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# Architecture and Fault Identification of Wide-area Protection System

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***Abstrak***

*Proteksi sistem untuk daerah yang luas (WAP) dipelajari untuk meningkatkan kinerja proteksi cadangan yang konvensional. Dalam tulisan ini, arsitektur sistem WAP diusulkan beserta kunci teknologinya dibahas dalam sudut pandang rekayasa. Suatu struktur campuran, struktur terpusat - terdistribusi yang lebih cocok untuk WAP jala-jala listrik terbatas, dapat diperoleh berdasarkan keuntungan dari struktur terpusat dan struktur terdistribusi. Selanjutnya, algoritma proteksi berdasarkan jarak diambil sebagai contoh untuk menggambarkan fungsi dari unit-unit penyusunnya . Komponen yang terganggu dapat dideteksi berdasarkan algoritma multi-sumber informasi sekering. Algoritma yang diusulkan tidak hanya dapat meningkatkan selektivitas, kecepatan dan keandalan proteksi tetapi juga memiliki kemampuan menoleransi kesalahan yang tinggi. Sebuah hasil simulasi jala-jala 220 kV di provinsi Hubei Paskah menunjukkan efektivitas dari sistem proteksi untuk daerah yang luas yang disajikan dalam tulisan ini.*

***Kata kunci:*** *proteksi daerah yang luas (WAP), identifikasi gangguan, struktur-terpusat-terdistribusi, proteksi daerah berdasar jarak.*

***Abstract***

*Wide-area protection system (WAPS) is widely studied for the purpose of improving the performance of conventional backup protection. In this paper, the system architecture of WAPS is proposed and its key technologies are discussed in view of engineering projects. So a mixed structure-centralized-distributed structure which is more suitable for WAPS in limited power grid region, is obtained based on the advantages of the centralized structure and distributed structure. Furthermore, regional distance protection algorithm was taken as an example to illustrate the functions of the constituent units. Faulted components can be detected based on multi-source imformation fuse in the algorithm. And the algorithm cannot only improved the selectivity, the rapidity, and the reliability of relaying protection but also has high fault tolerant capability. A simulation of 220 kV grid systems in Easter Hubei province showed the effectiveness of the wide-area protection system presented by this paper.*

***Keywords****: Wide-area protection, fault identification, centralized-distributed structure, regional distance protection*

## 1. Introduction

Protective relaying is an important line of defense in power grid. Its reliability and rapidity are essential to fault isolation and prevention of accident expansion. According to statistics, nearly 75% of power system disturbances are caused by the mal-operation of backup protection [1]. The conventional backup protection, which relies on in situ information, has some problems in setting coordination. These problems have become more acute under current circumstance of widely interconnected grid and bulk power transmission over long distances [2],[3]. The cascading trip accidents incurred by mal-operation of backup protection under heavy loading condition, as well as the hidden failures caused by setting coordination errors, will increase the risk of instability of power grid [4],[5].

In recent years, with the development of wide-area measurement system (WAMS), WAPS based on multi-information fusion has emerged as a promising tool in addressing the mentioned problems above [6],[7]. According to the description of CIGRE, researches on WAPS can be divided into two aspects: one focuses on the study of the security and stability control of power grid based on wide-area information, which is mainly focus on monitoring, analyzing and

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evaluating the stable operating state of power grid [8]; the other focuses on improving the performance of conventional relaying protection with the use of wide-area information. It should be noted that the existing primary protection of high-voltage grid is mainly pilot protection, which boasts the advantages of rapidity, independence of load transfer, easy setting and high rate of accuracy. In contrast, WAPS has limitations in terms of the synchronicity of information sampling, the timeliness, reliability and security of information transmission. Therefore, when mentioned that wide-area information to improve the performance of relaying protection, it is usually referred to backup protection.

Researchers at home and abroad have made preliminary studies into the architecture of WAPS and the principle of faulted components detection. Wide-area protection can be divided into three types according to the architecture they took, which are centralized structure, distributed structure and mixed structure. In the centralized structure, the core decision system is concentrated at a central point. This structure can acquire maximum information with little communication traffic, which is conducive to integrate between relaying decision system and stability control system. Yet, centralized decision center is vulnerable to interference and increase the risk of single point failure [9]. In the distributed structure, the core decision system is located in Intelligent Electronic Devices (IEDs) which distributed over the wide-area grid, and the entire protection function is fulfilled by the cooperation of these IEDs. This structure boasts strong adaptive capacity and there is no risk of single point failure, but the involved heavy communication traffic, the limited information available to decision units, and the complex system design are its shortcomings [10]. The mixed structure integrates the advantages of centralized structure and distributes structure while makes up for their shortcomings, but there lacks a detailed scheme to implement this structure and insufficient cooperation between the distributed IED and centralized core unit will lead to single point failure risk [11]. Hence, in order to meet the actual needs in wide-area relaying protection engineering, studying the architecture of wide-area protection system is great significance.

Considering the application characteristics of WAPS and starting from the introduction of the responsibility and requirements of relaying protection, this paper first proposes a centralized-distributed structure for WAPS and then discusses a faulted component identification algorithm which called regional distance protection based on multi-information.

## 2. Centralized-Distributed System Architecture

### 2.1. Limited Wide Area Protection

The core idea of wide-area protection is to detect faulty components by fusing multi-information sampled synchronously over wide area grid and to isolate these faulty components reliably and quickly by simple logic coordination. Multi-information fusion does not literally mean the fusion of information of the entire grid, neither does it imply that the more information, the better. Therefore, to construct a WAPS covering all the substations and to promote information exchange in the entire grid is unnecessary. Making full use of information in the limited area grid to improve relaying performance is not only a reasonable developing trend for WAPS, but also further current research of the principle of WAPS 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 WAPS is still to isolate faulty components.
2. Limited information. Wide-area decision center only requires highly sensitive information from near faulty point to make fault decision. If the protection system brings together the fault information from all the substations, useful information will be lost in a sea of redundant data, thus increasing the information retrieval difficulty.
3. The implementation of WAPS is a gradual process. Dividing the whole grid into different regions and implementing the relaying protection function region by region is a reasonable developing trend for the power grid in the long term and it is conducive to system engineering.

So, partitioning power grid into multi limited regions is the foundation of WAPS [12]. At the same time protection region is bound to affect the architecture of WAPS.

### 2.1. System Architecture

The conventional distributed architecture and centralized architecture have their own advantages and disadvantages. In this paper, a novel mixed architecture, centralized-distributed architecture, is proposed based on the advantages of two conventional architectures. The centralized-distributed nature is manifested in several ways: in the substation, a great variety of information is first collected form and controlled by the IEDs located at intervals in the substation in a distributed manner before it is centralized and treated in the substation processing unit. When it comes to the regional centralized decision-making, the processing unit of each substation applies the distributed mode while the decision center applies the centralized mode. In this way, this mixed system architecture not only combines the advantages of two conventional architectures, but also meets special characteristics of limited wide area protection, thus providing foundation for the safe and stable computation of region grid in the future. Figure 1 is an illustration of the proposed structure.

In Figure 1, the substation S is the decision center, and noted as master station. Besides completing information collection, protection and control of the substation, the master station is responsible for centralized decision-making with multi-information from regional grid. Transforming stations other than the master station are called the sub-stations of the system. Functions fulfilled by each unit in system are as follows:

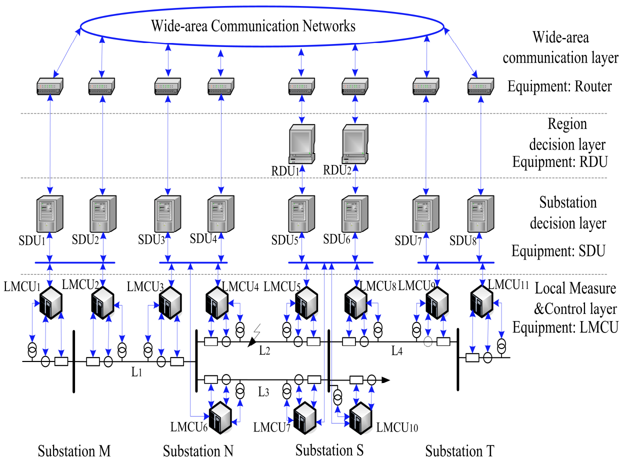


Figure 1. System architecture of wide area protection

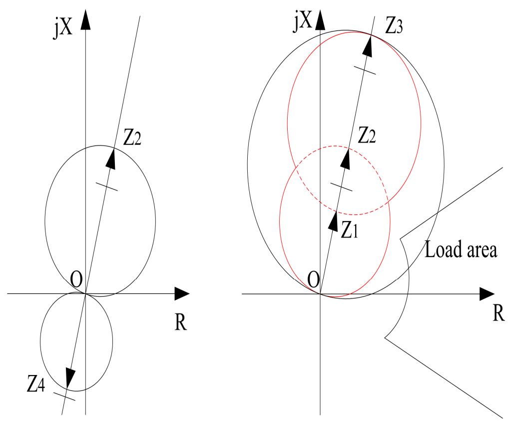


Figure 2. Characters of distance protection

1) Local measurement and control unit (hereinafter referred to LMCU). LMCU is mainly responsible for collecting in situ measurement information about current transformer and voltage transformer and status information about circuit breaker; executing breaker operation; performing conventional main protection function; judging the startup of backup protection components; as well as completing communication function with substation decision unit (hereinafter referred to as SDU). Besides, in the case that LMCU loses contact with SDU, it can accomplish the conventional backup protection for SDU.
2) Substation decision unit (SDU). SDU is mainly responsible for integrating information from LMCU and making corresponding decision, and for communicating with regional decision unit (hereinafter referred to as RDU) and LMCU. As a gathering point for all the information and communication of the whole substation, SDU is a key unit in the substation. Therefore, in order to avoid single equipment failure and to achieve the effective protection, SDU in each substation adopts dual configuration: SDU1 is the master device while SDU2 is the hot backup. Both of them simultaneously receive information from LMCU and RDU and conduct computation and processing. SDU1 sends information to RDU or the corresponding LMCU, and to SDU2. Under normal conditions, SDU2 serves as monitoring and supervision equipment for SDU1, which will not send information to RDU with the view to reducing wide-area communication traffic. In the case that SDU1 breaks down, SDU2 will be automatically switched into the master device. Moreover, when both SDU1 and SDU2 lose communication with RDU, communication with the SDU of adjacent substation

will be started automatically. The adjacent substation will complete fault detection of buses and connect lines, serving as the backup protection of RDU.

3) Regional Decision Unit (RDU). RDU is mainly responsible for gathering information from substations in the region, identifying faulty component based on multi-information, and making protection action strategy as well as communicating with SDU. RDU is the core of WAPS and the key to faulty component detection with multi-information. In order to avoid the risk of single point failure, RDU in master station adopts dual configuration: RDU1 is the master device while RDU2 is the hot back-up device, both of them receive information from SPPU and conduct processing. RDU1 sends decision information to RDU2. Under normal conditions, RDU2 serves as the monitoring and supervision equipment for RDU1. In the case that RDU1 breaks down, RDU2 is automatically switched into the master device.
4) Other functions. The system also fulfills other functions, such as clock synchronization function based on the entire power grid, information exchange with protection systems of other regions and so on.

The main purpose of utilizing multi-information to fulfill wide-area relay protection is to improve the backup protection performance and solve some problems existing in conventional backup protection based on situ information. The coordination among various processing units can improve the main protection performance. At the same time, if properly handled, the backup protection can be used as the main protection. Because of the protection partition and the multi-layer protection structure, the scope of protection and control is large. The local decision center should be able to develop and implement more reliable, selective backup protection action strategy so as to improve the ability deal with complex field wiring.

## 3. Regional Distance Protection

Depending on different system architecture, the implementation of the same fault detection algorithm varies greatly. Referring to the algorithm for main protection of power system, the current study in fault detection algorithm focuses on extending principles of directional comparison pilot protection [13] and current differential protection [14] to the wide-area protection and utilizing expert system to enhance tolerance capability. However, both of the protections have some shortcomings. For current differential protection, it is susceptible to the influence of capacitive current and accumulated wide-area measurement error; while for the directional comparison pilot protection, it is liable to cause flow transfer mal-operation, and other complex problems such as setting and time delay.

Based on wide-area communication system, RDU can integrate multi-information in protected regions. How to utilize the information in faulty components detection has been always a research hotspot. Based on the architecture of WAPS, the paper discussed the operating characteristics of protected elements and faulty component detection algorithm, and finally proposed the principle of regional distance protection.

### 3.1. Characteristics of Protection Start-up Components

Conventional backup protection is a mainly three-zone distance protection, achieved by setting and delay coordination, which not only increases the difficulty of setting but also hampers fast faulty component isolation, bringing damages to the equipment and further affecting security and stability of the power grid. Particularly in large-scale flow transfer, the mal-operation of zone 3 protection may lead to cascade tripping, and even large blackouts.

To enhance the reliability, rapidity and selectivity of WAPS, the start-up components on zone 2, zone 3 and zone 4 protection installed on LMCU (here means action information of protection components without time delay) can be utilized. Then through simple logical computation on multi-information, RDU or SDU will complete relay protection accurately and rapidly. Meanwhile, to avoid mal-operation of the conventional zone 3 protection during large-scale flow transfer and to improve the reliability of the protection system, this paper improves the zone 3 protection. The operating characteristics of distance protection components are shown in Figure 2. Zone 2 and zone 4 is the same with conventional distance protection. The scope of protection zone 2 and zone 4 are in Figure 2 (a).

When non-grounding fault occurs, there exists no zero-sequence current in the system. In order to prevent mal-operation of zone 3 protection during large-scale flow transfer, within the protection scope of zone 3 protection, a new relay is adopted, as shown in Figure 2 (b). The operation equation is shown in Equation 1

$$\begin{cases} 90^\circ < \arg \dfrac{Z}{Z - Z_{II}} < 270^\circ \\ 90^\circ < \arg \dfrac{Z - Z_I}{Z - Z_{III}} < 270^\circ \end{cases} \quad (1)$$

$$90^\circ < \arg \frac{Z}{Z - Z_{III}} < 270^\circ \quad (2)$$

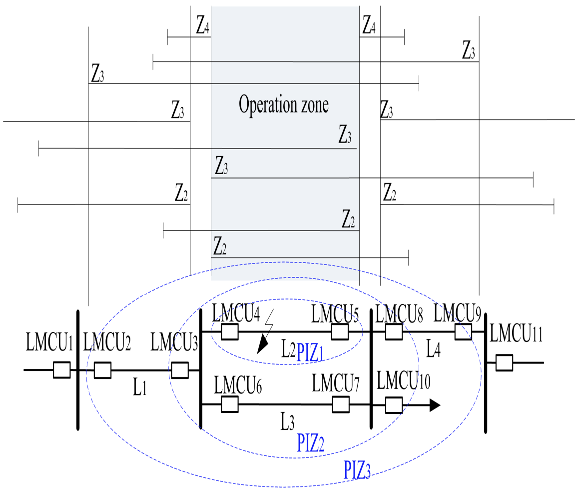


Figure 3. Protection information zone of wide area protection

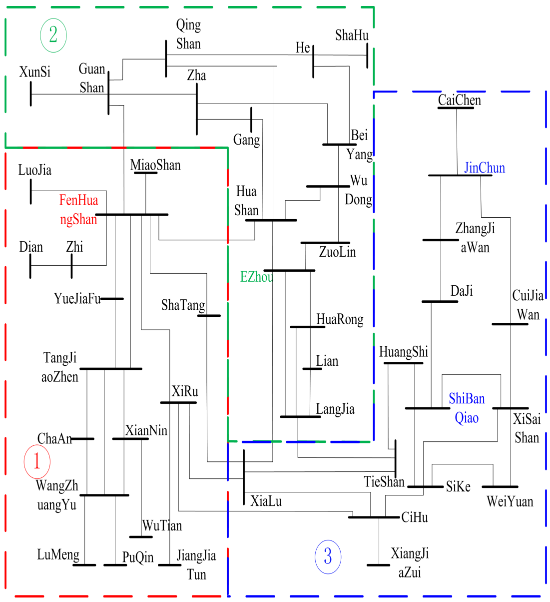


Figure 4. 220kV eastern Hubei province power grid

When a ground fault occurs, the monitoring function of zero-sequence current is put into use. When $I_0 \geq I_{set}$, the operation characteristic of the zone 3 ground distance is automatically changed into an ohm relay so as to improve anti-grounding resistance of the distance protection. The operation equation is shown in Equation 2, where $I_{set}$ is the monitoring setting of zero-sequence current, which is adjusted by the principle that the sensibility must be ensured when earth faults through high impedance (100 ~ 300 ohm) occurs in the end of the protected lines.

### 3.2. Principle of Fault Decision-making

Take the transmission system shown in Figure1 as an example, zone 2, zone 3 and zone 4 protections are installed at both sides of the line. According to different information adopted, the decision center can divide protected objects into different PIZ (Protection Information Zone). Take L2 in Figure 1 as an example, the information zone constitutes three parts: the zone enclosed by the protected object is the minimal zone PIZ1. The information from substations at both sides of the line constitute intermediate information zone PIZ2. The remote back-up protection information of one line constitutes the maximum information zone PIZ3. The information protection zones and their protection scope are shown in Figure 3.

When fault occurs to the line, the decision center will follow the following principle to identify fault component:

1) PIZ1 information constitutes protection criterion 1, and the principle is the same with the conventional pilot distance protection. The zone 2 or zone 3 protections at both ends of the line will start up simultaneously to identify the internal failure, as shown in Equation 3:

$$AV_{L2\_1} = \sum_{i=2}^{3}(Zi_4 \cap Zi_5) \tag{3}$$

Where $AV_{L2\_1}$(Action Value) is the operating value of criteria 1 for the line L2; $Z2_4$ is the startup value of zone 2 protection of LMCU4. Other components are named in the same rule.

2） PIZ2 information constitutes protection criterion 2. According to common operation characteristics of protection in the overlapped zone, the startup information at zone 2 protection of the line, along with the non-startup information of zone 4 protections at the opposite side of the line and zone 2 protection of the next line identifies the fault of line L2. Or, the startup information at zone 3 protection of the line, the non-startup information of zone 4 protection of the opposite side of the line and the zone 3 protection of the next line combine to identify the internal fault which occurs to L2. The whole process is shown in Equation 4:

$$AV_{L2\_2} = \sum_{i=2}^{3}[(Zi_4 \cap \overline{Z4_5} \bigcap_{j=8,10}\overline{Zi_j}) + (Zi_5 \cap \overline{Z4_4} \cap \overline{Zi_3})] \cap \overline{AV_{L3\_1}} \tag{4}$$

3） PIZ3 information constitutes protection criterion 3. According to common operation characteristics of protection in the overlapped region, the startup information of zone 3 protection of the line, and the non-operation information of zone 4 protections of the other lines on the same bus and zone 2 protection of the next line combine identify the internal fault which occurs to the line. The whole process is shown in Equation 5:

$$AV_{L2\_3} = \sum_{i=2,9}(Z3_i \bigcap_{j=4}^{7}\overline{Z4_j} \bigcap_{j=3,8,10}\overline{Z2_j}) \cap \overline{AV_{L3\_1}} \tag{5}$$

The main purpose of utilizing multi-information to fulfill WAPS is to improve the back-up protection performance and solve some problems existing in conventional back-up protection based on in situ information. Instead of relying on delayed coordination, the regional distance protection proposed in this paper has definite selectivity and satisfactory rapidity. Of course, the coordination among various processing units can improve the main protection performance. At the same time, if properly handled, the back-up protection can be used as the back-up primary protection.

## 4. Regional Distance Protection

### 4.1. Communication System

Communication system is the foundation of WAPS. It restricts the scope of protection and control. With the development of Wide Area Measurement System (WAMS) and optical fiber communication technology, as well as the gradual popularization of the digital substation based on IEC61850, GOOSE transfer mode grouping all the information in a substation into a data set has become the developing trend of information transmission in wide-area protection [15]. At the same time, the rapid development of SDH fiber ring network has laid a solid foundation for the formation of communication network of wide-area protection. For lines where no fiber channel is laid, pilot protection channel is regarded as a sound choice for the construction of wide-area communication network.

### 4.2. The Principle of Faulty Component Detection

Affected by the delay in communication and system instability, the proposed WAPS cannot completely replace conventional main protection. The measurement, judgment, communication and control of the conventional main protection is realized in each LMCU; while RDU mainly fulfills the backup protection based on multi-information fusion. One thing worth should be noticed is that one protection criterion is not enough to fully determine the faulty components. As WAPS is influenced by many factors, such as time synchronization, system communications, fault information and system operating mode, etc, different protection algorithms are subject to different restrictions. Therefore, RDU uses a variety of protection criteria in compliance with different principles to guarantee the reliable fault detection effectively.

### 4.3. Cooperation of Multi-layer Process Units

Although RDU and SDU adopt dual configuration, the decision error may happen at times due to the large scope of wide-area protection. Once the failure or decision error occurs, there will be huge damages to power grid. In order to address this problem, we shall take the following measures:

1) Besides adopting dual configuration, RDU and SDU must establish a master-slave mechanism in which master device conducts information processing and decision making while the slave device conducts monitoring and supervision function, and sends the supervision results back to the master device in time. If the master equipment gives a reply, the master equipment will conduct fault tolerance treatment. If the reply is not given, the slave equipment will be automatically switched into the master equipment.
2) When SDU losses contact with RDU, SDU will set up communication with the SDU in the adjacent substation, and cooperate with it to achieve the back-up protection for the substation and lines.
3) In the event that communication between SDU and main network is cut off, SDU will directly use information of the substation to provide back-up protection.
4) When error occurs to SDU, each LMCU of the substation will fulfill regular back-up protection and guarantee the current state of conventional relay configuration.

### 4.4. Fault-tolerant Design

Information loss or error is likely to happen during the process of measuring, judging, communicating and transmitting wide-area information. Considering this fact, the faulty component detection of WAPS based on incomplete or erroneous information has the risk of mal-operation. Therefore, the design of protection criterion based on fault tolerance has become one of the focuses of the studies. Currently, a number of intelligent algorithms have been widely discussed, but they still require further verification before being put into practice [12, 16]. In this paper, the fault-tolerance design takes into account the problems of N-1 system and employs the information fusion of various information zones to remove the adverse effect of failed protection components so as to ensure the performance of the protection system.

Since the principle of pilot protection is applied in the protection criterion, the protection criteria will not mal-operate when there is regional information loss or error. To improve the protection reliability, the action information of at least two protections criteria is required for fault-tolerant judgment to avoid protection malfunction, as shown in Equation (6).

$$AV_1 \geq 1 \cup AV_2 \geq 2 \cup AV_3 \geq 2 \qquad (6)$$

## 5. System Simulation

To verify the algorithm, electromagnetic transient simulation software PSCAD/EMTDC is applied to model 220kV power system in eastern Hubei region for simulation, as shown in Figure 4. The grid is made up of three regions, FengHuangShan, EZhou and ShiBanQiao are selected as the decision centers of Region 1~3 respectively.

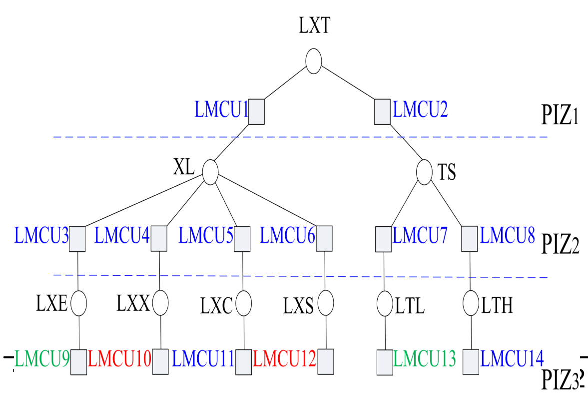


Table.1. Fault Detection under Some Wrong Information

| Active Value | Wrong Information | | | | | | |
|---|---|---|---|---|---|---|---|
| | no | Z22 | Z31 | Z42 | Z21 Z32 | Z22 Z32 | Z28 Z35 |
| AV1 | 2 | 2 | 2 | 2 | 1 | 0 | 2 |
| AV2 | 4 | 3 | 3 | 2 | 2 | 2 | 2 |
| AV3 | 6 | 6 | 6 | 4 | 6 | 6 | 4 |

Figure 5. Information tree

Assume that fault occurs to the line LXT from Xialu to Tieshan in Region 3, and consider this fault as internal fault. It can be known from Figure 4 that though LXT belongs to Region 3, the remote backup information for it is beyond Region 3. It can be known from the information tree in Figure 5 that LMCU9 and LMCU13 belong to Region 2, LMCU10 and LMCU12 belong to Region 1. Region 3 needs to exchange information of LMCU9, 10, 12, 13 with Region1 and Region 2 to complete the internal protection of PIZ3. Another way is to convey information of Region 3 to Region 1 or Region 2 to complete fault detection of LXT, but in this way the information amount in the exchange is larger. Thus, the latter method is not suitable for WAPS.

Information Tree in Figure 5 can well illustrate the protected information zones. With the fault decision principle of regional distance protection, distance protection criterion of the line LXT can be easily constructed as equation (7~9).

To illustrate the fault detection algorithm more clearly, in the simulation, the paper set a ground fault occurring in the line LXT. The case that information is complete and accurate and the other that information is incomplete or erroneous information are considered respectively. Under these two conditions, the information redundancy of different information zones is utilized to validate the reliability of fault component detection. The result is shown in Table I.

As shown in Table I, when one or two bits of information is missing or wrong, the protection action values adopting fault-tolerant design of protection criterion as shown Equation (6) can reliably identify faulty components.

1) The protection criterion based on PIZ1:

$$AV_1 = \sum_{i=2}^{3}(Zi_1 \cup Zi_2) \tag{7}$$

2) The protection criterion based on PIZ2:

$$AV_2 = \begin{cases} \sum_{j=2}^{3}(Zj_1 \cap \overline{Z4_2} \bigcap_{i=7}^{8}\overline{Zj_i}) + \\ \sum_{j=2}^{3}(Zj_2 \cap \overline{Z4_1} \bigcap_{i=3}^{6}\overline{Zj_i}) \end{cases} \tag{8}$$

3) The protection criterion based on PIZ3:

$$AV_3 = \sum_{i=9}^{14}(\overline{Z3_i} \bigcap_{i=3}^{8}\overline{Z3_i} \bigcap_{i=1}^{2}\overline{Z4_i}) \tag{9}$$

## 6. Conclusion

To resolve the current problems in conventional backup protection, this paper presented a relay protection system based on wide-area information. Starting from introducing requirements and responsibilities of the relay protection as well as the engineering characteristics and special requirement of wide-area network, the paper focused on exploring the architecture of limited wide-area protection system and the key technologies to implement it.

1) Based on the concept of limit, limited wide-area power grid is proposed.
2) Combining the advantages of distributed architecture and centralized architecture, this paper proposed a mixed architecture for the protection system. The architecture is based on the three-layer structure of LMCU, SDU, and RDU. The decision modes of inter-layer communication, independent processing and the back-up model can better ensure the reliability of WAPS.
3) On the basis of cooperation mechanism of WAPS, a regional distance protection algorithm is proposed. With the use of the logic calculation of different information zones, the reliable and

quick detection of fault component is achieved. The malfunction of distance protection during large-scale flow transfer can be avoided through improving zone 3 protection.

**Acknowledgment**

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**References**

[1] J C Tan, P A Crossley, P G McLaren, P F Gale. Application of a Wide Area Backup Protection Expert System to Prevent Cascading Outages. *IEEE Trans. Power Del.* 2002; 17(2): 375-380.
[2] D Novosel, G Bartok, G Henneberg, P Mysore, D Tziouvaras. IEEE PSRC report on performance of relaying during wide-area stressed conditions. *IEEE Trans. Power Del*. 2010; 25(1): 3-16.
[3] Das Priyanath, Nee Dey, Sunita Halder; Chakrabarti, Abhijit; Datta. Tanaya.Assessment of voltage stability using network equivalent. *TELKOMNIKA*. 2011; 9(3): 595-604.
[4] A G Phadke, J S Thorp. Expose hidden failures to prevent cascading outages. *IEEE Comput. Appl. Power*. 1996; 7: 20–23.
[5] M G Adamiak, A P Apostolov, M M Begovic. Wide area protection-technology and infrastructures. *IEEE Trans. Power Del*. 2006; .21(2): 601-609.
[6] Vladimir Terzija, Gustavo Valverde, Deyu Cai. *Wide-Area Monitoring, Protection, and Control of Future Electric Power Networks.* Proceedings of the IEEE. 2011; 99(1): 80-93.
[7] X N Lin, Z T Li, K C Wu, H L Weng. Principles and implementations of hierarchical region defensive systems of power grid. *IEEE Trans. Power Del*. 2009; 24(1): 30-37.
[8] Panjaitan Seno D, Hartoyo Aryanto. A lighting control system in buildings based on fuzzy logic. *TELKOMNIKA*. 2011; 9(3): 423-432.
[9] X Y Tong, X R Wang, K M Hopkinson. The modeling and verification of peer-to-peer negotiating multiagent colored petri nets for wide-area backup protection. *IEEE Trans. Power Del.* 2009; 24(1,): 61-72.
[10] Yin Xianggen, Wang Yang, Zhang Zhe. *Zone-division and tripping strategy for limited wide area protection adapting to smart grid.* Proc. CSEE. 2010; 30(7): 1-7.
[11] Lin Xiangning, Ke Shuohao, Li Zhengtian. A fault diagnosis method of power systems based on improved objective function and genetic algorithm-tabu search. *IEEE Trans. Power Del*. 2010; 25(3): 1268-1274.
[12] Sheng, K K Li, W L Chan. Agent based self-healing protection system. *IEEE Trans. Power Del.* 2006; 21(2): 610-618.
[13] M M Eissa, M E Masoud. A novel back up wide area protection technique for power transmission grids using phasor measurement unit. *IEEE Trans.* Power Del. 2010; 25(1): 270-278.
[14] Serizawa Y, Myoujin M, Kitamura K A, Shuto I. Wide-area current differential backup protection employing broadband communications and time transfer systems. *IEEE Trans. Power Del*. 1998; 13(4): 1046-1052.
[15] Nian Liu, Jianhua Zhang, Wenxia Liu. Toward Key Management for Communications of Wide Area Primary and Backup Protection. *IEEE Trans. Power Del*. 2010; 25(3): 2030-2032.
[16] Zijad Galijasevic, and Ali Abur. Fault Location Using Voltage Measurements. *IEEE Trans. Power Del*. 2002; 17(2): 441-445.