Study on Power Grid Partition Method for Wide-area Relaying Protection

Zhenxing Li[1], Xianggen Yin[1], Zhe Zhang[1], Yuxue Wang[1]
[1]*State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Xin Dongmolou , Luoyu Road,1037#, Wuhan, P. R. China, phone:+86134298968091*
lizhenxing@smail.hust.edu.cn

Abstract—**Recently, wide area relaying protection (WARP) is attracting wide concern for its advantages in coping with challenges to traditional backup protection. It is essential for power grid partition based on limitation of WARP having real-time and rapidity. As a result, a novel concept, limited wide area relaying protection system, is proposed and some basic partition principles, including main substation selection, regional scope and multi-regional overlap, are elaborated for helping to realize WARP in whole power grid. Furthermore, the implementation methods of grid partition is proposed by using matrix calculation on grid topological structure of graph theory, and the process is given based on IEEE 11 nodes system partition. A simulation of 220 kV grid systems in Easter Hubei province shows the effectiveness of grid partition for wide-area relaying protection.**

Index Terms—**Graph theory, electrical safety, wide area relaying protection, partition, limit.**

I. INTRODUCTION

The conventional backup protection, which relies on situ information, has some problems in setting coordination and adapting to grid topological change. These problems have become more acute under current circumstance of widely interconnected grid and bulk power transmission over long distances [1]. The mal-operation of backup protection under heavy loading condition increases the risk of instability of power grid especially [2].

In recent years, with the development of wide area measurement system (WAMS), WARP based on multi-source information has emerged as a promising tool in coping with challenges to traditional backup protection [3], [4]. The main direction of WARP focus on the research about fault element identification algorithm based multi-information fusion, but the scope of information region and the relationship among multi-regions studies rarely.

Compared with the traditional relaying protection, the so-called wide area information of WARP is not confined to on situ information or measurement information of the protected equipment. The wider region of measurement information of multi-equipment could be utilized to enhance performance of the protection system. The size of the region scope determines the technical requirements of WARP [5]. However, the whole grid cannot be protected by a WARP for its rapidity and reliability. Therefore, it is essential for the large grid to divide into a number of protected regions. A self-governed WARP is set in each region, and the overlap design of protected multi-regions realizes a large grid of wide-area protection system together in collaboration.

Security and stability issues have been considered in previous literature on power grid partition [6]. Different from emergency control system, the relay must quick identify fault element and isolate it rather than performs a lot of computations based more information for system stability consideration. The emergency control system can be effective only once the fault element isolated. therefore, the partition study of WARP is of great significance.

Combined with the application characteristics with protection engineering inheritance and feasible under existing condition, the paper proposes the concept of limited wide area relaying protection and some basis partition principles and implementation scheme.

II. LIMITED WIDE AREA RELAYING PROTECTION

The core idea of wide area relaying protection is to detect fault element by fusing multi-source information sampled synchronously over wide area grid and to isolate the element reliably and quickly by simple logic coordination. The multi-source information fusion doesn’t literally mean the fusion of information of the entire grid, neither does it imply that the more information, the better. Therefore, to construct a WARP covering all the substations and to promote information exchange in the entire grid is unnecessary [7]. Making full use of information in the limited area grid to improve relaying performance is not only a reasonable developing trend for WARP, but also furthers current research of principles of WARP and meets the requirement in real engineering. The concept of limited wide-area protection is manifested in the following aspects:

1) Limited responsibility. The major responsibility of WARP is still to isolate fault element quickly. The emergency control system cannot be effective before fault element is not isolated;

2) Limited information. WARP only requires highly sensitive information from near faulty point to make fault

Manuscript received February 23, 2012; accepted May 17, 2012.
This work was financially supported by the National Natural Science Foundation of China (50837002, 50877031).

decision. If the protection system brings together the whole fault information from the substations in power grid, useful information will be lost in a sea of redundant data, thus increasing the information retrieval difficulty;

3) Self-serving characteristics. Relay must have rapidity and sensibility. The rapidity is affected if WARP obtains too much information and the sensibility is hard to guarantee if WARP use further fault information from fault location;

4) Communication restriction. The capacity of communication and processing power of WARP computers becomes a restriction for accounts of information in the whole grid. Furthermore, synchronization measurement in the wide area is hard to WARP;

5) Engineering requirements. The implementation of WARP is a gradual process. To partition the whole grid into different regions and implement the relaying protection function region by region is a reasonable developing trend for the power grid in a long term and is conducive to system engineering.

Based on the concept of limited wide area relaying protection, it is a better solution for WARP by partition to the grid. The protection criteria adopted in different regions are independent each other, while the scopes of regions overlap. Adjacent regions only exchange limited information, mainly including the remote backup protection startup information in overlap regions and fault decision information of WARP. The system structure with distributed measurement and concentrated decision has been accepted in the more studies [8]. The structure and grid partition are shown in Fig. 1. There a master station with decision function and some sub-stations with measurement function in each region. Master station and sub-station are connected with wide area communication networks.

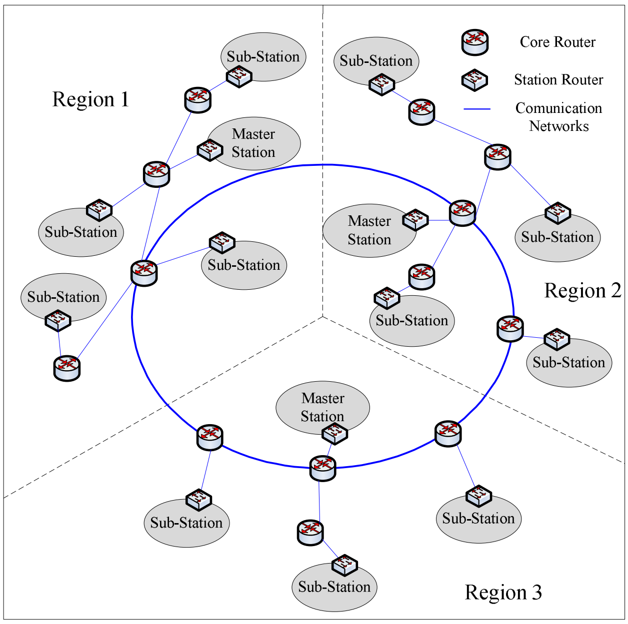

Fig. 1. Protection partition of limited wide area protection.

Partition a complex power grid into multi-regions for protection and control not only helps to reduce communication traffic, but also promotes the realization of WARP in engineering.

III. GRID PARTITION SCHEME FOR WARP

Grid partition is important for implementing WARP. It intuitively visualizes the finiteness of system space and scope of protection and also serves as an important basis for the design of WARP algorithms and tripping strategies. Following principles need to be taken into account in protection partition:

1) Selection of master station. As shown in Fig. 1, it is required to select a location in each region where regional information gathers together as the decision center of WARP, also known as the Master Station. Different from the master station of emergency control system, the master station of WARP can not only quickly acquire needed information in the region but also make decision rapidly and send out the control commands. Therefore, the selection should consider the connections between nodes of the transmission system, and the connections between inter-node communication systems. Generally speaking, some special substations or communication center are best option for a decision center, considering artificial, geographic, communication and other factors; the second best option are the transforming substations with more adjacent nodes and intensive associated paths. Only in exceptional circumstances will other substations be chosen as backup decision centers;

2) Scope of protection region. The larger region enables WARP to acquire sufficient redundancy information and is helpful to improving WARP's reliability from the point of view of WARP information tolerant. But the larger region may make communication traffic and increase operation difficulty of system decision when all the fault information sends to master station at the same time. Furthermore, information exchange between regions should keep to the minimum. In a word, the scope of protection region is not too big or too small. So far as protection function is concerned, WARP, as a backup protection for the protected object, is supposed to be capable of both conventional local backup protection and remote backup protection. And in order to achieve best engineering effect, it is important that backup protection should be fulfilled by use of regional own information. Therefore, WARP should be able to achieve remote backup protection for majority elements (apart from boundary station) in the region under the condition that communication capacity can meet the technology requirement of WARP. In other words, the scope should reach the end of the next line of mast station as well as be able to extend appropriately;

3) Process of grid boundary. As it is well known, power system is a network of electrical elements used to supply, transmit and use electric power. Power generation and electricity consumption is the starting point and ending point of the whole process. Even under the circumstances of operation mode changes or system splits, these two points seldom change. Therefore, the starting point and ending point should be preferred in the grid partition. Meanwhile, the power grid construction is a long-term development project, so when partition, the possible node access in the

future planning should be taken into account to avoid unnecessary labor in the future;

4) Overlap between regions. Fig. 2 presents four types of overlap between regions. In Fig. 2(a), a point is overlapped, leaving substation B2 unprotected. In Fig. 2(b), a substation is overlapped. In this case, neither any region can give effective protection to substation B2, line L1, and L2 independently if DC failure occurs to substation B2. In Fig. 2(c), a line is overlapped. The remote backup protection of line L2 requires integrated information from two different regions though the problems in above two cases are avoided in this situation. In Fig. 2(d), two lines and the midway substation are overlapped. In the meanwhile, the problems above are avoided, but a new problem emerges that too large overlap zone results in heavy communication traffic. To sum up, in order to guarantee the timely fault elements isolation when DC failure occurs to substations or breaker fails, two adjacent regions should have at least one line overlapped, and more when necessary.

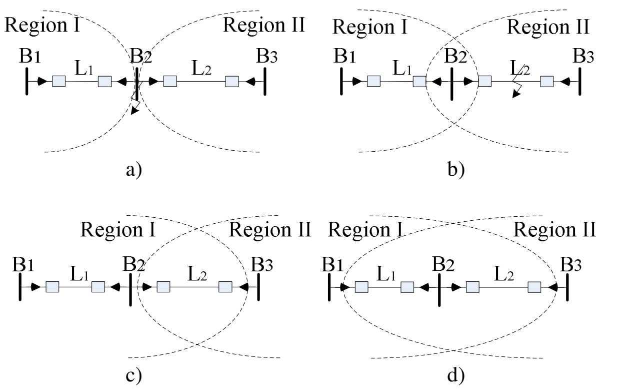

Fig. 2. Overlay zone between regions: a – overlap a point; b – overlap a substation; c – overlap a line; d – overlap a zone.

When choosing master stations for multi-regions, we should try to avoid choosing two adjacent substations; otherwise the overlap zone will be too large, further complicating the partition of the whole grid, which is bad for the implementation of WARP. What's more, we should bear in our mind that grid building is a dynamic process involving a lot of factors, such as the system planning and scheduling, operation mode, security and stability control, protection and communications, and specific requirements put forward by experienced operating personnel. Appropriate adjustment when partitioning should be made according to varying conditions to achieve better engineering effect.

IV. Implementation Method of Grid Partition for WARP

Graph theory is a branch of Topology. The research on it has developed quickly and it has been applied to a wide range of fields. When the theory is applied in limited wide-area relaying protection, it can provide theoretical basis and mathematical description for grid partition and fault detection algorithms [9]. In this paper, in accordance with the partition principles of WARP, the basic theory of graph theory is used to conveniently implement the partition based on simple matrix computation.

It should be noted that the partition is operated at maximum running modes under off-line system. Only in this way can all the elements get protections when system changes. At the meanwhile, the partitioned grid is mainly to transmission networks at the same voltage class. So, the buses having the same voltage class in a substation may be regarded as a node and multi-circuit transmission lines process as well.

According to the above technology requirement and graph theory, simplifying grid topology, programming nodes number and constructing nodes matrix are firstly made. And then the partition is process based the matrix. IEEE 11-node network shown in Fig. 3 is taken as an example to demonstrate the partition method of WARP. In the networks topological graph of power grid, buses, lines and other protected elements are defined as nodes $V_1, V_2, \cdots, V_n$. Line CT and breaker are defined as branches $e_1, e_2, \cdots$.

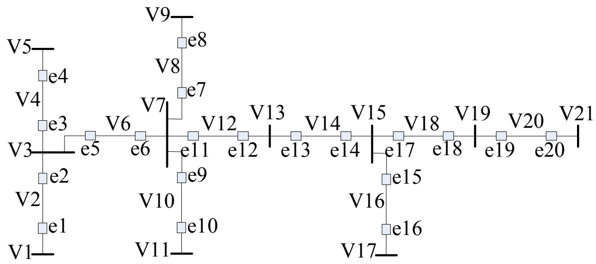

Fig. 3. IEEE 11 nodes system.

The n×n matrix **C** denotes the adjacency matrix of nodes according to graph theory, defined as

$$C_{ij} = \begin{cases} 1, & \text{node i adjoins node j}, \\ 0, & \text{node i does not adjoin node j}. \end{cases} \tag{1}$$

According to the system in Fig. 3, the adjacency matrix **C** is written as:

$$C = \begin{array}{l|ccccccccccccccccccccc|l}
 & V_1 & V_2 & V_3 & V_4 & V_5 & V_6 & V_7 & V_8 & V_9 & V_{10} & V_{11} & V_{12} & V_{13} & V_{14} & V_{15} & V_{16} & V_{17} & V_{18} & V_{19} & V_{20} & V_{21} & \\
 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_1 \\
 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_2 \\
 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_3 \\
 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_4 \\
 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_5 \\
 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_6 \\
 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_7 \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_8 \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_9 \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_{10} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_{11} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_{12} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V_{13} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & V_{14} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & V_{15} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & V_{16} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & V_{17} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & V_{18} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & V_{19} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & V_{20} \\
 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & V_{21}
\end{array} . \tag{2}$$

The rows and columns of the matrix **C** map the corresponding nodes of the system in Fig. 3.

Adjacency matrix only represents a direct impact on relations between system elements. However, it is more concern whether some nodes can influence further nodes though between them from system change of view for

WARP. For example, traditional protection only uses measurement information of adjacency node while WARP prefers to get information of more than adjacency nodes. Therefore, the key points of grid partition are to confirm which nodes make up the scope of WARP, and this would involve up the concept of the reachable relationship. Here, we define it is reachable from v_i to v_j when node v_i can directly or indirectly effect node v_j. The matrix describing the reachable relationship of all the nodes in the region is defined as reachability matrix **P**, defined as follows:

$$P_{ij}^{m} = \begin{cases} 1 & \text{node i is reahable for node j,} \\ 0 & \text{node i is not rechable for node j.} \end{cases} \quad (3)$$

The logical operation relations between reachability matrix **P** and adjacency matrix **C** could be calculated as follows

$$P^{m} = C \cup C^{2} \cup \cdots \cup C^{m}, \quad (4)$$

where m is reachable distance in (3) and (4).The reachable distance should be determined on the principle of scope of protection region. The size of m directly effect on the number of partition regions and size of each region, and thus effect system communication and process of WARP. According to actual relaying protection engineering and the remote backup protection function requirement of WARP, the scope of region is center with master station, radius inside the end of the next line of master station at least. As the buses and lines are described as nodes of graph theory, the distance should be four-node long, and m is recommended to set as 4. The reachability matrix $\mathbf{P}^4$ can be calculated on the system in Fig. 3:

$\mathbf{P}^4 =$ (5)

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21
V1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V2	1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0
V3	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
V4	1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0
V5	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
V7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
V8	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
V9	0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
V10	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
V11	0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
V12	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0
V13	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
V14	0	0	0	0	0	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0
V15	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1
V16	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0
V17	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0
V18	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
V19	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
V20	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1
V21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1

Taken m=4 for example, the simple partition process is shown as follow:

Step 1. Calculate the vertex degree (VD) of all the nodes. The result is shown in (6):

V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	VD
1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	10
1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	13
1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	10
1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	14
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	15
0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	14
0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	9
0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	12
0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	9
0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	15
0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	15
0	0	0	0	0	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	13
0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	11
0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	9
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	7
0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	10
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	9
0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	7
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	5

V1 V2 V3 V4 V5 V6 V7 V12 V13 V14 V15 V16 V17 V18 V19 V20 V21

. (6)

Step 2. Find the nodes of maximum degree, and get V7, V13 and V14. V14 as a line is let out.

Step 3. The cross point between V1 column and V7 row is found on the process principle of grid boundary. So, V7is firstly defined as the master station.

Step 4. The nodes whose elements is 1 in V7 row constitute a region.

Step 5. Find the nodes of maximum degree in surplus nodes (including boundary station of other regions), and get V15.

Step 6. The cross point between V21 column and V15 row is found on the process principle of grid boundary. So, V7is defined as the other master station.

Step 7. The nodes whose elements is 1 in V15 row constitute a new region.

Step 8. Examine whether the results of partition comply with the overlap principle. If it is, partition is over. Or jump to Step 5.

The system in Fig. 3 is divided into two protected regions based on the implementation method of grid partition with m=4. The results are shown in Fig. 4.

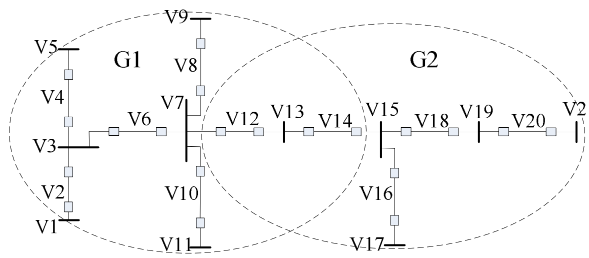

Fig. 4. The partition results of IEEE 11 nodes system.

Based on the principle and example of the partition, the search program is activated in **P**, gaining the final partition results of WARP. The flow is shown in Fig. 5.

V. Simulation Results and Analysis

To verify the partition method, the model 220kV power system in eastern Hubei province of China region is used to preliminary simulation. The system includes 45 substations and 62 lines and can represent a complex system for WARP.

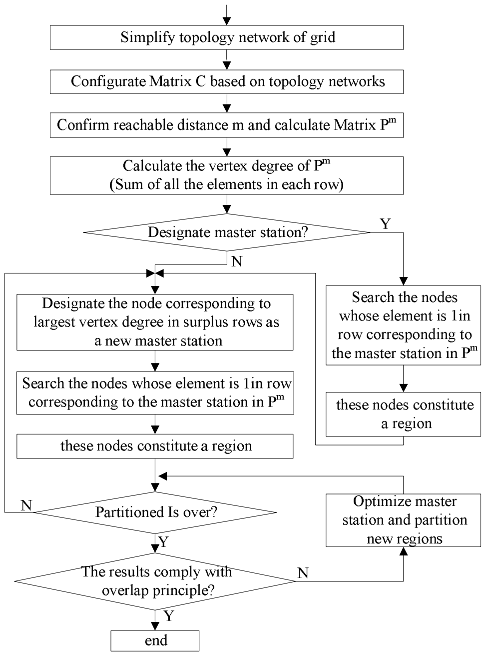

Fig. 5. Flow chart of the partition.

The system mode is shown in Fig. 6. Firstly, take the reachable distance m equal to 4 for example, the process of the partition shows as follow. Firstly, three substations with most incoming and outgoing lines, FengHuangShan, Sike, and Ezhou are selected as master stations and named as Region 1 (Master Station: FengHuangShan), Region 2 (Master Station: Sike), Region 3 (Master Station: Ezhou). According to the partition principle, in the rest regions, we strive to use the least complex region division to cover the whole grid, thus forming Region 4 adjoining with Region 1 (Master Station: WangZhuangYu); Region 5 adjoining with Region 2 (Master Station: Qichun); and Region 6 adjoining with Region 3 (Master Station: Beiyang). In the same manner, the regions can be get when m=6 and m=8. The partition results of the grid in Eastern Hubei are shown in Table I. The results show that the m value is bigger and the number of regions is the less, this in return would the scope of the region is bigger and the communication traffic is worse. So, the reachable distance with m=4 is recommended from the view of remote backup protection function of WARP.

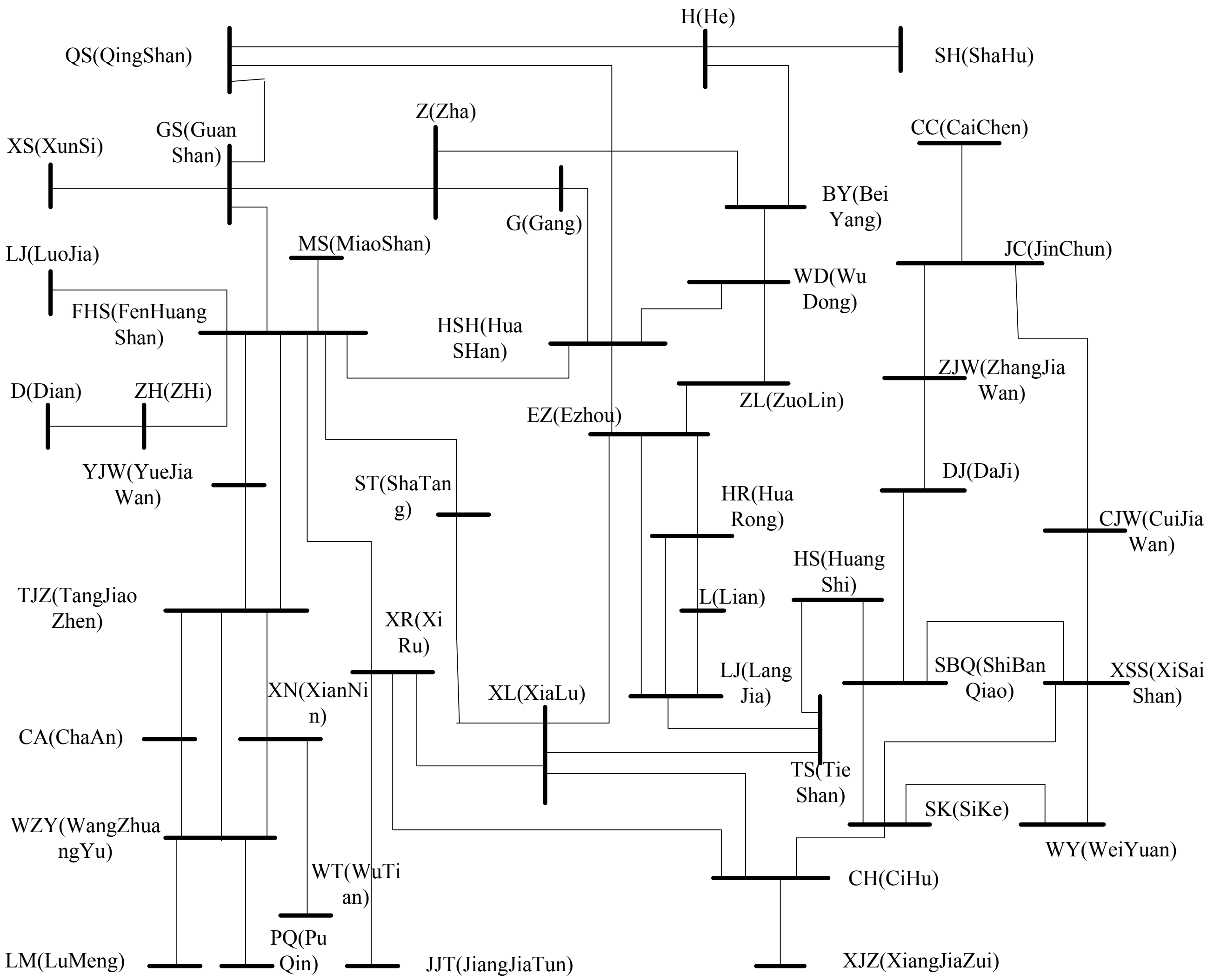

Fig. 6. 220kV eastern Hubei province power grid.

TABLE I. THE RESULT OF PARTITION FOR 220KV EASTERN GRID WITH M=4.

m value	Num.	Master Station	Sub Station	Boundary Station
m=4	1	FHS	GS, HSH, ZH, YJW, XR, ST, G,	XS, QS, LJ, D, TJZ, JJT, XL, WD, H, Z
	2	SK	CH, WY, XSS, SBQ, HS	DJ, CJW, XJZ, TS, XR, XL
	3	EZ	HSH, ZL, HR, L, LJ, TS, XL	G, WD, XR, CW
	4	WZY	CA, XN, TJZ	YJW, LM, PQ, WT
	5	QC	ZJW, J, CJW	CC, SBQ, XSS
	6	BY	ZJW, DJ, CJW	CC, SBQ, XSS
m=6	1	FHS	QS, GS, Z, G, HSH, ZH, YJW, XR, ST,XL	XS, QS, LJ, D, TJZ, JJT, EZ, CH, WD, H, Z
	2	WZY	CA, XN, TJZ	YJW, LM, PQ, WT
	3	EZ	H, Z, G, HSH, XL, BY, WD, ZL, HR, L, LJ, TS	SH, QS, Z, FHS, ST, XR, CH, HS
	4	SBQ	JC, ZJW, DJ, CJW, XSS, SK, WY, CH, TS, HS	CC, XJZ, LJ, XL, XR
m=8	1	FHS	QS, GS, Z, G,HSH, ZH, YJW, XR, ST, TJZ, YJW,CA, XN, WZY	XS, LJ, D,MS, LM, PQ, JJT, XL, EZ, WD, H, BY
	2	EZ	H, Z, HSH, BY, WD, ZL, HR, L, LJ, TS, XL	QS, GS, ST, XR, CH, HS, SH
	3	SBQ	JC, ZJW, DJ, CJW, XSS, SK, WY, CH, TS, HS	CC, XJZ, LJ, XL, XR

VI. CONCLUSIONS

To promote the realization of wide area relaying protection in engineering, the partition method based on graph theory is proposed. The main idea of the method is partitioning a complex grid into multi-regions to implement protection and control system. The method considers not only electrical connection among grid nodes but also communication connection and the scope of protection region. Through simple matrix computation and search processing, a suitable implementing scheme of the proposed method is given, which proves effective when carrying out wide area relaying protection based on limited area information. Simulation results show that the proposed partitioned method can serves as a powerful supplement to wide area relaying protection engineering.

REFERENCES

[1] D. Novosel, G. Bartok, "IEEE PSRC report on performance of relaying during wide-area stressed conditions", *IEEE Trans. Power Del.,* vol. 25, pp. 3–16, 2010. [Online]. Available: http://dx.doi.org/10.1109/TPWRD.2009.2035202

[2] J. C. Tan, P. A. Crossley, "Application of a Wide Area Backup Protection Expert System to Prevent Cascading Outages", *IEEE Trans. Power Del.*, vol. 17, pp. 375–380, 2002. [Online]. Available: http://dx.doi.org/10.1109/61.997902

[3] "Wide Area Protection and Emergency Control, Working group c-6, system protection subcommittee", IEEE PES power system relaying committee final report, 2002.

[4] S. Sheng, K. K. Li, "Agent based self-healing protection system", *IEEE Trans. Power Del.*, vol. 21, pp. 610–618, 2006. [Online]. Available: http://dx.doi.org/10.1109/TPWRD.2005.860243

[5] M. G. Adamiak A. P. Apostolov, "Wide area protection-technology and infrastructures", *IEEE Trans. Power Del.*, vol. 21, pp. 601–609, 2006. [Online]. Available: http://dx.doi.org/10.1109/TPWRD.2005.855481

[6] "System Protection Schemes in Power Networks", CIGRE, Task Force 38.02.19, Report, 2001.

[7] Zhi Qin He, Zhang Zhe, "Wide-area backup protection algorithm based on fault component voltage distribution", *IEEE Trans. Power Del.*, vol. 26, pp. 2752–2760, 2011. [Online]. Available: http://dx.doi.org/10.1109/TPWRD.2011.2165971

[8] Xu Tian Qi, Yin Xiang Gen, "Analysis on functionality and feasible structure of wide area protection system", *Power System Protection and Control,* vol. 38, pp. 93–97, 2009.

[9] Lin Xiang Ning, Li Zheng Tian, "Principles and implementations of hierarchical region defensive systems of power grid", *IEEE Trans. on Power Del.,* vol. 24, pp. 30–38, 2009. [Online]. Available: http://dx.doi.org/10.1109/TPWRD.2008.2002973