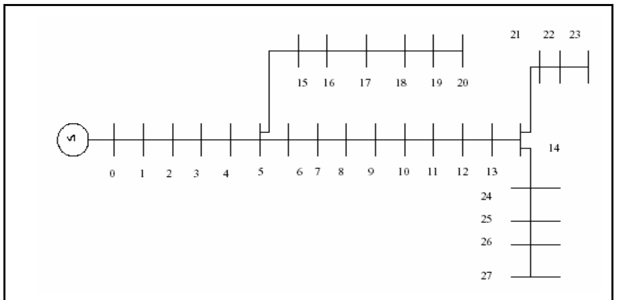

Fig. 6. Diagram of 29 Bus Distribution System

A practical 29 bus radial distribution of Puth-Kalan, North Delhi, India is given in Figure 6. APDRP has been implemented for this system. The results provide the amount of savings obtained by this study. Figure 7 shows the optimal capacitor allocation using genetic algorithm. The objective function curve is shown in figure 8.

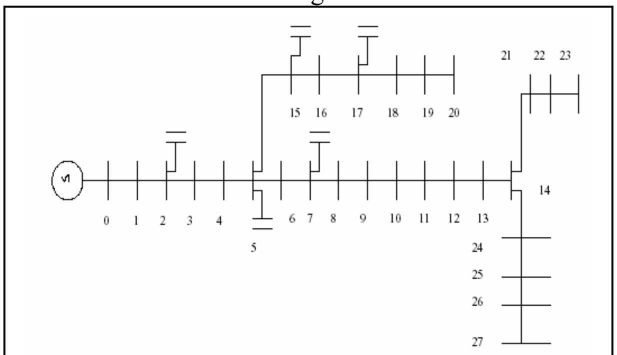

Fig. 7. 29 Bus Distribution System with capacitors.

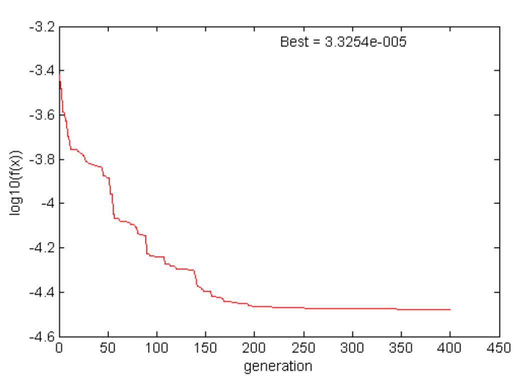

Fig.8 Objective Function for 29 bus System.

The cost constants for the 29 bus distribution system are Kp=3 Rs/kWh and Kc=250 Rs/Kvar. Sum of capacitors = 1500 kVAR. Annual Savings = Rs.40,472. Table 5 shows the capacitor allocation and loss reduction for the 29 bus system.

TABLE 5: CAPACITOR ALLOCATION AND LOSS REDUCTION :29 BUS SYSTEM

	Without Capacitor		With Capacitor		
Node No.	Voltage (p.u)	Angle (deg)	Voltage (p.u)	Angle (deg)	Q-Cap (kVAR)
2	0.9993	-0.0083	0.9996	-0.0184	300
5	0.9979	-0.0267	0.9985	-0.0557	300
7	0.9977	-0.0286	0.9984	-0.0595	300
15	0.9979	-0.0268	0.9985	-0.0578	300
17	0.9979	-0.0270	0.9986	-0.0623	300
				Total Capacitors	1,500
Without Capacitor		**With Capacitor**		**Improvement**	
P Loss	Q Loss	P Loss	Q Loss	P Loss	Q Loss
5.32E-05	**6.36E-05**	**3.78E-05**	**4.54E-05**	**1.54 E-05**	**1.82 E-05**

Case Study 3 : Practical 34 Bus Distribution System.

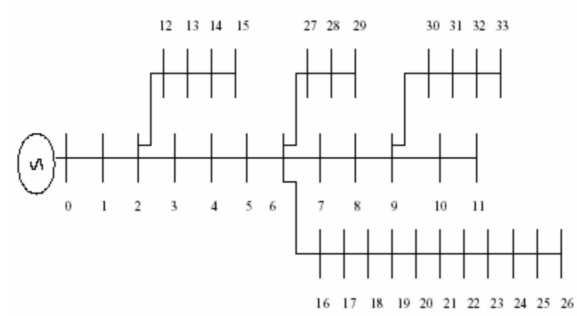

Fig. 9. Diagram of 34 Bus Distribution System

Figure 9 shows the case study 3 where a practical 34 bus radial distribution is considered.. Figure 10 shows the optimal capacitor allocation using genetic algorithm. The objective function curve is shown in figure 11.

The cost constants for the practical 34 bus distribution system are Kp=3 Rs/kWh and Kc=250 Rs/Kvar. Sum of capacitors = 1800 kVAR. Annual Savings = Rs. 1,340,280. Table 5 shows the capacitor allocation and loss reduction for the 29 bus system.

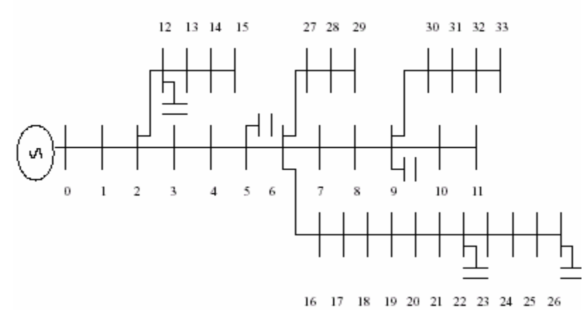

Fig. 10. 34 Bus Distribution System with capacitors.

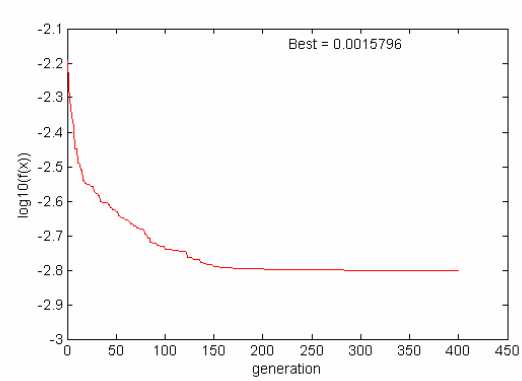

Fig.11 Objective Function for 34 bus System.

TABLE 6: CAPACITOR ALLOCATION AND LOSS REDUCTION :34 BUS SYSTEM

	Without Capacitor		**With Capacitor**		
Node No.	Voltage (p.u)	Angle (deg)	Voltage (p.u)	Angle (deg)	Q-Cap (kVAR)
5	0.9705	0.4082	0.9734	-0.0840	300
9	0.9609	0.6350	0.9643	-0.0061	300
12	0.9887	0.1070	0.9901	-0.0937	300
22	0.9461	0.9005	0.9515	-0.2010	600
26	0.9418	1.0071	0.9474	-0.2029	300
			Total Capacitors		1,800
Without Capacitor		**With Capacitor**		**Improvement**	
P Loss	Q Loss	P Loss	Q Loss	P Loss	Q Loss
2.21E-03	**6.49E-04**	**1.70E-03**	**4.98E-04**	**0.51E-03**	**1.51E-03**

VII. CONCLUSION

Capacitor allocation by genetic algorithm is a relatively easy technique for finding out precise location of capacitors for loss minimization. As regards to traditional methods like Non linear programming or sensitivity analysis where the problem formulation is complex and requires consideration of number of parameters. Genetic algorithm gives optimum results with simpler formulation accommodating all the necessary constraints.

The method improves the voltage profile and reduces losses in the power distribution system simultaneously. It can large number of variables (capacitor sizes) and constraints without affecting the accuracy of the results.
The method can be easily applied to ill posed power distribution system network where the results will be more appreciated. Considerable loss reduction is achieved by capacitor allocation in distribution networks, which amounts to huge monetary gains.

Optimal capacitors allocation can provide the utility industry with a very effective cost reduction method. With plant costs and fuel costs continually increasing, electric utilities benefit whenever new plant investment can be deferred or eliminated and energy requirement reduced. Thus capacitors allocation aids in minimizing operating expenses and allow the utilities to serve new loads and customers with minimum system investment.

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