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Optimal placement of fast cut back units based on the theory of cellular automata and agent

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Abstract. The thermal power generation units with the function of fast cut back could serve power for auxiliary system and keep island operation after a major blackout, so they are excellent substitute for the traditional black-start power sources. Different placement schemes for FCB units have different influence on the subsequent restoration process. Considering the locality of the emergency dispatching rules, the unpredictability of specific dispatching instructions and unexpected situations like failure of transmission line energization, a novel deduction model for network reconfiguration based on the theory of cellular automata and agent is established. Several indexes are then defined for evaluating the placement schemes for FCB units. The attribute weights determination method based on subjective and objective integration and grey relational analysis are combinatorically used to determine the optimal placement scheme for FCB unit. The effectiveness of the proposed method is validated by the test results on the New England 10-unit 39-bus power system.

1. Introduction
Power system has been developed as one of the world's largest artificial network. With the increasing complexity of network structure, partial faults caused by improper handling may lead to cascading failures in the system, and eventually result in major system blackout accidents and bring out huge economic losses. After blackouts, guided by black-start power sources such as traditional hydroelectric generating sets, units without the self-starting capability will start generally, and then the entire grid will be restored. However, the output of hydro-power plants is generally smaller and its construction is harsh to the environment. Therefore, in the lack of traditional black-start power supply area, after technological transformation in conventional thermal power units, they are having fast cut back (FCB) function which could restore power rapidly, and act as black-start power. This technological transformation is of great significance[1, 2]. By FCB technology transformation of the units in different locations in the power grid, the impact on the subsequent recovery of the system is also different. So the research has critical significance to optimization layout scheme FCB [3].

In recent years, many researchers have carried out extensive research on system recovery, literature [3] uses discrete particle swarm optimization algorithm to achieve the goal of determining the framework of the network; the research focus of the literature [4] and the literature [5] is the optimization of the start-up sequence of the unit; literature [6] and [7] focus on the optimization of the
reconstruction path. The optimization of unit start-up sequence and the optimization of the reconstruction path are simultaneously carried out by the literature [8] and [9]. However, the actual recovery process in the power grid [10] frequently, unpredictable situation such as over-voltage in lines, makes recovery process cannot be carried out according to pre-optimized scheme. Meanwhile, in the actual restoration process, the urgency of the situation makes dispatchers tense. So the order tends to be conservative and with local characteristics. These factors are not well considered in the above studies. Therefore, in order to determine the optimal and global recovery FCB unit layout schemes, they always differ from the actual situation.

In order to overcome above shortcomings, this paper introduces the concept of cellular automata [11] and agent [12], and the model of network reconfiguration is established. Based on the model, the process of network reconstruction in placement schemes of FCB units is simulated many times, and a number of indicators to evaluate the effectiveness of network reconfiguration is extracted. Several indexes are then defined for evaluating the placement schemes of FCB units. The attribute weights determination method based on subjective and objective integration and grey relational analysis are combinatorially used to determine the optimal placement scheme for FCB unit.

### 2. Important parameters involved in the process of network reconfiguration

Important parameters in the process of network reconfiguration include the following three parts: line’s weighted value, importance degrees of nodes, and circuit switching failure rate. The calculation of line weights is about charging reactive power of path, and importance of nodes refer to the calculation method in literature [13].

This paper considers the operating overvoltage and the circuit switching failure rate caused by environmental factors. And in literature [14], the operating overvoltage is considered. A lot of equipment in the system is exposed, so the probability of equipment failures will be greatly increased. In essence, the environmental dependence of outage means only the dependence exist in system components to the environment, rather than the correlation between the components and components. Harsh environment usually refers to unsuitable weather conditions such as wind, rain, snow and so on. If the failure frequency of components in normal or bad weather conditions are known, the system risk under the two climatic conditions can be evaluated separately, and the final risk index is weighted by the probability of the two weather conditions.

\[
f_{no} = f_{ad}P_{ad} + f_{no}(1-P_{ad})
\]  

Equation (1) the failure frequency of \( f_{ad} \) and \( f_{no} \) are in the form of severe and normal weather conditions respectively.

### 3. Network reconfiguration model based on cellular automata and intelligent agents

#### 3.1 Application of cellular automata in network re-configuration

In the power grid, the basic definition of cellular automata model for network reconfiguration is as follows:

1) Definition and state of cells. The cell is defined as the actual node and numbered cellular orderly arrangement from small to large. The state of the cell is represented by the state of the corresponding node in the network, such as: 1 indicates that the node is recovered; 0 indicates that the node is in a fault state.

2) Definition of cellular spaces. According to the actual situation of the power grid, this paper directly determines the space of each unit cell, and accurately reflects the distribution of the grid components.

3) Definition of cellular neighbors. In this paper, the definition of cellular floor is proposed, the other cell directly connected to a cell is defined as the first floor neighbor of the cell, the cell connected to a cell with crossing another cell is defined as the second floor neighbor, and so on.

4) Cellular transformation rule. The rule of cellular transformation is combined with the concept of intelligent agents, which is analyzed in detail in the next section.
3.2 Application of agents in network reconfiguration

All the bus nodes are all configured as bus agents. In the whole network, a facilitator agent (FAG) is configured to simulate the scheduling control of the intervention system. Next, the BAG (a bus agent) and FAG models are described respectively.

The purpose of BAG is to restore the load in corresponding bus. Each BAG has the following simple rules:

1) Target selection rules: If there are many restorative-available points or boundary points between the energized and de-energized area, then the BAG has to restore its own bus through the restorative-available point with the maximum capacity.

2) Communication rule: If the BAG is restored, the BAG tries to make a communication with its neighboring BAGs.

3) Joint rules: Joint mode exists between BAGs. When a BAG can only be returned to normal power through another BAG, there is a joint pattern between the two BAGs, that is, when the first level BAG failed to recovery, the current BAG directly labeled as recovery failure.

FAG is a special agent that facilitates the process of the multi-agent system, and it is not reflected in the restoration, but above the all of BAGs. After a power outage occurs, the FAG will start to perform the recovery process.

Simple rules of FAG are as follows:

1) Before each step of the recovery, parameters are obtained from each BAG, and nodes need to recovery also selected from these BAGs.

2) Through a re-operation at least, BAGs selected by FAG still fail to recover or another BAG fail to recover during the recovery process. FAG will select the new BAG to be restored.

3) When the top BAG of the BAGs in the combined mode fail to recover, the FAG will send the failure message directly to the rest of the BAGs.

4) All the BAGs in the concern list of FAG recover successfully or cannot recover, that means the end of network reconfiguration.

Rules that FAG select BAGs to be restored are as follows:

According to the data in the critical matrix, FAG looks for three floors of neighbors from the restored BAGs. If there are power plant BAGs without recovery in it, they will be added to the list to be restored. If all the plant BAGs are recovery, FAG will find the neighbors in the two floors. If there is the load BAG without recovery, it will be added to the list to be restored. If the load BAGs are more than one, the node in max importance degree is selected by FAG, and then the recovery of BAGs is ended. If there are the load BAGs without recovery in the two floor, FAG will find the neighbors in the one floor and the max importance degree of BAGs, and it will be added to the list to be restored.

4. Evaluation system

The evaluating indicator of optimal placement scheme for FCB unit is defined: \( V_1 \) is the numbers of recovery failed units, \( V_2 \) is the times of line charging, \( V_3 \) is the numbers of recovery failed lines, and \( V_4 \) is the numbers of related recovery lines. In the literature [15], a method of determining the attribute synthetic weights of the subjective and objective integration is proposed. In this paper, this method is adopted to determine the weight of \( V_1 \), \( V_2 \), \( V_3 \) and \( V_4 \). Combined with the grey relational analysis[16] to evaluate the optimal placement scheme for FCB unit, the greater the grey weighted correlation degree, the better the scheme is. Figure 1 is the flow chart of the optimal placement scheme for FCB unit.
Initialize and determine the recovery node

Fail to recover or restore

According to the message uploading to FAG, determine the node number in 1, 2, and 3 floor

Based on rules, select BAG node need to recover and save it in _re1

Through floyd algorithm and communication among BAGs, FAG determine the beginning BAG node, and call it fin1

Recover to _re1?

Through the communication among BAGs, determine the next BAG node, and called it fin2

Recover to the certain line?

Through the floyd algorithm and communication among BAGs, FAG determine the beginning BAG node, and call it fin1.

set fin2 node to the sign of failure

Through the joint mode between BAGs, to determine whether there is a bundle of BAG nodes, these nodes are set to a sign of failure

Figure 1. The flow chart of the network reconfiguration.

5. Simulation result

The effectiveness of the proposed method is validated by the test results on the New England 10-units 39-bus power system. Considering the generator node 32 to the FCB unit node, Figure 2 illustrates the simulation results base on the network reconfiguration of the cellular automata. Red lines represent successful operation lines at the first time, yellow lines represent successful operation lines heavy after once re-operation, blue lines represent failed lines after once re-operation, and green lines represent not involved lines.

Figure 2. The network reconfiguration of the FCB unit with 39 nodes.
Particularly, on the way to recover node39, node9 failed to recover, and FCB send query command again. Node39 and node9 are not in joint state, so node39 cannot be considered fail to recover and node30 is selected as the new node to be recovered. The indexes involved in this reconstruction are shown in Table 1:

**Table 1. Indicator values of the network reconfiguration.**

| V1 | V2 | V3 | V4 |
|----|----|----|----|
| 0  | 43 | 2  | 35 |

The recovery process of the network reconstruction is shown in Table 2:

**Table 2. Recovery target and recovery path at each time step.**

| Step k | recovery target node | Recovery path |
|--------|----------------------|---------------|
| 1      | 13                   | 32-10-13      |
| 2      | 31                   | 13-12-11-6-31 |
| 3      | 4                    | 6-5-4         |
| 4      | 39                   | 5-8-9         |
| 5      | 30                   | 4-3-2-30      |
| 6      | 39                   | 2-1-39        |
| 7      | 37                   | 2-25-37       |
| 8      | 38                   | 25-27         |
| 9      | 15                   | 4-14-15       |
| 10     | 33                   | 15-16-19-33   |
| 11     | 34                   | 19-20-24      |
| 12     | 36                   | 16-24-23-26   |
| 13     | 35                   | 23-22-35      |
| 14     | 27                   | 16-17-27      |
| 15     | 38                   | 27-26-29-38   |

According to the simulation method of network reconfiguration based on Cellular Automata, generator node30~39 are selected as the FCB nodes and execute the network reconfiguration 100 times. Indicators V1~V4 are obtained by statistics and averaged. Determine the weight of the four indexes according to the method of the subjective and objective integration. And then, grey relational analysis is combinatorially used to evaluate the optimal placement scheme for FCB unit.

![Figure 3. Weighted grey relational of the optimal placements scheme for FCB units.](image-url)
From figure 3, transforming node37 into FCB node have largest correlation degree than node30 and node39, so node37 is the optimal transformation program of FCB unit. In addition, at the top of the diagram of the node30, node37 and node39 have the best effect than others under the diagram to transform to FCB units.

6. Conclusion
In this paper, we have presented a multi-agent consisting of several Bus Agents (BAGs) and a single Facilitator Agent (FAG). It is of great significance for the power restoration to transform generator units in proper position into FCB units with better black start performance. It also has important significance to guide the operator to make the corresponding FCB location plan. Future work should be directed towards expanding the proposed method to meet the requirements of the decentralized control environment, which has resulted from the world wide promotion of deregulation of electric power systems.

References
[1] SHEN Chong-qi, ZHOU Xin-ya, and YAO Jun 2007 FCB function of coal-fired power unites and its application in power grid restoration Shanghai Electric Power No 3 pp 251-4
[2] LI Jianhui, LU En, and WANG Ning 2013 Optimal Placement of FCB Units for the Shortest Duration of a System Restoration Guangdong Electric Power 26 pp 63-66 p 75
[3] LU En, NING Jian and LIU Haoming 2014 An Ordinal Optimization Based Locating Scheme of Fast Cut Back Thermal Power Units Power System Technology 38 pp 1216-22
[4] Pérez-Guerrero R, Heydt G T, Jack N J, et al 2008 Optimal restoration of distribution systems using dynamic programming IEEE Transactions on Power Delivery 23 pp 1589-96
[5] LIU Qiang, SHI Libao, ZHOU Ming, et al 2009 Optimal start-up strategy of units during power system restoration Electric Power Automation Equipment 29 pp 1-5
[6] LIN Zhenzhi and WEN Fushuan 1987 A New Optimization Method for Determining Restoration Paths Based on Weighted Complex Network Model Automation of Electric Power Systems 2 pp 740-1
[7] HAN Zhong-hui, GU Xue-ping and LIU Yan 2009 Optimization of Restoration Paths Considering Unit Start-up Time Requirements at Early Stage of Power System Restoration Proceeding of the CSEE 29 pp 21-26
[8] ZHU Dongxue, GU Xueping and ZHONG huirong 2013 A Multi-Objective Optimization Method for Post-Blackout Unit Restoration Power System Technology 37 pp 814-20
[9] ZHANG Can, LIN Zhen-zhi, WEN Fu-shuan, et al Multi-Objective network reconfiguration strategy for power systems considering uncertainties Journal of North China Electric Power University 39 pp 13-23
[10] TANG Si-qing, ZHANG Mi, LI Jian-she, et al 2006 Review of Blackout in Hainan on September 26th ---Cause and Recommendations Automation of Electric Power Systems 30 pp 1-7 p 16
[11] YU Qun, CAO Na and GUO Jianbo 2011 Power System Self-Organized Criticality Simulation Model Based on Cellular Automata Automation of Electric Power Systems 35 pp 1-5
[12] Nagata T and Sasaki H 2002 A multi-agent approach to power system restoration IEEE Transactions on Power Systems 12 pp 457-62
[13] LIU Yan and GU Xue-ping 2007 Node Important Assessment Based Skeleton-network Reconfiguration Proceedings of the CSEE 27 pp 20-27
[14] ZHANG Yu-qiong and GU Xue-ping 2005 Computation and Statistical of Operating Over-Voltages in Black-Start of Power Systems TRANSCATIONS OF CHINA ELECTROTECHNICAL SOCIETY 20 pp 92-97
[15] WU Jian, LIANG Chang-yong and LI Wen-nian 2007 Method to determine attribute weights based on subjective and objective integrated 29 pp 383-7
[16] SI Shou-kui and SUN Xi-qing 2011 Mathematical Modeling National Defence Industry Press