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Fault Diagnosis in Power systems Considering Malfunctions of Protective Relays and Circuit Breakers

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Abstract— ***It is well known that sometimes Protective Relays (PRs) malfunction and trip the Circuit Breakers (CBs) giving a wrong signal of what has actually happened. There were several analytical models for fault diagnosis each having its own limitation to address the possible malfunction possibilities leading to an incorrect diagnosis. Based on these models, a new analytical model was developed to take into account of the possible malfunctions of PRs and CBs and further to improve the accuracy of the fault diagnosis. This model does not only estimate the faulted sections but also identify malfunctioned PRs and CBs. This thesis proposes to validate this model on a 8-bus system with a three phase fault on a bus. Software is developed using MATLAB programming for the fault scenarios considered. The results are presented and analyzed.***

Key words — **Tabu search, fault diagnosis, malfunctions of protective relays and circuit breakers, power system.**

I. INTRODUCTION

When a fault occurs on a section in a power system, the corresponding protective relays (PRs) should operate to trip related circuit breakers (CBs) off, so as to isolate the fault section from the healthy part of the power system. If a malfunction or malfunctions are happening with these PRs and/or CBs, the outage area could be significantly extended. Under complicated fault situations, a flood of alarm information could be dis- played on the console in the control center, and lead to the difficulty for dispatchers to identify the faulted section in a short time. Thus, precise and effective method for power system fault diagnosis plays an important role in supporting network restoration for dispatchers. Up to now, the most established approaches, which have been put into or of potential for practical applications, can be grouped into three categories: the expert system-based [1]–[6], artificial neural network-based [7]–[10], and the analytic model-based methods [11]–[17]. In addition, other artificial intelligent methods such as the rough set (RS) [18], Petri net [19], [20], and Bayesian networks [21] have also been proposed for power system fault diagnosis in recent years with preliminary research results reported. are needed to cope with fault diagnosis problems, expert systems (ES) have been extensively used in on-line fault diagnosis of power systems. Take two practical applications for instance:
1) a Generalized Alarm Analysis Module (GAAM) employing the techniques presented in [1] was integrated into the EMS

Since a great deal of expertise and the logic based reasoning (Energy Management System) environment at control centers in Italy; 2) A fault diagnosis ES for distribution substations presented in [2] has been installed in a local control center in Korea as a part of an intelligent guidance system for the SCADA operators. In [3] the problem of fault section estimation is dealt with by combining artificial neural network (ANN) and ES techniques: ANNs are employed to model the protection systems with particular emphasis on handling the uncertainties involved with PR operation and CB tripping messages; An expert system is then used to complement the results provided by the ANNs with the network topology considered. In [1]–[6], ES based approaches were proposed for fault section estimation with mal- functions of PRs and CBs taken into account. These approaches could work well if all received alarms are correct. However, once there are incorrect or missing alarms, false diagnosis results may be obtained. The analytic model-based methods for power system fault diagnosis were developed in [11]–[17]. A key issue in this kind of methods is to build up a criterion that could well reflect the discrepancy between the actual and the expected states of PRs and CBs. Then an optimization method, such as the Genetic Algorithm (GA) [11], [12], Tabu Search (TS) [13], [14], Particle Swarm Optimization (PSO) [15], and Evolution Algorithm (EA) [16], can be employed to search for a fault hypothesis (FH) or hypotheses (FHs) which minimize the criterion, i.e., to find the most likely FH(s) that could well explain the received alarm messages. In the analytic model-based methods, the power system fault diagnosis is formulated as an unconstrained 0–1 integer programming problem, and as a result this kind of methods could deal with complicated fault scenarios, especially the ones with incorrect or missing alarms. In the existing analytic models for the power system fault diagnosis, a FH only involves the information about “the actual states of section(s) in the outage area (healthy or faulted)”. In determining the expected states of PRs and CBs, their possible malfunctions are not taken into account and this may lead to false diagnosis results if one or more malfunctions of some PRs and/or CBs associated do occur. Based on the work presented in [11]–[17], an analytic model is developed for power system fault diagnosis with malfunctions of PRs and CBs taken into account, and the problem is then formulated as an integer programming problem and solved by the well developed TS method. The main contributions of this paper include the following three aspects.

1) A new form of the FH is presented, including the information about "the actual states of section(s) in the outage area (healthy or faulted)", as well as "the actual operating states of PRs and CBs (normal or malfunctioned)".
2) A novel criterion is presented (i.e., the objective function of the optimization problem) with malfunctions of PRs and CBs taken into account. Here, the key issue is to deter- mine the expected states of PRs and CBs corresponding to a given FH. The fault diagnosis model to be developed could not only estimate fault section(s), but also identify the malfunctioned PRs and CBs, as well as the incorrect and missing alarms.
3) Based on the developed fault diagnosis model, a software system is designed and implemented to meet the requirements of actual power systems. The developed software package has been employed by Guangdong Power Dispatching Center in south China. Actual fault scenarios are employed to demonstrate the feasibility and efficiency of the developed model and approach.

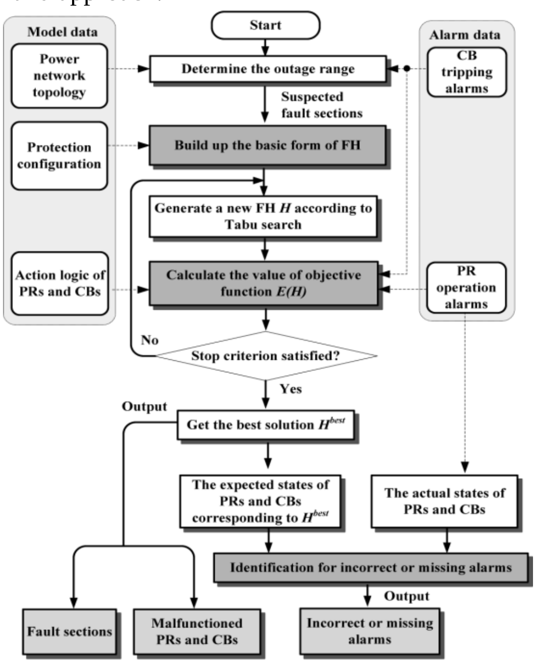

Fig. 1. Framework of the Developed Fault Diagnosis Method.

II. THE FRAMEWORK OF THE DEVELOPED ANALYTIC MODEL-BASED APPROACH

The framework of the developed analytic model-based approach for power system fault diagnosis is shown in Fig. 1. First, the outage area is identified to obtain the suspected fault sections using a real-time network topology determination method [22], so as to reduce the scale of the optimization problem to be formulated in the next step. Three key modules, namely "Build up the basic form of a FH", "Calculate the value of the objective function", are presented in Section III, Section IV, , respectively.

The diagnosis results include the following three types:

1) Fault sections;
2) Malfunctioned PRs and CBs;
3) The incorrect and missing alarms.

III. THE FAULT HYPOTHESIS

For the convenience of presentation, several sets are defined first as follows:

1) $\{d_1, d_2, \ldots, d_{n_d}\}$ is the set of sections located in the outage area, and d_i is the ith section in this set;
2) $\{r_1, r_2, \ldots, r_{n_r}\}$ is the set of PRs which are configured for $d_1, d_2, \ldots, d_{n_d}$; and r_i is the ith PR in this set;
3) $\{c_1, c_2, \ldots, c_{n_c}\}$ is the set of CBs which are connected to $d_1, d_2, \ldots, d_{n_d}$ before a fault occurs, and c_i is the ith CB in this set.

A fault hypothesis (FH) is used to represent "what happened to trigger the received alarms". If a FH is consistent with actual fault situation, then the FH is deemed true. The defined FH here not only involves the information about "the states of section(s) in the outage area (healthy or faulted)", as well as "the operating states of PRs and CBs (normal or malfunctioned)". Malfunctions of PRs and CBs can be classified into four types:

1) a PR fails to operate;
2) a PR operates incorrectly;
3) a tripping signal is sent from a PR, but the CB associated fails to be tripped off;
4) no tripping signal is sent from a PR, but the CB associated is tripped off (i.e., the CB is tripped incorrectly).

With malfunctions of PRs and CBs taken into account, a FH is defined mathematically as follows:

$$H=[\ D\ \ F\ \ M] \quad (1)$$

Where

D= $[d_1, d_2, \ldots, d_{nd}]$, and d_k represents the state of the k^{th} section in the outage area, with d_k = 0 and 1,respectively, corresponding to its normal and faulted state;

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F = $[f_{r1}, f_{r2}, \ldots\ldots, f_{rnr}, f_{c1}, f_{c2}, \ldots\ldots, f_{cnc}]$. If r_i operates incorrectly, then $f_{ri} = 1$, otherwise $f_{ri} = 0$. Similarly, if c_j is tripped off incorrectly, then $f_{cj} = 1$, otherwise $f_{cj} = 0$;

M = $[m_{r1}, m_{r2,\ldots\ldots}, m_{rnr}, m_{c1}, m_{c2,\ldots\ldots}, m_{cnc}]$. If r_i fails to operate, then $m_{ri} = 1$,otherwise $m_{ri} = 0$. Similarly, if c_j fails to be tripped off, then $m_{cj} = 1$, otherwise.$M_{cj} = 0$.

A. THE OBJECTIVE FUNCTION

1. The Basic Form of the Objective Function The objective function E(H) reflects the credibility of H. A smaller E(H) suggests a higher credibility of H. Thus, the power system fault diagnosis problem could be formulated as an optimization problem, with the objective of finding a FH (or FHs) that minimizes E(H).

E(H) is Determined by the Following Procedure:

if H is an unreasonable FH, H must not be a correct solution of the fault diagnosis problem. Thus, once H is an unreasonable FH.E(H) , should be assigned a large value such as E(H)=100000 , so that an unreasonable FH will, in any case, not be the optimal solution of the fault diagnosis problem;

2) if H is a reasonable FH,E(H) is determined as follows:

$$E(H) = w_1\left(\sum_i^{n_r}|\Delta r_i(H)| + \sum^{n_c}|\Delta c_j(H)|\right) + w_2|H|$$

$$= w_1\left(\sum_i^{n_r}|r_i - r_i^*(H)| + \sum_j^{n_c}|c_j - c_j^*(H)|\right) + w_2\left(\sum_k^{n_d}|d_k| + \sum_i^{n_r}(|f_{ri}| + |m_{ri}|) + \sum_j^{n_c}(|f_{cj}| + |m_{cj}|)\right).$$

Equation consists of the following two parts:

1) The Discrepancy Index

This index reflects the discrepancy between the expected and actual states of PRs and CBs, i.e., $|\Delta r_i(H)|=|r_i - r_i^*(H)|$ and $|\Delta c_j(H)|=|c_j - c_j^*(H)|$ Here, r_{ij} represents the actual state of the i^{th} PR, and $r_i=0$ or 1 or 1 corresponds to the nonoperational or operational state; represents the actual state of the j^{th} CB, and $c_j=0$ and 1 corresponds to the tripped (open) or non-tripped (closed) state; $r_i^*(H)$ represents the expected state of the i^{th} PR corresponding to H. If the i^{th} PR should not operate, $r_i^*(H)=0$, otherwise $r_i^*(H)=1$; $c_j^*(H)$ represents the expected state of the j^{th} CB. If the j^{th} CB should not be tripped off. $c_j^*(H)=0$ otherwise $c_j^*(H)=1$

The Minimum Index

The contribution of this part is: if the total number of the fault sections as well as the malfunctioned PRs and CBs $\left(\sum_k^{n_d}|d_k| + \sum_i^{n_r}(|f_{ri}| + |m_{ri}|) + \sum_j^{n_c}(|f_{cj}| + |m_{cj}|)\right)$ is large, the probability of to be the optimal solution will be low. Here, and are the weights of the discrepancy index and minimum index, respectively, and $w_1 >> w_2$. In this work, it is specified that $w_{1=100}$ and $w_2=1$; $w_1>>w_2$ means that the discrepancy index is much more important than the minimum index. The specified large weight of the discrepancy index is used to guarantee that FHs which are able to well explain the received alarms can be found. Then, after taking the discrepancy index into account, the purpose of imposing the minimum index is to select the FH which includes the smallest number of fault sections, malfunctioned PRs and CBs, because the probability of multiple faults and multiple malfunctions of PRs and CBs is smaller than that of a single event (fault or malfunction). The procedure of determining E(H) is shown in Fig. 5.2. In this figure, and $a_{ri}(H)$ and $a_{cj}(H)$ represent the expected states of r_i and c_j, respectively. If PRs and CBs work properly, $a_{ri}(H)$ and $a_{cj}(H)$ could be determined directly according to the operating logics of PRs and CBs $r_i^*(H)$ and $c_j^*(H)$ and represent the expected states of r_i and c_j, respectively, with malfunctions of PRs and CBs taken into account.

2. Determination of $a_{ri}(H)$ and $a_{cj}(H)$

1) The Determination of $a_{ri}(H)$

First, some symbols are defined below:

1) $\otimes$ and $\oplus$ represent logic multiplication and summation, respectively;
2) $Z(r_i)$ is the set of sections in the protection zone of ;
3) $R(c_j)$ is the set of PRs which trip off;
4) p_a,c_j, p_b,c_j and p_c,c_j represent that the tripping phase of s phase A, B, and C, respectively.

ferent kinds of relay protections

Main Protection (MP)

ɪpose that r_i is the MP of d_k . The operating logic of r_i is: fault occurs on d_k , r_i should operate, i.e.,

$$a_{ri}(H)=d_k$$

2) Primary Backup Protection (PBP)

Suppose that r_i and r_x are the PBP and MP of , respectively. The operating logic of r_i is: if a fault occurs on d_k, and fails to operate (i.e.$m_{rx}=1$,), then should operate,i.e.

$$a_{ri}(H)=d_k \otimes m_{rx}$$

3) Secondary Backup Protection (SBP)

Suppose that , r_i, r_x and r_y are the SBP,MP, and PBP of d_k, respectively. The operating logic of r_i is as follows.

a) If a fault occurs on d_k, and both $r_x$and r_y fail to operate (i.e., and), then should operate, i.e.,

$$a_{ri}(H)=d_k \otimes m_{rx} \otimes m_{ry}$$

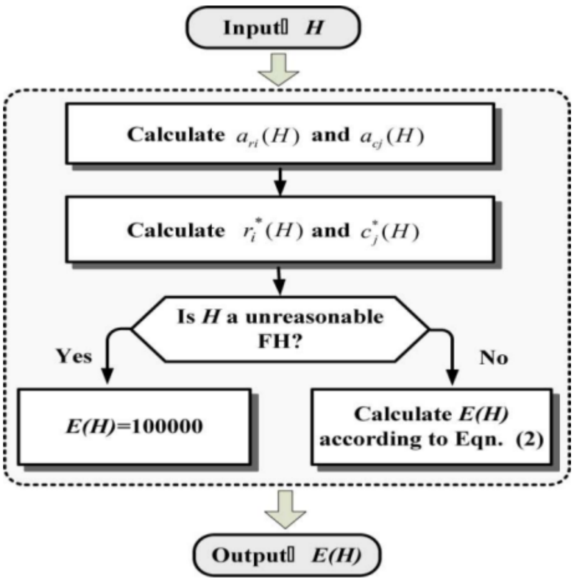
b) First, the concepts of the related section and related path are defined. As shown in Fig. 5.3(a), the related sections of are the sections in the protection zone of but excluding the local section . For the example shown in Fig. 5.3(a), $Z(r_i)=\{d_1d_2d_3d_4d_5d_6d_7\}$ $p(r_i,d_j)$ the related path from r_i to d_k , represents the acyclic electrical path from the location of to r_i its related section . It is defined that $p(r_i,d_j)=\{c_{r1},c_{r2},c_{r3}\ldots\ldots c_{rn}\}$,and here $c_{r1},c_{r2},c_{r3}\ldots\ldots c_{rn}$ are the

sequence of the CBs along the path. For the example shown in Fig. 5.3(a), $p(r_i,d_5)=\{c_1,c_2,c_5\}$,. As shown in Fig.5.3(b), r_i protects its related section $d_j \epsilon Z(r_i) p(r_i,d_j)$ through $p(r_i,d_j)$. If a fault occurs on d_j, and all CBs along $p(r_i,d_j)$ are closed (i.e.,
This means that the fault has not yet been cleared. In this case, r_i should operate, i.e.,

$$a_{ri}(H)=\sum_{d_j\in Z(r_i)}\left(d_j\otimes\prod_{c_p\in p(r_i,d_j)}\overline{c_p}\right).$$

Then, can be determined as

$$a_{ri}(H)=d_k\otimes m_{rx}\otimes m_{ry}\oplus\sum_{d_j\in Z(r_i)}\left(d_j\otimes\prod_{c_p\in p(r_i,d_j)}\overline{c_p}\right). \qquad (7)$$



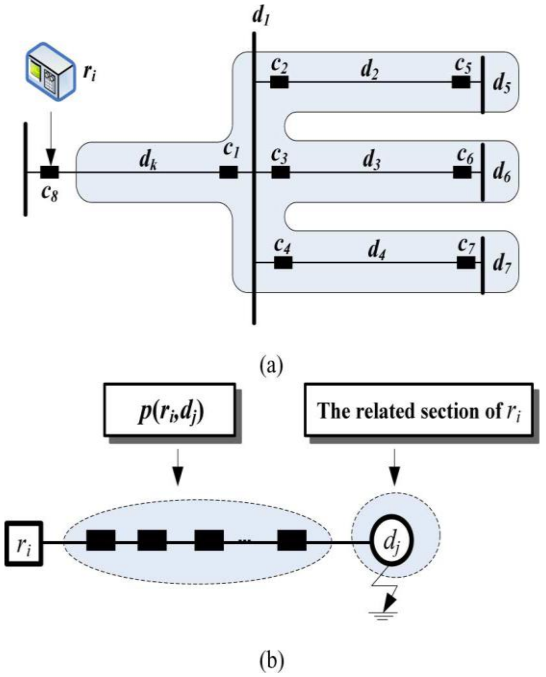


Fig-2: (a) Determination of the related section according to the protection zone of r_i. (b) Related path from ri to d_k .

4) Breaker Failure Protection (BFP)

Suppose that c_j is connected to d_k,r_i is the BFP of c_j. The operating logic of r_i is: if any tripping signal is received from $r_x \epsilon R(c_j)$, but $c_j$fails to be tripped off, then should operate,

$$a_{ri}(H)=\left(\sum_{r_x\in R(c_j)} r_x\right)\otimes m_{cj}$$

i.e.,

5) Automatic Recloser (AR)

There are several types of ARs. Only the single-phase AR is considered as an instance in this work. Suppose that ri is the AR of ,d_k and c_j is the reclosing CB corresponding to r_i. The operating logic of r_i is: if $r_x \epsilon R(c_j)$ operates and c_j is tripped off with a single phase, then r_i should operate to reclose c_j, i.e.,

$$a_{ri}(H)=\left(\sum_{r_x\in R(c_j)} r_x\right)\otimes c_j\otimes(p_{a,cj}\otimes\overline{p_{b,cj}}\otimes\overline{p_{c,cj}}\oplus\overline{p_{a,cj}}\otimes p_{b,cj}\otimes\overline{p_{c,cj}}\oplus\overline{p_{a,cj}}\otimes\overline{p_{b,cj}}\otimes p_{c,cj})$$

2) Determination of a_{cj}(H) *:* The operating logic of CBs is: if tripping signals are received from $r_x \epsilon R(c_j)$, then should be tripped off, i.e.,

$$a_{cj}(H)=\sum_{r_x\in R(c_j)} r_x^*(H).$$

3. Determination of r_i*(H)and c_j*(H)

based on a_{ri}(H)and a_{cj}(H) obtained r_i*(H)and c_j*(H) can be determined as follows:

$$r_i^*(H)=\overline{m_{ri}}\otimes\overline{f_{ri}}\otimes a_{ri}(H)\oplus\overline{m_{ri}}\otimes f_{ri}\otimes\overline{a_{ri}(H)}$$
$$c_j^*=\overline{m_{cj}}\otimes\overline{f_{cj}}\otimes a_{cj}(H)\oplus\overline{m_{cj}}\otimes f_{cj}\otimes\overline{a_{cj}(H)}$$

Moreover, as shown in Table I, unreasonable FHs can be grouped into three types.

1) "$m_{ri}=f_{ri}=1$", or $m_{cj}=f_{cj}=1$"
2) "$a_{ri}=0$ and $m_{ri}=1$", or "$a_{cj}(H)=0$ and $m_{cj}=1$"
"$a_{ri}=1$ and $f_{ri}=1$", or "$a_{cj}(H)=1$ and "$f_{cj}=1$.

IV. APPLICATION EXAMPLES

The power system in Guangdong Province, China, is com- posed of 25 substations, 57 transformers, and 73 transmission lines with a voltage level of 500 kV, and 511 substations, 511 transformers and 594 transmission lines with voltage level of220 kV. Many actual fault scenarios from the Guangdong Power System are used to test the developed on-line fault diagnosis software package, and the diagnosis results are correct except for one case with many missing alarms. The proposed approach may not work well for situations with many missing alarms, and the detailed analysis for the reason will be presented in part C in this section. Due to the space limitation, only two tested scenarios are presented in this section. To facilitate the under- standing of the developed model and approach, the

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first fault scenario will be described in detail, and only the diagnosis re- sult will be presented for the fault scenario 2.

A. The Fault scenario 1

This actual fault scenario happened in Qingyuan Substation on May 2, 2006. The related power network and received alarms are shown in Fig. 5 and Table V, respectively. The fault scenario is detailed as follows

1) A fault occurred on L2387.
2) The MP of L2387 in Qingyuan Substation operated and then a signal was sent to trip off CB2387–2, but the phase A of CB2387–2 was burning and failed to be tripped off.
3) The BFP of CB2387–2 operated to successfully trip off

CBs connected to B3, i.e., CB2722–1, CB2855–1, CB2202 and CB2012-QY.

4) Due to the tripping of CB2722–1 and CB2855–1 in Qingyuan Substation, the blocking signals of pilot sys- tems cannot be transferred to the other terminals of L2722 and L2855. Thus, the pilot protections of L2722 and CB2855 operated to trip L2722–2 and CB2855–2 off, respectively.
5) Finally, the outage area is formed as shown in the shadow area in Fig. 5.

The fault diagnosis procedure by the proposed method is car- ried out as follows.

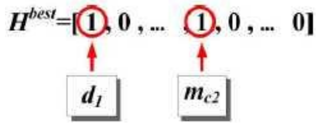
1) The first step of the proposed method is to determine the outage area, and the sections included in this area are the suspected fault sections. They are encoded in Table III.
2) The related PRs and CBs can be determined as listed in Table 6.1. Then, the basic form of a FH is obtained as

$$H = [d_1, \ldots d_6, f_{r_1}, \ldots f_{r_{37}}, f_{c_1}, \ldots, f_{c_8}, m_{r_1}, \ldots m_{r_{37}}, m_{c_1}, \ldots m_{c_8}].$$

3. Determine the basic form of the objective function E(H) as stated in Part A, Section IV. The key issue lies in the determination of r_i*(H)and c_j*(H)according to the method proposed in Section IV. For better understanding the operation of the proposed fault diagnosis model, take the determination of r_{14}*(H) and c_4*(H) for instances

$$a_{r14}(H) = (r_1 \oplus r_4 \oplus r_7) \otimes m_{c2}$$
$$r_{14}^*(H) = \overline{m_{r14}} \otimes \overline{f_{r14}} \otimes a_{r14}(H) \oplus \overline{m_{r14}} \otimes f_{r14} \otimes a_{r14}(H)$$
$$a_{c4}(H) = r_{14}^*(H) \otimes r_{34}^*(H) \otimes r_{35}^*(H) \otimes r_{36}^*(H) \otimes r_{37}^*(H)$$
$$c_4^*(H) = \overline{m_{c4}} \otimes \overline{f_{c4}} \otimes a_{c4}(H) \oplus \overline{m_{c4}} \otimes f_{c4} \otimes \overline{a_{c4}(H)}.$$

4. According to the reported alarms, r_i and c_j, the actual states of PRs and CBs, can be obtained: $r_1,r_{13},r_{17},r_{20},r_{21},r_{24},r_{26},c_1,c_3,c_4,c_5$and c_7, are all equal to 1; and other r_i and c_j equal to 0. By now, for a given FH, the value of E(H) could be determined.
5. Using the TS method, the optimal solution of the optimization problem could be obtained as:



i.e., L2387 was the fault section (d_1 =1) and CB2387-2 was failed to be tripped off (m_{c2}=1).

The diagnosis result report generated by the implemented software is shown in Table IV. They are consistent with those actually happened

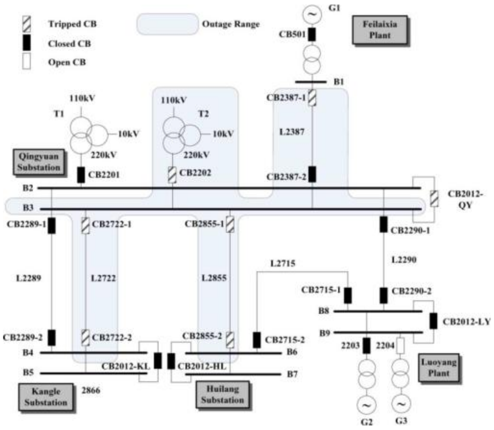


Fig. 3. Power System Diagram Associated With the Fault Scenarios

Table 1: Outage Area of Fault-1

Suspected Fault Sections in the Outage Area			
L2387	d_1	B2	d_4
L2722	d_2	B3	d_5
L2855	d_3	T2	d_6
Related CBs			
CB2387-1	c_1	CB2855-1	c_5
CB2387-2	c_2	CB2855-2	c_6
CB2012-QY	c_3	CB2722-1	c_7
CB2202	c_4	CB2722-2	c_8
Related PRs			
MPs of L2387, L2722 and L2855 (Qingyuan)			r_1~r_3
PBPs of L2387, L2722 and L2855 (Qingyuan)			r_4~r_6
SBPs of L2387, L2722 and L2855 (Qingyuan)			r_7~r_9
ARs of L2387, L2722 and L2855 (Qingyuan)			r_{10}~r_{12}
MP, PBP, SBP and AR of L2387 (Feilaixia)			r_{13}~r_{16}
MP, PBP, SBP and AR of L2722 (Kangle)			r_{17}~r_{20}
MP, PBP, SBP and AR of L2855 (Huilang)			r_{21}~r_{24}
BFPs of CB2387-1, CB2387-2, CB2012-QY, CB2202, CB2855-1. CB2855-2, CB2722-1, CB2722-2			r_{25}~r_{32}
MPs of B2 and B3			r_{33}, r_{34}
MP, PBP and SBP of T2			r_{35}~ r_{37}

TABLE 2.Diagnosis Result Report

The Diagnosis Result Report	
Occurrence Time	11:06:02 May 2, 2006
Outage Area	L2387, L2722, L2855, B2, B3, T2
Fault Sections	L2387
Malfunction PRs	-
Malfunction CBs	Qingyuan Substation: CB2387-2 (Failed to be tripped off)
Missing Alarms	-
Incorrect Alarms	-

B. The Fault Scenario 2

This fault case happened in Zengcheng Substation in the Guangdong Power System in China on September 18, 2008.

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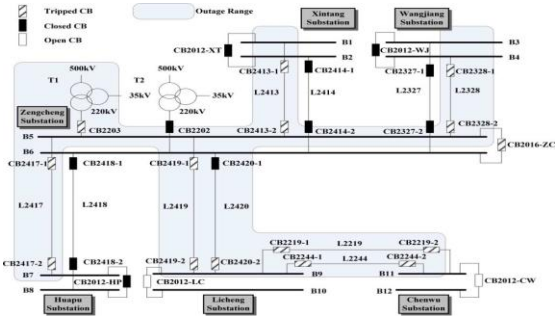
Volume 3, Issue 1, July 2013

The related power network and received alarms are shown in Fig. 6 and Table VI, respectively.



The fault scenario is detailed as follows.

1) A fault occurred on the transmission line L2417.

2) The MP of L2417 in Zengcheng substation operated and then a signal was sent to trip off CB2417–1, but CB2417–1 failed to be tripped off.

3) The BFP of CB2417–1 operated to trip the CBs surrounding
CB2417–1.

4) The BFP of CB2219–1 in Licheng substation operated incorrectly.

As the result, the CBs surrounding CB2219–1 were tripped off.

5) Finally, as shown in Fig. 6, the outage area was formed. The developed software package was used to test the fault case, and obtained diagnosis results are shown in Table V. The fault diagnosis results are consistent with those actually happened.

Table 3:Report of the Diagnosis Result

The Diagnosis Result Report	
Occurrence Time	16:10:35 September 18, 2008
Outage Area	L2417, L2419, L2420, L2219, L2244, L2413, L2328, T1, B5, B9, B11
Fault Sections	L2417
Malfunction PRs	Licheng Substation: BFP of CB2219-1 (Operate incorrectly)
Malfunction CBs	Zengcheng Substation: CB2417-1 (Failed to be tripped off)
Missing Alarms	-
Incorrect Alarms	-

V. CONCLUSION

Based on the existing analytic model-based methods, a novel analytic model is presented for power system fault diagnosis with malfunctions of PRs and CBs taken into account. The developed model could not only estimate the fault sections, but also identify the malfunctioned PRs and CBs, as well as the incorrect and missing alarms. With the application of GPS clocks in recent years to synchronize the data acquisition of Sequence of Events (SOE), the time tagging accuracy of about 1 ms could be achieved. A software package can be developed for actual applications in power utility companies. It is demonstrated by many actual fault scenarios of an actual power system in China that the developed model is correct, and the method is efficient.

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