Using PSO for Optimal Planning, and Reducing Loss of Distribution Networks

Leila Mohammadian[1], Mehrdad Tarafdare Hagh[1], Ebrahim Babaei[1] and Saeid Khani[1]

[1]Tabriz University, Tabriz, Iran
Lm_b81@yahoo.com

Abstract

In this paper the practical planning of distribution system includes the selection of optimal conductor size and capacitor placement in radial distribution network considering increasing rate of loads. Technical operational constraints are available conductors and capacitors, voltage limit, maximum permissible carrying current of conductors and maximum reactive power could be injected. The power loss minimization problem is solved using particle swarm optimization (PSO). By applying this method, final cost of network planning, losses and their cost are considerably reduced and voltage profile of the network has improved to a semiflat shape. Simulation results are investigated on a practical radial distribution network in Iran (Miandoab 20 kv distribution network), in addition self supporting cables are used for optimization which avoids illegal use of electricity.

1. Introduction

The close propinquity of distribution network to the consumers of electricity has made it a necessity to explore the area of practical planning of distribution system. Because of the growing effort to reduce system losses, many papers have been published in recent years referring to optimal distribution planning, but in all these attempts, its significant sub problems of optimal conductor size selection, optimal place of capacitors to obtain minimum possible loss, still need to be further studied. Some articles have been published dealing with optimal planning of distribution networks [1, 3, 5, 6, 7], in general have focused on reducing cost through optimizing the conductor profile, capacitor cost, and in some cases cost of losses. But in these all, increasing rate of load for future years is not considered. In addition, in most articles there is not any special way to solve power flow problem in distribution system and they simultaneously have solved power flow problem and minimized the objective function. In this paper a software package is developed to determine radial distribution system parameters just having line data matrix, and technical data for available capacitors and conductors. PSO method for solving optimization problem is presented. The mentioned method is tested on a practical radial distribution network, with 5types of available self supporting cables and 11different sizes of capacitors, considering 8 years for load growth.

2. Problem formulation

2.1. Power Flow

Load flow is very important and fundamental tool for analysis of any power system and is used in the operational as well as planning stages. Certain application, particularly in distribution automation and optimization of power system, requires repeated load flow solution. In these applications, it is very important to solve the load flow problem as efficiently as possible. The Newton-Raphson and the fast decoupled power flow solution techniques and a host of their derivatives have efficiently solved for “well behaved” power systems. Researchers however have been aware of the shortcomings of these algorithms when they are generally implemented and applied to ill conditioned power systems.

Power flow in a distribution system obeys physical laws such as (Kirchhoff laws and Ohms law) which became part of the constraints in the capacitor placement problem. The distribution system power flow solution is to be used as a subroutine in each iteration. Therefore, it is essential to have a computationally efficient and numerically robust method for solving the distribution system power flow. By radial distribution system, we mean a system which has a single simultaneous path of power flow to the load. We have used a method, that exploits the radial structure of the distribution network and the relationship between the bus powers and branch powers is expressed as a non-singular square matrix known as element incidence matrix. The power flow equations for a radial distribution system are derived as the relationship between the specified complex bus powers and the bus voltages.

Let S_{ij} is the complex power flowing from bus ‘i’ to bus ’j’, so we have:

$$S_{ij} = P_{ij} + jQ_{ij} = V_i\left(V_i^* - V_j^*\right)Y_{ij}^* \qquad (1)$$

The ‘i’th bus powers are expressed as:

$$\mathrm{P_i + Q_i} = \sum_{\mathrm{i\in k(i)}} \mathrm{P_{ij} + Q_{ij}} + \sum_{\mathrm{i\in k(i)}} \mathrm{V_i\left(V_i^* - V_j^*\right)Y_{ij}^*} \qquad (2)$$

Where, k(i) is the set of nodes connected to node i, and P_i and Q_i denote the real and reactive power at node i, respectively. The above complex non linear equations are to be solved to determine the bus voltages. The real and imaginary parts of the equations are separated and solved using numerical methods.

2.2. Formulation of Proposed Method

The formulation of proposed method is based on this fact that an N bus radial distribution network has only N-1 lines (elements) and the branch currents (powers) can be expressed in terms of bus currents (powers). For an element ij connected between nodes ‘i’ and ‘j’ the bus current of node j can be expressed by a linear equation as follows:

$$\mathrm{I_j = I_{ij} - \sum I_{jk(j)}} \qquad (3)$$

Where, K (j) is the set of nodes connected to node j. For the slack bus the power is not specified so it is excluded and the relationship between bus currents and branch currents are derived as a non-singular square matrix as follows:

$$\mathrm{I_{bus}} = \mathrm{kI_{branch}}, I_{bus} = [I_{b2}\; I_{b3} \ldots I_{bn}]^T \tag{4}$$

The matrix K is element incidence matrix. It is a non singular square matrix of order N-1.The elemental incidence matrix is constructed in a simple way similar to bus incidence matrix. In matrix K each row describes the element incidences. The elements are numbered in conventional way i.e. the no. of element 'ij' is j-1.

1. The diagonal elements of matrix K are one. The variable j is denoting the element number.
   K (j, j) =1
2. For each 'j' th element let m (j) is the set of element numbers connected at its receiving end. K (j, m (j)) = -1
3. All the remaining elements are zero. It can be observed that all below the main diagonal elements of matrix K are zero.

$$\mathrm{I_{branch}} = \mathrm{k^{-1} I_{bus}} \tag{5}$$

The relationship between the branch currents and bus currents can be extended to complex branch powers and bus powers. The sending end power and the receiving end powers are not same due to the line loss. The line loss is included as the difference between the sending end, and receiving end powers.

The relationship between branch powers and bus powers is established in same way of bus, and branch currents. Multiplying both sides by element incidence matrix K:

$$S_{bus} = K[S_{branch}^{sending} - TL_{branch}]$$
$$S_{branch} = K^{-1}.S_{bus} + TL_{branch} \tag{6}$$

The power flow equations are complex quadratic equations. These are solved as [2] and the results we can get are voltage magnitude, voltage angle, active and reactive losses, complex current of branches. The advantage of this method is that it does not require a flat start. The formulation can be extended to unbalanced three-phase networks. The reactive power injections at multiple ends can be effectively calculated to improve the voltage profile.

2.3. Objective Function

In each optimization problem, objective function should be defined. In the proposed approach, objective function can be formulated as following equation; the proposed objective function aims at minimizing the total annual cost due to capacitor placement, conductor selection and power losses considering load growth in period of instrument life, with constraints that include limits on voltage, maximum permissible carrying current of conductors, size of installed capacitors and type of selected conductors, and maximum permissible reactive current to be injected to avoid over voltage.

$$\begin{aligned} J = &\sum_{l=0}^{n_s} L_l \times C(con_l) + \sum_{j=1}^{J} K_j^c \times Q_j^c + \\ &+ \sum_{i=1}^{N} P_{loss,i} \times C_E \times P_W^i \times 8760 \times LSF_i + \\ &+ \sum_{k=1}^{m} \{\max(0, V_{\min} - V_k)^2 + \max(0, V_k - V_{\max})^2\} + \\ &+ \sum_{l=1}^{n_s} (I_l - I_{\max}^l)^2 + \sum_{j=1}^{m} (Q_j^c - TQloss_j)^2 \end{aligned} \tag{7}$$

Where:

$$P_W = \left(\frac{1 + \operatorname{int} r}{1 + \inf r} \right) \tag{8}$$

According to mentioned constraints we should have:

$$I_{\max}^l = \begin{cases} I_{\max}(ConType_l - 1) \rightarrow if \begin{array}{c} I_{\max}(ConType_l) \le |I_l| \\ ConType_l \ne 1 \end{array} \\ \\ I_{\max}(ConType_l) \rightarrow else \end{cases} \tag{9}$$

$$V_{\min} \le |V_i| \le V_{\max} \tag{10}$$

$$I_l \le I_{\max(l)} \tag{11}$$

Where:

ns: Number of sections in the feeder,
Lj: Length of section *j* (km),
C(Conj): Cost of used conductor in section *j* (\$/km),
J : the buses in which the capacitor is installed,
m : the number of buses,
K_j^c: the capacitor annual cost per kvar,
Q_j^c : the shunt capacitor size placed at bus *j*,
$V_{\max}$, V_{min} : minimum & maximum permissible bus voltages
$\mathrm{I}^{\mathrm{l}}_{\max}$: maximum permissible carrying current of installed conductors in l_{th} section,
$ConType_l$: type of installed conductor in l_{th} section
N: Life period of lines (year)
Ploss,i: Real power loss in the *i*th year (kW)
CE: Cost of energy (\$/kWh)
Pw: Present worth factor
LSFi: Loss factor in *i*th year
Intr: The interested rate
Infr: The inflation rate

While computing the cost by defined objective function, load growth is considered as: (12)

$$load_i = \begin{cases} load \times (1+r)^i & \rightarrow i = 1,2,3,\ldots,M \\ load \times (1+r)^M & \rightarrow i = M+1,\ldots,N \end{cases}$$

Where, load i is the load in i'th year, r is the annual growth rate and M is a plan period up to which the feeder can take load growth.

The peak load growth during the planning period is illustrated in below figure.

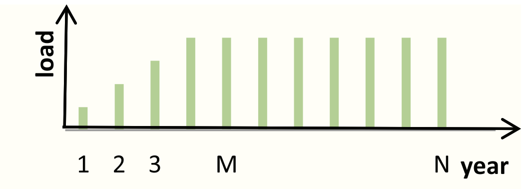

Fig.1. Peak load growth during planning period

Variation of load is considered with loss factor parameter in objective function.

The objective function includes six statements which are described as followed:

*Statement1:*The cost of power losses considering load growth,
Statement2: the cost of the installed capacitors,
Statement3: the cost of the installed conductors,
Statement4: the constraint of voltage limit,
Statement5: the constraint of maximum permissible carrying current of the conductors,
Statement6: the constraint to avoid over voltage, or having sufficient capacitor installation.

3. Proposed Computational Algorithm

In GA, a candidate solution for a specific problem is called an individual or a chromosome, and consists of a linear list of genes. Each individual represents a point in the search space, and hence a possible solution to the problem. A population consists of a finite number of individuals. Each individual is decided by an evaluation mechanism to obtain its fitness value. Based on this fitness value and undergoing genetic operators, a new population is generated iteratively with each successive population referred to as a generation. The PSO conducts searches using a population of particles which correspond to individuals in GA. A population of particles is randomly generated, initially. Each particle represents a potential solution and has a position represented by a position vector $\overline{x_i}$, A swarm of particles moves through the problem space, with the moving velocity of each particle represented by a velocity vector $\overline{v_i}$,At each time step, a function f_i representing a quality measure is calculated by using x_i as input. Each particle keeps track of its own best position, which is associated with the best fitness it has achieved so far in a vector v_i. Further, the best position among all the particles obtained so far in the population is kept track of as p_g. At each time step t, by using the individual best position $p_i(t)$ and global best position $p_g(t)$, a new velocity for particle i is updated as follows:

$$\begin{aligned}&\overline{v}_i(t+1)\\&=\chi[(\overline{v}_i(t)+c_1\phi_1\{\overline{p}_i(t)-\overline{x}_i(t)\}\\&+c_2\phi_2\{\overline{p}_g(t)-\overline{x}_i(t)\}]\end{aligned} \tag{13}$$

Where c1 and c2 are positive constants, φ1 and φ2 are uniformly distributed random numbers in [0,1] interval, and χ controls the magnitude of v. Changing velocity in this way enables the particle i to search around its individual best position, p_i , and global best position, p_g . Based on the updated velocities, each particle changes its position according to the following equation:

$$\overline{x}_i(t+1)=\overline{x}_i(t)+\overline{v}_i(t+1) \tag{14}$$

Computation of PSO is easy and has a slight computation load. Based on the encoding scheme, Ps individuals forming the population are randomly generated. These individuals are regarded as particles in terms of PSO.

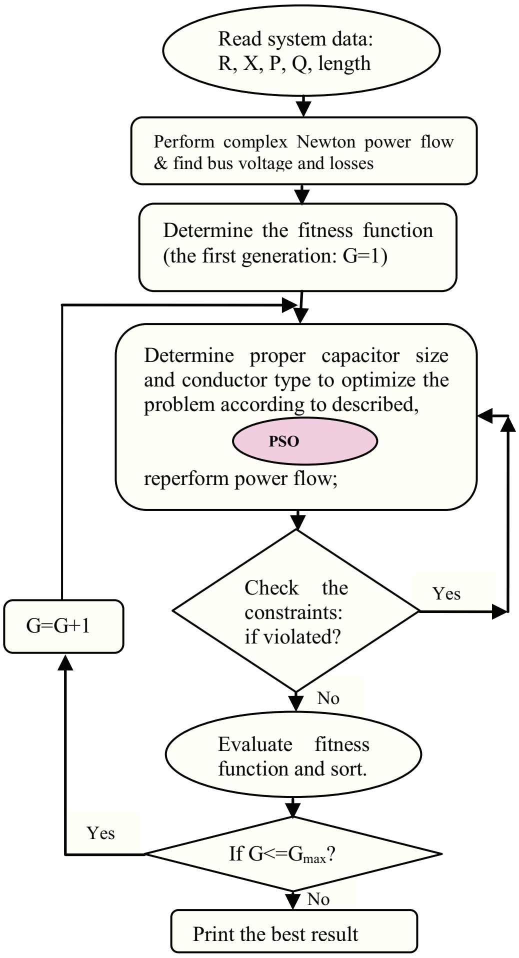

Fig.2. Flowchart of the whole proposed method

4. Computational Test

Based on the proposed algorithm, a software was developed using MATLAB programming language for proper conductor and capacitor selection considering load growth in distribution networks. The proposed method was tested on a practical distribution network by use of prepared software to evaluate its effectiveness. The test case is a 20 kV radial distribution network that has 24 nodes and 23 sections. Network and load data of radial test feeder is shown in table 1. The technical and economical data of available conductors and capacitors are given in tables 2 and 2, respectively. Other input data needed for evaluating the objective function are as follows:

N:20,M:5,Intr:17%,Infr:14%,r:7%,Vmax:1.03pu,V_{min}:0.95pu
LSF:0.63 for all loads, Cost of energy:50 ($/kWh)

Table1. Data for the test feeder

section	from	to	Resistance (actual)	reactance (actual)	Load of ending node[KVA]	section length(km)
1	0	1	0.2745	0.2695	0	0.3
2	1	2	0.2745	0.2695	250	0.45
3	2	3	0.2745	0.2695	100	0.3
4	3	4	0.2745	0.2695	50	0.36
5	4	5	0.2745	0.2695	200	0.255
6	5	6	0.2745	0.2695	200	0.4
7	6	7	0.2745	0.2695	100	0.6
8	7	8	0.2745	0.2695	0	0.65
9	8	9	0.2745	0.2695	0	1.35
10	9	10	0.2745	0.2695	0	0.3
11	10	11	0.2745	0.2695	160	1.5
12	11	12	0.2745	0.2695	25	1.35
13	1	13	0.6795	0.2980	0	0.26
14	2	14	0.6795	0.2980	100	0.15
15	4	15	0.6795	0.2980	50	0.16
16	5	16	0.6795	0.2980	315	0.365
17	7	17	0.6795	0.2980	100	0.2
18	8	18	0.6795	0.2980	100	0.34
19	8	19	0.6795	0.2980	250	0.55
20	9	20	0.6795	0.2980	50	0.2
21	10	21	0.6795	0.2980	50	0.71
22	11	22	0.6795	0.2980	250	0.98
23	22	23	0.6795	0.2980	25	0.44

PF for all loads=0.85

Table2: Technical and economical data of capacitors

capacitor type	size(kvar)	price($/kvar)
1	0	0
2	150	0.5
3	300	0.35
4	450	0.253
5	600	0.22
6	750	0.276
7	900	0.183
8	1050	0.228
9	1200	0.170
10	1350	0.207
11	1500	0.201

Table3:Technical& economical data of available self supporting cables

conductor type	R(Ω/km)	X(Ω/km)	Price ($/km)	max. current
1	0.265	0.129	26.25	340
2	0.325	0.133	21	300
3	0.411	0.138	16.625	260
4	0.822	0.158	8.75	170
5	1.11	0.158	6.125	140

5. Results

Simulation results are clearly illustrated in following figures and tables. By solving the optimization problem, the size of the capacitor banks, the types of the conductors and the amplitude of the bus voltages are determined. The total cost, power losses, minimum and maximum of the voltages in each node are obtained. Figure3 shows the system performance. Figure4 compares voltage magnitudes before and optimization. Figure 6 compares voltage angles before optimization with them after performing optimization;

Fig3.The chosen distribution network for implementation of proposed method

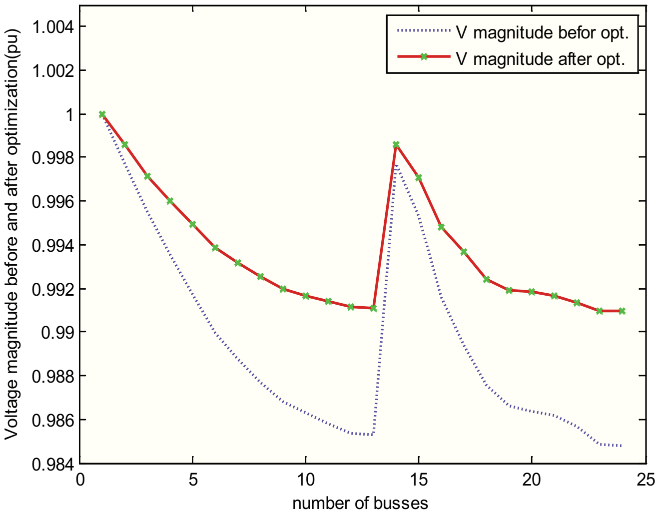

fig.4:Comparison of voltage magnitude before and after performing PSO

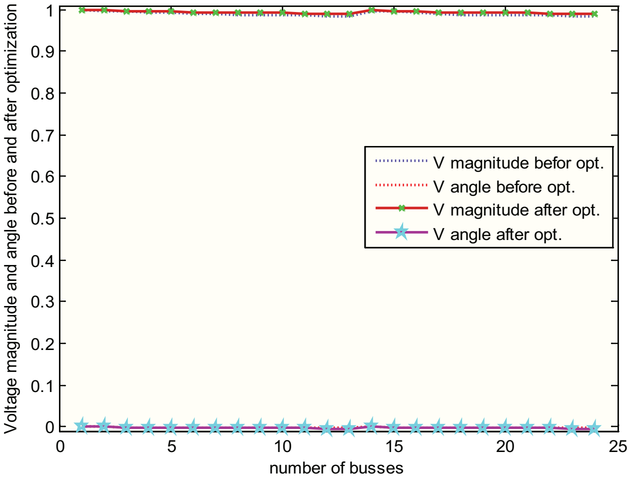

fig.5:Comparison of voltage profile before and after performing PSO

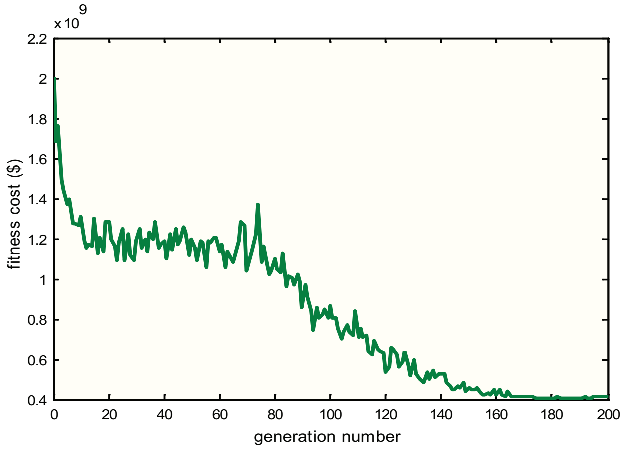

fig.6: Fitness optimized using PSO

The PSO best cost is 3.8202*10^8$.

Table 4.comparison of voltage magnitudes before and after performing PSO

Bus number	Voltage magnitude before optimization	Voltage magnitude after optimization
0	1.0000	1.0000
1	0.9977	0.9986
2	0.9955	0.9972
3	0.9936	0.9960
4	0.9917	0.9949
5	0.9900	0.9939
6	0.9887	0.9931
7	0.9877	0.9925
8	0.9868	0.9920
9	0.9863	0.9917
10	0.9858	0.9914
11	0.9853	0.9912
12	0.9853	0.9911
13	0.9977	0.9986
14	0.9953	0.9971
15	0.9916	0.9948
16	0.9894	0.9937
17	0.9876	0.9924
18	0.9866	0.9919
19	0.9863	0.9919
20	0.9862	0.9916
21	0.9857	0.9914
22	0.9848	0.9910
23	0.9848	0.9910

Table5. comparison of power losses before and after performing PSO

	Before optimization	After optimization
TPloss(kw)	0.0195	0.0133
TQloss(kvar)	2.5348	0.4224

Table 6. Result of conductor selection and capacitor placement after performing PSO

Sending end(i)	Receiving end(i)	Conductor type	Capacitor type
0	1	1	1
1	2	1	1
2	3	1	1
3	4	1	2
4	5	1	1
5	6	1	2
6	7	1	2
7	8	1	1
8	9	1	1
9	10	1	1
10	11	1	2
11	12	5	1
1	13	2	1
2	14	3	1
4	15	4	1
5	16	1	2
7	17	3	1
8	18	3	1
8	19	1	1
9	20	1	1
10	21	1	1
11	22	1	2
22	23	1	1

6. Conclusions

In this paper, using PSO the conductor selection has been incorporated in the conventional optimal capacitor placement, considering load growth in life period of instruments (like capacitors). By solving the optimization problem by PSO method, the optimal size and place of the capacitors and the self supporting cables are defined. The method has been applied to a practical radial distribution network and the results show the reduction of total loss especially active power loss, in addition to improvement of voltage profile. According to the results, the bus voltages of the ending buses are in the permissible limits. The obtained results show the efficiency of proposed method.

7. References

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