전력계통의 고장진단을 위한 전문가 시스템의 연구

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An Expert System for Foult Diagnosis in a System

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ABSTRACT

A knowledge based expert system is a computer program that emulates the reasoning process of a human expert in a specific problem domain. This paper presents an expert system to diagnose the various faults in power system. The developed expert system is represented considering two points; the possibility of solution and the fast processing speed. As uncertainties exist in the facts and rules which comprise the knowledge base of the expert system, Certainty Factor, which is based on the confirmation theory, is used for the inexact reasoning. Also, as the diagnosis problem requires the inductive reasoning process in nature, the solution is imperfect and not unique in general. So the expert system is designed to generate all the possible hypothesis in order of the possibility and also it can explain the propagation procedure of the faults for each solution using the built in backtracking mechanism. In realization of the expert system, the processing speed is greatly dependent upon the problem representation, reasoning scheme and search strategy. So, in this paper, the fault diagnosis problem itself is analyzed from the view point of Artificial Intelligence and as a result, the expert system has the following basic features. 1) The certainty factor is adopted in the inference engine for inexact reasoning. 2) Problem space is represented using the problem reduction technique. 3) Bidirectional reasoning scheme is used 4) Best first search strategy is adopted for rapid processing. The expert system was developed using PROLOG language.

1. INTRODUCTION

With the recent progress of artificial intelligence and computer technology, many problems which requires symbolic - not purely analytical knowledge can be resolved by expert system. Making toward the power system automation, many expert systems have been proposed for various problems in power system - power system restoration, fault section estimation, intelligent alarm processing, reactive power control etc. This paper presents an expert system to diagnose various faults in power system. When some faults occurs, related information is transmitted to the control panel and presented to the operator in the form of alarms and then the fault section should be estimated and restoration should be proceeded to minimize the power interruption during the faults. In this situation, the possible operations of protective devices can can be classified as follows.

(1) Normal operation : when the relay or CB, which is to operate, operates.
(2) Normal non-operation : when the relay or CB, which is not to operate, does not operate.
(3) False operation : when the relay or CB, which is not to operate, operates by malfunctioning or inappropriate setting of the relay
(4) False non-operation : when the relay or CB, which must operate, does not operate.

In the normal case of (1) and (2), only the fault section is separated and there is no problem in judging the fault section. In the case of (3) and (4), the isolated section becomes very large by backup protection and it is difficult to judge the fault section. Though this problem may be solved with some algorithmic approach, expert system is more effective for this kind of problem in the sense of emulating human thinking and some network dependant heuristic knowledge can be easily utilized. The developed expert system is represented considering fast processing speed and the reliability of solution. As uncertainties exist in the facts and rules which comprise the knowledge base of an expert system, Certainty Factor approach is adopted to deal with uncertainty. Also the expert system is designed to generate all the possible hypothesis in order of the possibility and it can explain the propagation procedure of the faults for each solution. as for the speed, the processing time is greatly dependent upon the problem representation, reasoning scheme and search strategy. So, in this paper, the fault diagnosis problem itself is analyzed from the view point of Artificial Intelligence and appropriate schemes are selected. A brief description on expert system is as follows.

1.1 Expert system

An expert system, which is a branch of artificial intelligence, is comprising both hardware and software that mimic an expert's reasoning process to solve complex problems in a specific domain. The structure of an Expert System is shown in fig.1.

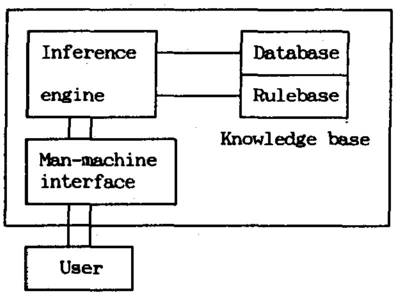

Fig.1. Structure of an expert system

Knowledge base consists of two components. One is a database that contains facts in the problem domain and the other is rule base that contains the relational information (analogy with formula in mathematics) which is represented by production rules in a production system.

The inference engine consists of the processes that work the knowledge base, do analysis,form hypothesis. In a word,the inference engine is the "thinker" of a problem solving system. Reasoning and search strategy which is the most important part in the problem solving, is controlled by the inference engine. In most expert system development tools or languages, basic reasoning strategy is provided (e.g. PROLOG; backward reasoning, OPS5: forward reasoning.) For search strategy PROLOG uses backtracking and unification, this scheme appears as depth first search strategy basically.

The man-machine interface is used in operation of an expert system that includes hardware (CRT terminal or others) and software (e.g. multiple graphic window).

1.2 Inexact reasoning

In realization of an expert system, the problem frequently occurs that there are many knowledge which are difficult to represent with conventional Boolian Logic. The presence of uncertainty is caused by a variety of sources: the reliability of the information, the inherent imprecision of the representation language, the incompleteness of the information, and the aggregation or summarization of information from multiple sources. To cope with this uncertainty, many models have been proposed and they can be classified as follows.

(1) Baysian approach based on conditional probability
(2) Certainty factor approach based on confirmation theory
(3) Dampster Shafer's belief function approach
(4) Fuzzy reasoning approach

In the above approaches, (3) and (4) have not been used vigorously, because of, in the author's opinion, the heavy burden of numerical calculation. As for the Baysian approach, the prior odds at every node in the inference network must be known and numerical interpolation must be performed at each step in the sequential inference. These are some complex aspects in a practical sense. In this expert system, certainty factor approach is adopted.

1.3 Certainty factor

The certainty factor(CF) approach, used in MYCIN, is based on Buchanan's confirmation theory and it has experienced several modifications. The inference engine in this expert system uses the modified version which is used in EMYCIN, the general expert system shell. Brief overview about the certainty factor is as follows.

The certainty factor CF(h,e) of a given hypothesis is the difference between a measure of belief MB(h,e) representing the degree of support of a evidence e and a . measure of disbelief MD(h,e) representing the degree of reputation of an evidence e. The measures of belief and disbelief could be interpreted as a relative distance on a bounded interval and the CF means the degree of confirmation. these have the following form.

$$MB(h,e) = \begin{cases} \dfrac{P(h,e) - P(h)}{1 - P(h)} & \text{if } P(h,e) > P(h) \\ 0 & \text{otherwise} \end{cases}$$

$$MD(h,e) = \begin{cases} \dfrac{P(h) - P(h,e)}{1 - P(h)} & \text{if } P(h,e) < P(h) \\ 0 & \text{otherwise} \end{cases}$$

In the above expression, some counter-intuitive behavior was detected. So with slight modification, the definition of the CF was changed as eq.(1), which was used in EMYCIN and is also adopted in this expert system.

$$CF(h,e) = \frac{MB(h,e) - MD(h,e)}{1 - \min(MB(h,e), MD(h,e))} \quad (1)$$

With some combination functions, the propagation equation(2) is obtained and in the case of conjunction, fuzzy operator is used as in eq.(3)

$$CFcombine(x,y) = \begin{cases} x + y - xy & \text{for } x>0,\ y>0 \\ \dfrac{x + y}{1 - \min(x, y)} & \text{for } xy<0 \quad (2) \\ x + y - xy & \text{for } x<0,\ y<0 \end{cases}$$

$$CF(x\&y) = \min\,[CF(x), CF(b)] \quad (3)$$

2. EXPERT SYSTEM FOR FAULT DIAGNOSIS

2.1 Protective Devices

In a power system, the protection scheme consists of several relays and circuit breakers. The relay information can be classified into two groups. One is the information for the kinds of faults (short fault, ground fault, open line fault etc.), the other is the information for the identification of fault section. Many relays are combined for multiple protection but We are interested in not each relay but several integrated relay types. In the previous work [Chihiro, 1986], Relays were well classified as five types and as in the above work, five types of reduced relays are also used in this expert system with slight modification for Korean power system. The other type of relay may be easily added if necessary. The five types of relay are:

(A) Pilot relay: It is usually carrier relay and is used for primary protection in 345 KV T/L in Korea.
(B) Line relay: Detecting the line faults from the electric values obtained at substations. It is usually distance relay. The distance relay may be classified as three steps. Z-1 relay: protect 80% of the line section that is equipped with the relay. This is also used for primary protection. Z-2 relay: protect 80% - 150% Z-3 relay: protect 150% - 225%
(C) Bus relay: Primary protection of bus. It is usually differential relay.
(D) CB failure relay: Detecting the circuit breaker trip failure and making the neighbor CBs trip.
(E) Transformer relay: Primary protection of transformer. It is operated by not only by electric values but mechanic al values.

2.2 Problem representation

To represent the problem in A.I., two models are generally used. One is state space representation and the other is problem reduction technique. In this paper, the fault diagnosis is modeled, as shown in fig.2, using the problem reduction technique because of its decomposability and considering the relation with realization of the expert system.

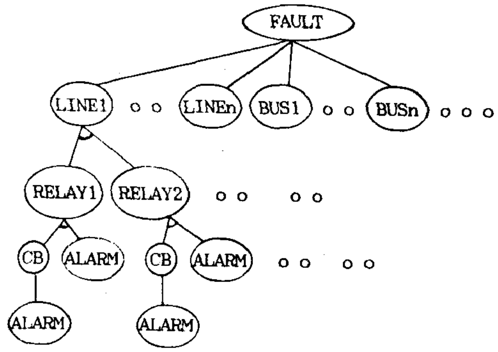

Fig.2. Problem representation by and/or tree

As shown in fig 2, a fault (line, bus or transformer,generator,load) activates the protective relays, an operation of relay activates CBs (or a CB) and action of relays or circuit breakers causes alarm set. But, in general, this is not always true. For example if a line fault occurs and one of the line relays, which are located in the line, is not operated then other line relay is operated by back up. In this case the cause of back up relay operation is the line relay failure. If a bus is faulted and the bus relay is operated and one of CBs, which are subjected to the bus relay, failed then the CB failure relay is operating. In this case the cause of the relay is non-operation of the CB. Detailed relations between cause and result are shown in fig.3.

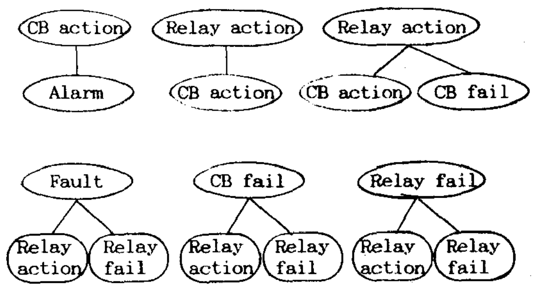

Fig 3. Detailed relationship

As explained above, the number of nodes in the AND/OR tree in actual power system is so large that effective search in the node spaces is an important point for the efficiency of expert system. This will be mentioned later.

2.3 Facts and rules

2.3.1 Facts

Basic facts in this expert system is classified as follows.

(1) Facts about the topology of power system.
(2) Facts about protective devices.
(3) Facts about the received alarm set, which are stored in dynamic database.

All these facts are really true, that means CF = 1, and this is one of the characteristics of power system different from the other fields. Thus CF can be omitted in representing base facts.

Network representation

In realization of the expert system, efficiency is seriously dependant upon the reasoning and search strategy. But the structure of represented data is as much as important. The network representation used in this expert system is based on the following definitions.

element: Basic unit of power system (i.e. CB, line, transformer, load, generator, bus)
cell: A set of electrically connected element when all the CBs of the system are off.
Subsystem: A set of cells connected electrically with each other in a given time.

The topology of power system network is fully described using cells information. To find the subsystem, in which source is not included, is to find the black out area for power system restoration. The cell predicates in the sample network (see fig.4) are as followings and they are stored in static data base.

```
cell(g(1),[cb(1),1]).
cell(g(1),[cb(4),1]).
cell(bus(1),[cb(1,1), cb(2,1)])
cell(bus(2),[cb(3,1), cb(4,0)])
cell(line(1),[cb(2,0), cb(3,1)])
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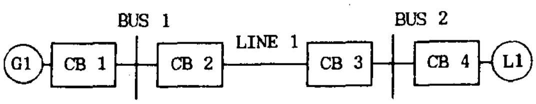

Fig.4 sample network

Relay data

As mentioned above, five types of reduced relays are considered.

```
pilot_relay (name,element(cb),element
            (line),pilot_relay)
line_relay (name,element(cb), zone)
bus_relay  (name,element(bus))
cb_f_relay (name,element(cb))
tr_relay (name,element(tr.))
```

Under an assumption that same kind of reduced relays are installed in the power system, initial information of relays is generated by some rules and stored in the dynamic database.

2.3.2 Rules

Although the cause of relay operation is not only fault as shown in fig.3 , let's assume that only a fault activates the relay for simplicity. Then some plausible rules can be thought as follows.

```
facts: CB_alarm , Relay_alarm
rules: Fault ---> Relay operation
       Relay operation ---> CB action
       Relay ---> Alarm
       CB action ---> CB alarm
```

Let the goal is to determine simply whether the fault is true or not. Logically it cannot be proved, because we have to prove the premise of a rule with only conclusions. In other words, the fault diagnosis problem requires inductive reasoning process in nature. Except some primitive languages which have no built-in reasoning process like LISP or C language, most of languages or tools for expert system provide the deductive reasoning scheme and of course, it is correct. thus the premise part and the conclusion part in each rule must be changed so as to solve the diagnosis problem by deductive reasoning process. An example of rule is as follows.

```
act(cb(X),cf1(Y),cf2(1)) if alarm(cb(X))
```

This rule says that CB(X) may operated if we have alarm of the CB. In this representation, cf2(1) is the certainty factor assigned to the rule itself and cf1(Y) is the certainty factor of the intermediate node "act(cb(X))". As mentioned above, alarm(cb(X)) is a basis fact and has no certainty factor (i.e. CF = 1). The rule base in this expert system contains the following knowledge.

(1) Operating rules of relays
(2) Heuristic rules about false operation of relays which has acquired from experts or from the analysis of past record about faults.
(3) network dependent heuristic rules acquired from experts

2.4 Reasoning and Search

Reasoning and search is the most important part in a expert system and it has deep relation with given programming language or tool. Some discussion about PROLOG language is as follows.

Briefly speaking, Prolog basically performs the resolution process with Horn clauses and is based on the first order predicate calculus. It has good built-in structure like backward reasoning and depth first search basically. Moreover there is some flexibility which means that the emulation of any other structure is possible. But the possibility of emulation does not mean the efficiency of it. It is not effective to construct the inference engine with PROLOG to deal with the propagation of uncertainty by CF approach because of the restrictive structure of PROLOG. Some primitive languages like LISP are thought to be more adequate. In spite of this demerit, the expert system has implemented using PROLOG because of the author's lack of practical deep experience about the other languages. Discussion about the reasoning and search scheme in this expert system is as follows.

As shown in fig.2, the number of nodes in the AND/OR tree is so large that it is necessary to confine the range of fault for better efficiency. It can be overcome by emulating the forward reasoning process with given alarm set. The final solutions are obtained from subproblems and the first level subproblem (which are candidate elements?) is solved by the forward reasoning process. From the solution of first level subproblem, the backward reasoning process begins. For example, as shown in fig.5, if a line 1 is fault then four cases may be considered. Node 1 means perfect operation of line relay and node 2,3,4 means backup operation. Best first search scheme can be performedused using the certainty factors as a heuristic function. In most cases, the certainty of false operation is smaller than that of normal operation. Thus by ordering rules, the searching time can be more saved.

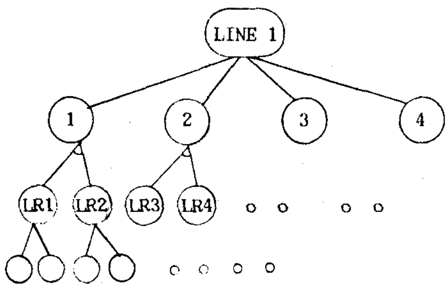

Fig.5 Second level subproblem for line 1

3. CONCLUSION

An expert system was developed which estimates fault section and generates all the possible hypothesis from the received alarm set. For the management of uncertainty in knowledge, certainty factor approach is adopted and bidirectional reasoning and best first search strategy was also adopted for fast processing. The entire system was developed using PROLOG language with 32 bit personal computer.

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