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Research On The Extended Black-Start Scheme Of Power System With Microgrid

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Abstract
Black-start is an indispensable issue to the security defense of power system. Reasonable black-start schemes are of great significance to the restoration of a power system after a major blackout, and the gradually mature microgrid will play an important role in solving various problems in power system. In view of the fact that microgrid has advantages such as flexible operation mode, good regulation performance and large capacity, a novel extended black-start scheme is proposed to restore the power system in a more rapid way, in which microgrid is taken as a single black-start source to start more than one unit to be started simultaneously. After a comprehensive analysis of the scheme's constraints, the improved Dijkstra algorithm is employed to search for the extended black-start paths and produce some reasonable extended black-start schemes combining with the average optimal distribution idea. Then an optimal black-start scheme can be screened out from above schemes after the evaluation and comparison by means of the entropy-weight fuzzy comprehensive evaluation method. The effectiveness of the proposed method is validated by the optimization results on the New England 10-unit 39-bus power system,and compare with the efficiency in different element factor..
Keywords: black-start; microgrid; Dijkstra algorithm; average optimal distribution idea;

1. Introduction

Black-start is the process that can restarting the units without starting ability by the black-start units,when the electric system power cut for breakdown.The black-start units can be grid connected operation with the units stopped before,enlarging the power supply range,letting the system work again [1-2].It is a complex proves,divided into black-start,grid rebuild and load recovery. [3-4] .

Since 1980s,the scholars have done many research and experiment on the generation and assessment on the black-start scheme.Literature [5] study the impact of Network topology analysis and Expert system on black-start,developing a system to generate the scheme.Literature[6] has effectiveness evaluation of black start scheme based on group decision characteristic root method, sovling the optimization of black start scheme problem by the method of matrix feature vector and numerical algebra.

Microgrid is a system unit which combines the distributed power supply, load, energy storage system and various control devices together to form a single controllable self control, protection and management autonomy function , providing electrical energy and heat energy to the user at the same time [7-9]. Micro grid has advantages of flexible control,high energy efficiency,high power quality and capacity expansion ability, showing great potential in being black start power.We suggest that the microgrid can be a black-start power unit.

Considering the constraints of power system extended black-start scheme with microgrid, combined with the solution of the optimal distribution of the average thought, improved and extended Dijkstra algorithm used to form black-start path,resulting reasonable black-start scheme.As a result, there may be many different black-start schemes, and the recovery effects of different schemes may be very different, so the multi attribute evaluation and optimal selection of the schemes is an important problem in the research of black start. Based on entropy weight fuzzy comprehensive evaluation method, this paper establishes a comprehensive evaluation objective function, which is used to evaluate several schemes to meet the constraint conditions, and then determine the optimal expansion of the black start scheme.

2. Feasibility analysis of micro grid as black-start power

Three requirements of black-start power : (1) restart by itself with the power supply; (2) start and stop fast,high add and subtract load speed; (3) large volume, can provide adequate active and reactive power[7-8].Besides,the microgrid discussed has some assumptions(Appendix 1)..

2.1 Capacity of Black-start power unit

In order to ensure that the unit auxiliary equipment can start normally, black-start unit volume can not be too low.The black-start power sunit is the first consideration when designing the black-start scheme of power system。

When the active power of the black-start power unit can not meet the power demand of the load, it will lead to the decline of the system frequency, which will eventually lead to the failure of the black-start.The main consideration of Black start power supply scheme is whether a black start power active power can meet the maximum active power requirements of the auxiliary startup.

Taking starting a 300MW thermal power unit(the data from Appendix 2 form 1) as an example, to illustrate the development of black start power scheme.To start the 300MW Thermal power unit ,it need to start the main auxiliary equipments: electric water pump, blower, induced draft fan, condensed water pump, circulating water pump, closed type water pump, primary air fan etc.

Black-start power unit has requestment of the power adjustment range and climbing speed in a certain period of time.For example,in the relevant provisions of the hydraulic generator of the primary frequency regulation, the power adjustment of the upper limit is 10%,and have to achieve the goal of adjusting the value of more than 90% in 15s, in order to start a electric water pump with maximum power of 5.5MW in form 1.Taking into account the black start power ramp rate and starting time and other factors, it needs a black-start power whose volume is above 66MW. And then consider the unit response lag and other factors, to start a 300MW turbine generator,it need a black-start power supply having volume at least 70MW of the above capacity..

2.2 Characteristics of typical microgrid [9-15]

(1)Microgrid has two modes,operation and grid connected mode. In the case of large power grid fault outage, the microgrid can be disconnected from the large power grid connected nodes, to maintain its own internal stability, keeping from being not paralyzed ; If the microgrid also due to a fault into the blackout,they have their own reliable distributed power and gas turbine, hydroelectric power station unit, in the disconnecting with grid connections, in a relatively short period of time to finish its black-start task, to achieve stable operation, and as a black start power supply again, connected to the power grid,providing output in black-start of large power grid.

(2)Microgrid has a considerable amount, different kinds of distributed power and gas turbine, hydroelectric power station unit inside,with large-scale electric vehicle as energy storage charging and discharging equipment.These power unit and equipment,having high creep speed and clear division of labor, adjusting the output within a short period of time,let micro grid change output power as the black-start power supply.

(3)Power units and supply units in microgrid has a clear division of labor,distributed power supply of V / F control mode stabilizing the bus voltage and frequency ; distributed power supply of PQ control model providing stable active and reactive power output,and distributed power supply of Droop control mode has a plug and the facilitation effects. This structure is easy to be put into the idle distributed power supply at any time，when the upper limit of the output of the micro grid is not satisfied,increase the output power with the free distributed power supply.

3. Extended black-start scheme with microgrid as black-start power unit

The basic idea of the extended black-start scheme with microgrid is that using the microgrid as the black-start power unit, the multiple breakdown units are charged to the recovery path of the breakdown unit, and multiple units are set to start quickly at the same time. Then let the breakdown units operate with the black-start power unit to form a larger capacity of the black-start power unit to start the other has not yet started. According to the actual situation of the fault network, it is divided into a number of recovery subsystems.Each subsystem in accordance with the above strategy for black-start, ultimately achieve the entire power grid restoration after the success of the tie.Compared to the traditional black-start scheme, the proposed scheme can provide greater power support and speed up the recovery process of the power system.

Considering the problem of self excitation and over voltage, power balance and a variety of problems and constraints in the power system restoration,the process to determining extended black-start scheme recovery with microgrid are:

(1)Under the conditions(Appendix 3) of power balance and startup time, using improved Dijkstra algorithm search option for many breakdown unit,distribute a certain number of breakdown unit for each of the black start-power unit with average optimal allocation strategy,determining the recovery path of each subsystem and the extended production of black-start schemes, combining the entropy weight and fuzzy comprehensive evaluation method for the optimal selection of the scheme;

(2)According to the determined optimal extended black-start scheme, the each subsystem of optimal recovery path is recharged,and black-start units are started at the same time;

(3)Microgrid and restarted successfully units in grid work together to build a few larger and stable system. In the same way,the unstarted units are being to be restarted, gradually expanding the system recovery range.

(4)Let the restarted subsystem work parallel, achieving the overall recovery of the power system ar last.
Based on the extended black-start strategy of power system with microgrid,the optimization of multiple black-start schemes can be realized.The evaluation objective function and solution to search for the schemes are showed in Appendix 4..

4. Examples and anaylse

The effectiveness of the way to search for the black-start path and the expansion of black-start scheme optimization algorithm, it is shown in graph 2 New England 10 machine 39 bus system(Appendix 5) as an example.In the system micro network node are set, and contains research on Microgrid extended black-start scheme.
In this system, the research of the extended black-start scheme is carried out. Assume the power system to a different location on whether microgrid node work as the black-start power unit, different geographical position and whether microgrid priority to meet the micro intranet significant load demand.Solve the extended black-start scheme,and make a comparison of the start of the scheme..

3.1 whether the micro grid node work as black-start unit

3.1.1 system does not contain microgrid as black-start unit

Assuming that the system does not contain microgrid, only 33 and 37 of the system node in the water storage power station for black-start. Assuming 33 hydro generator can provide 45MW power, 37 hydroelectric generating units to provide 320MW power.

3.1.2 Situations containing micro-grid nodes not participating in black-start

Assuming when the power system is in failure, the node 32 and node 38 as micro-grids are enter the island operation. In the black-startup phase, they don’t work as the black-start power unit.

3.1.3 Situations containing micro-grid nodes participate in black-start

Assuming that in the system, the node 32 and the node 38 are used as black-start power unit in black-start process.

Then, compare and analyze a black-start scheme with extended black-start scheme(from Appendix 6), which contains one, two and three micro-grid successively. The contrast of the scheme is shown in sheet 3.

Sheet 3 comparison results of the schemes

Scheme	*Start Path*	*time /h*
without microgrid	37-31;33-38; 37-32;33-34;38-30; 37-35;33-36,39	3.465
one microgrid	33—31,32.36;34-38.35 33—30;34—39;34-37	2.58 7
two microgrid	38—34;32—36;33—31,35;37-30,39	1.93

From the above table, the expansion of the black-start scheme containing three micro-grids has more advantages. When without containing the micro-grid played as black-start power unit, the water turbines in 33 and 37 nodes have to be relying on. Because the water turbines provide a lower initial power than the micro-grid, when used in black-start system, there is a longer time-consuming. While micro grid as a black-start power unit, it can provide stable power, including hydropower, wind power, photovoltaic power generation, benefiting to the black-start.

3.2 Microgrid location

Assuming that nodes 33 and 34 work as the microgrid connect to the system and work as a black-start power unit in the black-start stage.

The distance between node 33 and node 34 is very close(Appendix 7). When further distance nodes are needed to start, such as node 30 and node 37, line loss and voltage drop will become apparent in long transmission lines. Thus, it is difficult to compose field subsystems effectively to restore the entire area of the unit. Not only the recovery time is growing, but also caused unnecessary losses from the economic point of view. The contrast of the scheme is shown in sheet 4.

Sheet 4 comparison results of various schemes

Scheme	*Start Path*	*time /h*
microgrid between far location	33—32,34,36,38;37—31; 33—35; 37—30,39.	1.93
microgrid between near location	33—31,32,36;34—38,35; 33—30;34 — 39;34 — 37	2.76

3.3 The microgrid output power as a black-start power

3.3.1 Microgrid giving priority to the supply of its own important load

The micro-grid itself has some important loads. Assuming that the node 33 and node 31 gaving priority to its own important load work as black-start power unit, the unit's output power is reduced. Assuming that the initial startup power provided by node 33 can be reduced by 150MW, the initial startup power provided by node 31 can be reduced by 150MW.
In this case(Appendix 8), although the node 33 and node 31 can restart the units effectively, not divide the respective black-start region clearly.

3.3.2 Micro-grid priority to provide output to black-start process

If the priority of the network node is assumed to be low, when it works in connected-grid pattern and aim at start the units with priority, the initial power which can be provided attain the maximal value. In order to achieve the comparison of conditions, the node 33 and node 31 act as the black-start power unit.

In this case(Appendix 8), the node 33 and node 31 can start the units effectively, they can't divide the respective black-start region clearly as well.

Compare the microgrid its own load priority level of node 33 and node 31, the comparison of the program is shown in sheet 5.

Sheet 5 comparison results of schemes

Scheme	*Start Path*	*time/h*
cantaining two microgrid with its load of high priority	33—38;31—36,34,35,39; 33—32; 31—30;38—37.	2.635
containing two microgrid with high priority to scheme	31—36,32,30;33—38,34; 31—35;33—39;36—37	2.147

After working out the startup path, the system forms the partition automatically. According to the starting line, form two recovery subsystems. Each subsystem contains a micro grid black-start power unit. Each subsystem restarts the units and connect to the system later. In the solving process of the black-start scheme, the microgrid or other black-start power units can start multiple units under the conditions of the generation power limitations,finally getting one or more extended black start schemes. Evaluate these solutions and obtain the evaluation values, then select the optimal scheme as the best scheme. According to the analysis of the calculation, the optimal scheme is the expansion of black-start scheme containing microgrid, thus validating the effectiveness of optimization method of the power system expansion black-start scheme containing microgrid.

3.4 Comparative analysis of black-start scheme [27-28]

3.4.1 Time required to start the breakdown units

Regular single black-start power unit's "one to one" black-start scheme to start all the breakdown units usually use more than 7 hours.However, for the extended black-start scheme containing one single microgrid, due to the "one to many" strategy of restarting multiple breakdown units at one time, the required time is greatly reduced to more than two hours; for the extended black-start scheme containing several microgrids, due to the "many to many" strateg, the required time is greatly reduced to no more than two hours,for example 1.9 hour or 1.1 hour only. When the power system contains a number of microgrid,use the proposed extension black-start scheme can greatly save the time required for the start of the units, building a favorable foundation for the following research of the microgrid and meeting the recovery.

3.4.2 Startup path

The regular black-start scheme has single path and takes a longer period of time, leading to spending more time on the restoration and recovery of system load. But,the extended black-start scheme with the microgrid is carried out at the same time to carry out multiple paths of charge recovery,forming several multiple recovery subsystem partition. After the completion of each unit and the line charging restart, due to the voltage support function of the micro grid nodes, the system can reduce the total number of charging on the line during the black-start restoration period.Then complete the recovery by connecting to the power system. In addition,because the microgrid guarantee the important load power supply, reducing the power loss caused by the economic losses and the load in the black-start recovery period needed to restare, eventually greatly saving system recovery time and the losses caused by power failure for a long time.

3.4.3 Recovery stability

At the recovery phase of black-start, because microgrid ensures one part of load required greatly, the load of extended black-start containing microgrid need to restore is greatly reduced,improving the spare capacity relativly in the system,improving the stability of the system. And in the regular black-start, the line loss and voltage drop are more obvious after a long transmission line. The microgrid has the function of nope voltage support to the electric power system. If this line passes through the microgrid nodes, the voltage support, will greatly improve the quality of its power. Therefore, in each partition of the microgrid, the various recovery subsystem has voltage support. The subsystem formed by a plurality of microgrid can also avoid the longer distance of power supply, which makes it more stable to provide power for the load.

In summary, in the solving process of expansion of black-startscheme containing microgrid, microgrid or other black-start power unit can restart several breakdown unit,getting the evaluation value, and the best value of the extended black-start scheme is selected as the best. After these paths are formed, the system partition is also completed. The recovery subsystem contains a micro grid black start power unit, and conducted several rounds of black-start in their respective regions, until all the units in the recovery subsystem are started up.Eventually, each subsystem is connected to the grid, and the black start process of the whole power grid is completed.

The results obtained by the algorithm program are the optimal scheme of black-start for the node system with micro network, which verifies the effectiveness of the extended blac-start scheme for power system with microgrid.

4. Conclusion

In this paper, the structure and various control modes of the micro network are introduced briefly. With its flexible operation mode, good regulation performance and larger capacity, the microgrid has the potential to act as a black-start power unit. Then, a new method is proposed to provide a new method for the development of black-start scheme, which is based on the black-start power unit with the microgrid and the multiple breakdown units can be started at the same time.Set entropy weight fuzzy comprehensive evaluation of maximum value as the goal, considering the constraints of black-start power system units and transmission lines, established optimization model of expansion black-start scheme containing microgrid power system.succeeding in solution and optimization of scheme with the average optimal distribution theory and the improved Dijkstra algorithm. Compared with the regular black-start scheme, extended black-start scheme containing microgrid can make sure the important load operatate normally when the power system is breakout, and under the precondition of satisfying the various constraints,restart several started units, greatly increase the recovery speed of black-start and network reconstruction.Besides,discuss the impart of the black-start units'geographical position,output capacity,on the time needed to restart.

Appendix

Appendix1

To simplify the problem to solve,make six assumptions of the microgrid：

(1)The microgrid can provide enough output power under the premise of meeting the stable operation of the important load;

(2)The path recovery time of each program is the same ,as well as the startup time of all the units being activated same;

(3)All power plant substation node, nodes and load nodes of the network topology model are abstracted as nodes in the network ,which is no difference, and do not consider the ground;

(4)In order to eliminate the multiple edges and self loops in the grid topology model, the paper eliminate the multiple edges and self loops in the grid topology model, which is combined with the transmission lines of the same tower and the grid structure;

(5)Each black-start power and successfully restarted unit can only restart 20 units at the same time;

(6)There will be no line fault during black start.

Appendix2

Form 1 lists the auxiliary motor volume configuration of 4 typical thermal power plant.

	A	B	C	D	E
Electric feed pump	5250	3300	5200	3500	5500
Blower fan	1250	710	560	450	710
Induced draft fan	1500	2600	1800	2100	1800
Condensate pump	710	1000	1000	1000	1000
water circulating pump	1600	1600	1800	1500	
Closed type water pump	400		355	355	
Primary air fan	400	1120	1700	1700	1120

Form 1 300MW power generator auxiliary configuration.

Appendix3

3.1 Constraint condition

Extended black-start restoration path must satisfy the breakdown unit, circuit, system and a series of constraints, these constraints can be selected to meet the requirements of the extended black-start scheme [16].

(1)Constraint of starting power

Extended black-start scheme is that a black-start power unit restarts multiple units at the same time,In order to ensure that all units can be started normally,the total required load of all units needed started should be less than the black-start power unit can provide.

$$\sum_{i=1}^{n_c} P_{ic} < K_1 P_0$$

In the formula : P_{ic} is the power requirement of the No.i restarted unit;n_c is the number of the restarted units;K_1 is the active reliability coefficient,its value less than 1;P_0 is the total power of theblack-start units provide,its value is

$$P_0 = \sum_{i=1}^{n_B} P_{Br}$$

In the formula：P_{Br} is the power of the No.i restarted unit provide,whose value,in addition to ensure the reliable operation of the black-start unit ,should also retain a certain amount of hot standby;n_B is the number of the black-start units.

(2)Thermal start time constraint of the black-start unit

After the recovery of the black-start path, the unit must be activated in the hot start time.So the maximum critical thermal start-up time of the breakdown unit should be greater than the path recovery time.，the constraint of start time is:

$$T_{iMAX} > t_0$$

In the formula：T_{iMAX}v is the maximum critical hot start time of No.i unit;t_0 is Path recovery time.

(3)Constraint of reactive power

In order to avoid the problem of the blackstart power unit, such as the shortage of reactive power absorbing ability and the transformer over excitation,harmonic distortion and harmonic voltage,the reactive power constraints of the recovery path are considered. The recovery path of the extended black-start scheme is considered to be less than the total reactive power absorption of the black start unit after considering the residual charge power of the high or low compensation.

$$\sum_{j=1}^{n_L} Q_{Lj} < Q_{B\max}$$

In the formula：n_L is the number of lines in the extended black-start recovery path;Q_{Lj} is the No.j line's reactive power of residual charge after high or low compensation is considered;Q_{Bmax} is the maximum reactive power absorbed by black-start power unit，its value is

$$Q_{B\max} = K_2 \sum_{r=1}^{n_B} Q_r$$

In the formula：K_2 is the reactive reliability coefficient,its value less than 1；Q_r is the No.r maximum reactive power absorbed by the black-start unit.

(4)Self excitation constraint

Black start units with long unloaded line prone to self excitation, so the program should consider the constraint conditions of self excitation, the line remaining charging power less than the product of black-start units rated capacity and short circuit ratio after considering high resistance and low resistance compensation.

$$\sum_{j=1}^{n_L} Q_{Lj} < \sum_{r=1}^{n_B} S_{Br} K_{CBr}$$

In the formula：S_{Br} is the rated capacity of the number r black-start unit;K_{CBr} is the short circuit ratio of the number r black-start unit.

(5)System power flow constraints

$$f\left(x, u, p\right) = 0$$

In the formula：x is the System state variable（generator output or node voltage mode value）;u is the system control variables（node voltage mode value and angle）;p is the system disturbance variable（load）.

(6)Breakdown unit, node voltage and line transmission constraints

The constraint conditions for active power output and reactive power output, node voltage and line transmission limit of generator sets are

$$P_{Gi\min} \le P_{Gi} \le P_{Gi\max}$$

$$Q_{Gi\min} \le Q_{Gi} \le Q_{Gi\max}$$

$$U_{i\min} \le U_i \le U_{i\max}$$

$$P_i \le P_{i\max}$$

In the formula：P_{Gi} is the active power generation；Q_{Gi} is the reactive power generation；U_i is the node voltage；P_i is the active power flow over a branch i.

Appendix4

4.1 Evaluation objective function

In the power system of a power outage, the black-start scheme meets the constraint conditions,and the optimal black start scheme can be selected effectively. According to the general principle of the black-start scheme, the 6 evaluation indexes, such as the voltage conversion times, the path length, the starting time, the breakdown unit capacity, the technical verification, and the breakdown power priority level, are selected. [17-18]. Using the entropy weight fuzzy comprehensive evaluation method to evaluate the black-start scheme, constraint checking,comprehensive evaluation value of each project,determining the optimal extended black-start schemes.

To make the evaluation index of the number I scheme set as $U_i=\{u_{i1},u_{i2},u_{i3},u_{i4},u_{i5},u_{i6}\}$,$u_{ij}$ (j=1,2,3,4,5,6) representing the value of the number j evaluation index of the number I program,while the evaluation matrix for number M alternatives is $C'=[u_{ij}]_{m\times 6}$, i=1,2,…,m.Using the standardization method of literature [18] and [19], the standardization of C' was processed,and the standardization evaluation matrix was obtained,the $C=[c_{ij}]_{m\times 6.}$

According to the definition of entropy and entropy weight, the entropy weight of the number j index is

$$\omega_j=\frac{1-H_j}{6-\sum_{j=1}^{6}H_j},0\le\omega_j\le 1,\sum_{j=1}^{6}\omega_j=1$$

In the formula : $H_j=-k\sum_{i=1}^{m}f_{ij}\ln f_{ij}$, the entropy for the number j index ; $k=1/\ln m$; $f_{ij}=c_{ij}/\sum_{i=1}^{m}c_{ij}$.

It can be known that the entropy weight reflects the information contained in the objective data, that is, the difference of the index in different programs, and the importance of the index should be decided by the experts according to the actual situation. So in the black-start evaluation will be a reasonable combination of the right to the entropy and expert weighting. Suggesting that the 6 evaluation indexes of experts' subjective weight vector are $\lambda=[\lambda_1,\lambda_2,\lambda_3,\lambda_4,\lambda_5,\lambda_6]$,then the comprehensive weight of the number j evaluation index is

$$a_j=(\omega_j+\mu\lambda_j)/\sum_{j=1}^{6}(\omega_j+\mu\lambda_j)$$

In the formula : μ is the relative validity coefficient of the subjective weight to the objective entropy weight,0.3<μ<3. As a result, the integrated weight vector is $A=[a_1,a_2,\ldots,a_6]$.

Fuzzy comprehensive evaluation method is forming the fuzzy evaluation matrix R by mapping the evaluation index of the evaluation object U to the comment set V, through the fuzzy mapping relationship (some membership function). Then fuzzy matrix is applied to the comprehensive weight vector and fuzzy matrix to get the fuzzy subset B which reflects the degree of membership of the evaluation object to the V.Finally, according to the comprehensive evaluation of the objective function,the optimal black-start scheme can be determined[20]. Set the evaluation factor set $V=\{v_1,v_2,v_3,v_4,v_5\}$={ Excellent, good, medium, qualified, poor }.The value of the evaluation factor set indicates the membership of a black-start scheme to the comment.Using the isosceles triangle membership function:

$$r_{ij}(v_k)\begin{cases}\dfrac{c_{ij}-p_k}{q_k-p_k},p_k\le c_{ij}\le q_k\\ \dfrac{s_k-c_{ij}}{s_k-q_k},q_k\le c_{ij}\le d_k\\ 0,\text{ot her}\end{cases}$$

In the formula : $r_{ij}(v_k)$ is the membership degree of number j index of the number i scheme relative to the comment v_k,k=1,2,…,5 ; p_k、q_k、s_k are constant relative to the v_k comment , q_1=0 , q_2=0.25 , q_3=0.5 , q_4=0.75 , q_5=1 ; the himline value of isosceles triangle is 1.6.

According to the above triangle membership function, the number I scheme fuzzy evaluation matrix is $R_i=[r_{ij}(v_k)]_{6\times 5}$,having fuzzy operation on matrix A and R_i , and performing normalization.Set b_{ik} as the membership degree of the number I scheme relative to comment k,its value is:

$$b_{ik}^{'}=\sum_{j=1}^{6}a_j r_{ij}(v_k),k=1,2,\ldots,5$$

$$b_{ik}=b_{ik}^{'}/\sum_{k=1}^{5}b_{ik}^{'},k=1,2,\ldots,5$$

As a result, the fuzzy comprehensive evaluation results of the I scheme are $B=[b_{i1}, b_{i2},b_{i3},b_{i4},b_{i5}]$. In order to get the comprehensive score of each extended black-start scheme, each comment set is assigned a score.The diversity evaluation is $V'=\{v'_1,v'_2,v'_3,v'_4,v'_5\}$.The evaluation objective function for schemes are

$$F = \max \sum_{k=1}^{5} b_{ik} v_k^{'}, i = 1,2,...,m$$

4.2 Solution and evaluation of extended black-start scheme with micro grid

The power system containing micro grid extended black-start process needs to consider a large number of the discrete control variables and constraints,the multi constraint multi-objective nonlinear optimization problem.The comprehensive evaluation model of the extended black-start scheme considers six evaluation indexes, such as the length of the path and the priority of the unit,giving subjective weights and objective weights.Finally,the evaluation of the objective function can be evaluated by the fuzzy transformation. In the process of solving the black-start scheme, it is needed to find a set of the units which meet the above starting time and active power constraint,with the power flow calculation and the related check of the unit.

In this way, the optimization problem of the extended black-start scheme can be transformed into a knapsack problem, which is composed of a plurality of constraints and an objective function. Knapsack problem belongs to the NP type of problem, there is no polynomial time algorithm to solve it. In this regard, this paper uses the Dijkstra algorithm and the average optimal allocation thought to solve the black-start scheme which meets the requirements. The average optimal allocation idea is to allocate the unit which needs to be restarted for each of the black-start unit,while Dijkstra algorithm search path restoration for each black-start schemes. In the end, the method of fuzzy comprehensive evaluation of entropy weight is used to evaluate the solution and find out the optimal solution.

4.2.1 Search extended black-start path algorithm based on Dijkstra

In the black-start process, long recovery path length will cause the too high voltage, too long recovery time and many problems.So many algorithms for solving the black-start schemes are considered, and regard it as the main factors. With the help of graph theory, the structure of the power system was converted into a acyclic undirected graph based on the length weight of the path between the units and the tree in graph theory used to solve the graph question is used to resolve the path restoration. This paper use Dijkstra algorithm to search the shortest path of recovery [21-24].

The basic idea of Dijkstra algorithm is to set two fixed points set T and S. The set S store points that have found the shortest path to the fixed-point set,while T store the points that haven't been able to find the shortest path point. Initially, the collection S only contains the origin point v_0 , and then continuously select the point u to join the collection S which have been able to find the shortest path path to point v_0;For each new vertex u in the set S, the shortest path length value of the fixed point v_0 to the remaining vertex of the set T is modified; The shortest path length value of each point in the set T is the shorter path length value between the shortest path length value to v_0 before and the shortest path length value to point v_0 plus to the value of the path length to point u; This process is repeated until the points of the set T are all added to the set S [25-26].

In solving algorithm,with micro network extended black-start constraints,search for the restarted units and build the black-start scheme in a certain order of arragement,which is the startup sequence of units in scheme.In particular, even if they are the same unit to start, it is a different black-start scheme because of the different startup order. Besides,Dijkstra algorithm is to find the shortest path to start the corresponding unit, depending on the starting sequence of the units in the program.

4.2.2 Solution and optimization evaluation based on the average optimal allocation

There is a difference between the extended black-start scheme and the conventional black-start scheme. On the one hand, the black-start power supply of the expansion of the black-start scheme ,under the premise that maintain its own load,start up several breakdown units, implementing the expansion strategy of "one to many", to achieve the optimal use of black-start power generation and improve black-start recovery efficiency. On the other hand, after the partitioning to breakdown network,there may has multiple black-start power recovery subsystem,with the implementation of “many to many”, greatly shorten the black-start required time.

For the above two cases, this paper puts forward average optimal allocation algorithm, to achieve the "one to many" or "many to many" expansion strategy in which the optimal allocation of breakdown units, combining with the Dijkstra algorithm and entropy weight fuzzy comprehensive evaluation method to achieve extended black-startup scheme for solving and optimization.

The average optimal allocation algorithm is as follows：

The first step: according to the priority of each started unit,sort these units, the same priority is set to start the unit in the same class.

The second step:searching from each power unit of black-start power set, let each of the black-start power unit search for a breakdown unit meeting the constraints from six levels of unit through the priority principle (priority for high grade activated units in the collection unit). If there is, then the unit will be removed from the breakdown set; if not,it means that this black-start power unit is not suitable, removing it from the power set.

The third step: each black-start power unit has a breakdown unit, and each black-start power unit has their black start scheme; Let each power supply scheme substituted into the objective function, calculating for evaluating value of these schemes.Then put all the schemes and their values into the RAM.

The fourth step: check whether each black-start power generation capacity is enough to start a more than one of the breakdown unit. If sufficient, the power supply is repeated for second,three and four steps, looking for a suitable breakdown unit and adding it to the scheme until all the units that have been assigned or each black-start power unit is assigned to the 20 set.If insufficient, the search for the power supply is stopped.

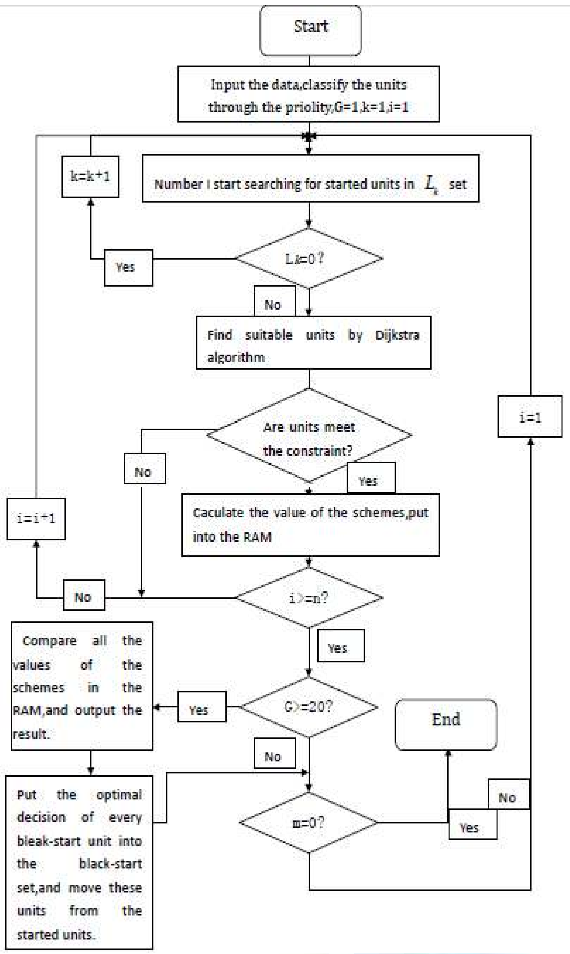
The fifth step:comparing all the value to get the largest value, the value of the corresponding solution is the optimal black-start schemes of the power supply units.

In the process of finding a suitable breakdown unit for each black-start power unit, the black-start power unit is screened from the high grade set type first. In the level of the activated unit, using Dijkstra algorithm to calculates the breakdown unit from the shortest distance of the black-start power unit, then determine appropriate started unit according to the load and path length constraints. If the black-start power unit can not choose the breakdown units in the level with the constraint condition, they continues to find the breakdown units at the next lower level categories,according to the above process, until it succeed. If they can not find in all the breakdown units to meet the constraints of the units, it means that the power unit is not suitable for black-start power unit,and it will be removed from the set of black-start power units.

When all black-start power units have their own optimal black-start schemes, the first start-up process can be executed.Then put those breakdown units who have been started successfully into the set of black-start power units set,until all the breakdown units have benn restarted.Now the scheme end,also the black-start process.

4.2.3 Solution of the scheme and the calculation procedure of the optimization evaluation algorithm

Combined with the Dijkstra algorithm, average optimal distribution theory and entropy fuzzy comprehensive evaluation method,micro network expansion of black-start scheme of calculation and optimization of process are shown in Figure 1. Among this, n is the number of units in the set of black-start power unit,m is the number of units in the set of the breakdown set.L_k （k=1,2，…,4） is the number of units in the set of the class of the number, G is the number(20 units) of units that can be activated at one time.



Picture 1 Flow chart of the selection of the extended black-start scheme with microgrid

Appendix5

Assuming the node 33 and node 37 are the water storage power station, the role of black-start power during the black-start process.

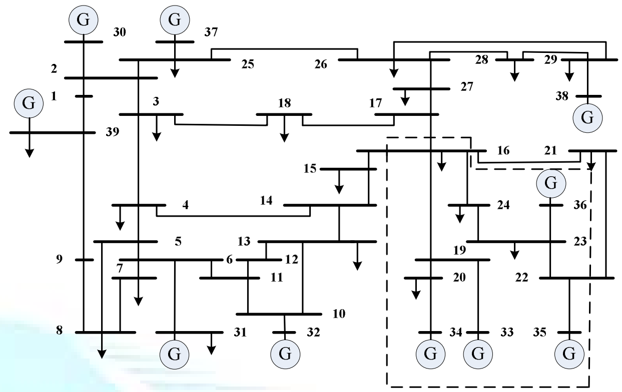


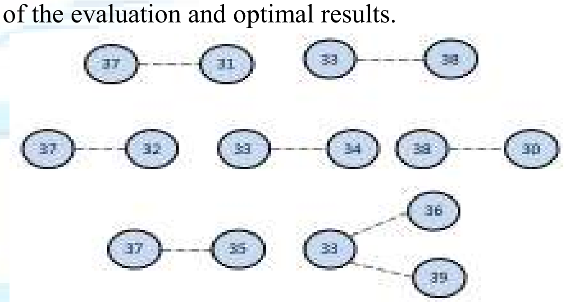
Figure 2 new England 10 machine 39 node system

Sheet 2 the startup parameters of the microgrid and started units

Unit Number	*Power generation /MW*	*Rated capacity /MW*	*Starting power /MW*	*Starting time /h*	*Short circuit ratio*	*priolity*
30	350	437.5	175	0.67	0.7	3
31	600	750	300	0.5	1.1	1
32	250	312.5	125	0.67	0.5	2
33	632	790	330	0.7	1.2	1
34	300	375	150	1.1	0.6	2
35	250	312.5	125	0.83	0.5	3
36	330	412.5	165	1.1	0.67	3
37	320	400	160	1	0.65	4
38	300	375	150	0.83	0.6	4
39	300	375	150	0.83	0.6	4

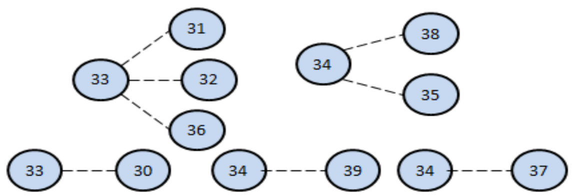
Appendix6

From the output results we can see, the path search in each line of the evaluation and optimal results.



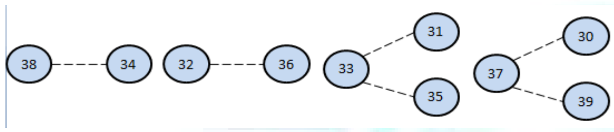
Picture 3-2 system does not contain microgrid as black-start unit

The output results show that the evaluation and optimal results of each line in the path search progress.



Picture 3-3 the expended black start recovery path containing a micro-grid which not participates in black start

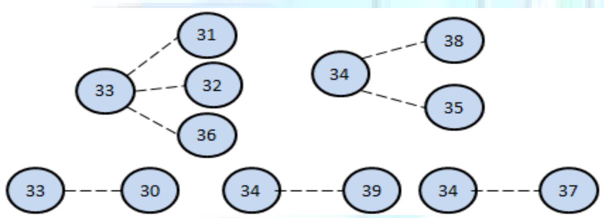
Get the results of the expansion of the black-start path scheme.



Picture 3-5 Containing three extended micro-grid black start recovery paths

Appendix7

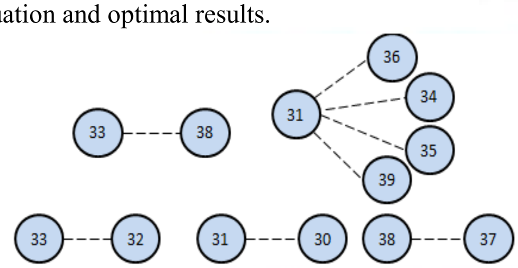
From the outputs, the evaluation and optimal results of the path search in each line is shown.



Picture 3-6 the recovery path of the espansion black-start scheme with near geographical position

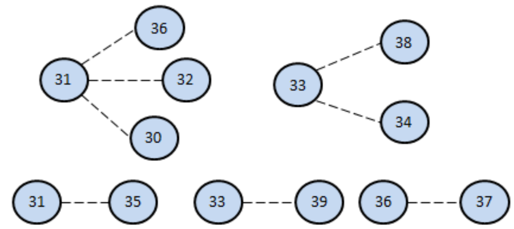
Appendix8

The output result shows the path search in each line of the evaluation and optimal results.



Picture 3-7 expended black start scheme recovery path with two microgrid with its load of high priority

The output result shows the path search in each line of the evaluation and optimal results.



Picture 3-8 expended black start scheme recovery path with two microgrid with high priority to scheme

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