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A New Integrated Fault Diagnosis And Analysis System For Large-Scale Power Grid

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Abstract: This paper describes an efficient methodology that can be used in an integrated fault diagnosis and analysis system (IFDAS) for large-scale power grid. The IFDAS extended from some software tools used in contemporary power grid consists of four main parts: fault information processing, fault diagnosis, power gird vulnerability analysis and prediction contingency analysis. It also has some innovative characteristics. First, the large-scale power system IFDAS in this paper is based on slow successive tripping procedure of cascading failure. Second, the concept of coordination is brought into the cascading failure analysis and defence scheme of IFDAS. Third, it is an on-line cascading failure analysis method which can trace real-time operation conditions. And last it makes full use of data acquisition channels and monitor system dynamic behavior. According to the slow successive tripping procedure character of the cascading failure and blackouts, the concept of a large-scale power system IFDAS is presented. And the features, structure, flow and responding mechanism of the IFDAS are all detailed discussed. Finally, case analysis shows that the IFDAS is a system good at fast identifying cause during cascading failure, supplying optimum dispatching strategy, and avoiding blackouts effectively.

Keywords: power system, fault diagnosis, cascading failure, blackouts

1. INTRODUCTION

In recent years, the serious unpredictable system cascading failure may cause system wide blackouts (Zhou Xiaoxin, Zheng Jianchao, Shen Guorong, 2003; Fu Shuti, 2005; Li Zaihua, et al., 2007), which attracts the attention of researchers to the fault diagnosis of power system. The need for the development of fault diagnosis system has been recognized since the 1960s (Human, et al., 1960). This need is even more pressing today due to the increased size and complexity of power system, the interconnections between large geographical areas, and the deregulation of power systems which introduces complexity in the control decisions (Elias Kyriakides, et al., 2007).

Several fault diagnosis systems have been developed and are used now. The prevailing fault diagnosis systems are based on expert system (Fukui, and Kawakami, 1986; Young, et al., 1997), artificial neural network (ANNs) (He, et al., 1999; Bi, et al., 2000) and optimal theory (Wen, and Han, 1994). The fault diagnosis systems based on fuzzy set theory (Lee, et al., 2000), information theory (Tang, et al., 2003; Zhow Hongshan et al., 2006) and rough set theory (Shu, et al., 2001) aim at settling the incomplete and uncertain information problem.

Souza et al. (J. de Souza et al., 2004) has presented a methodology that combines the use of artificial neural networks (ANNs) with fuzzy logic to form fault diagnosis systems. The inputs of the ANNs are alarm patterns while fuzzy relations are established to form a database employed to train the ANNs. Each neuron of the ANN is responsible for estimating the degree of membership of a specific system component into the class of faulted components. Results of an application on an actual system show that the proposed method allows for good interpretation of the results, even in the presence of corrupted alarm patterns.

McArthru et al. (S. McArthur et al., 1996) present a model based reasoning application to system protection. Model based reasoning is applied to the comprehensive validation of protection performance. All of these are integrated with Supervisory Control And Data Acquisition (SCADA).

While all contemporary software tools presented in the above papers have solved parts of problems, there are still many problems existing illustrated as follows and shown in figure 1.

- Local system and without global view during blackouts analysis
- On-line strategy support system
- Isolated system without cooperation
- Single fault diagnosis without the relation analysis of the successive faults
- Without the concept of slow successive tripping

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- Weak in decision making assistance during cascading failure

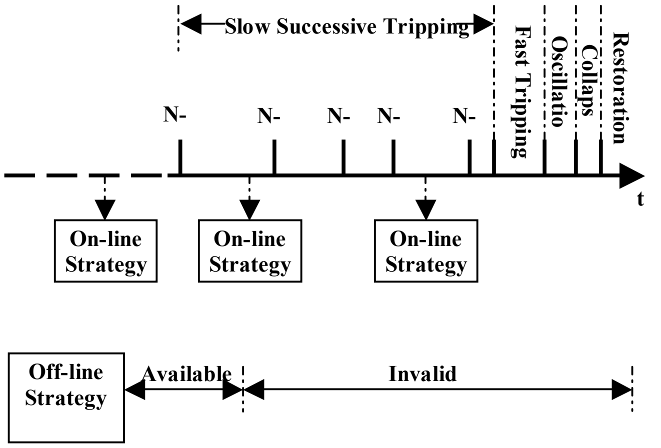

Fig.1.Problems of contemporary software tools during blackouts

These characteristics are unbefitting for fault diagnosis and analysis during blackouts. This paper presents a methodology for new large-scale power system IFDAS, which is based on slow successive tripping procedure of cascading failure. The IFDAS's concept, features, structure , responding mechanism and application fields are all detailed discussed in this paper .

2. CONCEPT OF IFDAS

There existing many causes for the grid blackouts and cascading failure, such as loss of synchronism, power oscillation, voltage collapse and thermal overloading. All factors interact with each other but different factor plays a leading role in different time spans. Several instability issues and thermal overloading phenomena with their time spans and preventive measures are illustrated in figure 2.

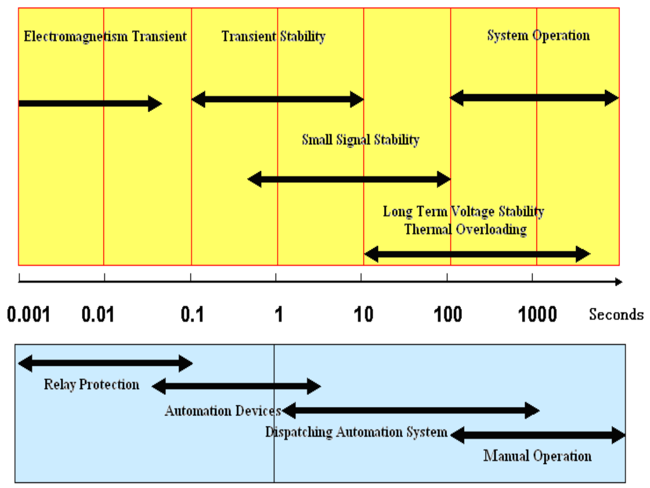

Fig.2. Power system cascading failure time spans and preventive measures

The main cause for cascading failure is thermal overloading following facility tripping. Firstly, one element trips under heavy power flow, then other elements face with overloading and have high probability of tripping successively. It is the beginning of cascading failure. In this paper, the IFDAS is presented, which mainly deals with the slow successive tripping procedure of the cascading failure.

3. FEATURES OF IFDAS

New IFDAS for cascading failure illustrated in this paper have be upgraded from the current off-line pre-decision to on-line pre-decision, from no slow successive tripping concept to with the concept of slow successive tripping, from the certainty to the probability and risk analysis, from local to global, from isolation to synergy, as well as several other important changes. The specific design gist is in the following elements:

1) It is necessary to use on-line cascading failure analysis method which can trace real-time operation conditions. In the process of cascading failure, what the independent system operator wants to know is the distance between current operation point and the stability limit. Furthermore, the operators want to receive analysis results and suggestions given by the strategy support system. In this condition, the off-line strategy form is less helpful. An on-line strategy support system is needed.

2) A unified, opened WAMS platform is necessary for the system design. Various contemporary SCADA systems mutually isolate, including no data share and great constrains for analysis and control. The existing SCADA system has no information that reflects real-time dynamics action, moreover, its channel network and database do not support the real-time dynamic information transmission and storage yet. As a result, it can only monitor the grid static characteristics, and could not surveil system dynamic behaviors. It is difficult for the current WAMS to fulfill the observability requirements of the grid, and it can well support the quantitative assessment of the right time response curve and the risk assessment of power system. However, the reliability of the information includes two aspects: data security and abundance. Therefore, we should make full use of data acquisition channels, effective exchange of information with external power grids, and obtain adequate static and dynamic time and space information.

3) The concept of coordination should be brought into the cascading failure analysis and defence scheme. There are proper analysis methods for most of the power system disturbances and abnormal conditions, however, coordination among them is insufficient. For example, the EMS(Energy Management System) hardly has communication with stability control equipment, and can't provide strategy support for stability control; The control strategy for different phases, including preventive, emergency, corrective and recovery control, are lack of coordination; Parameters setting and tuning of every defence-line is isolated from others. To solute the problems above, the concept of coordination is brought into the design of a new strategy support system, which is IFDAS illustrated in this paper.

4. STRUCTURE OF IFDAS

Since the time span of thermal overloading is under the control of system operator, IFDAS aims to provide strategy support of cascading failure prevention for system operators. The primary scheme is shown in figure 3.

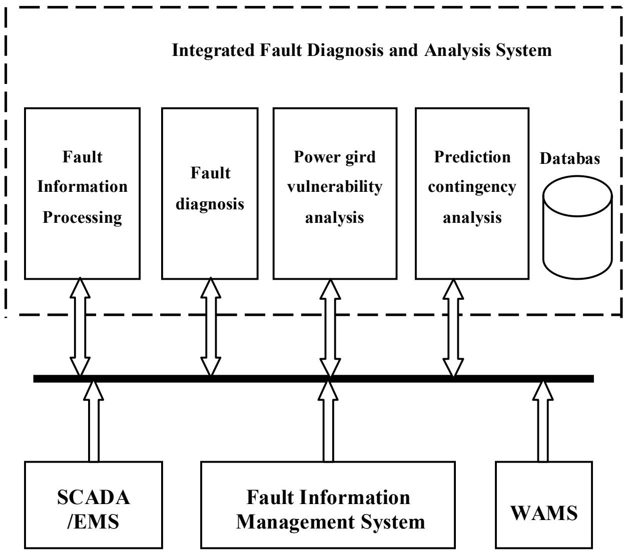

Fig.3. Structure of the IFDAS

Fault information processing, fault diagnosis, power gird vulnerability analysis and prediction contingency analysis are the four main parts of this system.

Fault information processing module and fault diagnosis module is based on the complex event processing technology (David Luckham, 2002), which is capable of dealing with complex and redundant alarm information with inconsistent data in fault diagnosis under cascading failure circumstance. The layering processing feature of the presented method is helpful both in controlling complexity of rule making and in enlarging the applying scope of diagnosis rules. Moreover, it is easily to drill down for tracking the reasons of diagnosis results, which make the fault diagnosis process clear and understandable.

The power gird vulnerability analysis module is performed respectively from the aspects of grid topology, protection hidden failure and system operation. In the view of grid topology, the small world network model (Watts D J *et al.*, 1998) is introduced and has been modified by taking the weight of the edges into consideration in order to model the power grid more precisely. The magnitude of the line impedance is considered as the weight of the edges (Jian Ding *et al.*, 2006). Some grids of China which are insensitive to the original model are upgraded to be small world networks by employing the modified model. In the view of protection hidden failure, the mechanism of gird vulnerability is implemented. For system operation, a novel grid operational vulnerability analysis method is implemented based on the two-dimensional accumulation means, which is helpful in cascading failure development process research.

The prediction contingency analysis module is based on Bayesian network. The power flow redistribution process after the initial disturbance is selected as the primary research focus. With the linear probability feature of protection hidden failure considered, the cascading failure analysis model based on Bayesian network is established for uncertainty reasons. Results of testing examples indicate that the method is able to find out the possible prediction contingency quickly after the initial disturbance and offer the corresponding probability estimation result.

5. FLOW AND RESPONDING MECHANISM OF IFDAS

In normal operation, the power gird vulnerability analysis module and the prediction contingency analysis module still execute. The results of vulnerability analysis and prediction contingency analysis would instruct defence of the power system. When disturbance or accidents happen, fault information processing module and fault diagnosis module will work and the results will serve for other on-line module. When accident happens successively, the IFDAS will trigger interaction repeatedly and supply on-line suggestion for cascading failure prevention. The detailed process flow of the IFDAS is illustrated the following figure 4.

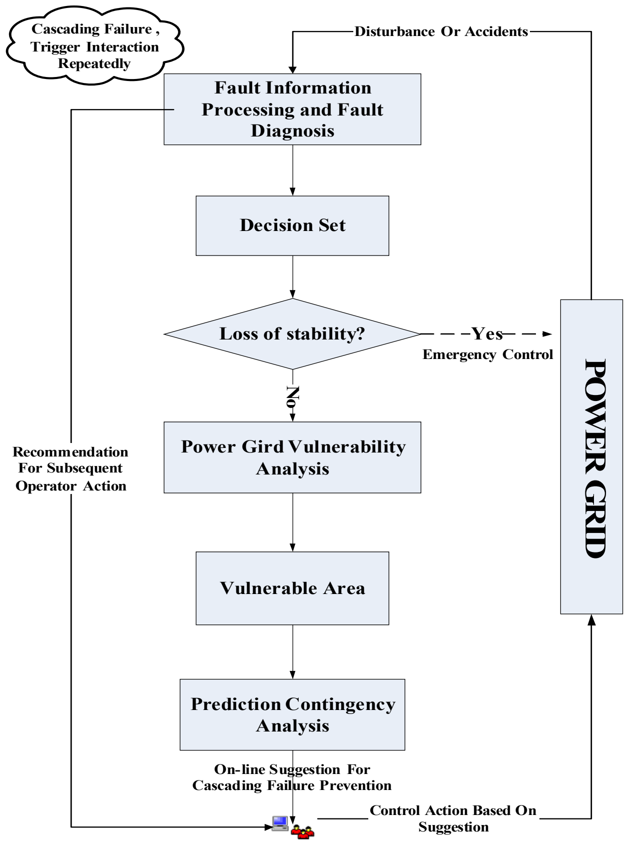

Fig.4. Flow of the IFDAS

The detailed responding mechanism of the IFDAS is illustrated in figure 5 when accident happens one after another.

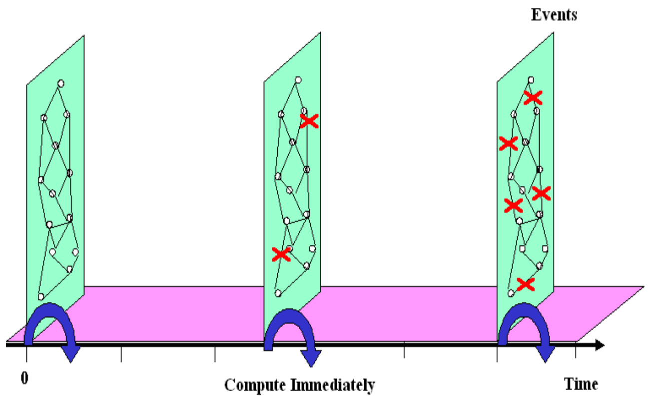

Fig.5. Rapid responding mechanism for successive stripping

6. CASE ANALYSIS

There is a practical cascading failure case happened in 2006. A portion of the power grid shows in figure 6, it's used to explain how the IFDAS works. The power flow before the cascading failure is shown in this figure. The bold lines in the figure are 500kV transmission lines. The normal lines in the figure are 220kV transmission lines.

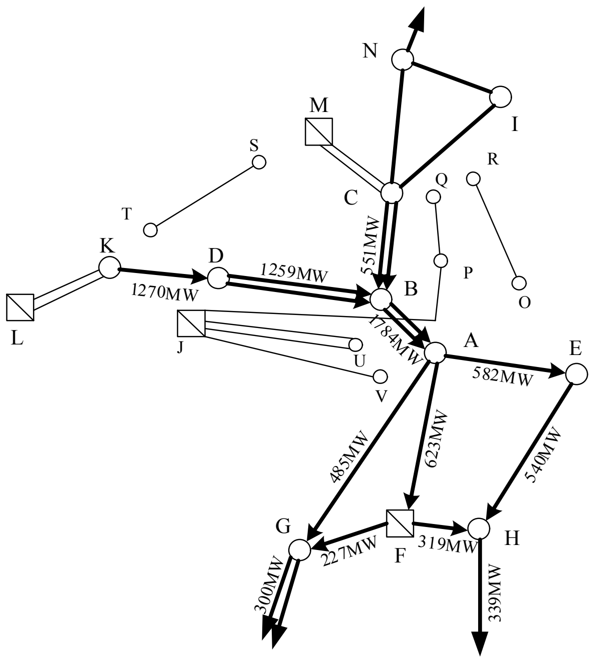

Fig.6. Portion of the power grid in a cascading failure case in 2006

Station A's electric diagram is shown in figure 7. Before the accident happens, Bus I of Station A is outage and Breaker 5011, Breaker 5021, Breaker 5031, Breaker 5041 are all outage.

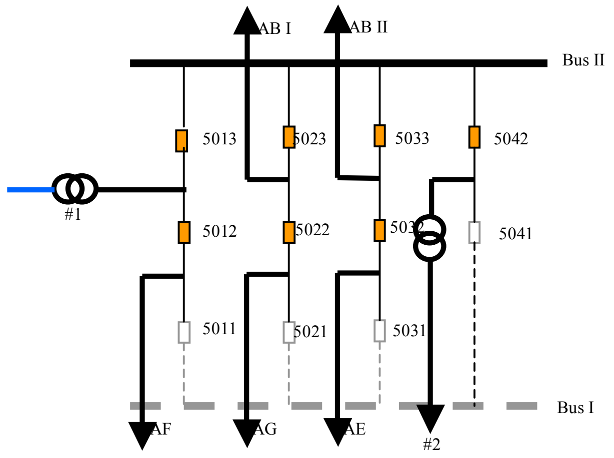

Fig.7. Electric diagram of Station A

The process of the blackouts is illustrated in the table 1.

Table 1. Process of the blackouts

Time	Events
20:48:00	500kV Line AB II: Current Differential Protection Action. C Phase Open. Unsuccessful Reclosure. Three Phases Open. 500kV Line AE: Open due to Bus I of Station A was outage.
20:48:10	500kV Line AB I: Overload Protection Action. Three Phases Open. 500kV Line AG: Open due to Bus I of Station A was outage.
20:48:10	Stability Control Equipment in Station B is resist-operation.
From 20:54 to 21:05	Line RO, Line QP, Line JU II, Line TS and other lines open. System Oscillation.

How the IFDAS working on this cascading failure process is presented in following.

At 20:48:00, Line AB II opens. Other fault diagnosis system could give the fault diagnosis results just based on the information of protection and breaker. However, fault information processing module of IFDAS explores that the power flow and the protection action are not unified. Fault diagnosis module of IFDAS detects this protection was mal-operation based on power flow. Furthermore, it gives out the strategy of manual closing the Line AB II and inspecting related equipment. The blackouts will be avoided when following the suggestion of IFDAS. Meanwhile the power grid vulnerability analysis module of IFDAS is triggered, and gets that Line AB I is a vulnerable line.

At 20:48:10, Line AB I opens. Fault diagnosis module judges that this protection action was mal-operation based on that overloading time is shorter than the setting value, and gives out the advice of manual closing the Line AB I. Then, the blackouts will be avoided when following the suggestion of IFDAS, too. When line AB I, II all opened, stability control equipment of Station B should work, while the stability control equipment was resist-operation. The fault diagnosis module of IFDAS immediately detects the situation and direct operators to shut down the generators. And the power grid vulnerability analysis module of IFDAS is triggered, recognizing Line RO, Line QP, Line JU I, Line JU II, Line TS as vulnerable lines.

The process of the blackouts is shown above the time line, while the main fault diagnosis results and dispatching strategies given by the IFDAS are shown below the time line in the figure 8.

From the analysis above, IFDAS is good at fast identifying failure cause during cascading failure, supply the best dispatching strategy, and avoid blackouts effectively.

7. APPLICATION OF IFDAS

This IFDAS can be implemented in the provincial or advanced dispatching centre. The former system has been used in a district power grid of Shandong province (Wei Zhao *et al*. 2006) and Hebei province in China, and has got a satisfied response from the user. This IFDAS also can be integrated in other system. This system has been integrated in the wide-area dynamic supervision system and will be used in the State Dispatching Centre of SGCC (State Grid Corporation of China).

8. CONCLUSIONS

The purpose of this paper was to develop a new methodology that can be used in integrated fault diagnosis and analysis system (IFDAS) for large-scale power grid. The methodology extended contemporary software tools used in power grid and also has its original features. First, the large-scale power system IFDAS in this paper is based on slow successive tripping procedure of cascading failure. Second, the concept of coordination is brought into the IFDAS. Third, it is on-line cascading failure analysis method which can trace real-time operation conditions. And last it makes full use of data acquisition channels and monitor system dynamic behavior. Case analysis shows that the IFDAS is good at fast identifying cause during cascading failure, supplying optimum dispatching strategy, and avoiding blackouts effectively. The former system of IFDAS has been implemented in a district power grid of Shandong province and Hebei province in China, and has got a satisfied response from the user. And more important to us, this system has been integrated in the wide-area dynamic supervision system and will be used in the State Dispatching Centre of SGCC.

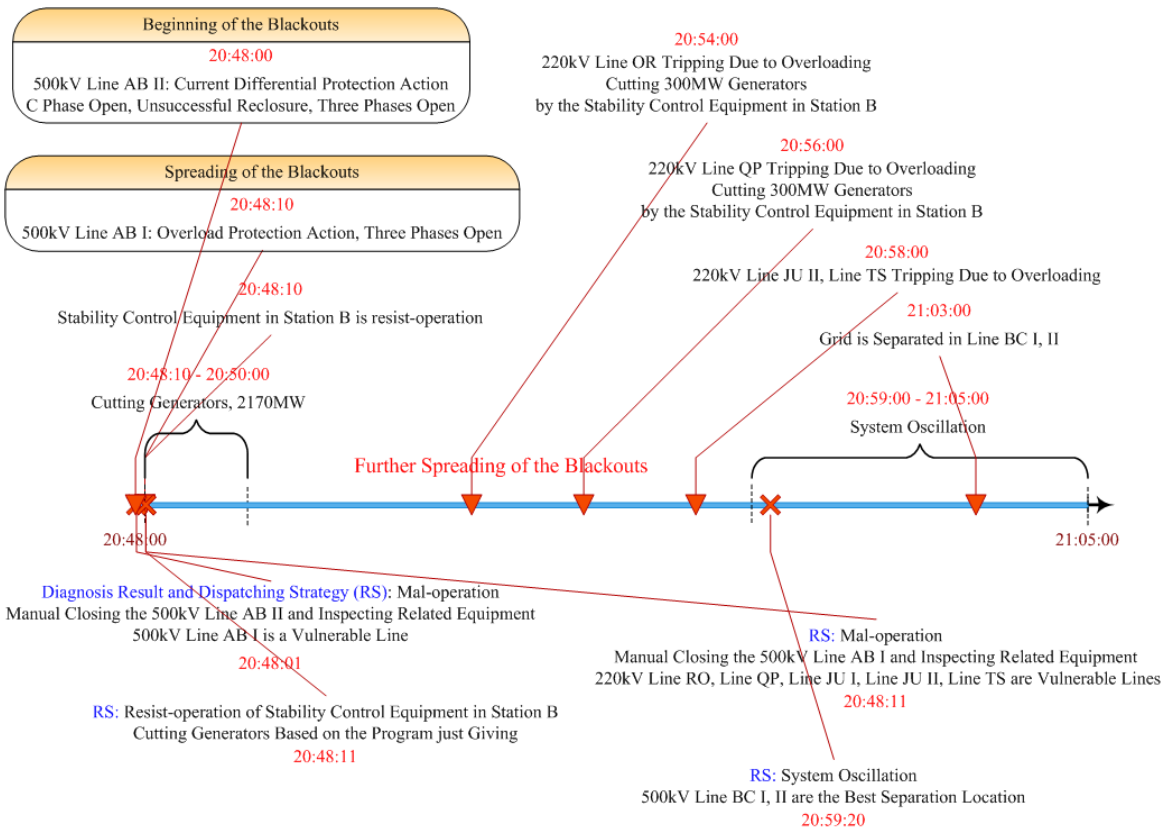

Fig.8. Process of the blackouts and the main fault diagnosis results and dispatching strategies given by the IFDAS

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