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The Application of Tabu Search Algorithm on Power System Restoration

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Abstract: -The essay is just according to the part of the Shanghai Electric System, which is in accident. The Breadth First Search (BFS) and The Depth First Search (DFS) will be used to solve the problem of the early search of the net, then The Tabu Search will be used to search for the fastest restore path. After these searches, C++ will be used to compile the BFS and the DFS; also it will be used to establish the tabu list. The result shows that the optimal restore path will be selected in power system restoration.

Key Words:- restoration; tabu search ; power system

1 Introduction

The control of power system restoration refers to load rejection after urgent regulation when there is an accident in power system; or measures of regulating the system to normal condition to the largest extent in shortest time when the system is separated. In distribution systems, accidents mainly indicate that a fault occurring in a certain component (line, transformer, etc) causes protection actions and the break of relative relays, thus causing loss of power in the regions supported by the equipment while segregating the fault source, or the operation of the equipment under overloaded condition. The task of restoration is to restore load as much as possible in power loss regions in shortest time and to shift load from overloaded equipment reasonably. The paper analyzes some factors based on power system restoration taking the status of separated system as its object.

(1) Start Power Supply

The key of successful restoration is start power supply. But not all the power supply can be used as the start power supply, while only those units with self-start , or black-start capabilities can work as the start power supply in separated system. The units with self-start capabilities mean that they can restore power supply rapidly without external help and transmit start power to other units through lines. Among the start power supply, the water turbine generators such as pumped storage generating units are the most convenient.

(2) Restore Path

After an accident in the power system, the restoration process should be in order and in line. Inappropriate order may cause another accident, so the establishment of restore path is an important part in restoring power system. The restore path includes:

 The restore path of power plant: restore path of the power plant without self-start capabilities in the system. Several factors such as high supply reliability, being closest to the start power supply, fewest switch operands etc, should be considered comprehensively while determining the path. The attributes of the power plant may also be taken into account that according to the importance of power plant, nuclear power plant should be restored first, then is the water power plant, the gas power plant, and the coal-fired power plant is the last.

 The restore of load: restore path of the load in power system. While comprehensively considered the factors as high supply reliability, being closest to the start power supply, fewest switch operands etc, the importance of load should also be considered. First class load which concerns the development and security of national economy must be restored first, then is the second and third class load.

 Restore load. Load should be restored according to the order of power transmission. Static stability of the system, frequency stability of the net, voltage stability of the bus, active and reactive power matching and other factors should be considered.

 Switch operating sequence and switch operand. Another factor concerning the process of power system restoration if switch operating sequence and switch operand. The power of load in the system should be restored rapidly while the security and accuracy is guaranteed. Thus the operation order of the switch operating sequence should be given out correctly and rapidly so the operator may operate on the switches in order.

2 The Principle and Application of Breadth First Search (BFS) and Depth First Search (DFS)

2.1 The Principle of Breadth First Search (BFS)

Breadth First Search (or Width First Search) is one of the most convenient graphic search algorithms and also the prototype of many important graphic algorithms. Dijkstra single-source shortest path algorithm and Prim least tree algorithm also take the similar idea as BFS.

While graph G and source point s are known, BFS tries to explore the border of G by a systematic way so as to find out all the points s can reach, and calculate the distance from s to these points (the least number of borders). The algorithm can create a breadth first tree that takes s as its root and can reach all the points. If v is any point that s can reach, the path from s to v in the breadth first tree corresponds to the shortest path from s to v in graph G, i.e. the path includes the least number of borders. The algorithm applies to both directional and nondirectional graphs.

Breadth First Search get its name because the algorithm always extends outwards through borders connecting the found and unfound points. It means that the algorithm first explores all the points which are at a distance of k from s, then explores other points that are at a distance of k+1 from s.

To keep the search track, BFS colors up every point: white, grey or black. At the beginning, all the points are white. With the search, the points gradually become grey, and then black. The first time a point is reached, it becomes nonwhite. So grey and black points means they have be found. But BFS distinguish them to ensure that the search is carried out according to breadth first principle. If $(u,v)\in E$ and point u is black, point v is grey or black (u and v are two search points, E is points collection of G). That is to say all the points adjoining black points have been found. Grey points can adjoin some white points and they represent the borders the found and unfound points.

In the process of BSF, a breadth first tree is created which only includes the root point, i.e. source point s. When scanning the adjoining table of found point u, if a white point v is found, v and the border (u, v) are added to the tree. In the tree, point u is called elder or parent point of v. Since one point can be found only once, it can have only one parent point. To root point, the definition of ancestor and descendant relations is the same as usual: if u is in the path from root s to point v, u is called ancestor of v and v is the descendant of u.

The input graph G is supposed to be

expressed by adjoining table in BFS. For each point u∈V, its color is stored in the variable color[u] and the parent points of u are stored in variable π [u]. If u has no parents (for example, u=s or u hasn't been found), π [u] is empty. The calculated distance from source s to point u is stored in variable d[u]. A FIFO queue is used to store the grey points collection.

2.2 The Principle of Depth First Search (DFS)

Just as its name tells, the strategy DSF follows is to search the graph as deep as possible. In DFS, if a newly found point has an unexplored border, exploration should be carried out through this border. When all the borders of the point v have be explored, the search will go back to the start point that connects v by that border. The process will keep on until all the points that can be reached from source point are found. If there are some unfound points, one of them should be selected as a source point to repeat the above process. The process should be repeated until all the points are found.

Similar as BFS, when scanning the adjoining table that contains the found point u and finding a new point v, DFS will make π [v] (the parent collection of v) u. The difference between BFS and DFS is that the parent child graph of the former algorithm forms a tree while that of the latter one can be composed of several trees as the search may be repeated from several source point. So the definition of DFS's parent child graph is slightly different from BFS's:

$$G_{\pi} = (V, E_{\pi}), E_{\pi} = \{(\pi[v]) \in E : v \in V \wedge \pi[v] \neq NIL\}$$

DFS's parent child graph forms a depth first forest composed of several depth first trees. The borders of Eπ are called branches.

Just like BFS, DFS also colors up the points in the process of search to represent the points' status. Each point is white at the beginning, becomes grey when found and set black at the end (i.e. when the adjoining table is thoroughly searched). The technique can ensure that the search of each point ends in one depth first tress, so these trees are separated.

Besides creating a depth first tree, DFS sets time mark for every point. Each point v has two time mark: the first time mark d[v] is set when v is first found （and v is set to grey）, the second mark f[v] is set when finishing checking the adjoining table of v. The time marks are used in many graphic algorithms and they are very helpful to DFS.

2.3 The Application of Combining BFS, DFS with Tabu Search Algorithm

The efficiency and simplicity of BFS and DFS makes them an effective method of operating path before using tabu search algorithm. Concretely, it means that in the net graph where connecting relations and node attributes are know, BFS algorithm is used first to search the net graph so as to find out those power supplies without self-start capability. The DFS algorithm is carried out to find out all the trees, taking each power supply as a start point. At the same time a search depth should be set according to the actual net graph. The search should stop when reaching this search depth to prevent the problem of low restore speed of the net graph that is caused by one tree's long restore path and the subsequent long power restore time of the load at the end of the tree. Finally a group of independent trees connected by directional lines between nodes can be formed by DFS. Those selected nodes are taken as public nodes through which the independent trees can be connected with each other to form a net graph of power restoration as necessary preparations for tabu search algorithm.

3 The Introduction of Tabu Search Algorithm's Principle

Tabu search （TS）is a universal inner heuristic optimal technique in the use of solving large-scale combination optimal problems. By flexible memory, it prevents search plunging into partial optimization. The basic concept of TS mainly includes “neighbor” and “reservation period”. Usually, TS starts searching from an initial solution which is created randomly or by an existing heuristic method. By “moving” the application operators, TS operates on the current solution and forms a group of neighbor testing solutions. In this process, the solution which best improves the judge function will be chosen as the new current optimal solution. If none of the “movements” can improve the judge function, it indicts the current solution is the partial optimal solution. To avoid plunging into partial optimization, a tabu list with a length is set in TS. The tabu list stores the recently realized “movements” and anti-“movements”, and it must be updated in each iteration. When forming a new “movement”, the “movements” in tabu list must be restrained since they will make the search process return to the visited space. Repeat the TS search process until the stop rule is satisfied.

4 The Application of Tabu Search Algorithm in power system restoration

4.1 The Mathematical Description of Power System Restoration

The problem can be solved by two aspects: the shortest time of power supply restoration and the shortest time of load restoration.

4.1.1 Power Supply Restoration

(1) Objective function

$$\min F(y,z) = \sum\sum (t_i y_i + t_j z_j)$$

Where y is switch collection; y_i=1 when switch closes from disconnection, otherwise y_i=0; t_i is the operation time y_i needs; t_j is the warm-up start time of the power plant; z is load collection; z_i=1 when the current plant is in power supply restoration, otherwise z_i=0.

(2) Restrictions

Capacity restriction: it refers to the capacity of total load allocated for a switch as well as the load of the branches connecting to it. It is described as:

$$\sum x_{ij} s_j \le M_k$$

Where x_{ij} is connection coefficient of relevant switches and branches, x_{ij} =1 when load z_j is supplied by y_i, otherwise x_{ij} =0; s_j is the load of the mono-branch connecting to the switch, M_k is load capacity. j =1,2,⋯.

Voltage decent restriction: certain reactive compensation must be carried out when putting into load to maintain the node voltage in the rating level. It is described as:

$$V_{\min} \le V_{it} \le V_{\max}$$

Where V_{it} is node voltage.

4.1.2 Load Restoration

(1) Objective function

$$\min G(x) = \sum\sum t_i x_i$$

Where x_i shows switch’s status, x_i=1 when switch closes from disconnection, otherwise x_i =0; t_i is operation time of switch.

(2) Restrictions

The capacity restriction and voltage descent restriction are similar as that of the power plant restoration.

Connection restriction: one load needs at

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least one power supply.

Power balance: at a time, the power that all load absorbs equals the power that all plants sends out minus the power those plants consumes.

Accumulator's lasting time: it is described as:

$$\sum t_i x_i < T_{xi}$$

Where T_{xi} is the lasting time of switch's accumulator, i.e. switch's lasting time should be longer than switch's operation time.

The power plant and the load should be considered comprehensively to get matched in solving the problem of power supply and load restoration.

4.2 Instance Analysis

The New Baogang systematic graph of Shanghai electrical net(fig.1) is taken as the example to illustrate how to use tabu search algorithm in determining the restore path after system separation.

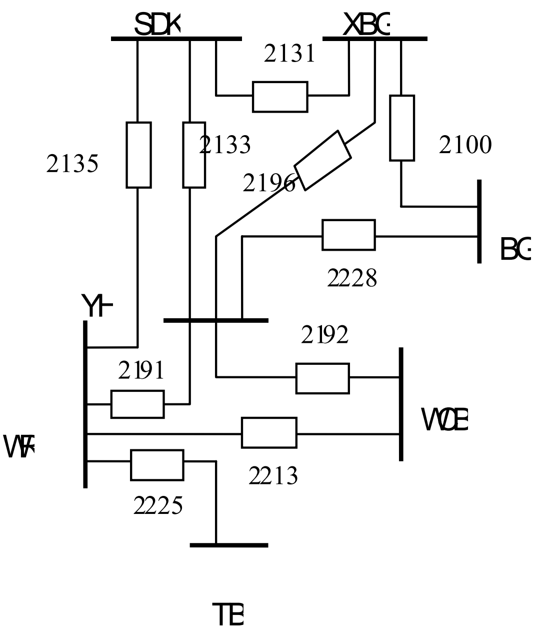

Fig.1 New Bao Steel power net

4.2.1 The realization of tabu list

To realize optimization in power system restoration, the essential is to realize fastest power supply restoration. And to realize the above object, tabu search algorithm can be used to change the power supply of each load so as to find out the best supply path. The search result, i.e. the power supply of each load, should be placed in a status list. So the expression of each change should be easy for storage and usage. The structure characteristics of the status list are as follows:

- The length of the list should be equal to the number of load that hasn't restored its power supply.
- The statistic includes all nodes of the power plant and load.
- Each location of the list represents the upper load or the power supply of the load.

So, the list shows the unrestored load is supported by which power supply respectively. Figure 2 shows the net graph after BFS and DFS algorithm of New Baogang systematic graph.

Table 1 is the start status list of figure 2. It's easy to establish the tabu list given the status list is established, since the function of tabu list is to prevent the search return to the status that have been reached. The storage content of tabu list is as follows:

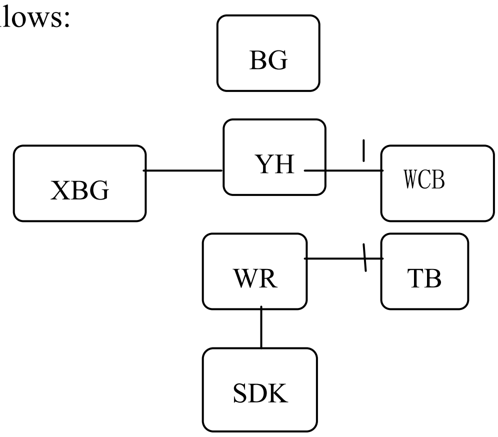

Fig.2 The power net after search

Tab.1 The start status table

Load	Power Supply
YH	XBG
WR	SDK
TB	SDK
WCB	XBG

- Net structure (status list);
- The current status's tabu length;
- Objective function.

Table 2 is the tabu table of figure 2.

Tab2. Tabu table

Net Structure							Tabu Length	Objective Function
XBG	YH	WCB	BG	SDK	WR	TB	5	F（X1）
XBG	YH	BG	WCB	SDK	WR	TB	6	F（X2）

Where F(X1) and F(X2) are general expression of the objective function.

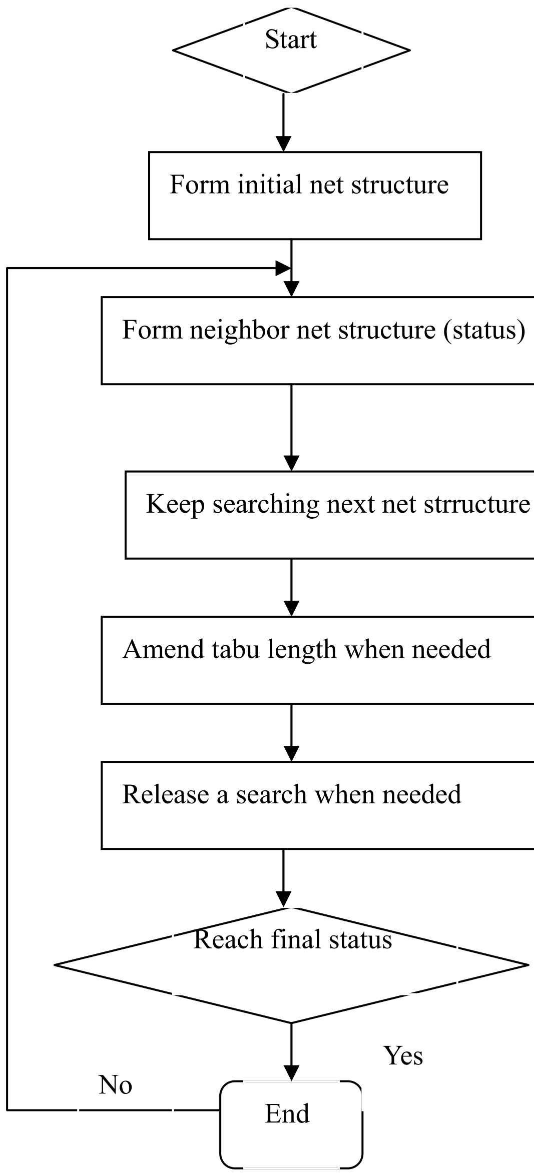

Fig.3 The flow chart of optimal restore path

4.2.2 The realization of search method (status change)

The search for neighbor status can be realized by change the power supply of the load in the current net. And the load whose power supply can be changed must meet the condition that its former and subsequent load is not supported by the same power supply, otherwise the load can't change its power supply. The steps of the search method are as follows:

- Select the load whose power supply can be changed in the current net structure.
- Form the neighbor status by changing the selected load in ①. The status are candidate status for ③.
- Select the status that is most suitable to the object function and isn't tabooed.
- Export the restore path graph of the chosen method.

Figure 3 is the flow chart of optimal restore path by tabu search algorithm.s

5 Conclusion

Based on TS algorithm's advantages on searching optimal power system restore path and discussions on BFS and DFS as well as how their combination provides search path with TS algorithm, the paper discusses the application of TS algorithm on power system restoration, and gives out the system structure of power system restoration based on TS algorithm. Program codes of searching net structure by combination of BFS and DFS as well as searching restore path were written by C++. Program codes of tabu list in TS algorithm were also finished. Complemented by the TS programs, these codes can solve the optimization problem of restore path of target net restoration in power system.

Reference

[1]ZHOU Ling,WANG Xing-nian,DING Xiao-qun,et al. Application of genetic algorithm tabu search combination algorithm in distribution network structure planning[J].Power System Technology，1999,23(9):35-37.

[2] HAN Li-min,WEI You-shuang, FENG Yun-cheng. The Convergence esu lts for TabuSearch Algorithm[J].The Practice and Theory of System Engineering, 1998,(10):6-10.

[3]ZHANG Xue-song, LIU Zuo, YU Er-kan. The strategy of distribution capacitor scheme based on tabu search[J] .Power System Technology，1998,22(2):33-36.

[4] LIU Da-peng, TANG Guo-qing, CHEN Hen. Tabu search based etwork partitioning for voltage control [J].Power System Automation, 2002,(3):18-22。

[5] CHEN Gen-jun, LI Ji-guang, WANG Lei. Distribution system planning by Tabu search approach[J].Power System Automation, 2001(4):40-44.

[6]WANG Hong-zhang, XIONG Xin-geng, WU Yao-wu. Power system reactive power optimization based on modified tabu search algorithm[J] .Power System Technology，2002,26(1):15-18.

[7]HAN Zhen-xiang, QIAN Yuan-ping,WEN Fu-shuan. Tabu search approach to fault diagnosis is in power systems using fuzzy abductive inference.Journal of Tsinghua University, 1993,39(3):56-60.

[8] Zhu Yong-li. Application actuality and latency appliance domain analysis in electric power systems by expert systems[J].Power Information, 1996, (3):5-9.

[9] ZHOU Yun-hai, MIN Yong, YANG Bin. Fault calculation in expert system of relay coordination management[J].Power System Automation, 2001,(15):43-46.

[10]QIU Xiao-yan, TANG Hai-ping. Power system restoration based-on expert system and numberical computation[J].Journal of Electrical Machine Engineering of China, 1996，16(6) : 413－416.

[11]Kirschen, D.S.; Volkmann, T.L. Guiding a power system restoration with an expert system, IEEE Transactions on Power Systems, Volume: 6 Issue: 2, 1991 Page(s): 558 -566

[12]T.Sakaguchi,K.Matsumoto,Development of a Knowledge Based System for Power System Restoration, IEEE Transactions on Power Apparatus and Systems, Vol.PAS-102, No.2,

February 1983 Page(s):320-329