Distribution System reconfiguration for loss minimization using Binary Coding Particle Swarm Optimization

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Abstract: This paper proposes an improved approach based on to study distribution network reconfiguration based on binary coding particle swarm optimization. The objective is to minimize the system power loss. Based on distribution feeder operations feeder reconfiguration is done as '1' & '0' arrangement combination of switches. Shift operators and shift operator sets are used for analysis and programming purpose. This makes simple algorithm and easier programming. The proposed method is tested on a 33-bus distribution network. Study results with brief overview of approached model are given in the paper.

Keywords: Optimization; Binary coding particle swarm optimization; Loss minimization; Distribution systems; Shift operators

1. Introduction

Distribution system is made of interconnected radial circuits. The configurations could be changed for optimum power flow, load redistribution and feeder requirements. These configurations include switches which are generally divided as sectionalizing-switches (normal closed) and tie-switches (normal open). By changing the on/off status of these distribution feeder switches, feeder reconfiguration can be done. This feeder reconfiguration can be used to maintain system balance, reduce feeder losses and improve system reliability.

There are many researches developed for feeder reconfigurations for example neural network, simulated annealing, refined genetic algorithm[1], ant colony optimization (ACO) [2,3] and particle swarm optimization (PSO)[4].

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. Through iterations of the evolution process, optimal solution is obtained.

However, it is not designed for discrete function optimization problems. Kennedy and Eberhart[5] also proposed a modified version of PSO called Binary Particle Swarm Optimization (BPSO) [6] that can be used to solve discrete function optimization problems.

Further improvement was done by Wu Chang Wu and Men-Shen Tsai in 2008. They proposed Binary Coding Particle Swarm Optimization for distribution feeder reconfiguration. Shift operators and shift operator set were used which made the technique easier for programming and analysis. Tests were performed for Taoyuan division, Taiwan Power Company with four feeders. Results obtained were better than previous methods.

Here in this paper the Binary Coding Particle Swarm Optimization for distribution feeder reconfiguration is performed to IEEE 33 bus test system. The system is tested to gain better insight of the technique and parameters selection for better analysis.

2. Objectives and Scope

The objective of study is to implement and study the application of Binary coding PSO in feeder reconfiguration for minimum power loss in IEEE 33 bus test system. Under the constraints of maintaining the radial structure of the system following objective is broadly defined:

2.1 Minimization of the power loses

Minimization of the real power loss is chosen as the objective for the feeder reconfiguration. The total power loss can be calculated as the sum of individual power line losses.

Minimize $f_1(X) = \sum |I_i|^2 X R_i$ (1)

3. Methodology

3.1 System under study

The research work is primarily based on analysis of binary coding particle swarm optimization technique for feeder reconfiguration in IEEE33 bus test system.

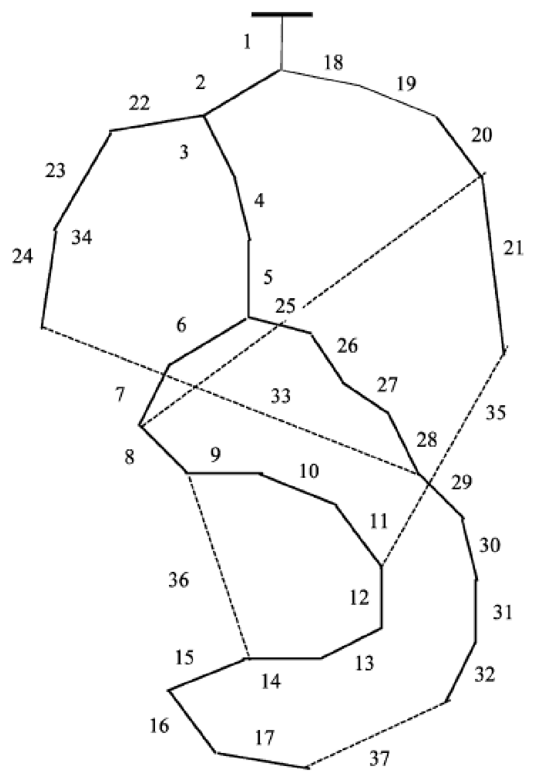

Figure 1: 33-bus test system

3.2 System modeling

3.2.1 Binary coding PSO

This method tries to construct a more feasible discrete PSO scheme based on the concept of typical PSO for feeder reconfiguration. Based on the characteristics of distribution feeder operations feeder reconfiguration is done as '1' & '0' arrangement combination of switches. Secondly the shift operators are used as in programming languages. Shift operator and shift operator set can be used to construct the binary coding particle swarm optimization for distribution feeder reconfiguration.

3.2.1.1 Shift Operator

Suppose m sectionalizing switches (normally closed, N.C.) and n tie switches (normally opened, N.O.) exist on a distribution system. The permutation combination of the status all switches (s=m+n) is [S1, S2, …, Ss] and it will be called 'sequence of switch states', or SSS.

Suppose a distribution system shown in Figure 1 has two feeders, five N.C.s. and one N.O. The SSS of this system is denoted as:

[1 0 1 1 1 1]

Figure 2: A simple distribution system

The shift operator is defined as SO (Bit_i, $Direction_{L,R}$, $Step_c$) which means that it will change the position of an N.O. in SSS.

Bit_i is the index of i-th switch in SSS.

$Direction_{L,R}$ indicates the direction of left or right shifting on the i-th switch.

$Step_c$ is the number of shifting steps.

The new permutation in SSS is defined as SSS'=SSS ⟨+⟩ SO. The symbol, ' ⟨+⟩ ', represents the shift operator. It applies SO to SSS to get a new SSS'.

Supposing a SO(2, R, 3) is applied on this SSS. The process of operation is described below.

The resulting SSS_2=[1 1 1 1 0 1]

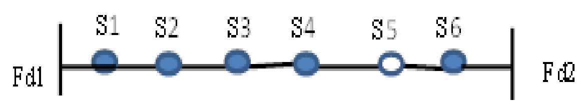

Figure 3: Distribution system after reconfiguration

3.2.1.2 Shift operator set

A set with at least one or more shift operators is called shift operator set (SOS). An SOS represents all actions about how to fill-in or shift normal open switches on distribution systems. The definition of shift operator set is as: SOS ={ SO_1 , SO_2 ,..., SO_n } (2)

where n is the number of shift operators.

Considering the three feeder sysem as shown in the fig 4 and 5 where two SSSes, SSS1 and SSS2, a set of shift operators transfers SSS_1 to SSS_2 needs to be identified. Two SSSes, SSS_1=[1 1 0 1 1 0 1] and SSS_2=[1 0 1 0 1 1 1], are used to explain how the shift operators are acquired. By comparing the position of normal open switch one by one in these two SSSes, the SOS ={SO_1(3,L,1), SO_2(6,L,2)}=SSS_2 Θ SSS_1.

The symbol, ' Θ ', is used to indicate an action to obtain the shift operators from SSS1 to SSS2.

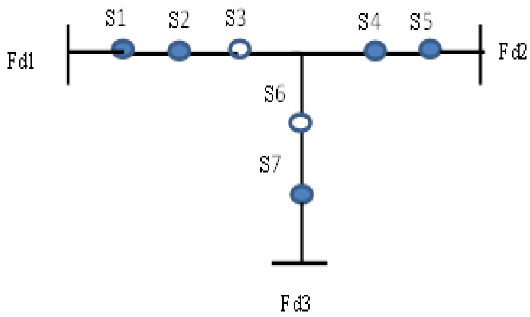

Figure 4: A simple 3 feeder distribution system

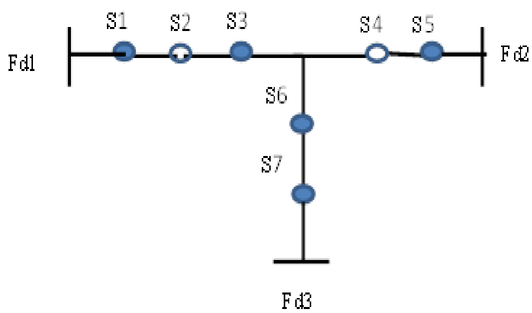

Figure 5: 3 Feeder distribution system after operation

3.3 *Use of Shift operator and update eqn.*

For the IEEE 33 buses with 5 tie lines and line parameters provided in table 1.

Consider normal closed switches as '1' and normal open switches as '0'.

The combination of status of switches called as the sequence of switch states (SSS) is defined as [S_1 S_2 S_3 …………S_n] where n= no of switches (sectionalizing + tie switches).

Here for the initial calculation

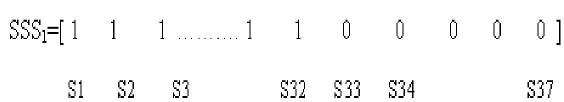

Figure 6: 33-bus system SSS

The system consists of five loops of switches with common paths which is obtained using Matlab. Maintaining radial structure and switching of switches in each loop is done. The update formulas (3) and (4) of PSO is redefined to solve the problem of feeder reconfiguration. The new update formula for the proposed binary coding PSO is as below:

v_{id}^{new}= (w ⊗ v_{id}) ⊕ (rand () ⟨×⟩ (pbest Θ x_{id})) ⊕ (rand () ⟨×⟩(gbest Θ x_{id})) (3)

$x_{id}^{new} = x_{id} <+> v_{id}^{new}$ (4)

The symbol, ' ⊕ ', is used for combining two shift operator sets. The symbol, ' ⟨×⟩ ', is used to select the number of shift operator, SO, in (pbest Θ x_{id}) or (gbest Θ x_{id}) randomly.

x_{id} is the original SSS of the i-th particle

pbest is the best SSS of the i-th particle

gbest is the best SSS of any particle in the population.

v_{id} is the original shift operator set of the i-th particle,

v_{id}^{new} is the new shift operator set of the i-th particle.

x_{id}^{new} is the new SSS of the i-th particle. rand () is a random number with a range of [1, n] where n is the number of SO in SOS.

In (3), w is the inertia weight. The role of w is used for adjusting searching areas. The searching areas are reduced progressively when the number of iteration increases. The calculation of inertia weight is shown as (5).

$$w = \frac{iteration_{max} - iteration_{now}}{iteration_{max}} X\ ShiftStep_{\ max} \qquad (5)$$

3.4 *Voltage and loss calculation*

Voltage calculations and loss calculations of the system will be done as proposed by Chakravorty and Das[7] using eqn (6) to (8).

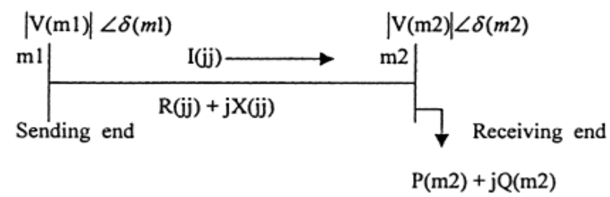

Figure 7: Electrical equivalent of sending and receiving line

$$|V(m2)| = 0.707[b(jj) + \{b^2(jj) - 4c(jj)\}^{1/2}]^{1/2} \quad ….(6)$$

Here,

b(jj)= $|V(m2)|^2 - 2P(m2)r(jj) - 2Q(m2)x(jj)$ ….(7)

c(jj)= $\{P^2(m2) + Q^2(m2)\}\{r^2(jj) + x^2(jj)\}$ (8)

The real and reactive power losses in branch jj is given by:

$$LP(jj) = \frac{r(jj)\{P^2(m2)+Q^2(m2)\}}{|V(m2)|^2} \qquad (9)$$

$$LQ(jj) = \frac{x(jj)\{P^2(m2)+Q^2(m2)\}}{|V(m2)|^2} \qquad (10)$$

3.5 Programming procedures

Different modules or functions programmed regarding IEEE 33 bus test system. The main programming modules with the flowchart are briefly explained as follows:

- Function bus33: This is the starting main function. This calls all subordinate functions sequentially according to their order. This function prints the output results.
- Function linepara: This function arranges parameters and switching data regarding using traceline, section and selection function. This also performs changing of parameters to pu system.
- Function selection: This includes modifying the switches according to the update input provided.
- Function traceline: This traces the power flow in the buses according to the switching condition. The results can be analysed as in Figure 9.
- Function voltcalc: This performs voltage calculations calling subordinate functions. Subordinate functions include newv, loss, linepara, and powersum.
- Function newv: Calculation of voltage using eqn. (6),(7) and (8).
- Function loss: Calculation of power loss using eqn. (9) and (10).
- Function powersum: Summation of loads and powerloss calculation of each bus.
- Function section: Closing all tie switches makes a meshed network as in Figure 10. For this system 5 loops are created the results obtained are discussed in table 1.
- Function update: Updates and changes the switching using update eqn. 3 and 4. Inputs data to selection.

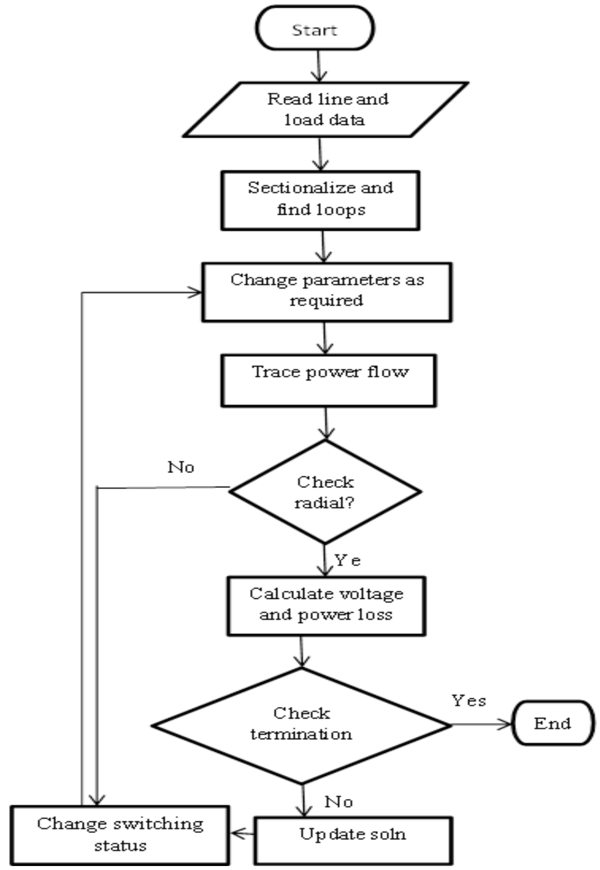

Figure 8. Flowchart of the proposed method

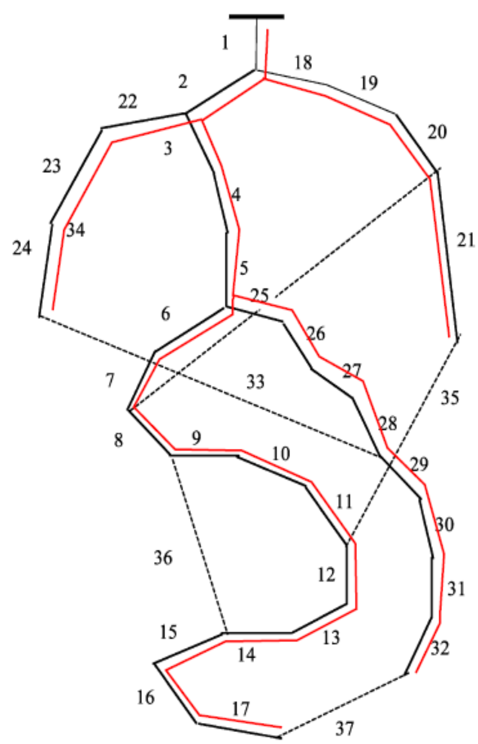

Figure 9. Tracing the power flow

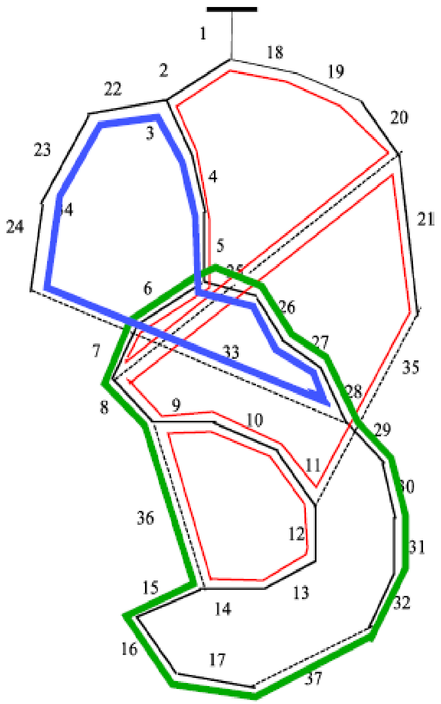

Figure 10. Closed loops in 33-bus system

4. Results

For reconfiguration the no. of loops formed in closing all the tie lines is required. This is solved as stated in table 1.

Table 1: Loop and lines in meshed network

Loop	Line no.
1	34 7 6 5 4 3 2 18 20 19
2	36 9 14 13 12 11 10
3	35 11 10 9 8 34 21
4	37 17 16 15 36 8 7 6 25 32 31 30 29 28 27 26
5	33 24 23 22 3 28 27 26 25 5 4

The voltage and power loss calculations for various configurations are shown in table 2.

Table 2: Results for 33-bus system

Radial networks	Original network	Results	
Open switches	Switch 33	7	7
	34	11	9
	35	14	14
	36	33	32
	37	37	33
Power loss(MW)	0.202692	0.143416	0.139558

Line parameters and receiving node voltage for the original network are shown in table 3.

Table 3. line parameters for 33-bus system with obtained receiving node voltage

Br no.	Sending no.	Receiving no.	R	X	PLo	QLo	V
1	1	2	0.0922	0.047	100	60	0.997
2	2	3	0.493	0.2512	90	40	0.9829
3	3	4	0.3661	0.1864	120	80	0.9755
4	4	5	0.3811	0.1941	60	30	0.9681
5	5	6	0.819	0.707	60	20	0.9497
6	6	7	0.1872	0.6188	200	100	0.9462
7	7	8	0.7115	0.2351	200	100	0.9413
8	8	9	1.0299	0.74	60	20	0.9351
9	9	10	1.044	0.74	60	20	0.9292
10	10	11	0.1967	0.0651	45	30	0.9284
11	11	12	0.3744	0.1298	60	35	0.9269
12	12	13	1.468	1.1549	60	35	0.9208
13	13	14	0.5416	0.7129	120	80	0.9185
14	14	15	0.5909	0.526	60	10	0.9171
15	15	16	0.7462	0.5499	60	20	0.9157
16	16	17	1.2889	1.721	60	20	0.9137
17	17	18	0.732	0.5739	90	40	0.9131
18	2	19	0.164	0.1561	90	40	0.9965
19	19	20	1.5042	1.3555	90	40	0.9929
20	20	21	0.4095	0.4784	90	40	0.9922
21	21	22	0.7089	0.9373	90	40	0.9916
22	3	23	0.4512	0.3084	90	50	0.9794
23	23	24	0.898	0.7091	420	200	0.9727
24	24	25	0.8959	0.7071	420	200	0.9693
25	6	26	0.2031	0.1034	60	25	0.9477
26	26	27	0.2842	0.1447	60	25	0.9452
27	27	28	1.0589	0.9388	60	20	0.9337
28	28	29	0.8043	0.7006	120	70	0.9255
29	29	30	0.5074	0.2585	200	600	0.9219
30	30	31	0.9745	0.9629	150	70	0.9178
31	31	32	0.3105	0.3619	210	100	0.9168
32	32	33	0.3411	0.5302	60	40	0.9166
34	8	21	2	2			
36	9	15	2	2			
35	12	22	2	2			
37	18	33	0.5	0.5			
33	25	29	0.5	0.5			

5. Conclusion

This improved method to study distribution network reconfiguration using binary coding PSO in IEEE 33 bus test system is presented in the paper. The approach gives optimum or near to optimum result depending upon the parameter selection, no. of iterations, and termination parameters. The approach reconfigures the status of switches to obtain the optimal result. The method is easy to implement and solve optimal problems. The paper also presents brief overview of the programming and computational approach to demonstrate the effectiveness of this methodology.

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