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FAULT SCENARIO AND FAULT EQUIPMENT IDENTIFICATION WITHIN TRANSMISSION SYSTEM USING INTELLIGENT APPROACHES

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จากการศึกษาที่ผ่านมา มีการนำเสนอวิธีการหลากหลายในการระบุอุปกรณ์ที่เกิดความผิดพร่อง การประยุกต์ใช้ความสัมพันธ์ฟัซซี่ในรูปแบบแผนภาพเชื่อมต่อมีข้อได้เปรียบในการผนวกรวมเงื่อนไขการป้องกันในระบบส่งที่มีความซับซ้อนได้เป็นอย่างดี อย่างไรก็ตาม จากงานวิจัยในอดีตพบว่า วิธีการดังกล่าว ต้องการข้อมูลการเชื่อมต่อกันของอุปกรณ์ทั้งระบบ ในวิทยานิพนธ์ฉบับนี้ นำเสนอวิธีการทางเลือกในการประยุกต์ใช้แผนภาพเชื่อมต่อในการระบุอุปกรณ์ที่เกิดความผิดพร่องในระบบส่งไฟฟ้ากำลังโดยไม่ต้องใช้ข้อมูลการเชื่อมต่อกันของอุปกรณ์ทั้งระบบ แต่ได้นำเสนอโปรแกรมในการระบุเซ็ทของบัสและโนดที่ถูกแยกออกจากระบบหลักภายในสถานีไฟฟ้าแบบเบรกเกอร์หนึ่งตัวครึ่งแทน โดยมีสมมุติฐานว่าข้อมูลที่จำเป็น สามารถใส่ไว้อย่างเป็นระบบในการตั้งชื่อช่องสัญญาณสำหรับเซอร์กิตเบรกเกอร์และรีเลย์ป้องกันของเครื่องบันทึกความผิดพร่องแบบดิจิตัล จากนั้น ขั้นตอนวิธีที่อาศัยความสัมพันธ์เชิงฟัซซี่ที่ได้นำเสนอ จะถูกใช้ในการระบุอุปกรณ์ที่ผิดพร่อง และขั้นตอนวิธีเชิงกฎจะถูกใช้เพื่อแยกแยะอุปกรณ์ที่ถูกตัดขาดออกจากระบบว่า อุปกรณ์นั้นๆ เป็นปกติดีหรือผิดพร่อง ผลการทดสอบโดยใช้ข้อมูลดิจิตัลจากเหตุการณ์การลัดวงจรที่บันทึกได้จากเครื่องบันทึกในระบบส่งไฟฟ้าจริงแห่งหนึ่งพบว่า ขั้นตอนวิธีที่นำเสนอทำงานได้อย่างถูกต้อง ซึ่งรวมถึงกรณีที่มีความซับซ้อนโดยมีการทำงานผิดพลาดของเซอร์กิตเบรกเกอร์หนึ่งหรือสองตัวด้วย

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There have been many methods proposed for fault section identification. Fuzzy relation implemented in a form of sagittal diagram offers an advantage in that complex transmission system protection schemes can be well incorporated. However, previous work shows that the method also requires thorough knowledge of system configuration. This thesis proposes an alternative way to apply the sagittal-diagram based method for the fault equipment identification within a transmission system with no requirement of system configuration information. Instead, an outage configurator program has been devised to detect the set of outage elements, that are buses and nodes within a breaker-and-a-half station, assuming that sufficient information can be encoded systematically in naming circuit breaker (CB) and protective relay channels of the digital fault recorder (DFR). Then, the proposed fuzzy relation-based algorithm will be used to identify fault equipment, and the proposed rule-based algorithm to differentiate among the set of outage devices, whether each of them is healthy or fault. The algorithm has been tested successfully using digital data of DFR collected when fault occurs in an actual transmission system, including the complex cases with one or two CBs failure.

Department: Electrical Engineering Student's Signature: ....

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Regarding the love and support of members in my family for which a word of thanks is by no means enough, I would like to dedicate this work and express my heartfelt appreciation to them.

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List of Notations

Symbols

21P1	Primary distance relay
21P2	Secondary distance relay
51C/51CG	Over-current relay/Ground over- current relay for capacitor
51K or 51T	Over-current relay for transformer on high side
50BF	Breaker failure relay
79	Auto-reclosing relay
86BF	Breaker failure relay that receives trip signal from 50BF
86A	Auxiliary tripping and lock-out relay for transformer (self protection)
86B	Auxiliary tripping relay for busbar
86DTT	Direct- transfer- trip relay
86K	Auxiliary tripping relay for transformer
87B	Differential relay for busbar
87K	Differential relay protecting transformer
94C	Auxiliary tripping relay for capacitor
94P or 94P1	Auxiliary tripping relay for line (receive trip signal from 21P1)
94BU or 94P2	Auxiliary tripping relay for line (receive trip signal from 21P2)

Acronyms

CB	Circuit breaker
DFR	Digital fault recorder
EGAT	Electricity Generating Authority of Thailand
EVN	Electricity of Vietnam
OCP	Outage configurator program

CHAPTER I

INTRODUCTION

1.1 Motivation

Ensuring security and reliability of the transmission system is very crucial from the system operators' viewpoints. In order to improve the reliability and security of power system, some actual systems such as Electricity Generating Authority of Thailand (EGAT) and Electricity of Vietnam (EVN) has already installed Digital Fault Recorders (DFRs) units at various locations in the systems to record essentially the voltages, currents, and various status of digital signals relating to protection systems, when it suspects that some fault may occur within the transmission systems. That leads to a need to determine which equipment is faulty one within a transmission system using DFR data when a short circuit fault occurs.

Fig.1.1 shows a transmission system in which stations of 230kV part has configuration of breaker- and- half. When a fault occurs within this system, it can be on busbar, transmission line, transformer or capacitor.

During the fault, the primary relay that protects faulty equipment responds to trip circuit breakers (CBs) so that just only that equipment would be isolated from the system. If primary relay operates incorrectly or some CBs fail to open, some healthy equipment may be isolated due to back up relays. Therefore, the fault scenario (set of equipments are outage due to fault) also needs to be known so that the system restoration can be done as soon as possible.

Fig.1.2 shows the situation in which primary protection operates correctly when one transmission line has short circuit. In this figure all CBs connecting to the faulty line are opened to isolate the line so that only the faulty line is isolated.

Fig.1.3 shows the situation in which one CB connecting to the faulty line fail to open, then back up protection work and isolate bus 1 of above station together with the faulty line. However, the bus that is isolated is not a faulty bus. Then, it needs to be energized.

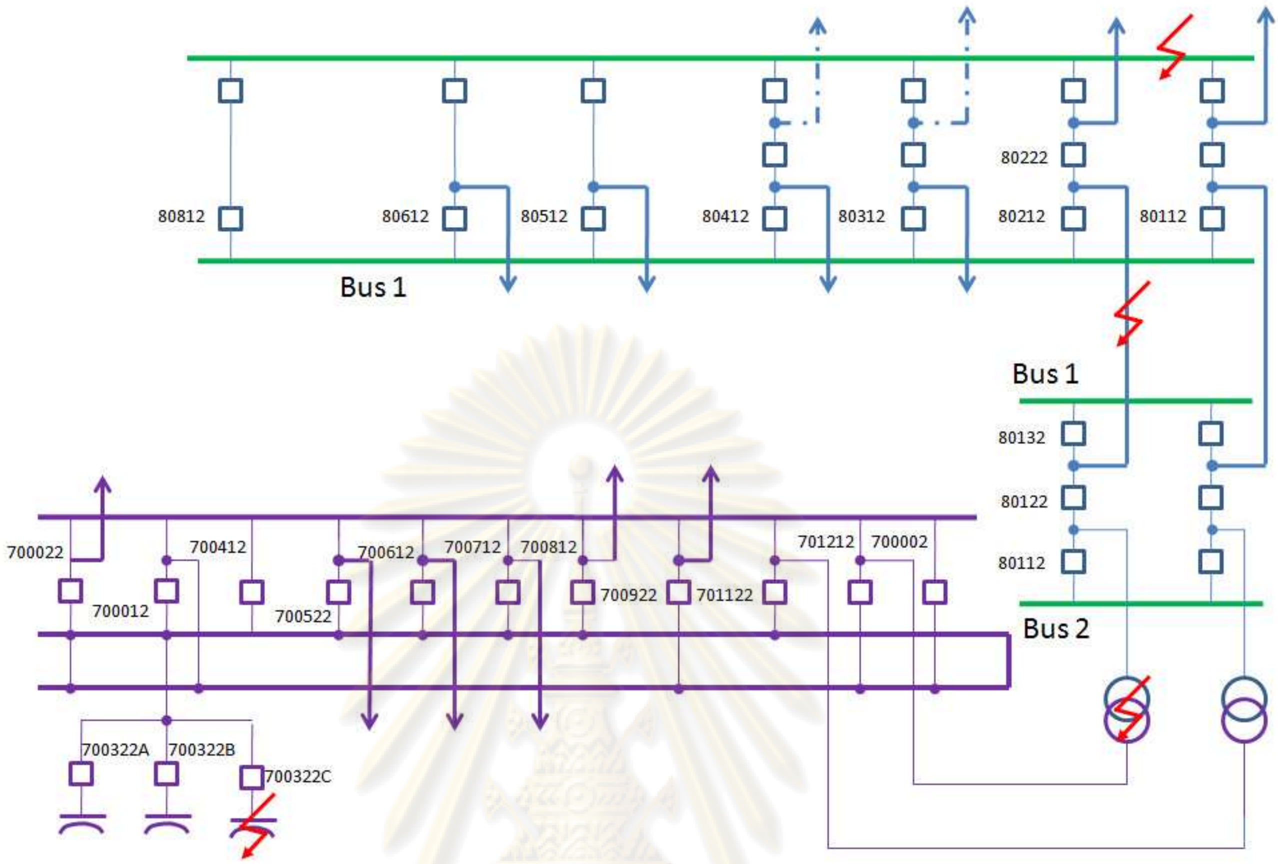


Figure 1.1: Fault occur on busbar, transformer, line or capacitor

1.2 Literature Review

1.2.1 Fault Section Identification

Intelligent technique application to fault section identification has been proposed in many research works. As earlier attempts, many kinds of expert system have been developed using the conventional knowledge representation and inference procedures such as rule based [1], model based [2] methods and abductive inference technique [3]. All of them required thorough knowledge of system configuration as database knowledge. Artificial Neural Network (ANN) model were also used [4]- [5] for fault section location, but it is difficult to deal with the case of large power systems. This is mainly because Neural Net that was proposed need to learn the behavior of the whole network. G. Cardoso has proposed a method [6] using ANN to model the protection system philosophy of busbar, transformer and transmission line instead of the configuration of the network so that it did not require information of system configuration. This method can deal with the size of the power system network, but it may be difficult to interpret the result obtained at ANN output, especially in cases

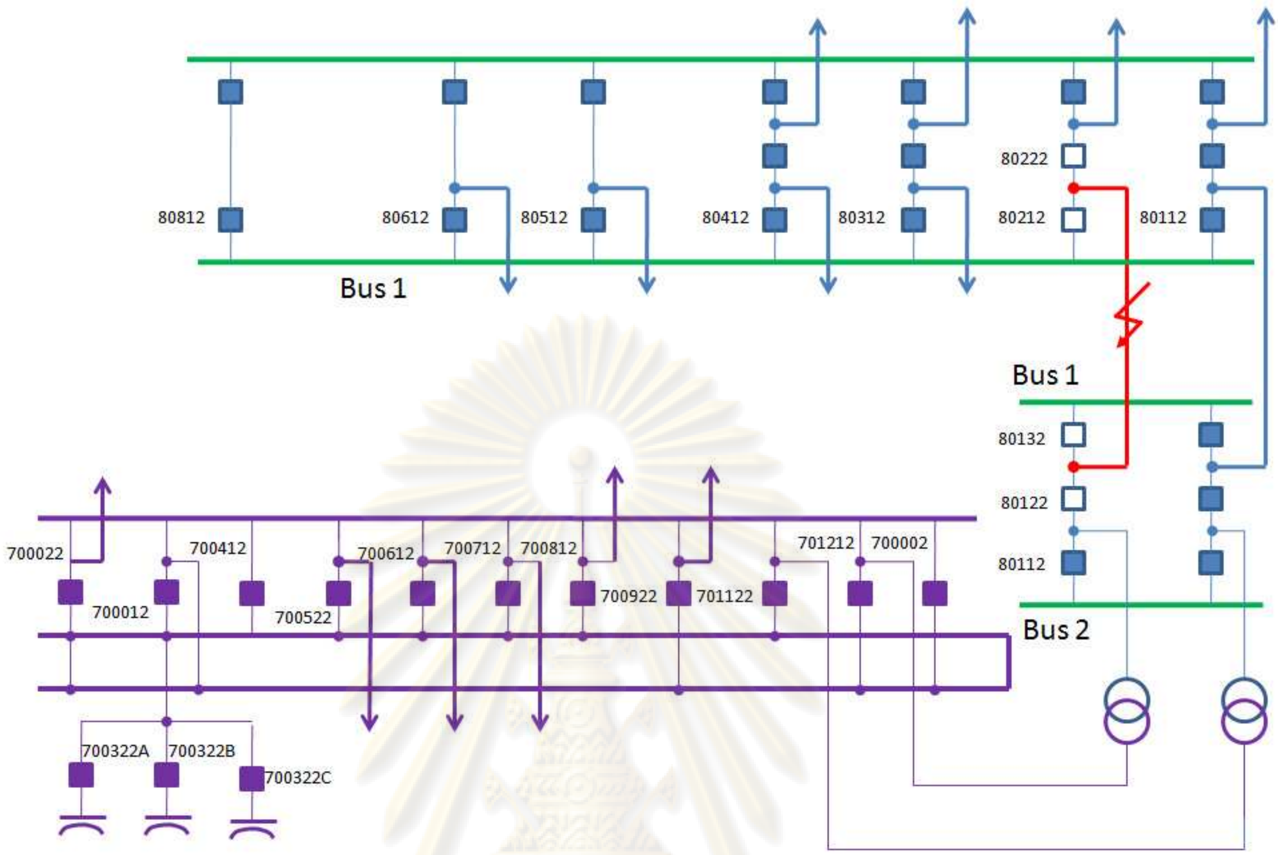


Figure 1.2: Primary protection operating correctly

of malfunction of protective devices. Besides, it needs extensive historical data, including complicated cases for training purpose, in which most actual systems can not supply.

Sagittal diagram - the word "sagittal" here means "pertaining to an arrow" - in which fuzzy relation is embedded [7] provide a convenient means for modeling uncertainties involving information available in processing of relay and breaker signals. In order to identify faulty section (section can be a line or a bus), in [7], H. J. Cho and J. K. Park have used sagittal diagram to represent protection scheme of transmission line and busbar. In the identification algorithm, the degree of membership of being fault set of each sagittal diagram was calculated using Yager's class for fuzzy function [8]. After that, the sagittal diagram calculation has explored with some another model of fuzzy function in [9], as well as considered the change of system topology in case of multiple fault in [10]. The configuration of system is also required and used to build the sagittal diagram. Besides, this method requires each sagittal diagram for each individual line or busbar, subject to their connection in transmission system. In other words, to apply this method to a transmission system that has 1000 lines, the method required 1000 sagittal diagrams are build in advance to be put in its database knowledge. Although the original sagittal diagram has not been applied for

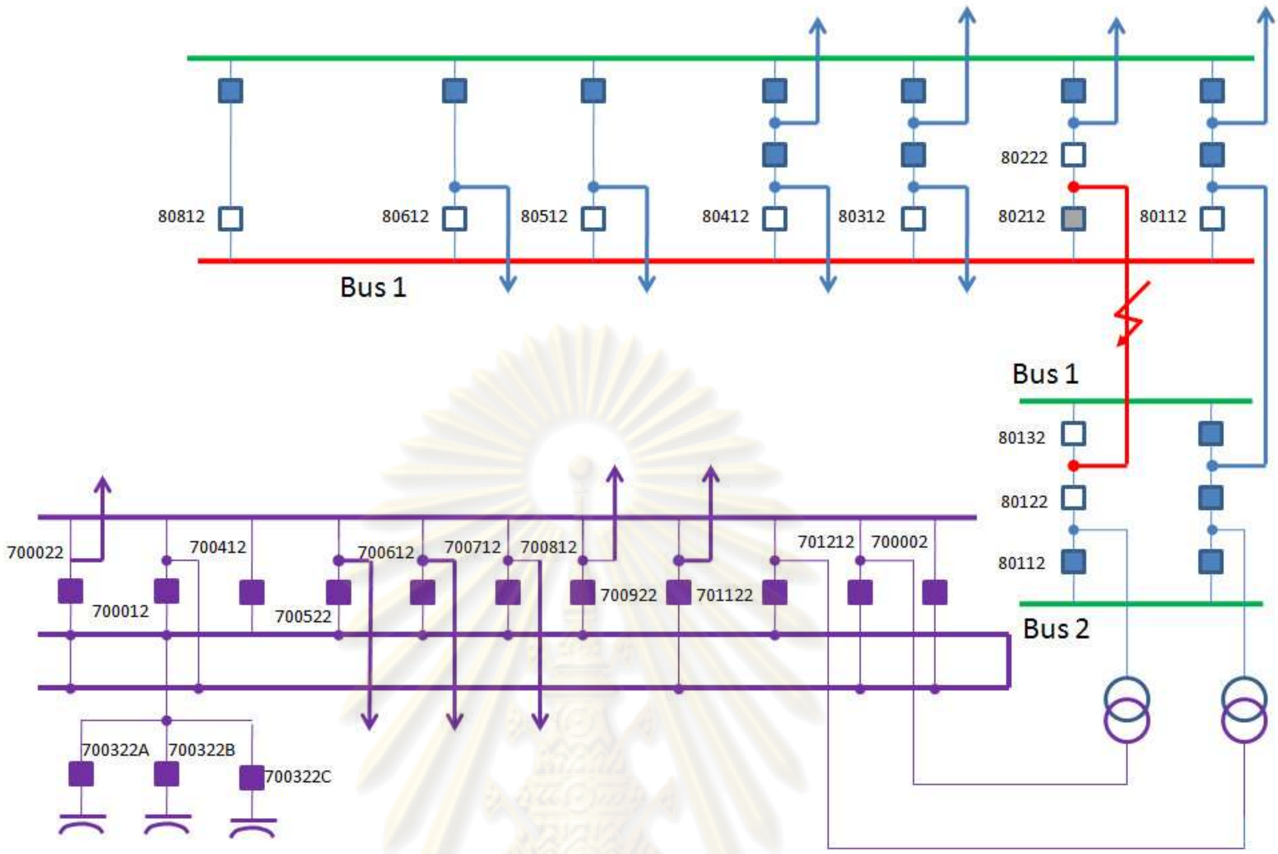


Figure 1.3: Operation of back up protection

transmission system with breaker- and- a- half- stations, and it requires thorough knowledge of system configuration, its concept has some considerable meaning with this kind of station in condition of lacking of information about both system configuration and alarm signal.

1.2.2 Fault Scenario Identification

Fault scenario is a set containing isolated equipment by protection devices then fault occurs on a equipment. Thus, it may contain not only fault, but also heathy equipment.

In most of previous research works, fault scenario was required for processing of fault section identification. It can be obtained based on some means. One of them is finding the difference in system configuration before and after fault occurrence. G. Cardoso has proposed an expert system called "configurator program" [11] to identify fault scenario. This configurator program works based on some of rules that convert two objects that are directly connected together to one object so that at the end separated part can be simplified. Objects here are buses, lines, CBs in transmission system. In order to do that, it also requires of information of system configuration such as connection between lines to stations and switching diagrams of each stations.

1.3 Objectives

The specific aims of this thesis is to apply an intelligent approach to some selected digital signal data of the fault digital recorder (DFR) for developing an algorithm that can identify the fault scenario and fault equipment within a transmission network of which its service station is of breaker and half station configuration.

1.4 Scope of Works

The focuses of the research are:

1. Examine protection scheme of a transmission network with breaker and a half stations: primary and back up protection of equipment in transmission network, including transmission line, power transformer, bus bar and capacitor.
2. Apply fuzzy relation and rule-based algorithm to identify fault scenario and fault equipment for each event detected by DFR.
3. Consider events that are short circuit faults, including both symmetrical and unsymmetrical types.
4. Neglect events that concern simultaneous faults.
5. Consider mainly the transmission stations with breaker- and-a- haft configuration.
6. Consider mainly cases in which back up relays are for breaker failure, and assuming that no more than two failure breakers during fault.
7. Require only some digital data from DFR as inputs.

1.5 Research Methodology

1. Literature reviews of background knowledge relevant to protection schemes on transmission system.
2. Literature reviews of Fuzzy/ ANN algorithms application to fault section identification in transmission network.
3. Study DFRs data from field measurement.
4. Develop an architecture of fault scenario and fault equipment identification using data of DFR as inputs.

5. Test performances of the proposal algorithm using actual event in a transmission network.

6. Conduct thorough analysis, make critical discussion, and revise the overall algorithms as necessary.

7. Make conclusion, and documentation for a thesis and publication.

1.6 Expected Contribution

1. An algorithm for fault scenario and fault equipment identification within a transmission system which require only digital data of DFRs.

2. A practice application of the above algorithm for restoration of the transmission system when protection system cause fault and healthy equipment outage. Also, the algorithm may be used to filtering nonsense alarm signals from some of DFRs when events occur on the transmission system.

In the next chapter, transmission protection scheme of transmission system in which breaker-and-a-a-half configuration is major station configuration will be described. An introduction of DFR data and digital data from DFR data will also be included. Next, chapter III will recall knowledge about fuzzy relation and original sagittal diagram so that the reader will easily understand concept of generalized sagittal diagrams which are proposed in chapter IV. Besides, chapter IV makes a demonstration of outage configurator program (OCP), a proposed tool for identifying outage elements due to fault based on the rules of naming CBs in breaker-and-a-half stations. Basing on OCP and these generalized sagittal diagrams as the two main tools, the overall algorithm of fault equipment and scenario identification can be performed with no need knowledge of system configuration. Chapter V shows the elaborate processing and the result of the six test cases that taken from field measurement of an actual system. The discussion, conclusion and future works of thesis are including in chapter VI.

CHAPTER II

TRANSMISSION SYSTEM PROTECTION AND DFR DATA

2.1 Transmission System Protection

Understanding of protection scheme is very important for operation engineer to identify faulty equipment when a fault occurs. Therefore, any method that automatically identifies the faulty equipment need to be built based on protection scheme of transmission system. Firstly, this part will introduce general principle of protection scheme for some kinds of equipment. Secondly, the protection scheme for each of equipment of an actual system that is tested in this thesis will be presented. The major configuration of stations in this actual system is breaker-and-a-half configuration.

2.1.1 General Protection Scheme

When a fault occurs at any equipment in a station, some of relays that respond to protect this equipment will be active. Conventionally, the primary relay will immediately trip CBs that connect this equipment to the system. In case of primary relay fail of sending trip signal or can not be active, after a very short time, the secondary relay will send trip signal to those CBs. If both of primary and secondary relays fail to activate, back up relay (over-current relay, zone 3 distant relay) at neighboring equipments of this equipment will be active after a delay time to isolate a fault set containing faulty equipment and its neighbor equipments. If either primary relay or secondary relay operates correctly, but there is CB fails to open, breaker failure protection will activate to trip neighboring CBs of failure CB so that the faulty equipment will be isolated together with some of healthy equipments. Beside the above three situations, there may be an occurrence of malfunction of primary or secondary relays at neighboring equipment while the faulty equipment is isolated correctly by its protecting relays.

In the actual system with station configuration is breaker-and-a-half, the case in which both primary and secondary relays fail to trip CBs is more severe than the case in which just CBs failure, although both of two cases are considered as cases of back up protection. In order to look in more detail, let consider a fault that occurs on transmission line 1 between station S1 and station S3 in a transmission system, and is followed by four situations presented by figs.2.1- 2.4, respectively.

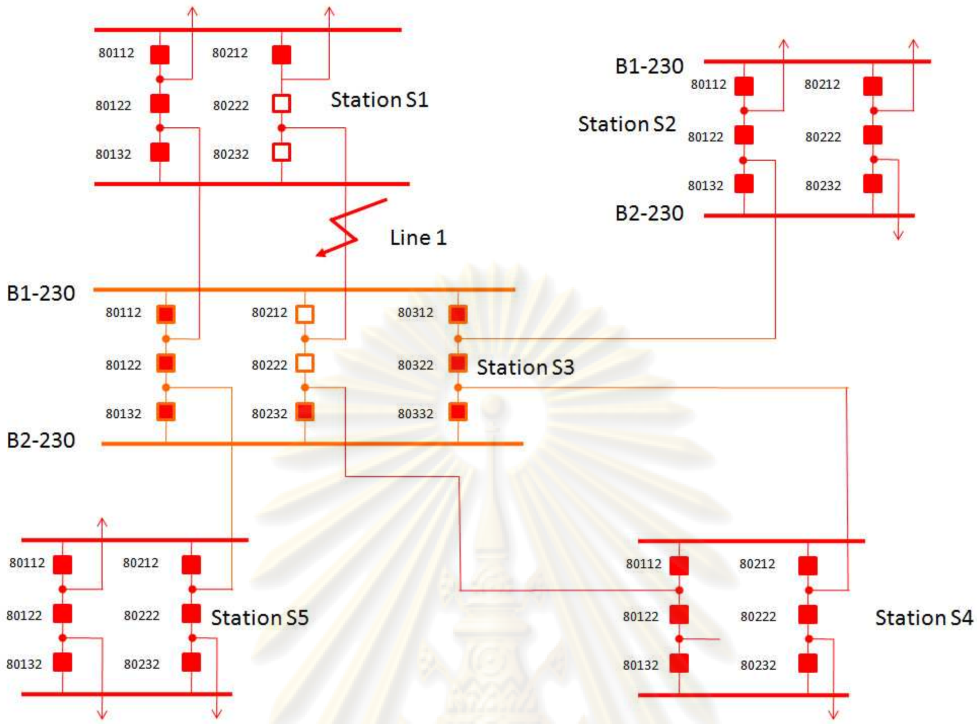


Figure 2.1: Illustration of fault line with only primary protection operate correctly

Fig.2.1 illustrates the case in which primary or secondary relay respond activate correctly to protect the fault line. Also, tripped CBs open correctly. Then, only the fault line is isolated from the transmission system.

Fig.2.2 illustrates the case in which primary and secondary relays respond to protect fault line from station S3 are malfunction. It lead to that back up relays of line 1 from S4, S5, S2 and S1 activate. Tripped CBs open correctly. As a result, station S3 and all lines connecting it to others station are isolated from the system.

Fig.2.3 shows the case with either primary or secondary relay responding to protect line 1 operate correctly. But there is one CB (80222 at s3) fails to open, make CBs 80232 at S3 and 80112, 80122 at S4 open. As a result, line 1 and line S3-S4 are isolated from system. Station S3 is still energized.

Fig.2.4 illustrate the case in which primary or secondary relay responding to protect line 1 activate and CBs open correctly, like situation 1. However, a relays at station S5 that is back up relay for line 1 is malfunction. Then, line 1 and the line that connects between S5 and S3 are isolated from the system.

In the above four kinds of situations, the situation in which both primary and secondary relays fail to activate, while fault occurs, has a very small probability to happen. Actually, we have not seen such a case in past data of this actual system. Hence, in this thesis, we

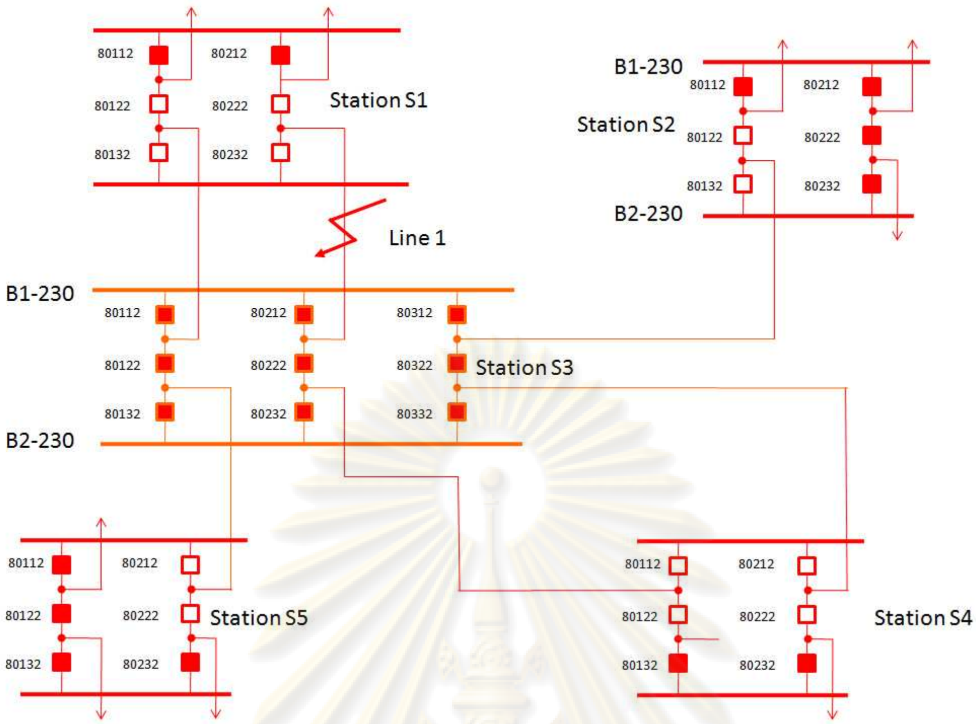


Figure 2.2: Illustration of fault line with only primary protection malfunction

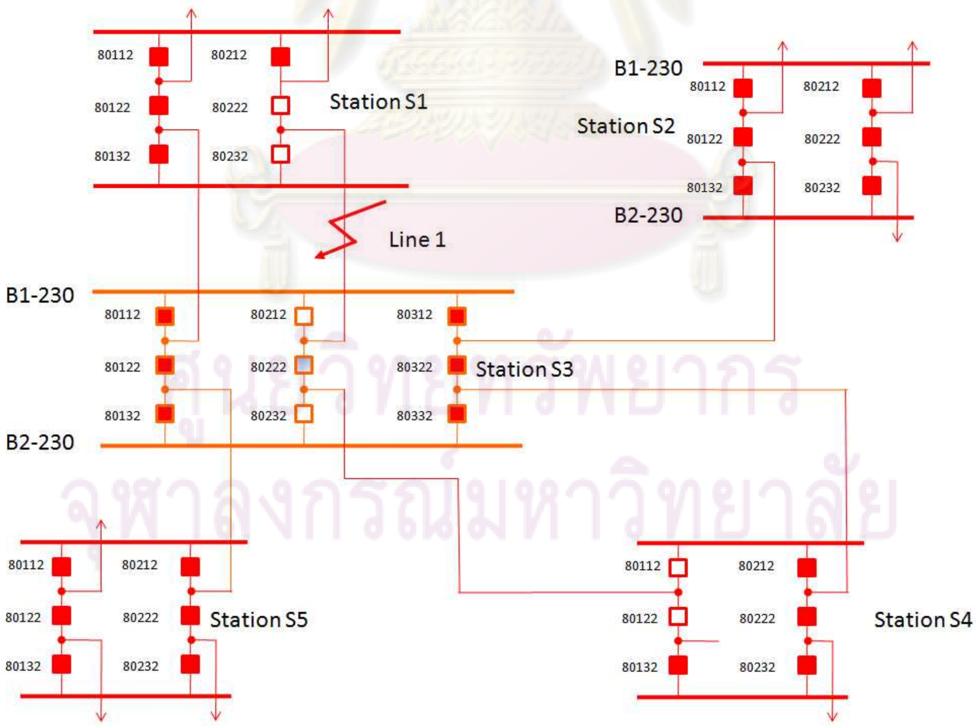


Figure 2.3: Illustration of fault line with one circuit breaker failure

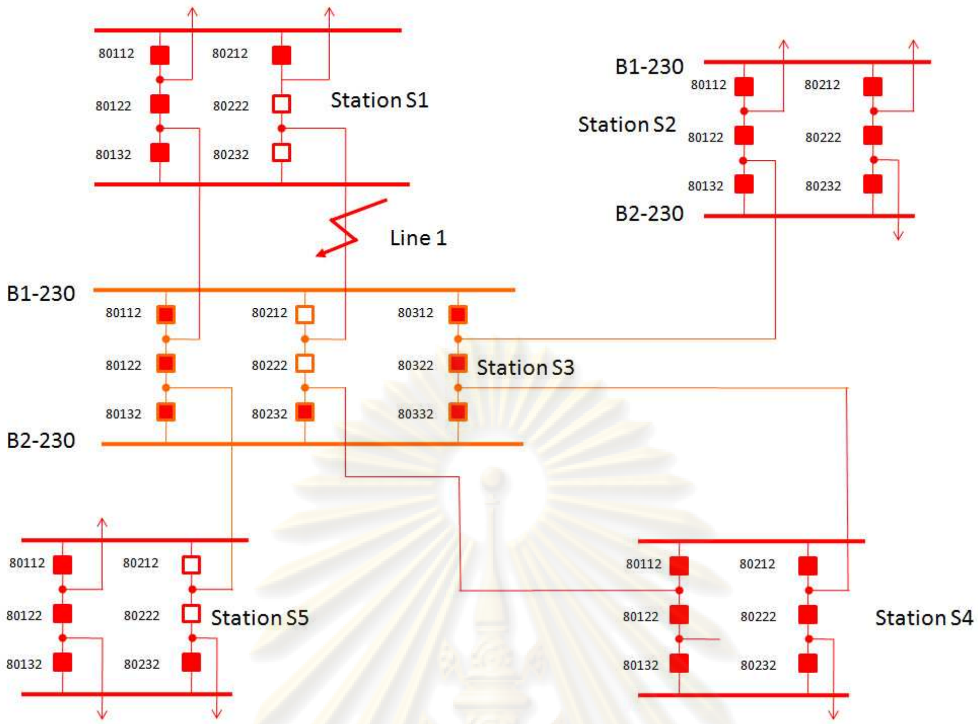


Figure 2.4: Illustration of fault line with back up relay malfunction

mainly consider breaker failure protection as back up protection.

The protection schemes of transmission line, power transformer and bus bar of the actual system (with station configuration is of breaker- and- a- half) are shown in the following sections.

2.1.2 Protection Scheme of Transmission Lines

Following protection scheme of transmission line, the main protection for transmission line at 230KV is distance relay. In this actual system, each 230kV transmission line has two levels of distance relay: primary and secondary. Each level has three zones of distance, zone 1, zone 2 and zone 3. Zone 1 will cover 80-90% of the main line that need to be protected. Zone 2 responds to protect all the main line, so its range will be 120- 150% of the main line. Zone 3 is backup protection with its range is the main line and the adjacent line together. Auto - reclosing relay is also one kind of relay that was active frequently on actual system.

Fig. 2.5 shows protective relays that protect line 1 from one end, in which 21P1 and 21P2 relays are distance relay corresponding to primary distance relay and secondary distance relay protection, respectively. 94P and 94BU relay are auxiliary tripping relay corresponding to 21P1 and 21P2, respectively. 79 relay is auto-reclosing relay. 86DTT relay is auxiliary tripping relay that will be active when it receives direct transfer tripping signal

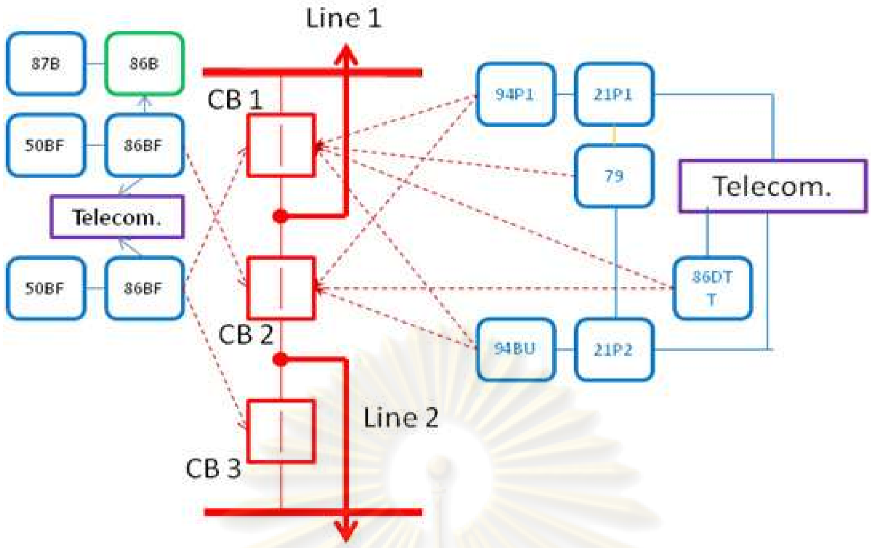


Figure 2.5: Protection scheme of a transmission line viewing from one end

from another end of this line. In this figure, each circuit breaker (CB) has an 50BF (breaker failure) relay, that will activate a 86BF relay. Then, the 86BF relay of a CB that connected directly to any bus will respond to activate 86B relay to trip all CBs connected to this bus at local station where as in case, the 86BF associated with the middle CB, it will respond to trip both CBs in aligning in the same bay. In both cases, 86BF will also send direct transfer trip signal to activate 86DTT relay at the other end of this line.

The protection scheme of transmission line is complex, so we just focus on some main relays, not all of relay of this scheme. These focused relays will be show in next section.

2.1.3 Protection Scheme of Transformers

Fig. 2.6 shows protection relays of a transformer in a breaker-and-a-half-station. Similarly to transmission line, there are three of levels of protection. The primary protection is 87K, differential relay. The secondary protection is 51T/51TG from high side voltage and 51/51G from low side voltage of transformer. Whether primary relay or secondary relay is active, they use 86K relay (auxiliary tripping relay) to trip all of CBs that connected transformer to station. However, in the case that the low side of transformer hasn't connected to other 115 or 230KV station, just high side CBs will be tripped by relay during fault. Also, 86A is auxiliary tripping and look-out relay of transformer (self-protection).

In case of breaker failure, such as 80112 in the fig.2.6 , the 86BF relay of 80112 will be active to trip the neighboring CB that is 80122 and the two CBs at another side of transformer. Beside, because CB 80112 connected transformer to bus 1, it will activate 86B of bus 1 to trip all another CBs that connected to bus 1. If the failure breaker is 80122, then its 86BF

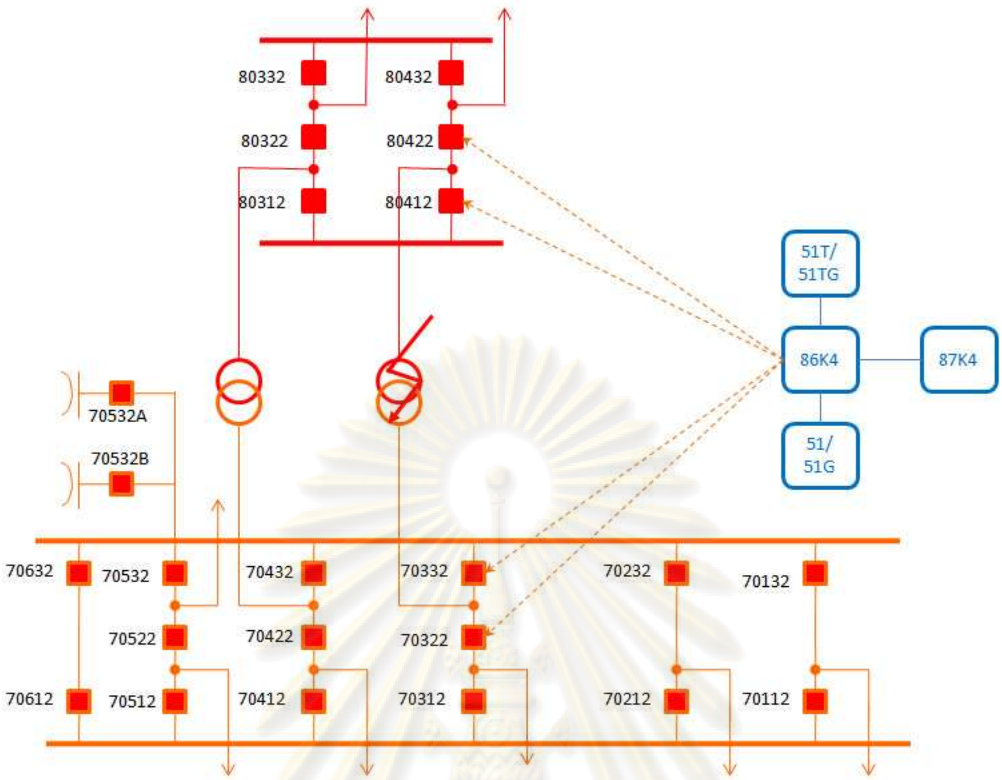


Figure 2.6: Protection scheme of a transformer

just activate neighboring CBs that are 80132 and 80112 and the two CBs at another side of transformer.

2.1.4 Protection Scheme of Busbars

Fig.2.7 shows protection relays of a bus in a breaker-and-a-half station. The main protection is 87B - differential relay. Relay 86B is auxiliary tripping relay. In case of breaker failure, 86BF relay will operate as describing in 2.1.2.

2.2 Digital Data From DFR

2.2.1 Overview

When an event occurs on transmission system, line currents, bus voltages, relay signals as well as breaker status will be recorded at each involved station that has DFR. Also, the data can be downloaded remotely from the control center. The record then will be exported in format of CFG file and DAT file. The CFG file contains name list of above analog and digital signals. The DAT file stores values subject to a period of time which can be divided into pre-fault, during-fault, and post fault period, respectively of these signals at event time.

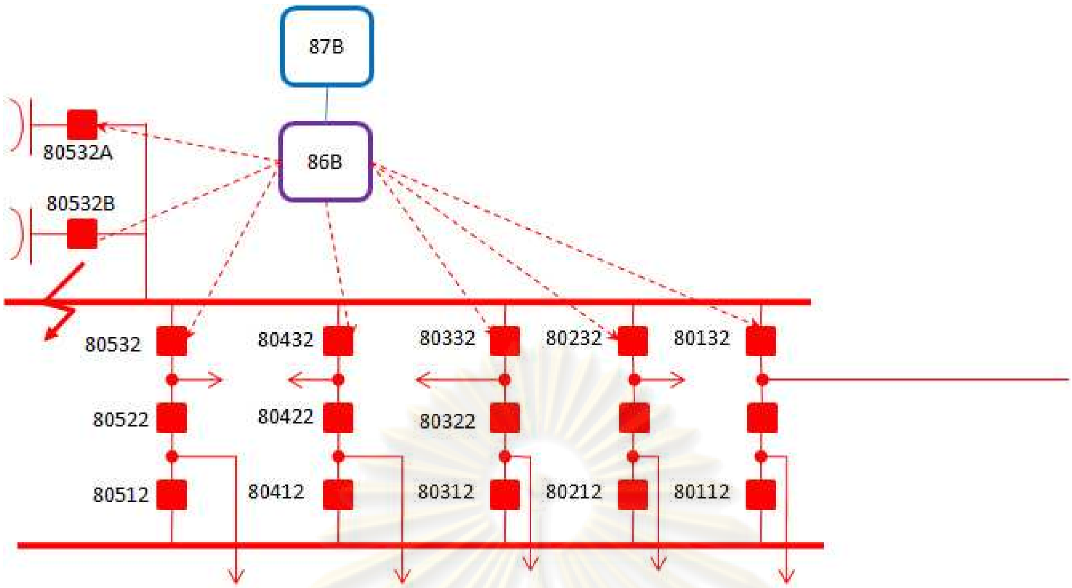


Figure 2.7: Protection scheme of a busbar

Fig.2.8-2.11 below are possible forms of relay and CB signals that are plotted from data in the DAT file.

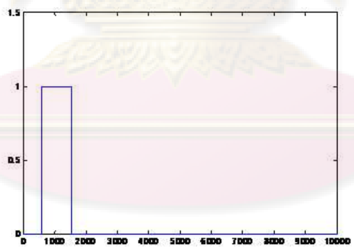


Figure 2.8: Active relay signal during fault

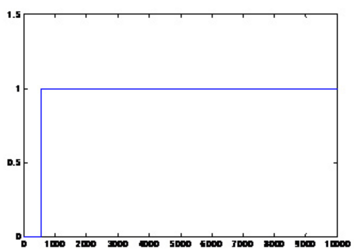


Figure 2.9: Tripped CB signal during fault

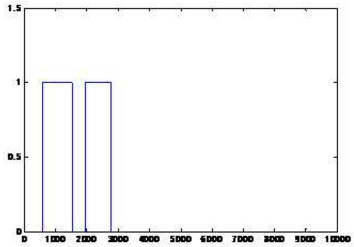


Figure 2.10: Signal of CB successfully reclosed

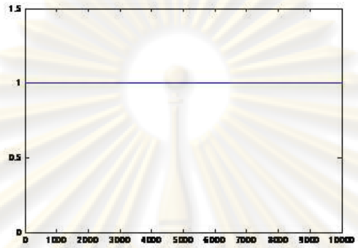


Figure 2.11: Signal of CB opened before occurrence of fault

In the CFG file, relays name and CBs name was listed. For the relay name, there are two strings that show kind of relay and the corresponding protected equipment, respectively, as in fig.2.12. CB name does not show to which equipment that it connected. Nevertheless, the way of naming CB in breaker-and -a-half station is based on some rules that can help us identify CB position in the switching diagram of station.

In order to retrieve the information of relay and CB name as well as their signal form at the time of event from CFG file and DAT file, Matlab program will be developed. With the ability of reading text file as well as dealing with string variables, the program can determine which relays are active at the fault time and which equipment it protects. Also, status of each CB can be known. In this research, the case in which CB has been reclosed successfully will not be taken into account.

2.2.2 The Rules of Naming Circuit Breakers

In a breaker-and-a-half station (230kV), CBs was named as a string of 5 digits. The first two digits indicate to voltage level. The next digit (third digit) indicates to the order of the CB bay that it belongs to. The forth digit indicates to CB's position (1: closes to bus 1, 3: closes to bus 2, 2: middle of the CB bay) in that CB bay and the last digit is always named by 2. Fig.2.13 below shows a example so that the rules can be understood easily.

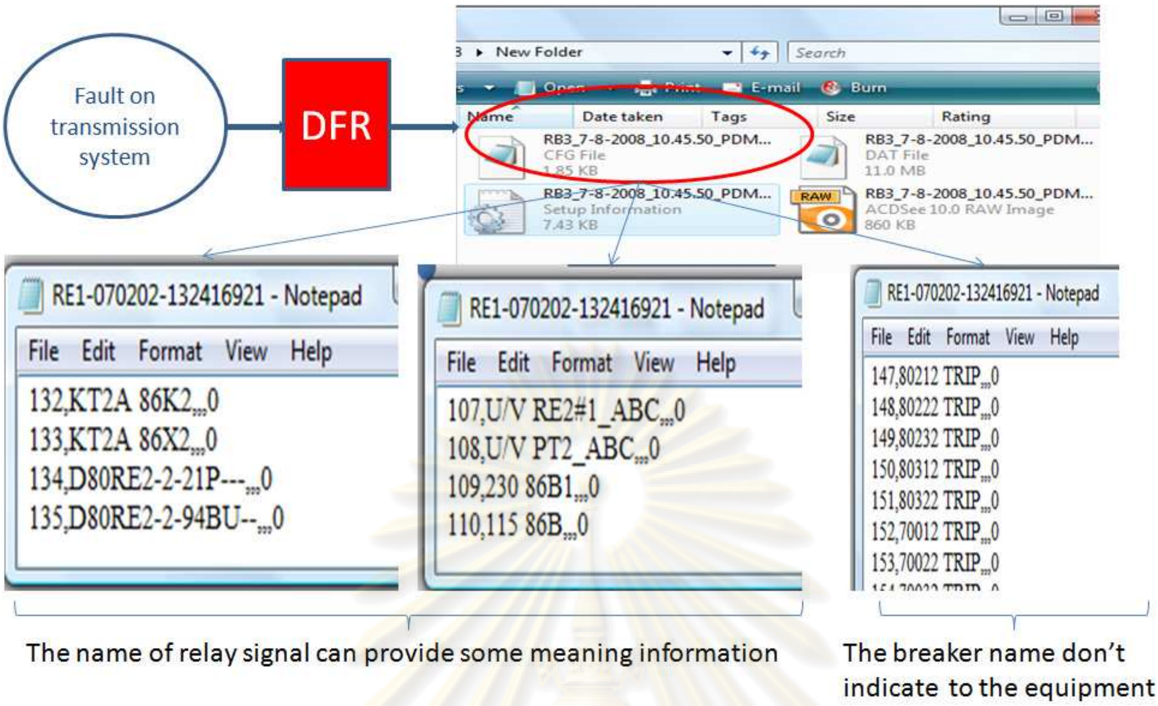


Figure 2.12: Name of relays and CBs in CFG file

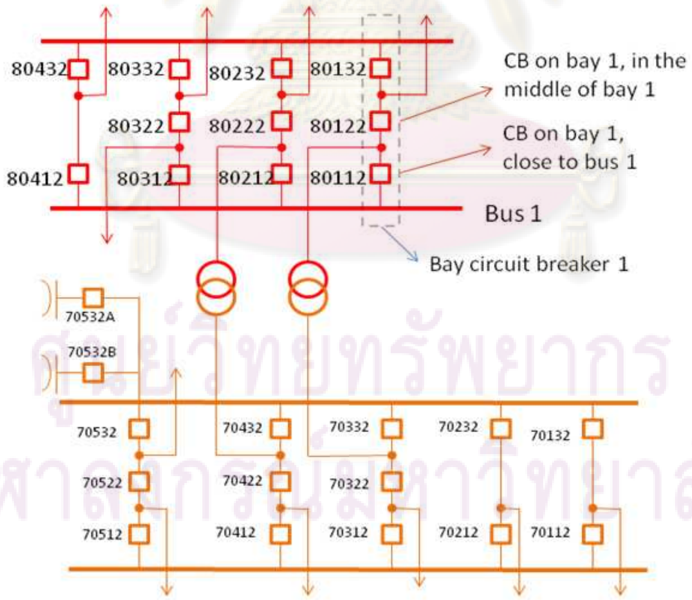


Figure 2.13: Naming CBs in the breaker-and-a-half-station

2.2.3 Selected Digital Signals

The more digital channels will be used in identification, the more accuracy result will be obtained, but the more complicated of protection scheme will be dealt with. Besides, not all of digital channels are available in a typical DFR installed. Therefore, in this research, we just focus on some of main relays signal of which shown in section 2.1 together with breaker failure relay(86BF) and CB signal. These digital channels are as bellow:

- All digital channel of CBs
- All 86BF relay signal
- Relay signals for transmission line protection : 21P1, 21P2, 94P, 94BU, 86DTT
- Relay signals for transformer protection : 87K, 86K, 86A, 51K
- Relay signals for bus bar protection : 87B, 86B

CHAPTER III

FUZZY RELATION AND SAGITTAL DIAGRAM

3.1 Introduction about Fuzzy Set Theory

Fuzzy set were introduced in the mid-sixties in order to mathematically formalize the treatment of imprecise notions and concepts found in almost every decision-making situation. There has been a phenomenal increase in research activities aimed at implementing fuzzy concepts in may engineering application[8].

3.1.1 Fuzzy Set and Membership Function

In a conventional set, an element either belongs to or does not belong to the set. That is, the membership for each element is crisp. That mean it is either yes (in the set) or no (not in the set).

A fuzzy set is a generalization of an ordinary set in that it allows the degree of membership for each element to range over the unit interval [0, 1]. The definition of a fuzzy set can be described following:

$$S = \{(x, \mu_S(x)) | \mu_S(x) \in [0, 1]\} \tag{3.1}$$

,where $\mu_S(x)$ is membership function of fuzzy set S subject to x.

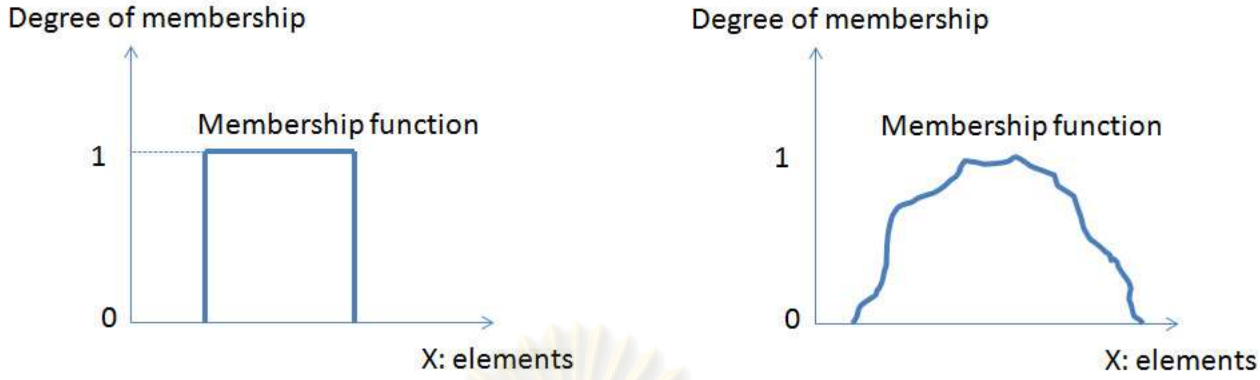
Thus, the membership function of a fuzzy set maps each element of the universe of discourse to its range space, which, in most cases, is assumed to be the unit interval.

Fig.3.1 shows us the membership function of crisp set and fuzzy set. One major difference between crisp and fuzzy sets is that crisp sets always have unique membership functions, whereas every fuzzy set has an infinite number of membership functions that may represent it. This enables fuzzy systems to be adjusted for maximum utility in a given situation.

3.1.2 Fuzzy Intersection and Union Based on Yager's Definition

The union of two fuzzy sets X and Y is specified in general by a function of form:

$$u : [0, 1] \times [0, 1] \rightarrow [0, 1] \tag{3.2}$$



a) Membership function of crisp set *b) Membership function of fuzzy set*

Figure 3.1: Membership function of crisp set and fuzzy set

For each element x in the universal set, this function takes as its argument the pair consisting of the element's membership grades in set X and set Y and yields the membership grade of the element in set constituting the union set of X and Y. Hence, degree of membership of element x in the union of the two set X and Y is:

$$\mu_{X\cup Y}(x) = u[\mu_X(x), \mu_Y(x)] \tag{3.3}$$

In common, the max operator was used to represent the union of fuzzy sets. In fuzzy set theory, there are some classes of function have been proposed whose individual members satisfy all the axiomatic requirement for the fuzzy union and fuzzy intersection [8]. The class of fuzzy union that has been chosen by [7] is Yager's class and is defined by the function:

$$u_w(a, b) = min[1, (a^w + b^w)^{1/w}] \tag{3.4}$$

where the value of parameter w also lie within the open interval $(0, \infty)$.

Similarly, for the intersection set of fuzzy sets X and Y, we also have the membership grade of elements in it as below:

$$\mu_{X\cap Y}(x) = i[\mu_X(x), \mu_Y(x)] \tag{3.5}$$

and Yager's class of fuzzy intersection function is:

$$i_w(a, b) = 1 - min[1, ((1-a)^w + (1-b)^w)^{1/w}] \tag{3.6}$$

where, as the same to the above Yager's class of fuzzy union function, the value of parameter w also lie within the open interval $(0, \infty)$.

3.2 Fuzzy Relation

A crisp binary relation (0 or 1) indicates the presence (1) or absence (0) of association, or interaction, between elements of two sets. Fuzzy binary relations generalize crisp binary relations to represent various degrees of association between elements. Degree of association can be represented by membership grades in a fuzzy binary relation much in the same manner that degrees of set membership are represented in the fuzzy set. As a result, fuzzy relations are also fuzzy sets [8].

Consider two crisp set X_1 and X_2, then a fuzzy relation on $X_1 \times X_2$ is:

$$R(X_1, X_2) = \{((x_1, x_2), \mu_R(x_1, x_2))|(x_1, x_2) \in X_1 \times X_2\} \tag{3.7}$$

,where

$R(X_1, X_2)$ is a fuzzy relation on crisp set X_1 and X_2, also considered as a fuzzy set

x_1 is an element of crisp set X_1

x_2 is an element of crisp set X_2

(x_1, x_2), the asociation between x_1 and x_2, is an element of fuzzy set $R(X_1, X_2)$

$\mu_R(x_1, x_2)$ is degree of membership of element (x_1, x_2) in fuzzy set $R(X_1, X_2)$

Thus, the fuzzy union and intersection functions can be applied on fuzzy relation, like on fuzzy set.

3.3 Original Sagittal Diagram

A fuzzy relation between two set X and Y can be represented easily by a sagittal diagram. Each of sets X, Y is represented by a set of nodes (or boxes) in the diagram. Elements of $X \times Y$ with nonzero membership grades in $R(X, Y)$ are represented in the diagram by lines connecting the respective nodes (boxes). These lines are labeled with the degree of membership.

For power system, H. J. Cho and J. K. Park have proposed sagittal diagrams [7] to represent protection scheme of line and bus. The protection scheme that they focused on and corresponding sagittal diagrams will be described following.

3.3.1 Protection Scheme of Line

Fig.3.2 describes a transmission system with 4 buses, 3 lines. At each end of every line, there are protection relays 21P, 21S and BR as primary, secondary and back up relay. When a fault

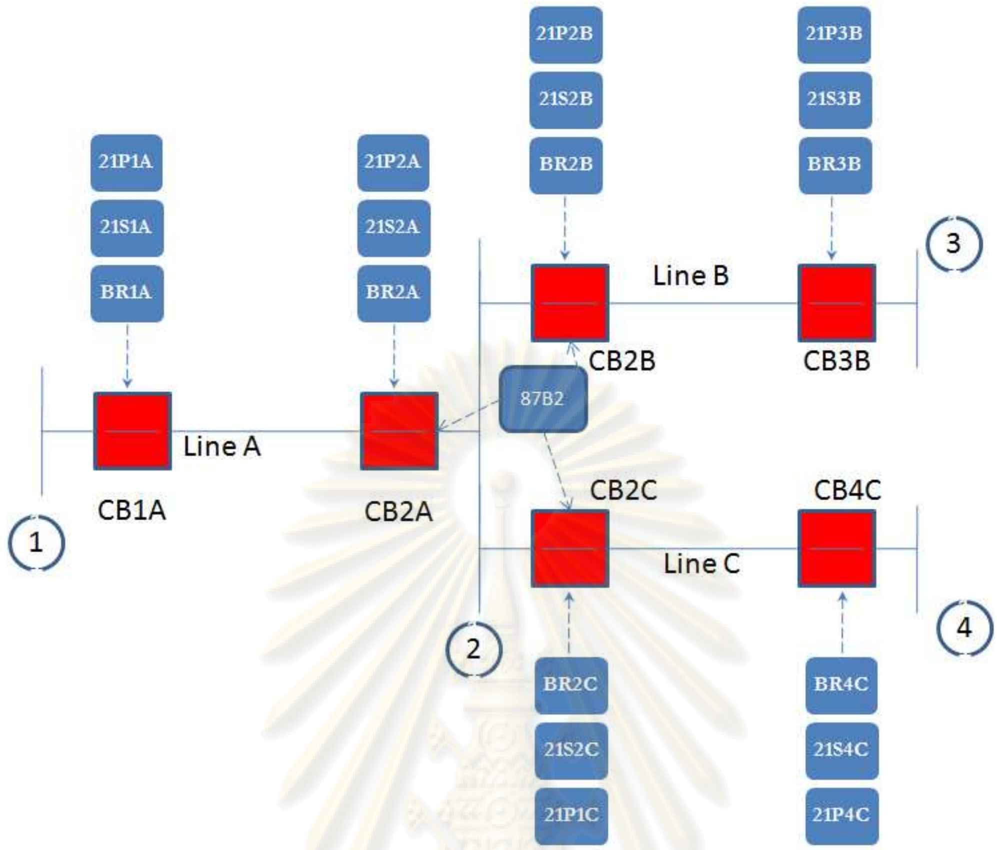


Figure 3.2: A sample protection system

occurs on line A (between bus 1 and bus 2), relays 21P1A and 21P2A will active to trip CB1A and CB2A, respectively. If 21P2A can not operate because of failure or overreach, 21S2A will operate to make CB2A trip. The same thing will happen with 21P1A and 21S1A. If the fault is not isolated after these actions (because CB2A fail in operation), BR3B and BR4C will trip CB3B and CB4C, respectively, to isolate the fault.

3.3.2 Sagittal Diagram for Representing Protection Scheme

Fig.3.3 shows the sagittal diagram for line A that has protection scheme as figure 3.2. The diagram has three sets of boxes: set 1 - section (transmission line), set 2 - relays and set 3 - CBs.

The diagram is build considering the causal operation of relays and CB in the occurrence of fault, and the causality is understood by the direction from left to right. The label on the connecting line between boxes is determined statistically considering the uncertainties of operation and the priorities of relay and CBs when fault occurs. Because a 21P (Zone 1) relay is mostly closely related to a section, the label of the line connecting between them is 0.8. The label of connecting line that connect a 21S (Zone 2) to a section is 0.7. As a BR

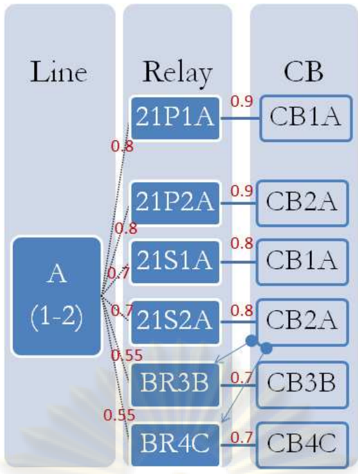


Figure 3.3: Sagittal diagram for line A

(Zone 3) control the CB of the adjacent section, the label of the line that connect a BR relay to a section is decreased some more, and its value was chosen at 0.55. Similarly, the label of the line that connects CB to relay is determined. Considering the characteristic of operation of relay and CB, CB contain less uncertainties than relay do. Relays installed in a substation use information on transmission line many kilometers away, and the information is transmitted to relay by the line exposed outside. However, CBs are only about 50 meters away from relays and the information transmission line is well protected against disturbances. Hence, in [7], the labels between relay and CBs were set larger than those between section and relays.

If a CB is tripped by a 21P relay(zone 1) or a 21S(zone 2) relay, the back up relay must not operate to isolate the non - fault section. Then, an inhibitory circle is introduced to represent this rule. In the figure 3.3, it mean that if CB2A active (open), then the information of BR3B and BR4C will not be considered.

3.3.3 Diagnosis Procedure

Before perform a diagnosis procedure when a fault occurs, it is necessary to form each sagittal diagram for each individual transmission line and bus in the power system. In [7], w was chosen by 3 after various simulations.

Step 1: Look at all available information about relays and CBs that was collected at a fault time. Mark active relays and opened CBs in corresponding sagittal diagrams that was built before. List all sections (lines and buses) that have active relay and opened CB in their sagittal diagrams. As the result, we have the fault set.

For each section in fault set that its sagittal diagram was listed:

Step 2: Calculate the intersection of labels of the lines that make a path to be through set 1, set2 and set3, provided that both the boxes of set 2 and set 3 operate.

Step 3: Calculate the union of the step's 2 result for the paths connected to one section (a box of set 1)

Step 4: The step3's result is determined as the degree of membership of the section's being in the fault set. Comparing candidate's degree of membership, we can identify the fault section.

3.3.4 An Example

Assume that when a fault occurs on line A of the sample system on fig.3.2, relays 21P1A, 21S2A trip CB1A, CB2A, respectively. At the same time, BR3B is wrong alarm and trip CB3B . The diagnosis procedure is described by fig.3.4 and fig.3.5.

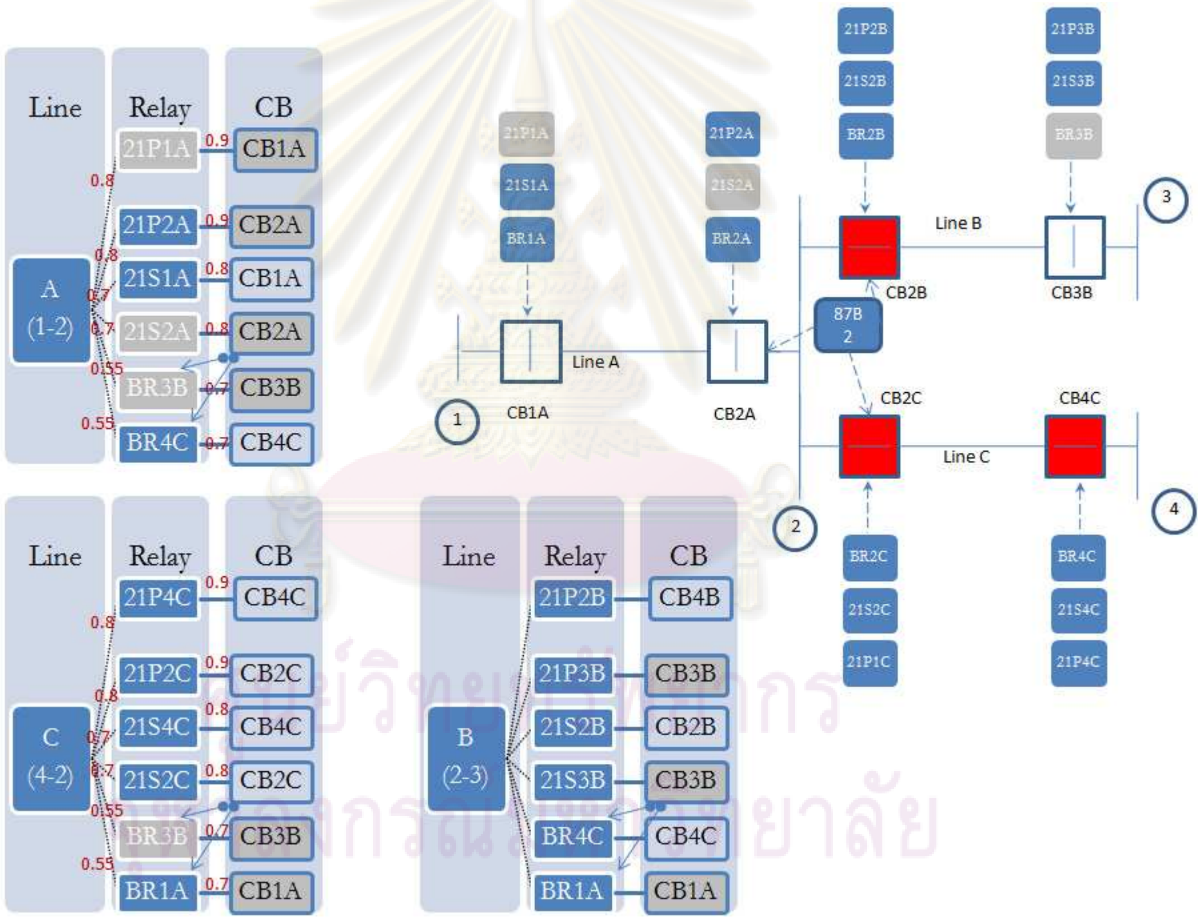


Figure 3.4: Sagittal diagrams for lines

Look at sagittal diagrams involving to relays and CBs that operate, it is obvious to recognize that the fault set contains line A and line C. In sagittal diagram of line A, there are three of available paths that will be corresponding to three of intersection. However, the path that connect line A to BR3B is not considered as mentioned above. Therefore, unions

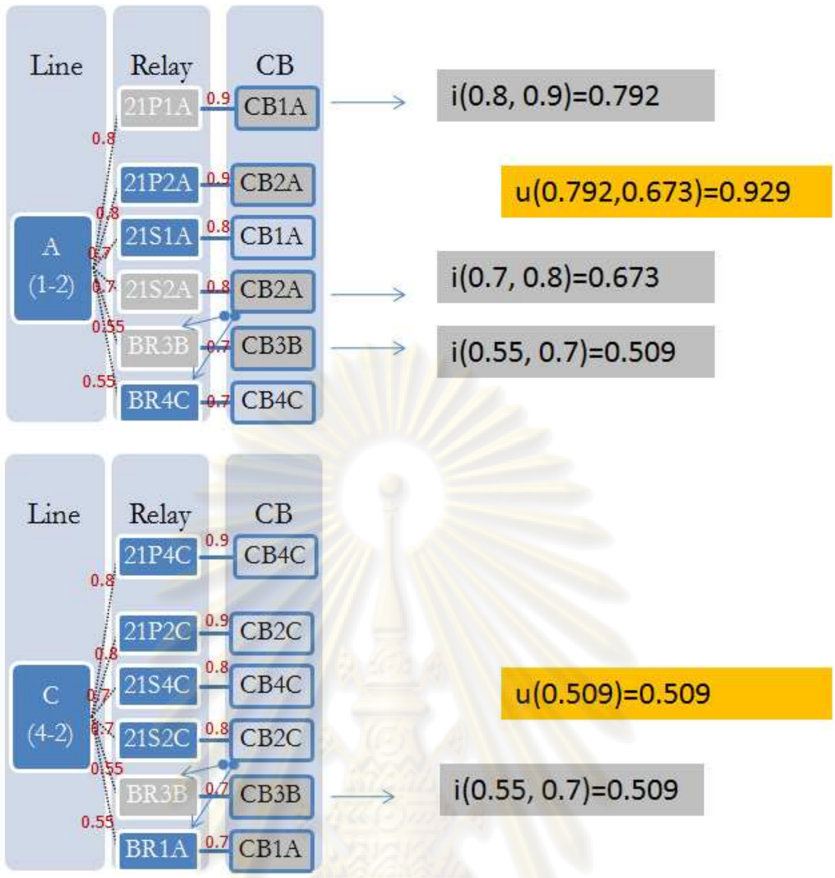


Figure 3.5: Intersections and union of available paths in sagittal diagram

of available paths in sagittal of line A and line C are shown on fig.3.5. Comparing the two degrees of membership result in that the line A is faulted line.

CHAPTER IV

FAULT SCENARIO AND FAULT EQUIPMENT IDENTIFICATION

4.1 Overview of The Proposed Algorithm

As mentioned in section 1.2 of chapter I, there are many methods proposed for fault section identification. Expert system approaches have significant development for fault section identification. They can give an explanation for the result they obtain. Among them, sagittal diagram in which fuzzy relation is embedded provides a convenient mean for modeling uncertainties involving protection scheme. However, all of them require the thorough knowledge of power system configuration. Besides, in order to build sagittal diagrams, they need to know which relay corresponds to which CB. For an actual system that needs to identify fault section using only DFR data as input, the knowledge about system configuration could not be known completely, because of the limitation of information from DFR data. Therefore, this method may have some difficulties to be applied.

This research proposes modified sagittal diagram for identifying the faulty equipment within transmission network in which stations have breaker-and-a-half configuration. The input data are only selected digital data from DFRs installed at stations. Instead of the requirement of information pertinent to system configuration, this research proposes an outage configurator program (OCP) to derive switching diagram in the station using only the breaker names and statuses from DFR, based on rules of naming CBs in breaker- and- a-half stations. The output of OCP is the set of outage elements in each station due to the fault occurrence. These elements containing buses, nodes (conjunction connecting lines or transformers to each station) and capacitors will be used in the third set (third column) of modified sagittal diagrams.

Fig. 4.1 shows the overall diagram of the proposed algorithm. When a fault occurs on an equipment in transmission system, some relays and CBs at some stations will be active. Then, these relay and CB signals will be recorded in DFRs at those stations. After that, they will be processed station by station so that active relays and opened CBs as well as list of CB names at each involved station can be recognized. At each station, the CB names list and CBs status then will be used as input for OCP to result in outage elements. Active relay names will be used to call sagittal diagrams of corresponding equipments. Output of OCP will be

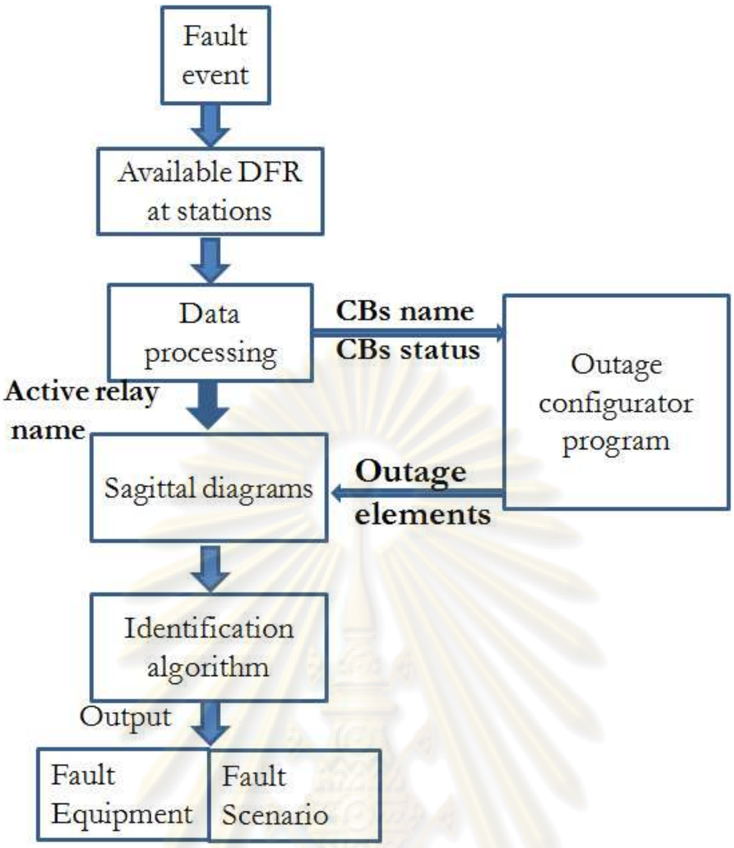


Figure 4.1: Description of thesis formulation

marked in the third columns of those sagittal diagrams. Next, all sagittal diagrams that are called for all involved stations will be calculated their degree of memberships of being in the fault set (fault scenario). The maximum one among these degrees of memberships indicates to the fault equipment. Besides, based on some rules proposed in identification algorithm, the fault scenario will be identified.

4.2 Outage Configurator Program (OCP)

DFR data does not provide thorough knowledge of power system configuration as well as switch diagram of any station. However, it can provide the name list of CBs in each station as well as name of CBs opened during fault. OCP performance based on rules of naming CBs for breaker-and-a-half station that were described in chapter II. Firstly, a matrix that describes the switching diagram in normal condition of station is built up using CB names list of that station. Secondly, this matrix will be processed using name of CBs that were opened pre fault and during fault. Thirdly, outage elements due to fault will be determined. In next sub-sections, these three step will be demonstrated sequently.

4.2.1 Describing CB Connection Matrix

The breaker and a half station have more CBs and nodes than some kind of station that has the same number of equipment connecting to. Chapter II has presented some rules for CB naming in kind of station so that we (program) can determine CBs 's position while looking at only CB names. Based on those rules, this research proposes a describing CB connection matrix (M) using only the list of CB names in DFR data of each station as input.

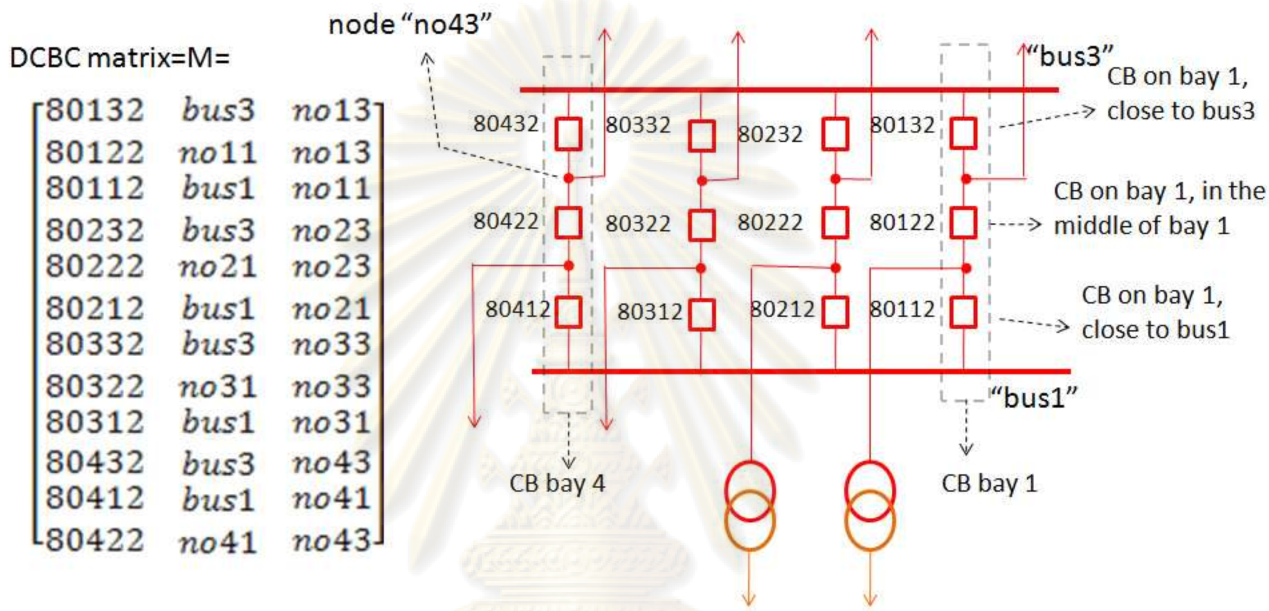


Figure 4.2: Configuration of a breaker-and-a-half-station

Fig. 4.2 shows a breaker-and-a-half station with CB names and bus names. We call "bus1" the bus that closes to CBs that have "1" in forth digit of their name. The remaining bus is "bus3". Actually, these two buses are named "230 bus 1" and "230 bus 2" in DFR data. We define a node is a conjunction that connects any transmission line or transformer to station. Each node will be named based on names of CBs which connect to it. Each CB bay has two nodes. A node that belongs to "CB bay x" and closes to "bus$y$" will be called "noxy".

For the station in fig. 4.2, the describing CB connection matrix M will be formed as shown in the same figure. In each line of matrix M, the first element (first column) shows name of CB . Actually, this CB responds to connect a bus to a node, or a node to another node. If it connects a bus to a node, the bus name and the node name will be shown in the second and third column, respectively. Otherwise, the two node names will be shown in that two columns, respectively. If there are only two CBs on a CB bay, the two nodes on that bay will be merged.

At this step, the configuration algorithm below just deal with cases that have at least one energized bus post fault.

4.2.2 Outage Configurator Program Algorithm

At each area of voltage level of station, this program will find the set of outage elements previous and post fault. The different set between the two above sets is the outage elements due to fault occurrence. Fig. 4.3 shows the flowchart of the algorithm finding the set of outage elements at one point of time (previous fault or post fault). In the algorithm flowchart:

$\{M\}$ is the set of elements in the second and third columns of matrix M

$\{M1\}$ is the set of elements in the second and third columns of matrix M1

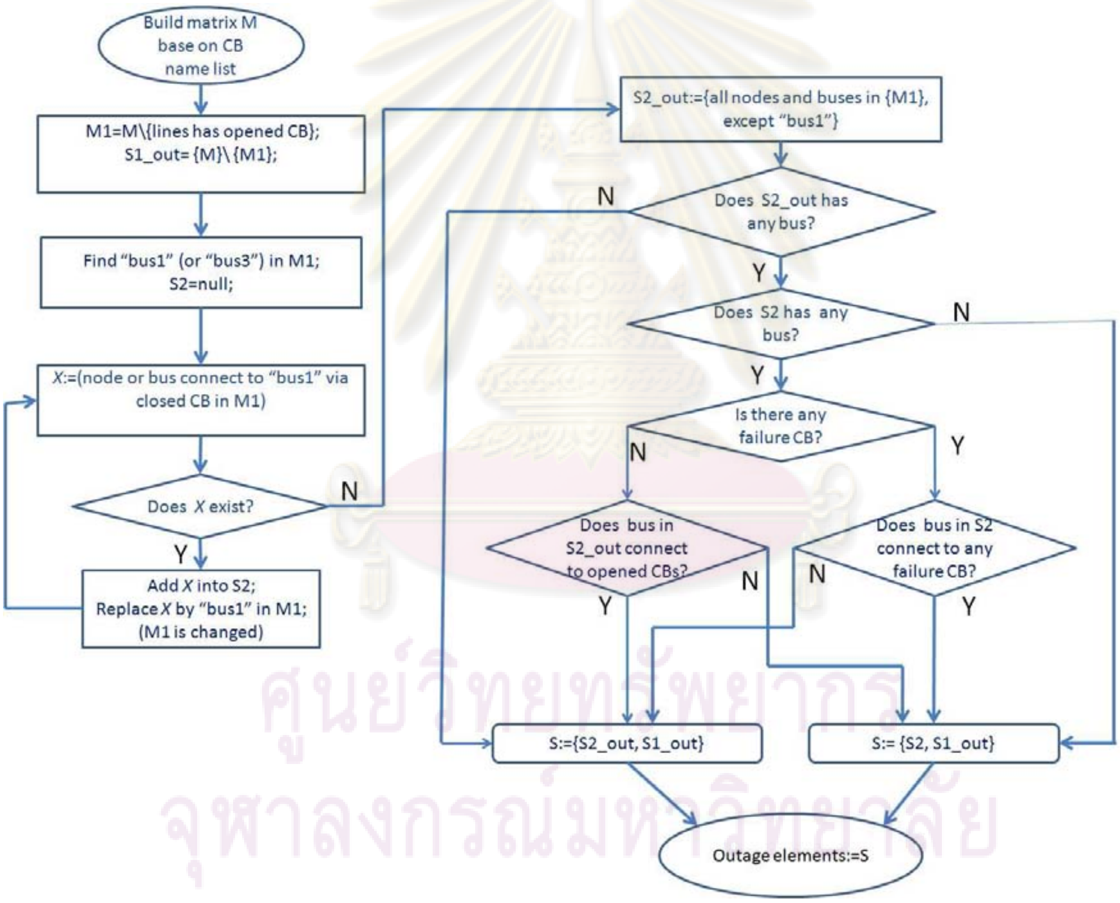


Figure 4.3: An algorithm for finding outage elements

In order to find sets of outage elements previous fault as well as post fault of a station, this program firstly deletes lines that have opened CBs in matrix M to form matrix M1. It is easy to see that any element being in $\{M\}$ but not in $\{M1\}$ does not connect to any closed CB. Then, these elements are not energized. They will be included in a set S1_out. Next, using M1, the program will start with any bus to search to neighboring elements via closed circuit breakers, until none of neighboring element is found. Then from M1, we have two separated part in result, S2 and S2_out. After that, the program will find out which one is not energized, between S2 and S2_out. The part that does not include any bus is not energized. If each part has one bus, the part has the bus connecting to the failure CB is not energized. If there is not any failure CB, the part has the bus connecting to open CBs is not energized. At last, the set of outage elements contains S1_out and the part that is not energized between S2 and S2_out. The format of outage elements by OCP is a set that contains nodes (conjunction that connect a line or a transformer to the station) and buses. Equipments that are connected to these nodes will be known after fault equipment and fault scenario are identified.

4.2.3 An Example

Let consider a station which has configuration shown by fig.4.4. There are two CBs (80422 and 80412) opening previous fault. A fault occurs on bus 1, lead to that a relay trips three CBs 80212, 80112 and 80312 open. However, CB 80212 is failure at this time, then CB 80222 is opened by 86B relay to isolate the faulty equipment.

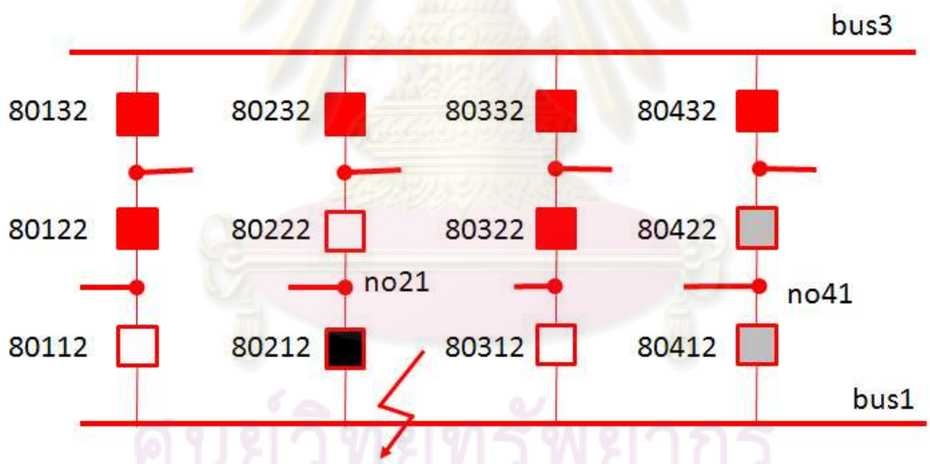


Figure 4.4: A station with fault on bus 1

DCBC matrix is built as following:

$$[\ M\ ] = \begin{bmatrix} 80112 & bus1 & no11 \\ 80122 & no11 & no13 \\ 80132 & bus3 & no13 \\ 80212 & bus1 & no21 \\ 80222 & no21 & no23 \\ 80232 & bus3 & no23 \\ 80312 & bus1 & no31 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80412 & bus1 & no41 \\ 80422 & no41 & no43 \\ 80432 & bus3 & no43 \end{bmatrix} \tag{4.1}$$

Step 1: Finding outage elements before fault. Opened CBs before fault are 80422 and 80412.

- Delete the two lines having opened CBs in matrix M to obtain M1.

$$[\ M\ ] = \begin{bmatrix} 80112 & bus1 & no11 \\ 80122 & no11 & no13 \\ 80132 & bus3 & no13 \\ 80212 & bus1 & no21 \\ 80222 & no21 & no23 \\ 80232 & bus3 & no23 \\ 80312 & bus1 & no31 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ \mathbf{80412} & bus1 & no41 \\ \mathbf{80422} & no41 & no43 \\ 80432 & bus3 & no43 \end{bmatrix} -> [\ M1\ ] = \begin{bmatrix} 80112 & bus1 & no11 \\ 80122 & no11 & no13 \\ 80132 & bus3 & no13 \\ 80212 & bus1 & no21 \\ 80222 & no21 & no23 \\ 80232 & bus3 & no23 \\ 80312 & bus1 & no31 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \tag{4.2}$$

Hence, S1_out={M}\{M1}={no41}

- Based on M1, search elements connecting to bus1 and bus3.

$$[\ M1\ ] = \begin{bmatrix} 80112 & bus1 & \mathbf{no11} \\ 80122 & \mathbf{no11} & no13 \\ 80132 & bus3 & no13 \\ 80212 & bus1 & no21 \\ 80222 & no21 & no23 \\ 80232 & bus3 & no23 \\ 80312 & bus1 & no31 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \text{->} \begin{bmatrix} 80112 & bus1 & bus1 \\ 80122 & bus1 & \mathbf{no13} \\ 80132 & bus3 & \mathbf{no13} \\ 80212 & bus1 & no21 \\ 80222 & no21 & no23 \\ 80232 & bus3 & no23 \\ 80312 & bus1 & no31 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \text{->}$$

$$\begin{bmatrix} 80112 & bus1 & bus1 \\ 80122 & bus1 & bus1 \\ 80132 & \mathbf{bus3} & bus1 \\ 80212 & bus1 & no21 \\ 80222 & no21 & no23 \\ 80232 & \mathbf{bus3} & no23 \\ 80312 & bus1 & no31 \\ 80322 & no31 & no33 \\ 80332 & \mathbf{bus3} & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \text{->} \ldots \begin{bmatrix} 80112 & bus1 & bus1 \\ 80122 & bus1 & bus1 \\ 80132 & bus1 & bus1 \\ 80212 & bus1 & bus1 \\ 80222 & bus1 & bus1 \\ 80232 & bus1 & bus1 \\ 80312 & bus1 & bus1 \\ 80322 & bus1 & bus1 \\ 80332 & bus1 & bus1 \\ 80432 & bus1 & bus1 \end{bmatrix} \tag{4.3}$$

From the last matrix in searching processing, it is obvious that there is no isolated part in {M1}: S2_out={}

Hence, $S_{pre} = \{no41\}$

Step 2:Finding outage elements post fault. Opened CBs post fault are 80422, 80412, 80112, 80222, and 80312.

- Delete the five lines having opened CBs in matrix M to obtain M1.

$$\left[\ M\ \right] = \begin{bmatrix} \mathbf{80112} & bus1 & no11 \\ 80122 & no11 & no13 \\ 80132 & bus3 & no13 \\ 80212 & bus1 & no21 \\ \mathbf{80222} & no21 & no23 \\ 80232 & bus3 & no23 \\ \mathbf{80312} & bus1 & no31 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ \mathbf{80412} & bus1 & no41 \\ \mathbf{80422} & no41 & no43 \\ 80432 & bus3 & no43 \end{bmatrix} \text{->} \left[\ M1\ \right] = \begin{bmatrix} 80122 & no11 & no13 \\ 80132 & bus3 & no13 \\ 80212 & bus1 & no21 \\ 80232 & bus3 & no23 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \tag{4.4}$$

Hence, S1_out={M}\{M1}={no41}

- Based on M1, search elements connecting to bus1 and bus3.

$$\left[\ M1\ \right] = \begin{bmatrix} 80122 & no11 & no13 \\ 80132 & bus3 & no13 \\ 80212 & bus1 & \mathbf{no21} \\ 80232 & bus3 & no23 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \text{->} \begin{bmatrix} 80122 & no11 & no13 \\ 80132 & bus3 & no13 \\ \mathbf{80212} & bus1 & bus1 \\ 80232 & bus3 & no23 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix}$$

$$[\ M1\ ] = \begin{bmatrix} 80122 & no11 & \textbf{no13} \\ 80132 & bus3 & \textbf{no13} \\ 80212 & bus1 & no21 \\ 80232 & bus3 & no23 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \text{->} \begin{bmatrix} 80122 & \textbf{no11} & bus3 \\ 80132 & bus3 & bus3 \\ 80212 & bus1 & no21 \\ 80232 & bus3 & bus3 \\ 80322 & no31 & no33 \\ 80332 & bus3 & no33 \\ 80432 & bus3 & no43 \end{bmatrix} \ldots \begin{bmatrix} 80122 & bus3 & bus3 \\ 80132 & bus3 & bus3 \\ \textbf{80212} & bus1 & no21 \\ 80232 & bus3 & bus3 \\ 80322 & bus3 & bus3 \\ 80332 & bus3 & bus3 \\ 80432 & bus3 & bus3 \end{bmatrix} \quad (4.5)$$

The searching process find out that there are two isolated parts post-fault in {M1}: S2={bus1, no21} and S2_out={bus3, no13, no11, no23, no33, no31, no43 }. Because bus1 is connecting to failure CB, $S_{post} = \{S1\_out, S2\} = \{no41, bus1, no21\}$. At conclusion, the set of outage elements due to fault is $S_{outage} = S_{post} \setminus S_{pre} = \{bus1, no21\}$, and it has a "bus connect node" connecting.

4.3 Generalized Sagittal Diagram

In the past, H. J. Cho and J. K. Park [7] have proposed sagittal diagrams to represent fuzzy relation in protection schemes of transmission lines and buses. Their model of a sagittal diagram contains three sets of nodes (boxes): sections (lines or buses), relays and CBs. The knowledge of system configuration was required so that relays and its corresponding CBs can be put into sagittal diagrams correctly. Besides, each line or bus required an individual sagittal diagram, subject to system configuration. That mean a system has one thousand lines will need one thousand sagittal diagrams built in database in advance.

DFRs data do not provide knowledge of transmission system configuration. We do not know which relay control a CB and which CB connect to an equipment (line, transformer). Lacking of these information, a sagittal diagram proposed by previous works can not be built. Therefore, this paper proposes a new model of sagittal diagram in which the third set will be replaced by outage elements found by OCP. Moreover, based on the unity of protection scheme of each kind of equipment, we just need to build only one sagittal diagram for each kind of equipment.

Based on protection scheme of transmission lines, transformers and buses that are described in section II, there are some of situations that happen when a fault occurs on an equipment, subject to outage elements during fault.

Tables 4.1-4.3 show situations subjected to outage elements when a fault occurs on transmission line, transformer or busbar, respectively. Based on these tables and the priority of active relays when fault occurs, sagittal diagrams for three kinds of equipment are proposed as following.

Table 4.1: Outage elements when fault on line

Equipment	Number of failure CBs	Outage elements
Line	0	Only one node
	1	”Node connect bus” or ”node connect node”
	2	”Node connect bus” and ”node connect node”

Table 4.2: Outage elements when fault on transformer

Equipment	Number of failure CBs	Outage elements(230kV)
Transformer	0	Only one node
	1	”Node connect bus” or ”node connect node”
	2	”Node connect bus” and ”node connect node”

Table 4.3: Outage elements when fault on bus

Equipment	Number of failure CBs	Outage elements
Line	0	Only one bus
	1	”Node connect bus”
	2	”Node connect bus” and ”node connect bus”

Each connection in a sagittal diagram will take a number representing the associate degree itself. These number were called degrees of membership in the fuzzy relation set which its elements are relations between set 1 and set 2 or between set 2 and set 3 of this sagittal diagram. In order to avoid an confusing between degrees of membership of these associations (these number) and the degree of membership of being fault set that will be calculated for each sagittal, we name these number as weighting factors of each connection.

The number factor on the connection between the equipment and a relay is smaller than that on the connection between that relay and outage elements, because operation of relays has a lower reliability than operation of CBs. In the same sagittal diagram, factors on connections between the equipment and relays were chosen based on priority of those relays, i.e. the factor on the connection of the primary relay is larger than that of secondary relay. In this research, firstly these factors are chosen following [7] to test events in an actual system. After that, they will be relaxed so that their effectiveness on the results can be estimated.

With the assumption that at least the primary relay or secondary relay operates correctly, the occurrences of failure breaker do not reflect the faulty equipment as much as active relays. Then, factors on connections between one relay (set 2) to various outage elements (set 3) are set to be the same.

4.3.1 Sagittal Diagram for Transmission Lines

Fig.4.5 shows the sagittal diagram for transmission lines. In this sagittal diagram, we use 0.8, 0.7 and 0.6 as factors of connections from the transmission line to 21Z1 relays, 21Z2 relay and the direct-transfer- trip relay (86DTT), respectively.

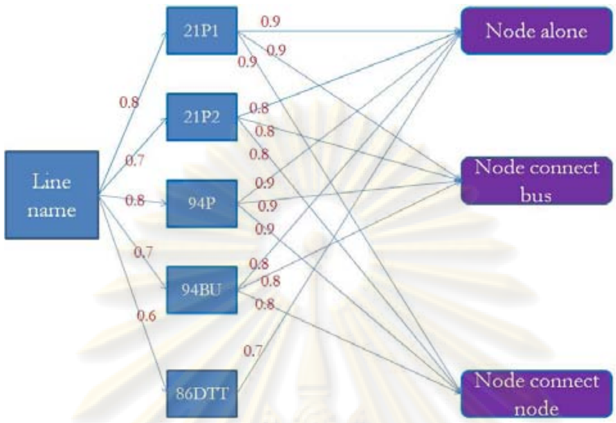


Figure 4.5: Sagittal diagram for transmission lines

4.3.2 Sagittal Diagram for Transformers

The same numbers are also applied for the sagittal diagram of the transformer as shown in fig.4.6, except the number on the connection between the 51K relay and the transformer that is chosen by 0.65. The reason is that the 51K relay is considered as a back up relay of transformer itself, while 86DTT relay is not only a back up relay of the line itself but also a back up relay for adjacent equipment by operation of 86BF relay. 86K relay is an auxiliary tripping relay that can be activated by 87K or 51K, so the factor on its connection should be less than 0.8 and more than 0.65.

4.3.3 Sagittal Diagram for Buses

The busbar has two kinds of relays putting in its sagittal diagram which is shown in fig.4.7. Because 86K is not the auxiliary tripping relay for only 87B relay and it may be active by some secondary relay, the factor on its connection to the busbar should be less than 0.8. Moreover, this relay will be activated in case that some breaker is failure when fault occurs on other equipment, so factors on connections between this relay and outage elements corresponding to breaker failure cases should be less than those on connections between the secondary relay and outage elements corresponding to breaker failure cases in other sagittal diagrams (of other equipment). Therefore, we chose these factors by 0.6, instead of 0.8.

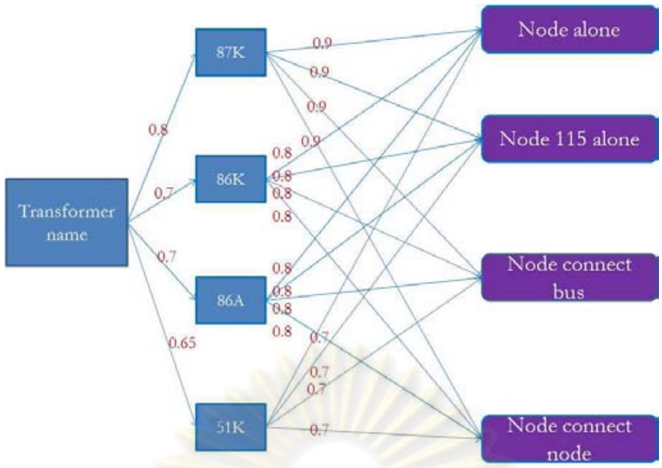


Figure 4.6: Sagittal diagram for transformers

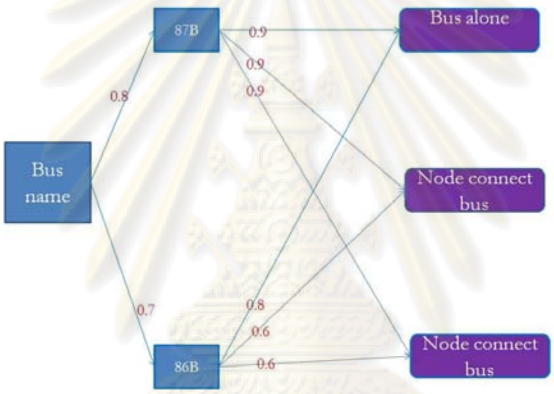


Figure 4.7: Sagittal diagram for bus

4.3.4 Degree of Membership Calculation

Sagittal diagrams is used for representing fuzzy relations in protection schemes of equipment. When a fault occurs on some equipment, at each involved station, active relays and outage elements will be marked in corresponding sagittal diagrams. Then, degree of membership calculation needs to be performed on each called sagittal diagram to estimate the likelihood of being faulty set of those equipment. Steps of degree of membership calculation for each sagittal are not different from those described in chapter III. Firstly, the intersection between the two weighting factors on each path that is available by marked active relays and outage elements will be calculated by Yager's fuzzy intersection. Secondly, the Yager's fuzzy union will be used to calculate the union between intersections of paths in each sagittal diagram. The result of the calculation is called degree of membership of being fault set of the corresponding equipment.

4.4 Identification Algorithm

4.4.1 Fault Equipment Identification Algorithm

Step 1 and step 2 are done at each station:

Step 1- After information about active relays from DFR data and the set of outage elements from OCP are obtained, corresponding sagittal diagrams will be called and marked based on those information.

Step 2 - Degree of membership calculation of all sagittal diagrams called.

Step 3 - Find if there are transmission lines that have the same name, from different stations. Then, for each such line, calculate its new degree of membership of being fault set based on the two previous old ones using Yager's union function.

Step 4 - Find the sagittal diagram that has maximum degree of membership among all diagrams of all involved stations.

u_{FE} =Max {u1, u2,uk, um/stations involve the fault}

The fault equipment is the equipment corresponding to the above sagittal diagram.

For example, fig.4.8 shows a sagittal diagram in which relay 1, relay 2 and OE 2 are marked. Hence, it has two available paths: relay1-OE 2 and relay 2-OE 2. Intersection and union calculation of this sagittal diagram will be done using these paths. Fig.4.9 gives an illustration in which there are many sagittal diagrams called at one station.

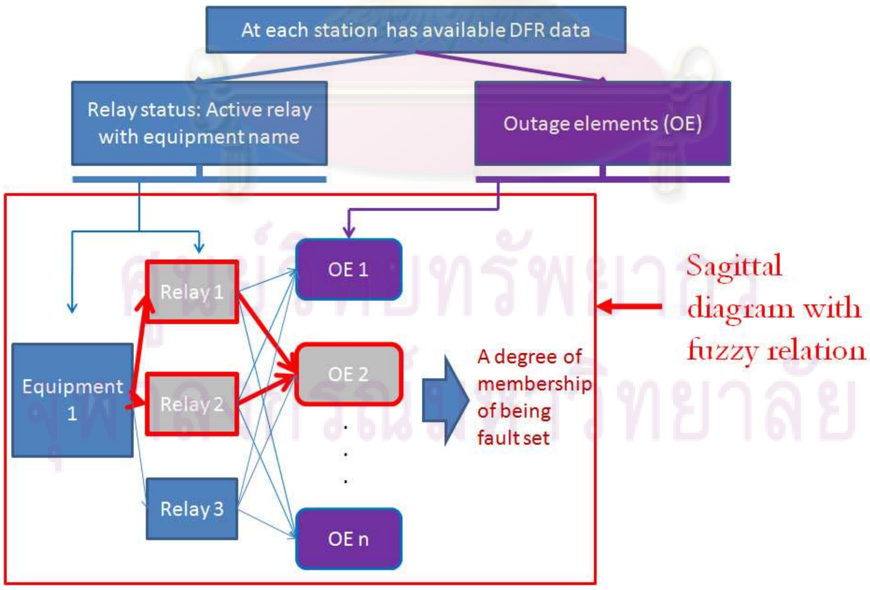


Figure 4.8: Active relays and outage elements marked in sagittal diagram

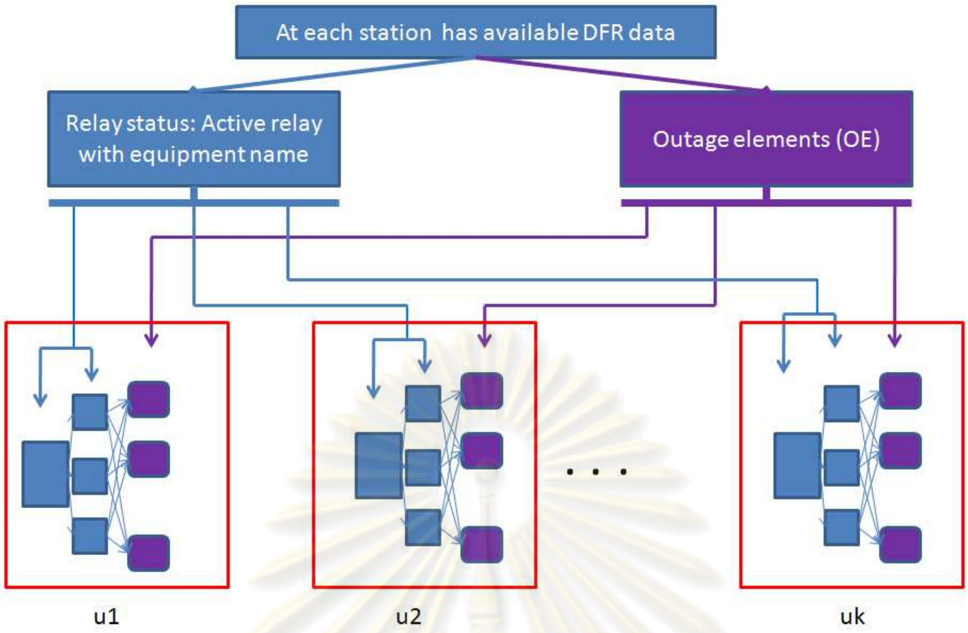


Figure 4.9: Degree of membership of being fault set for all called sagittal diagram

4.4.2 Fault Scenario Identification Algorithm

This algorithm will identify equipment that were isolated during fault at each station involved a fault event.

We use following rules to identify outage equipments at each station. These rules were built based on protection scheme of transmission system described in chapter III.

Rule 1 - In one involved station, the number of outage equipments is the same to the number of outage elements.

Rule 2 - All equipment names which their sagittal diagrams are called and have at least one available path will be considered as candidates of fault scenario.

Rule 3 - In cases that number of outage elements during fault less than number of sagittal diagrams called: the larger degree of membership sagittal diagram result in, the higher likelihood equipment has in the fault scenario.

Rule 4 - If a station has no any sagittal diagram of transformer called, but its outage elements include ”node 115kV alone” with ”node connect bus” or ”node connect node”, this station has one transformer isolated.

Because a transmission line or a transformer connects to a station (230kV area) by a node and the OCP can recognize nodes and buses isolated from a station, the number of outage elements (nodes and buses) is the same to the number of outage equipment. Therefore, Rule 1 is obviously to be confirmed.

Rule 2 comes from the fact that: if a line or a bus is isolated from a station, there must be some of relays protecting it were active during fault, whether it is fault equipment or healthy equipment. For example, 86DTT relay responding to protect a line will trip CBs which connect to one end of this line if the CB connecting to the remaining end of this line is failure when fault occurs on other equipment.

When a transformer is isolated from a station due to breaker failure from 230kV part of the station, there is not any active relay that can show the transformer name. Then, Rule 2 is useless to identify the transformer in the fault scenario. However, the node that connects the transformer to 115kV part is outage in this case. Therefore, Rule 4 will help to identify the transformer.

When a fault occurs, if some relays are active but there is no signal carried to trip their corresponding CBs, the number of sagittal diagrams called will be more than the number of outage equipment. In this case, conveniently, these relay are back up relay with a lower priority in protection scheme of the fault equipment. Then, Rule 3 will help to identify correctly fault scenario.

4.5 Implementation

Fig.4.10 shows the architecture for the implementation. When a fault occurs, DFRs at some of involved stations are recorded. Then they will be put to the program as the only input. For each station, its DFR data will be analyzed to result in list of active relay names, list of CB names and CB statuses. The list of CB statuses and list of CB names of each station then will be put in OCP to result in forms of outage elements. There are four types of outage element forms such as ”node alone”, ”bus alone”, ”bus connect node” and ”node connect node”. After that, sagittal diagrams corresponding to active relays will be called. Next, active relays as well as forms of outage elements will be marked in these sagittal diagrams, for each station. The fault scenario rules will be applied to each station to find out outage equipment at each station, which will be updated station by station to form Fault Scenario. Also, list of sagittal diagrams of all station will be arranged according to their degree of membership of being fault set. The maximum one of this list will indicate to fault equipment.

Notice that the fault equipment and fault scenario identification algorithm work based on degree of membership calculation. Because a sagittal diagram has no any available path will result in its degree of membership as 0, just DFRs having active relay and outage elements will be tackled. By another way, the station having active relays but no opened CBs will be neglected in the identification algorithm.

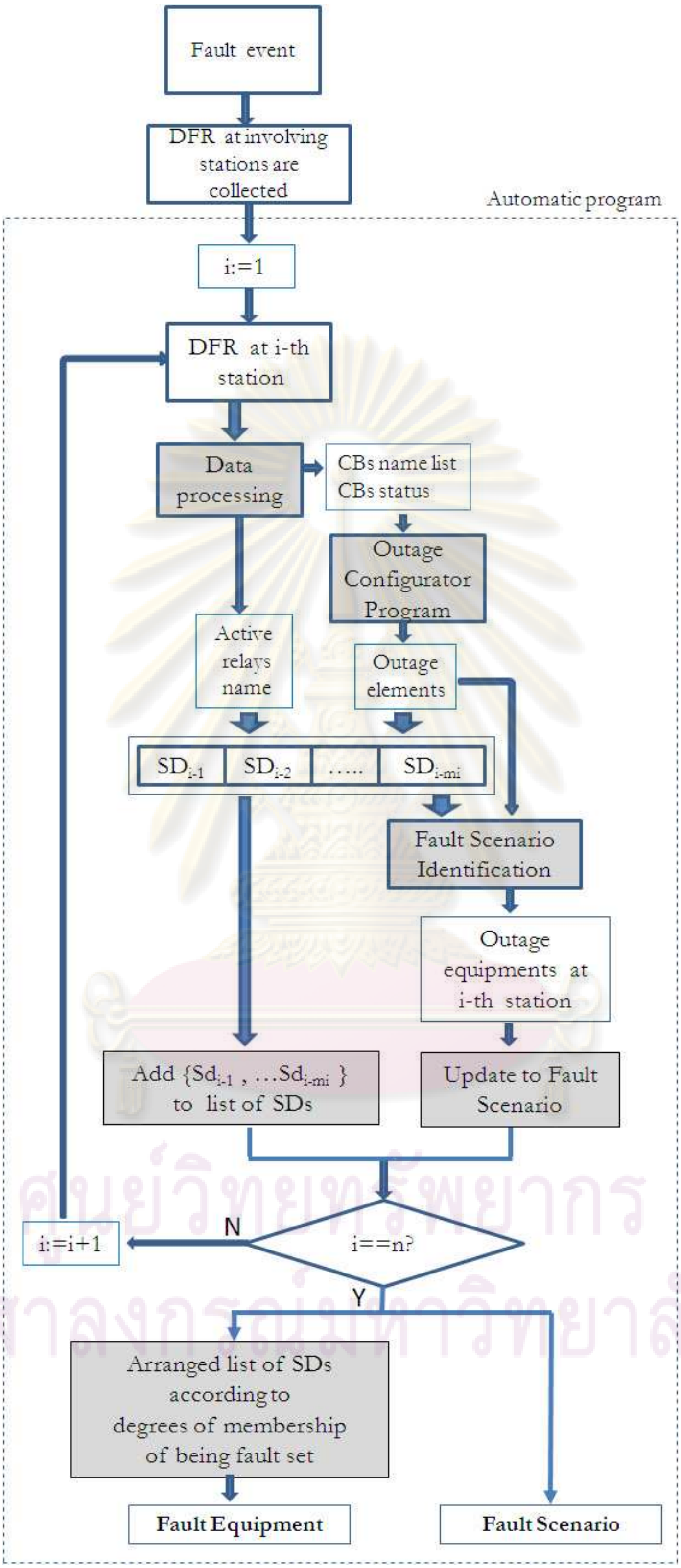


Figure 4.10: Implementation architecture

CHAPTER V

CASE STUDIES

Field measurements have been used for off-line-testing the overall algorithm. However, it is very difficult to expect the occurrence of many complicated fault events in the actual system. Besides, most of events are simple fault events on transmission line. This chapter will make an elaborate description of performances of overall algorithm on real cases, from the simple to the complicated one. All of results here were verified by looking at analog signal of DFR. Also, all complicated event results were matched with the conclusion of operator engineer of the actual system.

5.1 Test Procedures

When a fault occurs on some equipment at some station, relays and CBs at that station and other stations may be active. At that time, information of relays and CBs at those stations will be recorded by DFRs. Then it can be found to form as a pack of data of that fault for testing. Fault events tested are not limited by an area of the actual transmission system. It can be occurred on one of three types of equipment in any breaker-and-a-half station of 230kV of this actual system.

A Matlab-based program has been developed for supporting the off-line testing work. It has some of sub-program corresponding to the blocks shown in fig.4.10 such as Data Processing, OCP, Sagittal Diagram calculation, Fault Scenario identification. The program can be used to automatically run with digital data from any DFR as input.

The case 4 in section 5.2 and case 6 in section 5.3 have no electronic data file saved, but the hard -copy reports from operators of the actual system. Thus, we have to prepare the active relays and open CBs for those cases to put in the program.

5.2 Fault on Transmission Lines

5.2.1 Case 1: The Simple Case

- None of node isolated before fault
- Primary relay activate only

- None of failure CB

A fault occurs on line as shown in fig5.1. Only DFR data of station LS is available for this fault, which was summarized in table 5.1

Table 5.1: Active digital data at station LS

	Active Relay and CB	Active time
LS	CB 80322	During fault
	CB 80332	During fault
	CB 80332	During fault

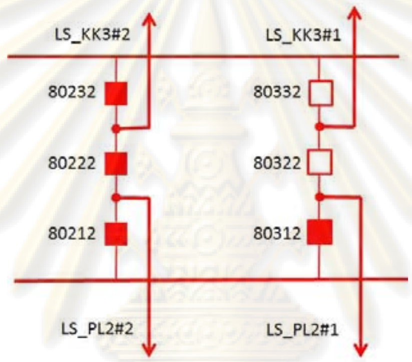


Figure 5.1: Configuration of station LS

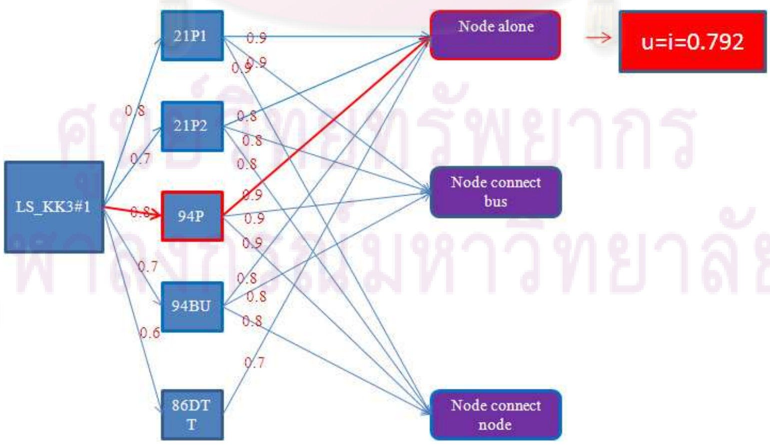


Figure 5.2: Sagittal diagram for line LS_KK3#1

At Station LS:

OCP: The OCP found that only node 'no33' was removed out of station during fault.

Sagittal diagrams: There is only one sagittal diagram called for transmission line LS_KK3#1. The degree of membership calculation was shown by fig5.2, and results in: $u_{LS\_KK3\#1} = u(0.792, 0) = 0.792$

Fault equipment: Because line LS_KK3#1 is the only equipment which its degree of membership is calculated, it must be the fault equipment.

Fault scenario: From rule 1, fault scenario contains only line LS_KK3#1. Hence, FO=FE={line[LS_KK3#1] }

5.2.2 Case 2: The Case with Circuit Breaker Open Before Fault

- One transmission line is isolated before fault
- Primary and secondary relays active
- None of failure CB

A fault occurs on line BN_SNO#1 as shown in fig5.3. Only DFR data of station BN which was summarized in table5.2 is available for this event.

Table 5.2: Active digital data at station BN

	Active Relay and CB	Active time
BN	CB 80522	Open during fault
	CB 80532	Open during fault
	CB 80612	Open before fault
	CB 80622	Open before fault
	94P_SNO#1	Active during fault
	94BU_SNO#1	Active during fault

At station BN:

OCP: In this case, two CBs (80622 and 80612) had been tripped before fault so that ”no61” was removed out of BN station. However, the OCP found that only node ’no53’ was removed out of station during fault.

Sagittal diagrams: There is only one sagittal diagram called that is the sagittal diagram for transmission line BN_SNO#1. The degree of membership calculation was shown by fig5.4, and result in: $u_{BN\_SNO\#1} = u(0.792, 0.672) = 0.929$

Fault equipment: FE= {line [BN_SNO#1]}

Fault scenario: FO= {line [BN_SNO#1]}

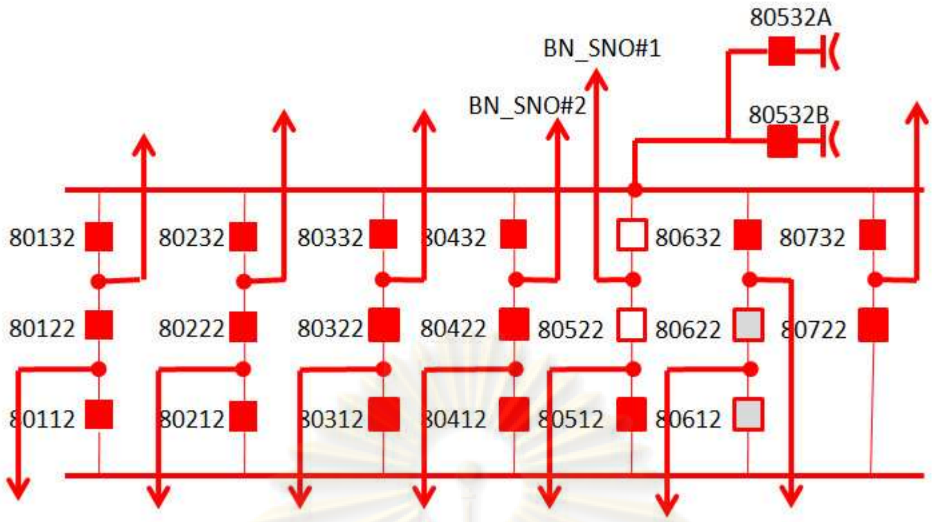


Figure 5.3: Configuration of station BN

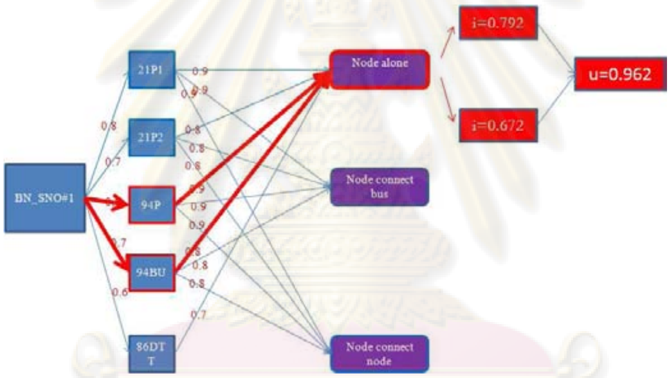


Figure 5.4: Sagittal diagram for line BN_SNO#1

5.2.3 Case 3: The Case with Back Up Relay Active

- Primary relay active correctly
- Relay protecting other equipment active
- None of failure CB

A fault occurs on line NS_BB#1 as shown in fig.5.5. Only DFR data of station NS which was summarized in table 5.3 is available for this event.

At NS station:

OCP: Only node "no31" was outage during fault.

Sagittal diagrams: Three sagittal diagrams were called. Their degree of membership calculations were shown in figs.5.6–5.8 below.

The degree of membership of line and transformers are shown in table5.4:

Table 5.3: Active digital data at station NS

	Active relay and CB	Active time
NS	CB 80322	Open during fault
	CB 80312	Open during fault
	51K_KT1A	Open during fault
	51K_KT4A	Active during fault
	94P_BB#1	Active during fault

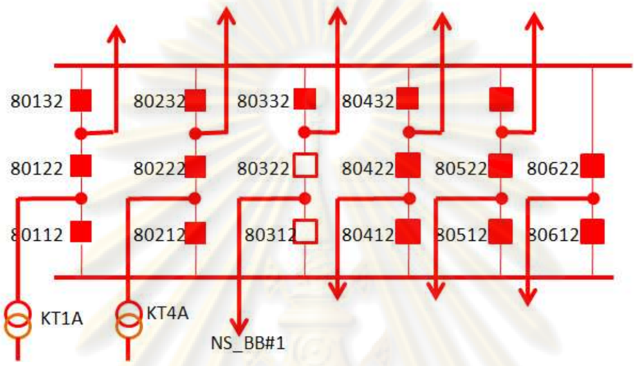


Figure 5.5: Configuration of station NS

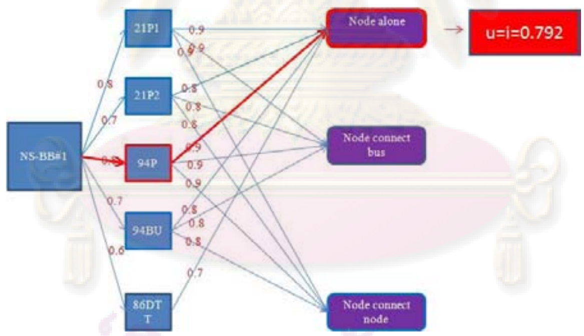


Figure 5.6: Sagittal diagram for line NS_BB#1

Table 5.4: Sumary of test results in case 3

Outage element	Active Relay	Equipment	Degree of membership
no31	51K_KT1A	KT1A	0.57
	51K_KT4A	KT4A	0.57
	94P_BB#1	NS_BB#1	0.792

Fault equipment: Because the degree of membership of being fault set of line NS_BB#1 is the highest one, line NS_BB#1 should be fault equipment.

FE = {line[NS_BB#1]}

Fault scenario: From rule 1, there is one equipment that was outage from station.

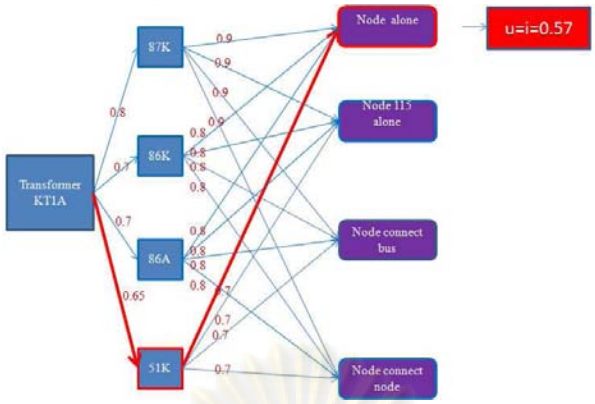


Figure 5.7: Sagittal diagram for transformer KT1A

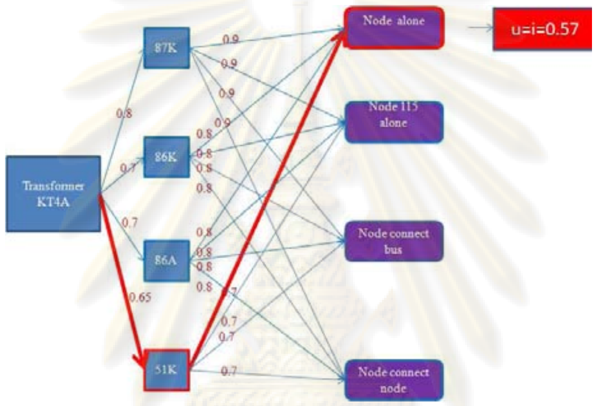


Figure 5.8: Sagittal diagram for transformer KT4A

However, three sagittal diagrams were called. Based on rule 3, the highest one has the highest likelihood to be in fault scenario. Hence, FO = {line[NS_BB#1]}

5.2.4 Case 4: The Complex Case with Two Failure Circuit Breakers

- Primary relay active correctly
- Two CBs fail to open
- The event involving to three stations

A fault occurs on line NS_AT2#1. Line NS_AT2#1, bus No. 2 of station AT2 and line AT2_SNO#1 were outage. However, just DFR data of station NS and AT2 which were summarized in table 5.5 and table 5.6 are available for this event. Fig.5.9 shows opened CBs and failure CBs in stations NS, AT2, and SNO during fault.

At station NS:

OCP: Only node "no51" was isolated from the station during fault.

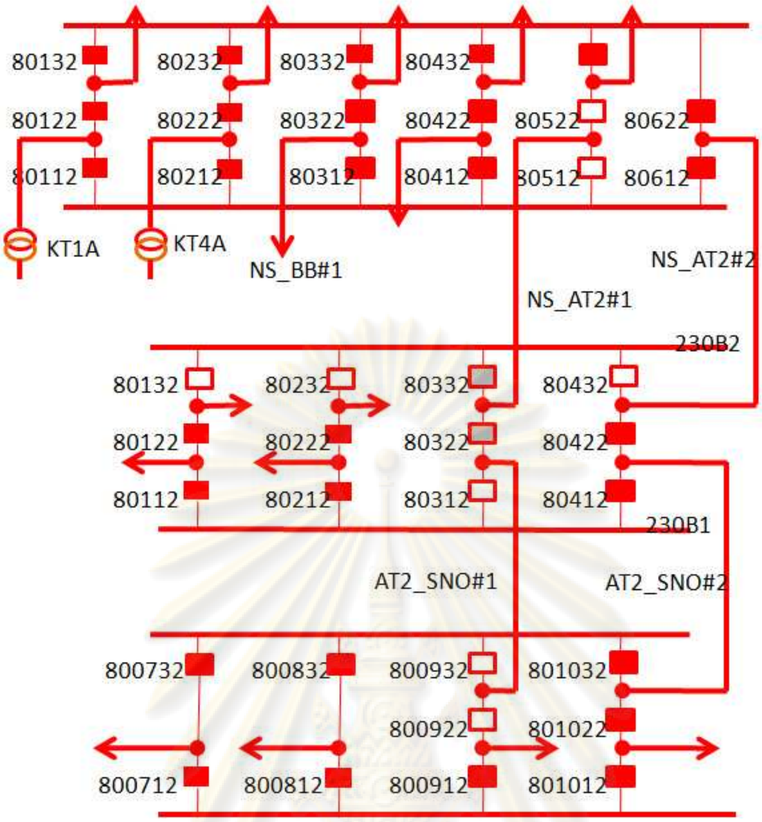


Figure 5.9: Configuration of stations NS-AT2-SNO

Table 5.5: Active digital data at station NS

station	Active relays and CBs	Active time
NS	CB 80522	Open during fault
	CB 80512	Open during fault
	94P_AT2#1	Active during fault

Table 5.6: Active digital data at AT2 station

station	Active relays and CBs	Active time
AT2	CB 80432	Open during fault
	CB 80232	Open during fault
	CB 80132	Open during fault
	CB 80312	Open during fault
	94P_NS#1	Active during fault
	230B2_86B	Active during fault
	86BF_80332	Active during fault
	86BF_80322	Active during fault

Sagittal diagram: Only one sagittal diagram for line NS_AT2#1 was called. The calculation of its degree of membership is shown in fig.5.10

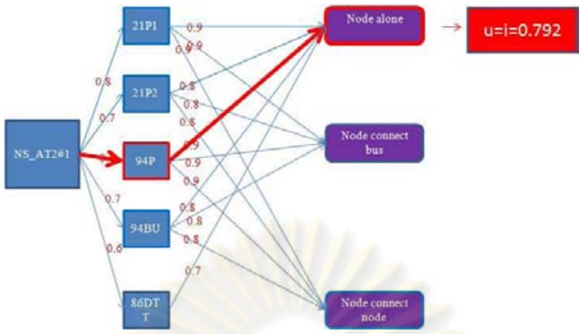


Figure 5.10: Sagittal diagram for line NS_AT2#1

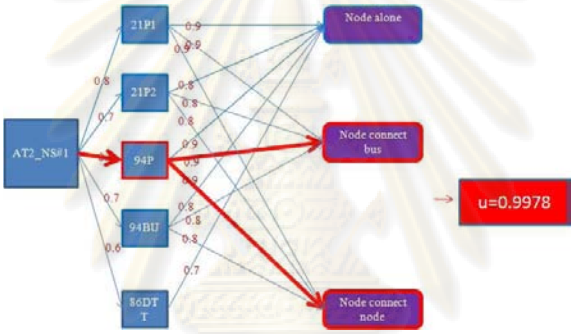


Figure 5.11: Sagittal diagram for line AT2_NS#1

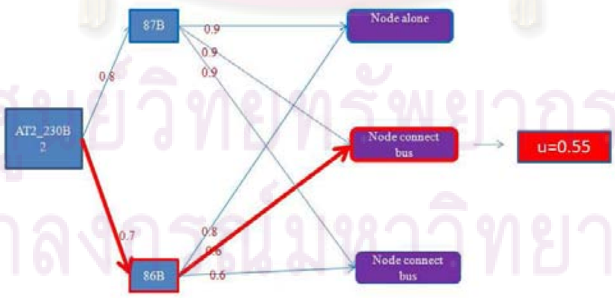


Figure 5.12: Sagittal diagram for bus AT2_230B2

At station AT2:

OCP: "Bus3", "no33" and "no31" were outage from the station during fault. Morever, they form "node connect bus" (via CB 80332) and "node connect node" (via CB 80322) types of connection.

Sagittal diagram: There are two sagittal diagrams called for line AT2_NS#1 and bus 230B2. Their degree of membership calculations are shown in fig. 5.11−5.12.

Degree of membership calculation results and active relays of this case are summarized in table 5.7 following.

Table 5.7: Sumary of test results in case 4

Station	Outage elements	Active relays	Equipment	Degree of membership
NS	no51	94P_AT2#1	line NS_AT2#1	0.792
AT2	bus3, no33	94P_NS#1	line NS_AT2#1	0.9978
	and no31	230B2_86B	Bus 230B2	0.55

Fault Equipment: FE = {line[NS_AT2#1]}

Fault Scenario:

At station NS: {line [NS_AT2#1]}

At station AT2: {line [AT2_NS#1], Bus [230B2], unknown equipment}. There are two sagittal diagrams called for station AT2, while the number of outage elements is three. Therefore, the fault scenario identification algorithm doesn't have enough information to make a complete result. If the DFR data at station SNO is available, sagittal diagram (for line SNO_AT2#1) will be called and the fault scenario can be determined completely.

5.3 Fault on Transformers

5.3.1 Case 5: The Simple Case

- Primary relay active correctly
- None of failure CB

A fault occurs on transformer KT2A of station BI2. Summarized DFR data of this event is in table 5.8 below. Additionally, two CBs in 115kV part of this station also open during fault. However, the OCP does not get this information. The opened CBs and faulty transformer are shown in fig.5.13.

At station BI2:

OCP: There is only node "no41" was isolated out of 230kV part of this station during fault.

Sagittal diagram: Only one sagittal diagram was called for transformer KT2. It was calculated as fig. 5.14 below.

Fault equipment: {Trans[KT2A]}

Fault scenario: {Trans[KT2A]}

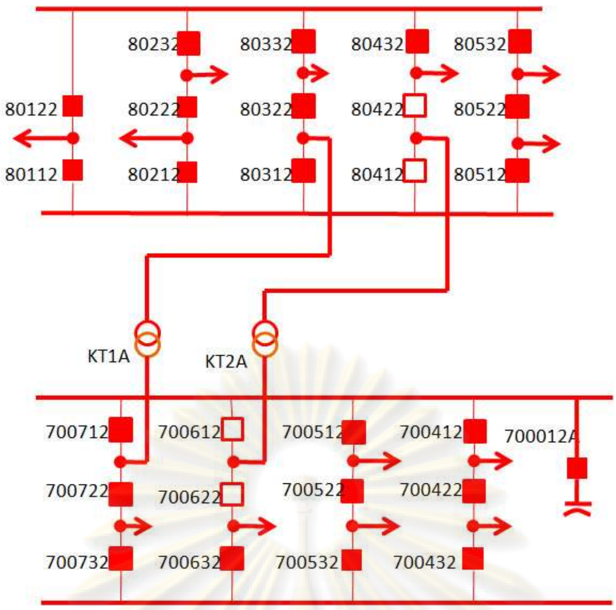


Figure 5.13: Configuration of station BI2

Table 5.8: Active digital data at station BI2

station	Active relays and CBs	Active time
BI2	CB 80412	Open during fault
	CB 80422	Open during fault
	KT2A_87K	Active during fault
	KT2A_86K	Active during fault

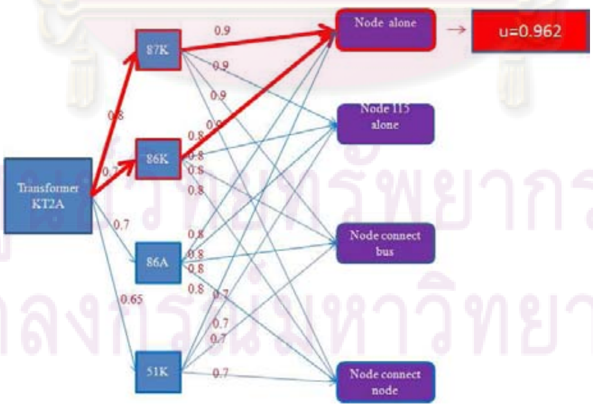


Figure 5.14: Sagittal diagram for transformer KT2A

5.3.2 Case 6: The Case with One Failure Circuit Breaker

- Primary relay active correctly
- One CB fail to open

A fault occurs on transformer KT4A of station CM3 as shown in fig. 5.15. Summarized DFR data of this event is shown in table 5.9 below.

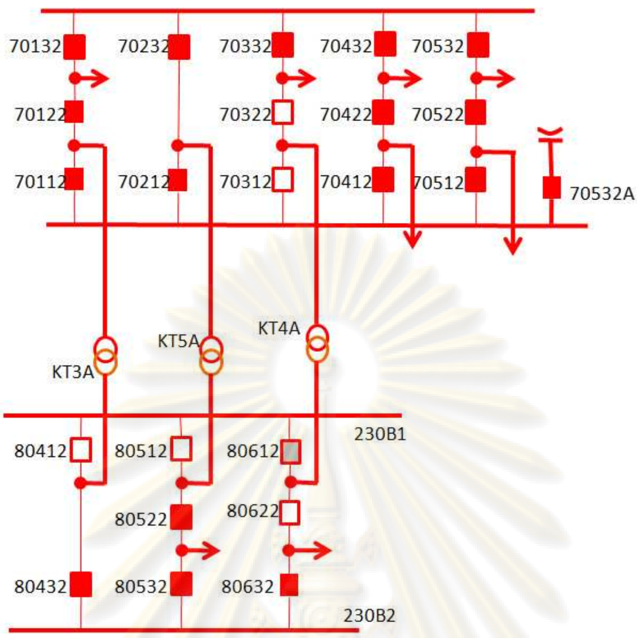


Figure 5.15: Configuration of station CM3

Table 5.9: Active digital data at station CM3

station	Active relays and CBs	Active time
CM3	CB 80622	Open during fault
	CB 80412	Open during fault
	CB 80512	Open during fault
	230B1_86B	Active during fault
	KT4A_86A	Active during fault
	86BF_80612	Active during fault

OCP: Two elements, ”bus1” and ”no61”, were removed out of station. Besides, they form ”node connect bus” (via CB 80612) type of connection.

Sagittal diagram: Two sagittal diagram were called for bus ”230B1” and transformer ”KT4A”. Their degree of membership calculations are shown in fig. 5.16−5.17.

Fault equipment: {Trans[KT4A]}

Fault scenario: {Trans[KT4A], Bus[230B1]}

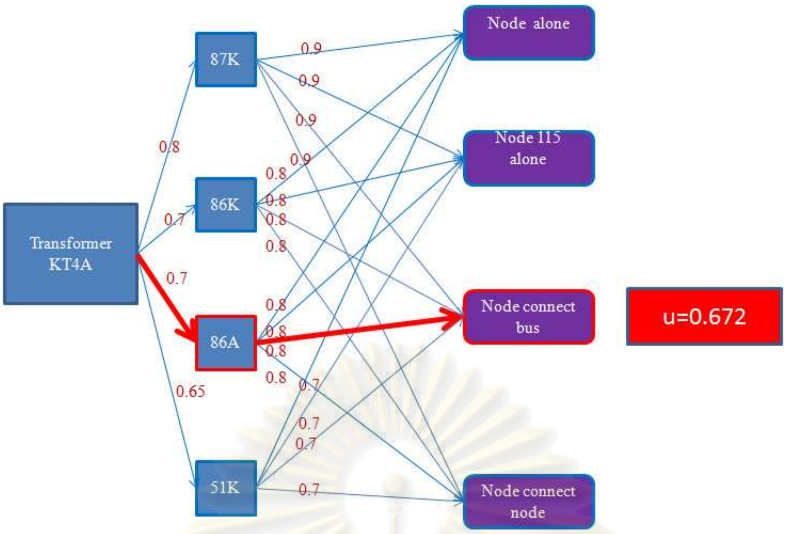


Figure 5.16: Sagittal diagram for transformer KT4A

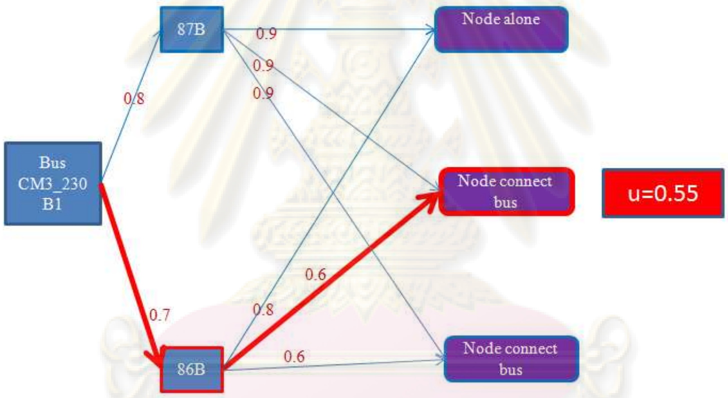


Figure 5.17: Sagittal diagram for bus CM3_230B1

5.4 Sensitivity Analysis on Weighting Factors

In above models of sagittal diagrams, their weighting factors were chosen from guideline in [7]. In order to estimate the effect of them on the result, we try to apply another set of weighting factors on these sagittal diagrams, after that, we will do the analysis on the obtained results. The first set of weighting factors in sagittal diagrams can be represented in following tables. Each table has two sub-tables, the first sub-table shows the weighting factors on connections between Equipment and Relay (ER), and the second one shows the weighting factors on connections between each Relay to Outage elements (RO).

Tables 5.10−5.12 show the first set of weighting factors that was used in sagittal diagrams for above tested cases. The difference between factors on connections to primary re-

Table 5.10: Weighting factors in sagittal diagram of bus

ER	Bus		RO	Alone bus	Bus connect node	Bus connect node
87B	0.8		87B	0.9	0.9	0.9
86B	0.7		86B	0.8	0.6	0.6

Table 5.11: Weighting factors in sagittal diagram of line

ER	Bus		RO	Alone bus	Bus connect node	Bus connect node
21P1	0.8		21P1	0.9	0.9	0.9
21P2	0.7		21P2	0.8	0.8	0.8
94P1	0.8		94P1	0.9	0.9	0.9
94BU	0.7		94BU	0.8	0.8	0.8
86DTT	0.6		86DTT	0.7	0	0

Table 5.12: Weighting factors in sagittal diagram of transformer

ER	Trans.		RO	Alone node	Alone node 115kV	Bus connect node	Node connect node
87K	0.8		87K	0.9	0.9	0.9	0.9
86K	0.7		86K	0.8	0.8	0.8	0.8
86A	0.7		86A	0.8	0.8	0.8	0.8
51K	0.65		51K	0.7	0.7	0.7	0.7

lays and secondary relay is 0.1. Factors on the connections to lower-level relays are smaller than those on connections to secondary relay about 0.05 to 0.1. These differences reflect the priority of relays in the protection scheme of each of equipment. Then, they lead to the difference in degrees of membership of being fault set of equipment, which the program based on to make a list of likely fault equipment.

Now we applied another set of these weigh numbers, in which the difference between the new weighing factors on connections is 0.02. The second set of the weighting factors is shown in tables 5.13−5.15.

Table 5.13: New weighting factors in sagittal diagram of bus

ER	Bus		RO	Alone bus	Bus connect node	Bus connect node
87B	0.8		87B	0.9	0.9	0.9
86B	0.78		86B	0.88	0.86	0.86

We apply this new set of the weight numbers to test the cases having more than one called sagittal diagram such as cases 3-4 in section 5.2 and case 6 in section 5.3. The obtained results and previous results are shown below:

The degree of membership of sagittal diagrams changed, but their sequence does not

Table 5.14: New weighting factors in sagittal diagram of line

ER	Bus		RO	Alone bus	Bus connect node	Bus connect node
21P1	0.8		21P1	0.9	0.9	0.9
21P2	0.78		21P2	0.88	0.88	0.88
94P1	0.8		94P1	0.9	0.9	0.9
94BU	0.78		94BU	0.88	0.88	0.88
86DTT	0.76		86DTT	0.86	0	0

Table 5.15: New weighting factors in sagittal diagram of transformer

ER	Trans.		RO	Alone node	Alone node 115kV	Bus connect node	Node connect node
87K	0.8		87K	0.9	0.9	0.9	0.9
86K	0.78		86K	0.88	0.88	0.88	0.88
86A	0.78		86A	0.88	0.88	0.88	0.88
51K	0.76		51K	0.86	0.86	0.86	0.86

Table 5.16: Comparison between the first and second sets of weighting factors in case 3

Outage element	Active Relay	Equipment	SD result with the first set	SD result with the second set
no31	51K_KT1A	KT1A	0.57	0.745
	51K_KT4A	KT4A	0.57	0.745
	94P_BB#1	NS_BB#1	0.792	0.792

Table 5.17: Comparison between the first and second sets of weighting factors in case 4

Station	Outage element	Active Relay	Equipment	SD result with the first set	SD result with the second set
NS	no51	94P_AT2#1	line NS_AT2#1	0.792	0.792
AT2	bus3, no33 and no31	94P_NS#1	line NS_AT2#1	0.9978	0.9978
		230B2_86B	Bus 230B2	0.55	0.763

Table 5.18: Comparison between the first and second sets of weighting factors in case 6

Outage element	Active Relay	Equipment	SD result with the first set	SD result with the second set
bus1 and no61	230B1_86B	230B1	0.55	0.76253
	KT4A_86A	KT4A	0.672	0.76869

change, then the result of the faulty equipment do not change, even though we reduce the difference between weight numbers on connections to 0.02. It can be explained by following two main facts:

- The fuzzy intersection and union are ”increasing functions”, subject to each of its variable in the interval of [0;1]

- In the above test cases, the active relay tripping the fault equipment out always has the priority higher than that tripping healthy equipment out.

If the second fact is available in all of fault events, we always get the correct result whether the difference between weigh numbers on connections is reduced to any small positive number.

Consider an assumed case in which a fault occurs on bus 230B2 of AT2 station. The 230B2_86B relay trips all CBs directly connecting to this bus. Because this bus is at the end of the line NS_AT2#1, there might be a possibility that the secondary relay 21P2 protecting that line is active and trips out the two CB directly connecting to that line at station NS. At the result, we have the situation that is shown in table 5.19−5.21 and figure 5.18.

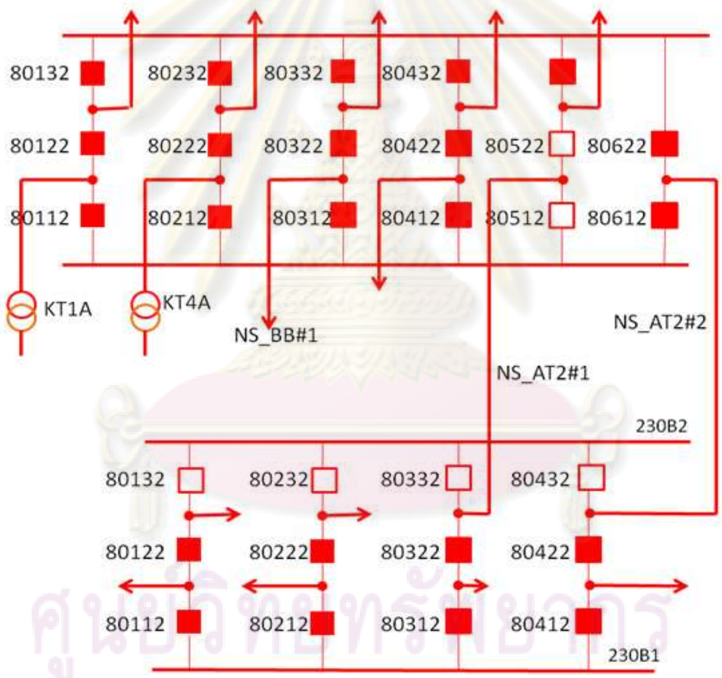


Figure 5.18: Configuration of stations NS - AT2

Table 5.19: Active digital data at station NS

station	Active relays and CBs	Active time
NS	CB 80522	Open during fault
	CB 80512	Open during fault
	94BU_AT2#1	Active during fault

In this case, as shown in table 5.21, degree of membership calculations show the same degree of membership of being fault set of the bus and the line, whether the first or the

Table 5.20: Active digital data at station AT2

station	Active relays and CBs	Active time
AT2	CB 80432	Open during fault
	CB 80232	Open during fault
	CB 80132	Open during fault
	CB 80332	Open during fault
	230B2_86B	Active during fault

Table 5.21: Summary of test results in the assumed case

Station	Outage element	Active Relay	Equipment	SD result with the first set	SD result with the second set
NS	no51	94BU_AT2#1	line NS_AT2#1	0.672	0.76869
AT2	bus3	230B2_86B	Bus 230B2	0.672	0.76869

second set of weighting factors is used, because the priority of active relay tripping the line and that tripping the bus are considered to be the same. Then we cannot get the correct result for this situation based on proposed sagittal diagrams. In order to overcome this problem, the secondary relay protecting a line should be included in the sagittal diagram of the bus connecting to this line. However, to build such a sagittal diagram, knowledge about system configuration needs to be used.

At conclusion, the weigh numbers on connections of sagittal diagrams do not need to be fixed, as long as they can reflect correctly the priority of relays in protection schemes of equipment. The more important thing is that we need to put more relays in sagittal diagrams, so that the nature of system protection can be modeled more accuracy.

5.5 Summary

Above test cases represented all test cases that have been tested with correct result. The three complicated test cases in which more than one sagittal diagram were called have verified numbers which are chosen in proposed sagittal diagrams. In case 4 of section 5.2, the algorithm can indicate to the correct fault equipment while one involving station has no DFR data. However, if there is no DFR data at the station that has faulty equipment, it is impossible for the algorithm to get the correct answer of fault equipment. In case of DFR data are available at all involving station, the result will be determined with a higher reliability.

CHAPTER VI

CONCLUSION

6.1 Discussion

In this thesis, the overall algorithm was carried out based on the two proposed tools: outage configurator program (OCP) and improved sagittal diagram. Besides, to apply the algorithm to a real system, it is necessary to discuss about how to work with DFR data in real time. This section discusses about them all so that they can be used effectively and improved later.

As mentioned in chapter one, this research is limited in a system in which most of stations are breaker-and-a-half stations. Moreover, it required at least primary or secondary relay to be active while a fault occur. The OCP here just work perfectly in the condition that at least one bus is still energized after protection devices clear the fault. All limitations here are not so tight. Actually, we realize them as main features of the actual system that we work with, after investigating many events on it from 2007 to 2009.

The advantage of this algorithm is that it considers digital data in DFR data as the only input so that information of system configuration as well as switching diagrams of stations is not required. Additionally, the algorithm just required to build three types of sagittal diagram for three types of equipment, regardless to the number of those equipment in the system. Then, the processing time can be reduced and the program does not need to update the system configuration every time it changed.

In the future, to make the OCP more powerful, some analog signals such as voltage signals at the two buses of station may be used. In that case, the OCP can deal with cases that both of two buses are outage during fault. Also, some of kinds of station configuration can be added into the scope of the algorithm, not just only breaker-and- a- half- configuration.

The weighting factors chosen to put into sagittal diagrams also need to be discussed here. It is obvious that it is not necessary to be fixed. They just need to reflect the priority of active relays when a fault occurs. In the future, there may be some of very sensitive events in which results of degree of membership calculations do not make the answer strongly because their differences are not significant to recognize the maximum one. In that case, those numbers need to be relaxed to become more suitable for the focused system. Then, artificial neural network (ANN) can be considered as a feedback tool to adjust those numbers. Another way to deal with sensitive cases is put more and more types of relays into sagittal diagrams. That way may require a very expensive system in which many types of relay signal are available in DFR data.

In a real system, when a fault occurs, DFR devices have the ability of recording digital and analog signals with their starting time ahead the fault time hundred of milliseconds. With that feature the DFR data from involved stations can be taken and processed every time when a fault occurs. To make the identification work more available in practice, a frame time needs to be chosen so that all of signal from DFR data at a fault time can be captured significantly and effectively. Besides, the problem in which DFRs of stations are not synchronize may need to be dealt in the algorithm.

6.2 Conclusion

This research has proposed outage configurator program and sagittal diagrams of transmission lines, transformers and buses for fault equipment identification within transmission system that has mainly breaker-and-a-half stations. Also, the rule-based algorithm has been proposed to identify the fault scenario. All available test cases using fault events from an actual system have given correct answers of fault equipment. The algorithm does not require knowledge of system configuration and switching diagram of the stations as required by some previous works. It just uses some selected digital data from DFR with DFR-channel names systematically encoded as only the input. Nevertheless, the fault scenario identification algorithm may need digital data from all involved stations in fault in order to make a completely correct identification.

6.3 Future Works

In future, the OCP will be improved so that it can be applied for double-buses-double-breakers stations. The line name from digital data of DFR will be used so that connection between station can be determined, then additional relays from neighboring stations can be put into sagittal diagrams of equipment at a station. The timing of relay and CB signals will also be considered to support the algorithm generating more accurate result.

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BIOGRAPHY

Ngoc Huynh Tran was born in Binh Dinh province, Vietnam, in 1980. He received his Bachelor's degree in electrical engineering from Ho Chi Minh University of Technology, Vietnam, in 2003. Since 2003, he has lectured at Faculty of Electronic Electrical Engineering, HCM University of Technology, Ho Chi Minh City, Vietnam with an emphasis on power systems analysis and power systems protection. He has been granted a scholarship by the AUN/SEED-Net (www.seed-net.org) to pursue his Master's degree in electrical engineering at Chulalongkorn University, Thailand, since 2008. He conducted his graduate study with the Power Systems Research Laboratory, Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University.