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Network Reconfiguration in Distribution Systems Using a Modified TS Algorithm

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Abstract: -This paper presents a modified TS algorithm for network reconfiguration in distribution systems. TS algorithm is an efficient meta-heuristic searching algorithm, and it has advantages of both high efficiency of local search of hill-climbing method and global search ability of intelligent algorithm. However, since network reconfiguration is a complicated combinatorial optimization problem with many constraints to be satisfied, TS algorithm is hard to reach the global optimum with high searching efficiency when directly used. In distribution network, each tie switch is only associated to one loop network. Based on this structure property and setting attribute values to each sectionalizing switch to decompose each tie switch associated loops, TS algorithm is modified to make optimization process be carried out in the continuous solution spaces and the global optimum solution can be gained along with the high searching efficiency. The proposed method is tested with two typical distribution systems and the promising results are gained.

Key-Words: -distribution network, TS algorithm, network reconfiguration, greedy searching, power loss

1 Introduction

Distribution network is designed in the loop structure but operated radially. It consists of a lot of sectionalizing switches and tie switches. By changing the open/closed status of sectionalizing and tie switches, the topological structures of the distribution network are altered to reduce active power losses when operating condition changes. During normal operating conditions, networks are reconfigured mainly for two purposes: (1) to reduce the system real power losses and (2) to relieve overloads in the network. And meanwhile it is necessary to satisfy the equality constraints and inequality constraints.

Algorithms proposed by previous researchers for network reconfiguration problem usually are the following two main classes: (1) Heuristic algorithms[1-4], i.e. branch-exchange algorithm, optimal flow pattern algorithm, etc. (2) Intelligent algorithms[5-9], i.e. genetic algorithm, simulated annealing algorithm, TS algorithm, etc. The former all are greedy searching algorithms. This kind of algorithms are easy to be implemented and with high searching efficiency, but generally they can't obtain the global optimum solution. The latter can lead the search converge to the global optimum solution at the probability 1 in theory, but it involves a huge amount of calculations and really is a time consuming method.

TS algorithm is a good, efficient intelligent searching algorithm. The searching speed is much faster than that of GA and SA algorithms. Since it is a single way searching algorithm compared with GA, it is very easy to be trapped into the local optima although the tabu idea is introduced to escape from the local optima. So how to modify TS algorithm and make it done much better global search is meaningful.

In this paper, based on the new encoding manner of tie switches and sectionalizing switches, which can guarantee the search in the continuous solution spaces, TS algorithm is modified and then applied to solve the network reconfiguration problem.

2 Problem formulation

In this paper, the objective function is to minimize active power losses. The problem is formulated mathematically as follows:

$$\min F = \sum_{i=1}^{n} \Delta P_i + K \cdot G(x) \quad (1)$$

where: ΔP_i is the active power losses at branch i; K is the penalty coefficient; $G(x)$ is the penalty function of system constraints violation

Equality constraint is operating constraint, i.e. power flow equation.

Inequality constraints include bus voltage, branch capacity constraints, as follows:

$$V_{i\,min} \le V_i \le V_{i\,max}$$
$$S_i \le S_{i\,max}$$

Where $V_{i\min}$ and $V_{i\max}$ are low and up bounds of bus voltage magnitude, S_i and $S_{i\max}$ are branch power flow and its up capacity bound.

Besides equality and inequality constraints mentioned above, there are still constraints in topological structure. The structure of distribution network must be a radial configuration and there should be no nodes without power supply path.

3 Modified TS algorithm and its use in network reconfiguration

3.1 TS Algorithm

TS algorithm is an extended local search algorithm. Through introducing tabu list, recording the latest solutions reached, TS algorithm can escape from current region and search other region by using the information in tabu list to guide the following searching process. Therefore, TS algorithm has advantages of high searching efficiency of local searching algorithm and global searching ability of intelligent algorithm.

The optimization procedure of TS algorithm generally can be described as follows:

Step 1: form an initial solution at a certain way, and establish tabu list.

Step 2: If stop rule is satisfied, then stop searching and output the final results. Otherwise, select candidate solutions that meet the tabu requirements to form the neighborhood $N(H, x^{now})$ of current solution x^{now}. Find the best one x^{next} among them to replace the current solution($x^{now} = x^{next}$),and if it better than the best-so-far solution, replaced the best-so-far. Upgrade the tabu list, repeat step 2. H denotes the neighborhood of current solution. $N(H, x^{now})$ denotes the selected neighborhood of current solution.

3.2 Modified TS algorithm

In distribution network, tie switch associated loop networks have some shared branches. If TS algorithm is used directly, there will be many infeasible solutions, which violate structure constraints, in the optimizing process, and this will bring considerable negative influence to searching efficiency and optimizing quality.

In this paper, the loop networks corresponding to tie switches are decomposed first by using attribute values of sectionalizing switches. Then TS algorithm is modified correspondingly to make good use of network configuration properties and to eliminate infeasible solutions in the searching process. The algorithm is developed as follows:

(1) Set attribute values to each sectionalizing switches and decompose the network. In this paper, the number of the sending node of a branch is used to number sectionalizing switch. For example, in the topological structure of the network illustrated in Fig. 1, switch 5 refers to the switch in the branch that links node 4 and node 5. The switch set of loop network corresponding to tie switch 24-28 is: {3, 4, 5, 25, 26, 27, 28, 22, 23, 24}, the switch set of loop network corresponding to tie switch 7-20 is: {2, 3, 4, 5, 6, 7, 18, 19, 20}. Among them, switch set {3, 4, 5} are the shared switches of these two loop networks. Of course, these shared switches should have same attribute values. To guarantee no infeasible solutions be created in the optimizing process, the switches with the same attribute values should be only one in the status of open. Using switch attribute values, network reconfiguration problems then are decomposed into each 'independent' loop network reconfiguration sub-problems. The dimension of the network scale is reduced.

(2) Tie switches are encoded into one character string and sectionalizing switches are encoded into strings corresponding to each tie switch. Under the radial network topological structure condition, find out all sectionalizing switches of a loop when closed a tie switch, encode them into one character string and this string is the searching neighborhood of this tie switch. At the beginning, the states of sectionalizing switches are set as " 1 ", and the state of the tie switches are set as " 0 ".As illustrated in Fig.1, tie switches are numbered as table.1.

Table 1. Tie switch character string

Branches	7－20	8－14	11-21	17-32	24-28
Switches number string	33	34	35	36	37
status	0	0	0	0	0

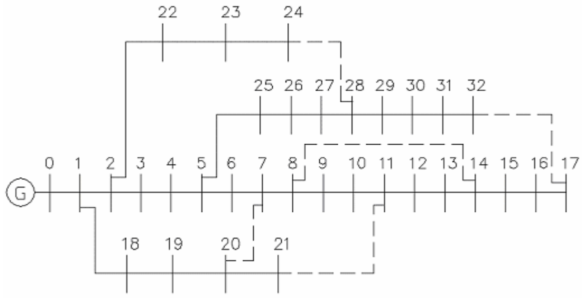

Fig.1 Single line diagram of the 33-bus system

Sectionalizing switch sets{2、3、4、5、6、7、18、19、20} corresponding to tie switch 33 are encoded as table 2.

Table 2. Sectionalizing switch character string

Switches string	2	3	4	5	6	7	18	19	20
status	1	1	1	1	1	1	1	1	1

While doing neighborhood search tries, the open/close status are exchanged only between a tie switch and a sectionalizing switch in the corresponding sectionalizing switch character string. In this way, the structure constraints will not be violated in the network reconfiguration process. When finished a set of neighborhood searching tries, find an exchange, which result in the maximum power loss reduction, and exchange both open/close status and locations in corresponding strings between tie switch and sectionalizing switch.

(3) Modified TS algorithm.

In this paper, according to the switch encoding manner mentioned above, the TS algorithm is modified as follows:

1) In neighborhood search tries of a tie switch, if solution is improved, the tabu is not introduced. It will make good use of the gradient drop search characteristics and enhance the searching efficiency of TS algorithm.

2) Set receptive probability. When solution stops improving in the neighborhood search of a tie switch, then at this preset receptive probability, randomly select a sectionalizing switch in the corresponding strings to exchange with this tie switch and record this exchange in tabu list to make search process jump out of the local optimum region. This improvement has two advantages:1) tabu list is used as conventional TS algorithm; 2) probability is introduced to disturb search course to jump out of local optimum region easily.

3) Tabu search is carried out within each loop network. In each iteration, every tie switch does a set of neighborhood search. It itself has the tabu search characteristic and avoids the greedy search within the each iteration. A tie switch and the corresponding sectionalizing switch set form a tabu search space. The attribute value of sectionalizing switches is used to ensure the feasible switch exchange in the loop network.

4) Determination of tabu table. In this paper, tabu list is set within each loop networks and the lengths all are 1.

3.3 The procedure of the algorithm

To minimize active power losses, the procedure of the modified TS algorithm in the network reconfiguration is shown in Fig.2 and described as follows:

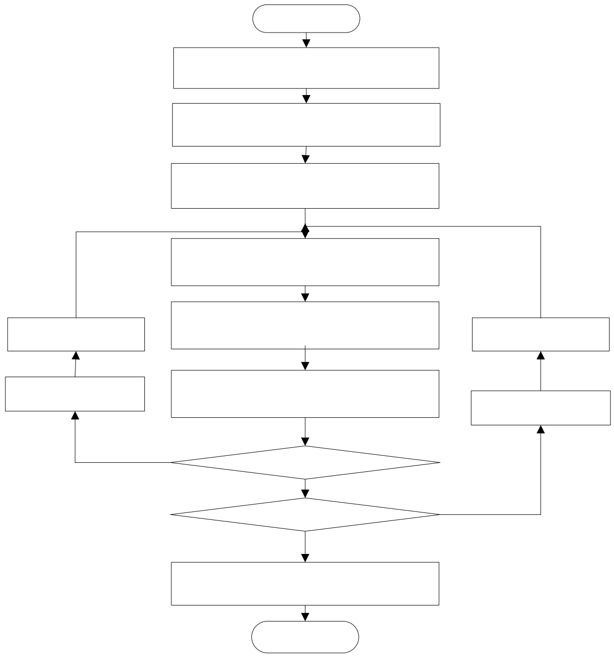

Fig.2 Flowchart of the Modified TS algorithm

(1) Reading network data and forming distribution network topological structure.
(2) Forming code string of tie switches, and scanning network to form the sectionalizing switch code strings corresponding to each tie switch. And setting attribute values to each sectionalizing switch.
(3) Calculating network power flow of the initial network structure and recording it as the best-so-far solution and recording the corresponding network topological structure.
(4) Carrying out neighborhood search from the first tie switch, and determining the optimal neighborhood switch exchange. If the active power losses of this optimal switch exchange is smaller than the best-so-far, executing this switch exchange and updating the record of the best-so-far and its corresponding network structure with this exchange.
(5) Carrying out neighborhood search of tie switches one by one in the each iteration then the number of iteration is added by 1.
(6) If stop rule is satisfied, stop searching, output the best-so-far solution and corresponding structure topology. Else go to step (4). Where stop rule is the preset iterative times.

4 Test results

The sample system has nominal voltage of 12.66kV. It has 32 branches and 5tie lines. The system data can be found in [3]. Results of network reconfiguration are given in table 3.

Table 3. Results before and after reconfiguration

	Original network	Modified TS algorithm	TS algorithm
Tie switch set	17－32	31－32	31-32
	11－21	8－9	8-9
	8－14	13－14	13-14
	24－28	24－28	27-28
	7-20	6－7	6-7
loss（kW）	202.681	139.553	139.98
The lowest bus voltage（p.u.）	0.9131	0.9378	0.9322

As shown in table 3, the active power losses of the distribution network are reduced greatly after network reconfiguration. And the optimization performance of the modified TS algorithm is better than that of TS algorithm. Efficiency comparison is given in Table 4. The computer system is a P3/500HZ computer. It is noted that the modified TS algorithm have 53 iterative times to reach global optimum solution and TS algorithm is failed to reach the same global optimum solution. The difference at the computation time is neglectable.

Table 4: Efficiency comparison of two algorithm.

	Modified TS algorithm	TS algorithm
First time to reach the optimum solution	53	7
Optimum solution	139.553	139.98
Defined iteration number	100	100
CPU run time（s）	0.161	0.16
power flow times	751	708

Searching process is given in Fig.3. It is clear that TS algorithm is gotten stuck in the local optimum and can't escape from it, whereas the modified TS algorithm is jumped out of the local optimum and reach the global optimum solution. The modified TS algorithm has better global searching ability at the cost of minor impairment of searching efficiency.

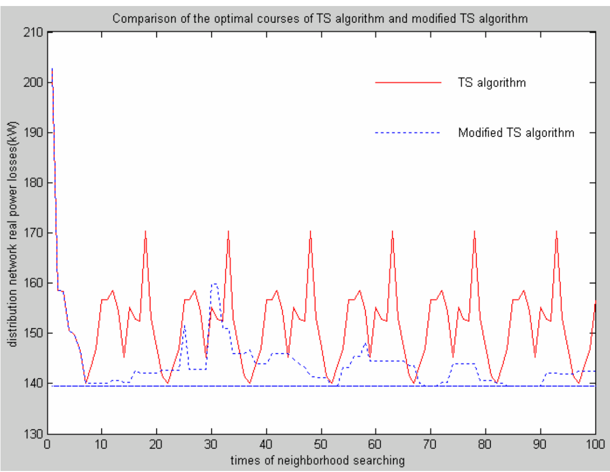

Fig.3 Searching process

About the same test system, result comparisons with other methods are given in table 5. The method used in [2] is a branch exchange method. The method used in [7] is a genetic algorithm and the method used in [8] is an evolutionary programming algorithm. From table 5, it is noted that the proposed modified TS algorithm has better optimizing performance than that of other methods.

Table 5 Result comparison of different methods

	Method in [2]	Method in [7]	Method in [8]	Proposed Method
Tie line set	(6-7) (9-10) (13-14) (26-27) (29-30)	(7-20) (8-9) (8-14) (27-28) (17-32)	(5-6), (8-9), (13-14) (24-28) (31-32)	(6-7) (8-9) (13-14) (24-28) (31-32)
Power Loss(kW)	161.01	146.37	142.83	139.553
Lowest V. (p.u.)	0.9043	0.9367	0.9390	0.9378
Lowest V. Bus	30	32	32	31

5 Conclusion

In this paper, a modified TS algorithm is proposed for network reconfiguration in distribution systems. Through set attribute values to sectionalizing switches, the distribution network reconfiguration problem is decomposed into each tie switch associated loop network reconfiguration sub-problems 'independently'. Based on this improvement, the TS algorithm is modified, by setting tabu table in each loop and setting receptive probability of solution evolving stagnation, to enhance the capacity of global search. Test results proved the global search ability and the validity of the proposed modified TS algorithm.

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