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A New Framework for Power System Fault Diagnosis

Lei Wang, Qing Chen, Zhanjun Gao

***ABSTRACT*--With the ever increasingly enlarge and complicate development of the power systems, operators office would be flooded with extraordinarily abundant alarm information of the relevant relay equipments which can hardly be processed whenever the fault occurs. Fault diagnosis system can locate the fault equipments and the improperly executed relays according to the structure of power grid and the fault information, and the fault location is the key issue among these function. Therefore it is an essential part of maintaining the stable operation of the power system to study on and develop a completed fault diagnosis method for power system, and the discrimination of fault elements is the premise of self-healing grid. In addition, knowledge is the basement of modern artificial intelligence. The establishment of its representation is the premise of intelligent algorithm. This paper expressed the thought that making fault diagnosis through 3-layer framework to reduce the complexity of the algorithm. The middle layer-knowledge layer is mainly discussed in this paper and it contains topology knowledge base and protection knowledge base. The frame is realized in UNIX system and it is shown by a case that the framework can be diagnosed correctly and effectively.**

***Index Terms*--fault diagnosis, inference method, knowledge, knowledge base, knowledge framework, Markov model, protection, protection knowledge base, power grid, topology analysis**

I. Introduction

When faults occur, how to make use of artificial intelligence program to judge fault sections is the main task of power system fault diagnosis. Because discrimination of fault elements is the premise of self-healing, fault diagnosis will play an important role in smart grid. Up to now, there are many methods such as artificial neural network (ANN) [1], Petri net system (PNS) [2][3], Bayesian network system (BNS) [4], analytic model-based methods [5]and expert system (ES) [6][7] have been applied to fault diagnosis. In addition, knowledge is the basis of artificial intelligence. In order to make computers intelligent, which can simulate human behaviors, we must let them possess knowledge. Therefore, the fault knowledge representation of power grid is decisive for fault diagnosis system.

Up to now, the research and development about power grid fault diagnosis mainly focuses on two directions. One is that proposing new fault diagnosis model to improve its adaptability and fault tolerance, the other is that improving the accuracy of model by perfective information. For example, the fault recorder data and information from SCADA are used to improve the completeness of information, and then the fault diagnosis model can judge the fault elements more accuracy. Since the integrality of information is subject to the communication technology and integrated automation system of substations, its application and relational research is not good enough. In practical applications, we find two problems which are as following:

1) The 2-layer C/S model is widely adopted by diagnosis framework. The work principle of traditional 2-layer C/S is: the client provides the basic man-machine interface and packages the affair rules, legal checking and finds the server through specified IP and port number. The server must design fixed IP and port number and ran the diagnosis program all the time. Because of the tight connection of client and server, the function will decline while the network data increasing after faults occur.

2) There is not an efficient way to built knowledge base for the power system fault diagnosis. In power system, protection setting method follows the principle of cascade tripping in order to meet the demand of selectivity. The selectivity of protection requires that “isolate the fault from power system within the smallest zone”, which is completely based on power grid topology information. Thus topological knowledge is an indispensable factor of fault diagnosis. But the knowledge representation of power system topology is never mentioned in the developed methods.

In consideration of above analysis, this paper proposes a new framework for power system fault diagnosis which bases on the fault knowledge base in 3-layer model. The feature of this model is that it adapts to all kinds of power system elements and networks, but the diagnosis process takes low time complexity.

II. The Design of Framework for Fault Diagnosis

Due to the large-scale, high-quality of data in the fault diagnosis system, network and the explosion of web knowledge bases, more and more designer want to get information and data from the web database. As the base of query and integration, the framework of fault diagnosis should be considered adequately in order to build high quality integrated interface and information expression.

The hardware connection is shown in Fig.1. In this figure, the FTU, RTU and TTU collect the alarm message after the faults occur. The function of substation is to send the signal to control center by Synchronous Digital Hierarchy (SDH) optical fiber cable communication network.

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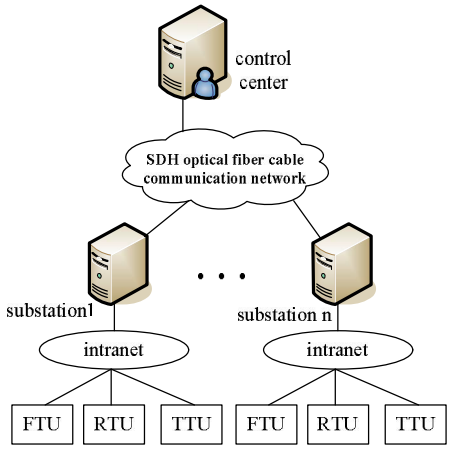

Fig.1 Hardware connection of power network

Because the data isn't pretreated before it is send to the control center, the server will receive too many data in the same time. This can lead to data traffic congestion or the paralysis of whole network.

Based on the above analysis, a 3-layer framework is designed for fault diagnosis which is shown in Fig.2. There are three layers in this framework. Resource layer is the integration of fault recorder, protection, CB, topology file and database. It can collect the alarm message from protection and CB, disturbance recorders in the form of COMTRADE from fault recorder, topology of power grid from topology file and other data from database. Knowledge layer contains the knowledge base which provides information to fault diagnosis program running on the diagnosis server. Diagnosis layer is the interface of system which carries the communication function between man and the system. In this layer, fault diagnosis server holds the diagnosis program which can judge the fault section by AI. And the self-healing program can be the advanced function of smart grid. The 3-layer effectively makes up the shortcomings of the traditional 2-layer C/S system. The key of realizing 3-layer system is the middleware. Middleware is a computer software component or program and their applications. Software consists of a set of services which allows plentiful processes running on one or more machines to interact. This method evolved to provide for interoperability in support of the access to coherent distributed architectures, which are most often used to support and simplify complex distributed applications.

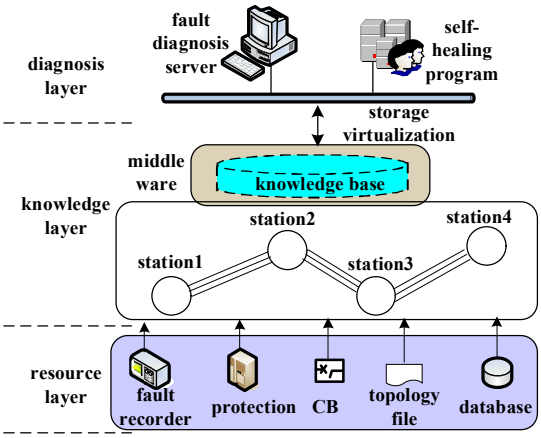

Fig.2 3-layer framework for fault diagnosis

III. KNOWLEDGE BASE IN UNIX

Though 3-layer C/S and B/S model have already become the mainstream of information system under the circumstances of Windows, currently most of the system based on UNIX is 2-layer C/S system. Mainly because many distributed system use the multi-layer design model of "Java + CORBA production + WEB". The speed of Java is not so fast and it takes up too much internal memory that Java is limited used in UNIX. C/C++ is also the main programming language in UNIX, which makes it hard to realize multi-layer distribute design. Today plenty of power stations widely using UNIX operation system in China, which brings many inconveniences.

This paper designs a knowledge base which can be the middle ware in UNIX for fault diagnosis system. There are two kinds of knowledge in knowledge base: topology knowledge and protection knowledge.

A. Topology Knowledge Base

In power system, protection setting method follows the principle of cascade tripping in order to meet the demand of selectivity. The selectivity of protection demands that the fault must be isolated from power system within the smallest zone. This technology is completely based on power grid topology information. On the other hand, every judge method such as Petri net [2][3] and expert system [6][7] has the same premise that the topology of power network has been represented and the outrage range can be determined by the CB tripping alarms. Thus topological knowledge is an indispensable factor of fault diagnosis.

A knowledge base is a special kind of database for knowledge management. The difference between knowledge base and database is that a knowledge base provides a means for information to be collected, organized, shared, searched and utilized. In this paper, the knowledge base is divided into three parts, which are domain ontology base, rule base and service base. Domain ontology base stores the connection relationship between power elements in substation. Rule base stores the inference rule which can format a power grid network by merge the common lines between substations. Service base holds some independent program and each program is a service, for example, the outage range service.

The process of getting topology of power grid contains three steps which are shown in Fig.3. First, the CIM-RDF data files are formulated by RDF Scheme Editor in step 1. Then the CIM-RDF data is used to integrate the SVG graphic in step 2. Step 3, elements that format the wiring diagrams of this station are queried by LINQ to XML [8], finally this data will be organized in the form of matrix or adjacency list. The abstract topology is stored in domain ontology base.

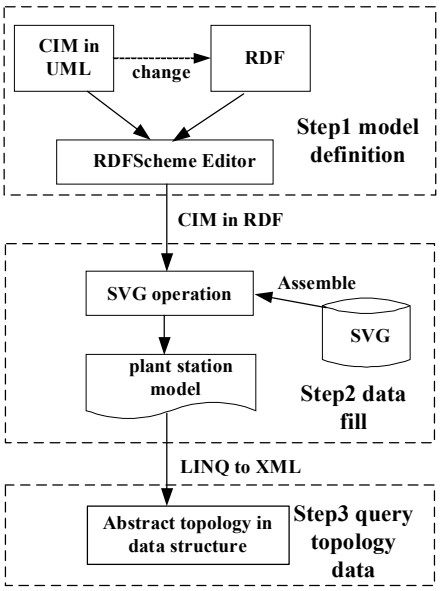

Fig.3 The proceeding of getting power grid topology

Rule base is composed of wiring analysis rules. There are two kinds wiring method: wiring in substation and wiring between substations. Wiring in substation contains single bus, double bus, ring bus and straight bus. Wring between substations contains single circuit lines and double circuit lines. The rules are lists as following:

Rule1: IF single bus in substation THEN search 1 line
Rule2: IF double bus in substation THEN search 2 lines
Rule3: IF ring bus in substation THEN search circle
Rule4: IF straight bus in substation THEN search 2 lines.
Rule5: IF single circuit lines between substations THEN search 3 phases.
Rule6: IF double circuit lines between substations THEN search 6 phases.

Service base only has outage range service at present. In the paper [9], outage range is the first step to judge fault sections. The flow chart of getting outage range is shown in Fig.4.

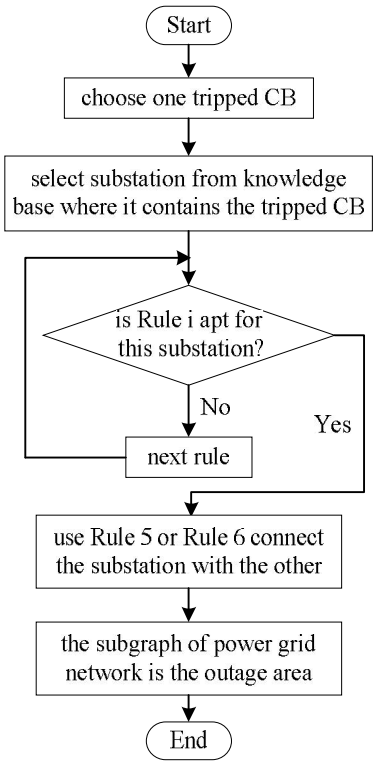

Fig.4 flow chart of getting outage range

B. Protection Knowledge Base

As the first defense of power system, protective relaying plays an important role in preventing failure and disturbance, it is significant part of power system, and whether it could work normally will bring important effect to power system. With the augmentation of power network, capability and the grade of voltage, the failures influence wide section and more customers. The protection knowledge base contains data about protection such as type, manufacturer, service life, etc. Aiming at the definition of correct action rate, this paper uses action number and operating time to measure the index which may be more reasonable, and correct action rate is defined as the sum of area fault correct action number and external fault correct not action number per unit time, incorrect action rate is defined as the sum of false action number and refusing action number per unit time. Aiming at microcomputer protection, based on traditional relay protection device, considering software factor, this paper evaluates the failure rate and the availability of protection device roundly.

Because the defect of hardware/software can lead the malfunction of protection, the expectation that protection engineers consider the tendency of protection system to operate correctly is defined as the reliability of protection. The way how to generate reliability base of protection is shown in Fig.5.

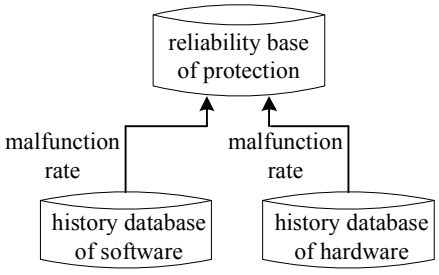

Fig.5 Generation of reliability base of protection

History database of software/hardware module which has been build rarely refers the effect of main and back-up protection. This paper applies Markov State Space Method [10][11] to analyze the all failure states of main and back-up protection, following the acted principle of protective relaying, builds the module which takes back-up protection into account, and calculates the availability of main and back-up protection, the module reflects real the effect of protective relaying system on power network. Then the module is validated in the reliability evaluation of distribution system.

There are seven states in the Markov model, and everyone has a meaning. For example, state 1 means main protection operates correctly, primary and second backup protection in the standby condition. State 2 means main protection operates correctly; primary backup protection in the standby condition and second backup protection make a false operation. λ1~ λ6 mean the malfunction rate of protection and μ1~μ6 mean the restoration rate of protection. The state space of protection is shown in Fig.6. According to the last data, the reliability of protection is as following:

main protection—0.974;

primary backup protection—0.958;

second backup protection—0.943.

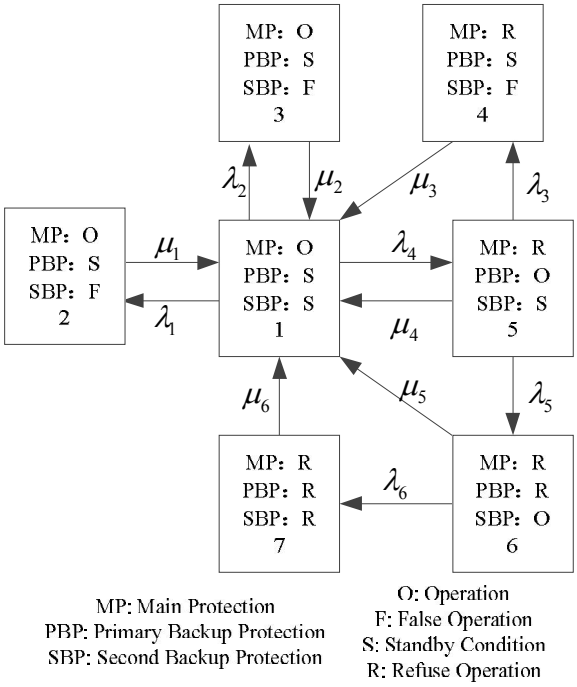

Fig.6 state space of protection

C. Inference Method

This paper designed the knowledge base and inference system in UNIX. The ORACLE database Server is used to store the Rules, and C++ is chosen to be programming language. The positive reference method is used to judge what kinds of knowledge should be activated. The flow chart is shown in Fig.7.

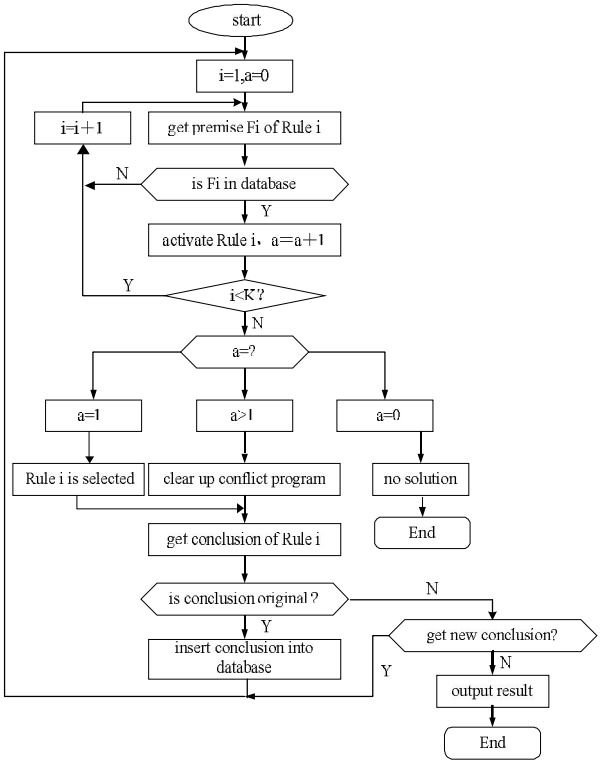

Fig.7 Flow chart of inference method

IV. APPLICATION

As is shown in Fig.8, a local sketch map of operational principle and protection configuration of protection system is given. In which 28 system elements, 84 protection, and 40 circuit breakers are included.

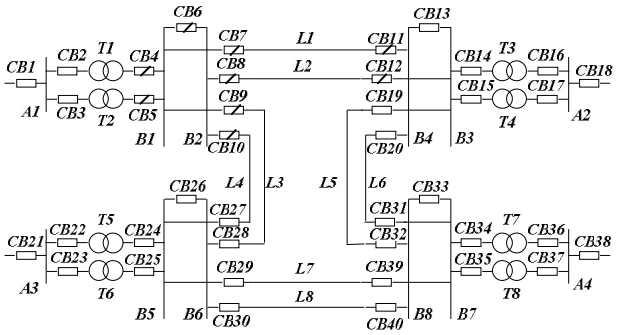

Fig.8 diagram for testing

The alarm messages are B1m, B2m, $L1_{B1m}$, $L1_{B4m}$, $L2_{B2m}$, $L2_{B3m}$. The tripped circuit breakers are CB4, CB5, CB6, CB7, CB8, CB9, CB10, CB11 and CB12. The outage range can be gotten by topology knowledge base that B1, B2, L1 and L2.

This paper use Petri net method [3] to do fault location. The final determination is listed in Table 1.

TABLE 1 FINAL DETERMINATION FOR ELEMENTS

element	In outage range?	reliability	Is fault element?
B1	Yes	0.992	Yes
B2	Yes	0.995	Yes
L1	Yes	0.96	Yes
L2	Yes	0.96	Yes
other	No	– –	No

V. CONCLUSIONS

This paper designs a framework of fault diagnosis system through analyzing in detail the foundation mechanism of fault diagnosis system in power grid which bases on the UNIX operating system and Oracle data base platform. It bases on 3-layer structure and resource layer, knowledge layer and diagnosis layer are contained. Topology knowledge base and protection knowledge base is mainly discussed and it is demonstrated by the test system that the developed model is correct and efficient.

VI. REFERENCES

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VII. BIOGRAPHIES

Lei Wang was born in Rizhao, Shandong Province, China. He received the B.S. and M.S. degrees in 2001 and 2004, respectively, both major in computer application. As a Ph.D student in Electrical Engineering, he is currently studying in school of Electrical Engineering of Shandong University, Jinan, China. His areas of research are mainly focused on power system relay protection, fault diagnosis and fault information system of power grid.

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