A genetic based algorithm for loss reduction in distribution systems

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The distribution system is considered not only as one of the important parts of the electric power system but one of the most complicated systems created by the mankind. It constitutes the link between electricity utilities and consumers. Usually, it suffers from unbalanced feeder structures and unbalanced loading which affects system power quality and electricity price. This paper introduces a Genetic based Algorithm (G.A) to determine the states of the switches for minimum loss configuration. The proposed G.A is applied for multi-objective programming to solve the reconfiguration problem in distribution systems. The problem of feeder configuration can be looked upon as an optimization problem, where the objective function reflects the different goals that the individual utilities may pursue. A weighed multi-objective function is used in this paper to investigate the utilities interests. The algorithm can be directed to minimize the losses which are a major sign of better power quality. Also, the operator has the ability to direct it to minimize the active power loss, voltage drop, complex power and neutral current of the main transformer. A radial distribution system is used to demonstrate the capability of the proposed G.A.

يعتبر نظام التوزيع واحد من أهم و اعقد الأجزاء في منظومة القوى الكهربية، فهو ينظم الربط بين شبكات تغذية الكهرباء و المستهلكين. وتعانى نظم التوزيع عادة من مشكلة عدم الاتزان في كل من تركيبات المغذيات و الأحمال مما يؤثر على جوده و سعر التغذية الكهربائية عند المستهلك. يقدم هذا البحث خوارزم مبنى على أساليب الجينات لتحديد حاله مفاتيح منظومة التوزيع (مفتوحة / أو مغلقه) و ذلك لتقليل الفقد،عن طريق تعديل شكل منظومة التوزيع للحصول على اقل فقد ممكن وفى نفس الوقت تحسين أداء المنظومة عن طريق تقليل كل من القدرة الظاهرية ، و الهبوط في الجهد و تيار التعادل في المحول الأساسي و التى تعتبر كل واحده منها سمه من سمات جودة التغذية . و قد تم ذلك باستخدام دالة متعددة الأهداف مثقله لامكانيه فحص متطلبات شبكات التغذية من اجل أعلى جوده. و قد تم تطبيق الخوار زم المقترح على منظومة توزيع شعاعية لتوضيح كفاءته و فاعليته.

Keywords: Distribution network, Reconfiguration, Multi-objective function, Loss reduction, Genetic algorithm

1. Introduction

Distribution systems are the networks that transport the electric energy from bulk substations or sources to many services or loads. In most cases distribution system is radially structured because it has some advantages over meshed network, such that lower short circuit and simpler switching and protecting equipment. On the other hand, it provides lower reliability. Generally, network reconfiguration is needed to provide service to as many consumers as possible following fault condition, or during planned outages for maintenance purposes, reduce system losses and balance the loads to avoid overloading of network elements.

During normal operating conditions, networks are reconfigured for two purposes:
(a) loss reduction to reduce overall system power loss.
(b) load balancing to relieve network overloads.

Many techniques have been proposed for solving feeder reconfiguration problem through switching operation. For example, Goswami et al. [1] presented a heuristic algorithm utilizing the concept of optimal flow pattern for the minimum loss configuration of distribution feeders. Jin-Cheng et al. [2] proposed a solution algorithm, based on a loss reduction formula and a line flow updating formula for the network reconfiguration problem. In [3], the developed algorithm is based on partitioning the distribution network into groups of load buses, such that the line section losses between the groups of nodes are minimized. M.S. Kandil et al. [4] presented an approach based on heuristic search strategies to determine the switching actions for minimum loss configuration and/or transformers load balancing. The authors of [5] proposed a network reconfiguration algorithm based on branch exchange for load balancing. S.I. Mohamed et al. [6] used artificial neural network (ANN) to reconfigure the feeder that reduces the active power losses. Feeder reconfiguration through switching operation is a complicated combinatorial optimization problem. Genetic algorithms have recently been used to solve many difficult engineering problems and are particularly effective for combinatorial optimization problems with large and complex search spaces. In this paper, a G.A is presented for multi-objective programming to solve the reconfiguration problem. Five objectives are considered in conjunction with network constraints.

The G.A is basically a stochastic searching algorithm. It is capable of solving non-smooth, non-continuous and non- differentiable problems for parallel computation to find global or near global optimal solutions. The results of the case studies demonstrate the effectiveness of the solution algorithm and proved that the G.A is suitable to solve this kind of problems.

2. Problem formulation

Distribution feeders contain a number of switches that are normally closed and others that are normally open. Under normal operating conditions, distribution engineers periodically reconfigure distribution feeders by opening and closing of switches in order to increase networks reliability and/or reduce line losses. In this section, the feeder reconfiguration problem is formulated as a multi-objective optimization problem, which can be solved efficiently using G.A [7]. Five different objective functions are considered. One or more of these objectives are considered by the distribution systems planning engineers.

2.1. Objective functions

a) Minimize the total complex power unbalance:

Min.

$$TS_u = \sum_{j=1}^{m} S_j^u \quad , \tag{1}$$

where; m is the total number of feeder segments of the object feeder and S_j^u is the unbalance of the three complex powers of phases.

$$S_j^u = \sqrt{\frac{1}{3} \sum_{p=a,b,c} \left| \bar{S}_j^p - \bar{S}_j^o \right|^2} \quad . \tag{2}$$

In which, the $\bar{S}_j^o$ stands for an ideal per phase loading , and can be determined through the following relation:

$$S_j^o = \left(\bar{S}_j^a + \bar{S}_j^b + \bar{S}_j^c \right) / 3. \tag{3}$$

and S_j^p is the complex power of individual loading phase p, $p= a, b, c$.

The S_j^u = 0 means the complex power of the j th feeder segment is perfectly balanced.

b) Minimize the total line losses:

Min

$$TL_\ell = \sum_{j=1}^{m} \sum_{p=a,b,c} (I_j^p)^2 . r_j^p + (I_j^{ne})^2 . r_j^{ne} \ , \tag{4}$$

where:

I_j^p and r_j^p are the current and resistance of phase p of the j th feeder segment, respectively.

The last term is included to count for the line losses in the neutral wire of the j th branch segment.

c) Minimize the average voltage drop:

Min.

$$AV_d = \frac{1}{n} \sum_{k=1}^{n} VD_k \ , \tag{5}$$

in which, n is the total number of load points of the object feeder, and

$$VD_k = \frac{1}{3} \sum_{p=a,b,c} \left| \frac{V_{nomi} - V_k^p}{V_{nomi}} \right| \times 100\% , \qquad (6)$$

in which V_{nomi} represents the nominal phase voltage, V_k^p denotes the magnitude of the phase voltage of phase p at load point k, and VD_k denotes the average of three phases voltage drops at load point k.

d) Minimize the neutral current of the main transformer:

Min.

$$I_t^N = \sum_{P=a,b,c} I_t^P \ . \qquad (7)$$

Where; I_t^p represents the current of phase p of the main transformer that feeds the object feeder, and I_t^N is the neutral current of the main transformer.

e) Minimize the total voltage unbalance factor:

Min.

$$T_{dt} = T_{d0} + T_{d2}. \qquad (8)$$

Where:

$$Td_0 = \sqrt{\frac{1}{n} \sum_{k=1}^{n} (d_{0,k})^2} \ , \qquad (9)$$

and

$$d_{0,k} = \frac{V_k^{(0)}}{V_k^{(1)}} \ .$$

$$Td_2 = \sqrt{\frac{1}{n} \sum_{k=1}^{n} (d_{2,k})^2} \ ,$$

and

$$d_{2,k} = \frac{V_k^{(2)}}{V_k^{(1)}} \ . \qquad (10)$$

$V_k^{(0)}$, $V_k^{(1)}$, and $V_k^{(2)}$ denote the zero-, positive- and negative- sequence voltage at load point k, respectively, and $d_{o,k}$ and $d_{2,k}$ denote the zero- and negative-sequence voltage unbalance factor at load point k, respectively.

3. Multi-objective optimization problem

Combining eqs. (1) through (10), a multi-objective function is obtained. In this paper a weighed multi-objective function is used by including weighting factor for each term of the objective function. The multi-objective optimization problem will be as follows:

Min.

$$F = w_1\ TS_u + w_2\ TL_l + w_3\ AV_d + w_4\ I_t^N + w_5\ Td_t , \qquad (11)$$

subject to:

$$\left. \begin{array}{ll} VD_k < VD^s & k = 1,\ldots., n \\ d_{o,k} < d_o^s & k = 1,\ldots., n \\ d_{2,k} < d_2^s & k = 1,\ldots., n \\ I_t^N < I_t^{N\,s} & \end{array} \right\} , \qquad (12)$$

and

$$w_1 + w_2 + w_3 + w_4 + w_5 = 1. \qquad (13)$$

In which VD^S, d_0^s and d_2^s are the specified values for voltage drop, zero-and negative-sequence voltage unbalance factors for all load points, respectively, I_t^{NS} is the specified neutral current for the main transformer at the distribution substation and w_k denotes a weighting factor that can be adjusted by distribution engineers for their request.

4. Solution algorithm for feeder reconfiguration

The selection of an optimum configuration among discrete numerous switching options requires solution of a complicated combinatorial optimization problem. G.A has recently proved as an effective tool for solving this type of problems with large and complex search spaces. The search of any G.A starts with a random generation of a population of strings.

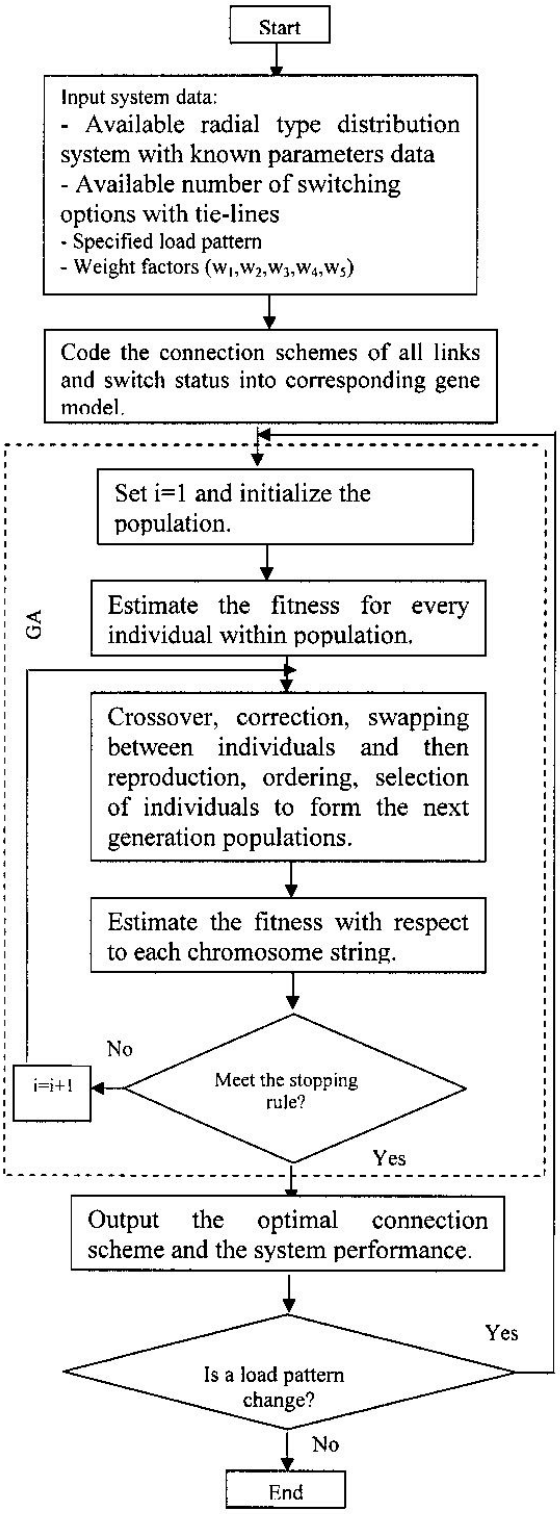

Fig. 1. The flow chart of the proposed G.A. approach.

Each string is divided into a number of sub strings equals the number of the problem variables. Each sub string consists of a number of genes to present one of the variables in a certain coding system. Fig. 1 depicts the flow chart of the proposed G.A approach.

5. Application

To show the validity, and efficiency of the proposed G.A, it is tested on the distribution system shown in fig. 2. This system includes one substation, four feeders, 32 branches, 5 tie lines, 32 buses and 37 switches [8]. The system data are illustrated in tables 1 and 2. The solution space contains 2^{37} possible combinations.

The proposed method can obtain the optimal solution rapidly and accurately.

We consider two different three-phase unbalanced load patterns to demonstrate the ability and efficiency of the proposed solution algorithm. The first load pattern in phases A, B and C is 0.4, 0.4 and 0.2 p.u respectively, while the second load pattern is 0.1, 0.2 and 0.7 respectively. For each load pattern five cases are considered according to the selecting weighting factors.

Case 1: $w_2 = 1$, which means that, the solution algorithm is directed only to minimize the total active power losses.

Case 2: all weighting factors are set to 0.2.

Case 3: $w_2 = 0.6$, while the remainder weighting factors are set to 0.1.

Case 4: w_1, w_2 and w_3 are all set to 0.1 while w_4 and w_5 are set to 0.35.

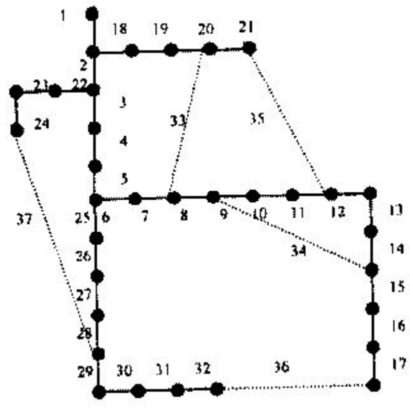

Fig. 2. Network structure of the test system.

Case 5: w_1, w_4 and w_5 are all set to 0.3, while w_2 and w_3 are set to 0.05.

The optimal decisions to reconfigure the distribution system under study for the first and second load pattern are given in tables 3 and 4, respectively.

From the results of tables 3 and 4 for the suggested load patterns, it can be noted that the G.A is a very effective tool when studying multi-objective functions. The results in table 4 demonstrate the flexibility and capability of the G.A in solving the feeder reconfiguration problem.

Table 1
Load data

Bus	P (kw)	Q(kvar)
1	-100	-60
2	-90	-40
3	-120	-80
4	-60	-30
5	-60	-20
6	-200	-100
7	-200	-100
8	-60	-20
9	-60	-20
10	-45	-30
11	-60	-35
12	-60	-35
13	-120	-80
14	-60	-10
15	-60	-20
16	-60	-20
17	-90	-40
18	-90	-40
19	-90	-40
20	-90	-40
21	-90	-40
22	-90	-40
23	-420	-200
24	-420	-200
25	-60	-25
26	-60	-25
27	-60	-20
28	-120	-70
29	-200	-600
30	-150	-70
31	-210	-100
32	-60	-40

Table 2
Line data

Line	From	To	R(Ohm)	X(Ohm)
1	0	1	0.0922	0.0470
2	1	2	0.4930	0.2511
3	2	3	0.3660	0.1864
4	3	4	0.3811	.1941
5	4	5	0.8190	0.7070
6	5	6	0.1872	0.6188
7	6	7	0.7114	0.2351
8	7	8	1.0300	0.7400
9	8	9	1.0440	0.7400
10	9	10	0.1966	0.0650
11	10	11	0.3744	0.1238
12	11	12	1.4680	1.0550
13	12	13	0.5416	0.7129
14	13	14	0.5910	0.5260
15	14	15	0.7463	0.5450
16	15	16	1.2890	1.7210
17	16	17	0.7320	0.5740
18	1	18	0.1640	0.1565
19	18	19	1.5042	1.3554
20	19	20	0.4095	0.4784
21	20	21	0.7089	0.9373
22	2	22	0.4512	0.3083
23	22	23	0.8980	0.7091
24	23	24	0.8960	0.7011
25	5	25	0.2030	0.1034
26	25	26	0.2842	0.1447
27	26	27	1.0590	0.9337
28	27	28	0.8042	0.7006
29	28	29	0.5075	0.2585
30	29	30	0.9744	0.9630
31	30	31	0.3105	0.3619
32	31	32	0.3410	0.5320
33*	7	20	2.0000	2.0000
34*	8	14	2.0000	2.0000
35*	11	21	2.0000	0.5000
36*	17	32	0.5000	0.5000
37*	24	28	0.5000	0.5000

*Normally open branches

Table 3
Genetic algorithm results with load pattern 0.4, 0.4, and 0.2

Case no. / Items	Case 1	Case 2	Case 3	Case 4	Case 5
Switch off	[7 9 14 28 32]	[7 9 14 28 32]	[7 9 14 28 32]	[7 9 14 28 32]	[7 10 14 28 32]
Switch on	[33 34 35 36 37]	[33 34 35 36 37]	[33 34 35 36 37]	[33 34 35 36 37]	[33 34 35 36 37]
TS_u (kva)	2252.682	2252.862	2252.862	2252.862	2247.555
TL_L (kw)	158.121	158.121	158.121	158.121	158.856
AV_d (%)	2.761	2.761	2.761	2.761	2.765
I^N_t (Amp)	126.607	126.607	126.607	126.607	126.61
Td_t (%)	2.011	2.011	2.011	2.011	2.014
Fitness* (p.u)	0.6711	0.6837	0.6774	0.7029	0.725

Table 4
Genetic algorithm results with load pattern 0.1, 0.2, and 0.7

Case no. / items	Case 1	Case 2	Case 3	Case 4	Case 5
Switch off	[14 20 21 25 29]	[7 9 14 28 32]	[10 19 22]	[10 16 20 23]	[9 15 21 23]
Switch on	[33 34 35 36 37]	[33 34 35 36 37]	[34 35 37]	[34 35 36 37]	[34 35 36 37]
TS_u (kva)	8943.48	6195.37	9862.03	9448.09	9372.76
TL_L (kw)	233.927	311.667	212.746	215.558	114.4
AV_d (%)	4.522	2.861	4.705	3.489	2.171
I^N_t (Amp)	221.676	374.67	175.001	184.712	199.892
Td_t (%)	6.233	5.945	7.225	9.058	6.428
Fitness* (p.u)	0.4228	0.6325	0.5296	0.6012	0.6632

*Fitness is the weighed multi-objective function

Case 5 in table 4 leads to lower active power losses than case1 in which the weighting factor is directed towards the minimization of losses only. So using the G.A for solving the multi-objective optimization problem for feeder reconfiguration leads to minimizing or improving total active power losses, total complex power, average voltage drop, neutral current of the main transformer and total voltage unbalance factor.

6. Conclusions

A genetic algorithm approach has been presented in this paper to solve the weighed multi-objective function for distribution system reconfiguration. Five different objectives are considered in conjunction with network constraints. Numerical results of four distribution feeders and 32 buses distribution system showed the efficiency and capability of G.A in solving this type of problems. The algorithm can be directed easily by experience of the operator to minimize the total active power losses and at the same time improving or minimizing total complex power, average voltage drop, neutral current of the transformer and total voltage unbalance factor which are a major sign of better power quality.

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