論 文
39~1~3

전력계통의 고장진단 전문가 시스템에 관한연구

Development of an Expert System for the Fault Diagnosis in power System

朴 永 文*·李 興 載**
(Young-Moon Park · Heung-Jae Lee)

Abstract- A knowledge based expert system is a computer program that emulates the reasoning process of a human expert in a specific problem domain. Expert system has the potential to solve a wide range of problems which require knowledge about the problem rather than a purely analytical approach. This paper presents the application of knowledge based expert system to power system fault diagnosis. The contents of expert system developed in this paper is judgement of fault section from a given alarm sets and production of all possible hypothesis for the single fault. Both relay failures and circuit breaker failures are considered simultaneously. Although many types of relay are used in actual system, experts recognize ones as several typical signals corresponding to the fault types. Therefore relays are classified into several types. The expert system is written in an artificial intelligence language "PROLOG". Best-first search method is used for problem solving. Both forward chaining and backward chaining schemes are used in reasoning process. The application to a part of actual power system proves the availability of the developed expert system.

1. Introduction

1.1 Present status of fault diagnosis

Faults may occur in system due to various causes. In order to protect electrical equipment, circuit breakers on both sides of the equipment are designed to be tripped by the protective relays in a few cycles after the faults. This information on power system is transmitted to the control panel and presented to the operator in the form of alarms. When some fault occurs, the fault section should be estimated according to the information of alarms and restoration should be proceeded. Although many computer technologies have been implemented in controls of power system, estimation of fault section and restoration at the overall system remained dependent on manual operation. In actual system there are often false operation of relays and circuit breakers. In this case, isolated section is very large by backup protection and it is difficult to judge fault section. To minimize the power interruption during the faults, it is necessary to estimate the fault section and isolate it as soon as possible. So the computer technology for fault diagnosis is required. First, according to rapid expansion of power system, expert's mistake or absence brings serious problems. Second, it is a preparation for the power system automation.

1.2 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.

Knowledge base consists of two components.

*正 會 員 : 서울大 工大 電氣工學科 教授·工博
**正 會 員 : 서울大 工大 電氣工學科 博士課程
接受日字 : 1989年 8月 1日
1次修正 : 1989年 10月 20日

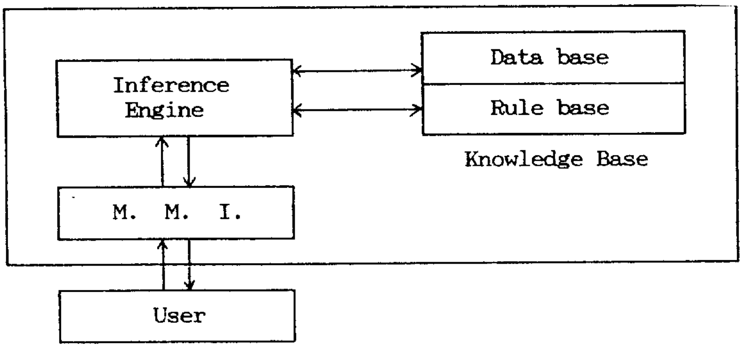

Fig. 1 Structure of an Expert System

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.

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 most important for 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). As for the search strategy, PROLOG uses backtracking and unification and 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 sorftware(e.g. multiple graphic window).

This paper presents an expert system to diagnose the faults of power system. With the knowledge of network, the necessary information for diagnosing the fault section is received alarms from relays and tripped circuit breakers. This expert system expresses all the possible fault sections and mis-operation of relays. It is very helpful to operator especially in a large system.

2. Expert System for Fault Diagnosis

2.1 Protective Devices

The definition of a power system protection is to ensure the maximum continuity of supply by determining the location of fault and disconnecting the minimum amount of equipment necessary to clear it. When a fault occurs, a number of relays will detect it, but only the relays directly associated with the faulted equipment are to operate. The relay information is classified into two groups. One is the information for the kinds of faults(short fault, ground fault, open line fault etc.) It is exempted in this paper, because we can recognize this information on the spot. The other is the information for the identification of fault section. Many relays are combined to protect a section. We are interested in not each relay but several integrated relay types. Four types of relays are used in this paper, we can easily add other types of relay if necessary.

(A) Line relay : Detecting the line faults from the electric values obtained at substations. It is usually carrier relay and distant relay. We classify the distant relay as three steps.
z-1 relay : protects 80% of the line section that is equipped with the relay.
z-2 relay : 120-150% setting.
About 20Hz of time delay w.r.t. z-1 relay.
z-3 relay : 220-250% setting.
About 120Hz of time delay w.r.t. z-1 relay.

(B) Bus relay : Primary protection of a bus.
It is ususlly differential relay.

(C) CB failure relay : Detecting the circuit breaker trip failure and making the neighbor CBs trip.

(D) Transformer relay : Primary protection of a transformer. It is operated by not only

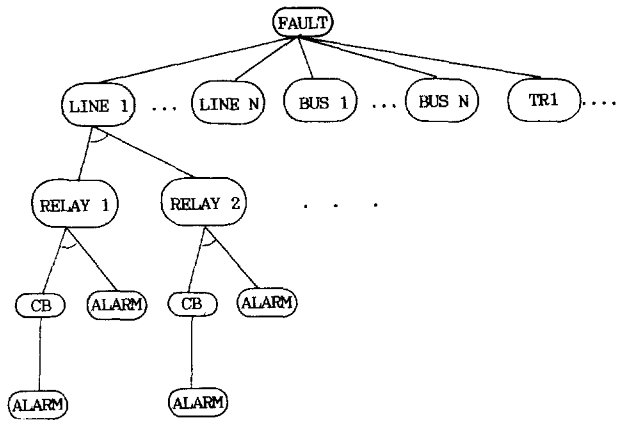

Fig. 2 Problem representation by and/or tree

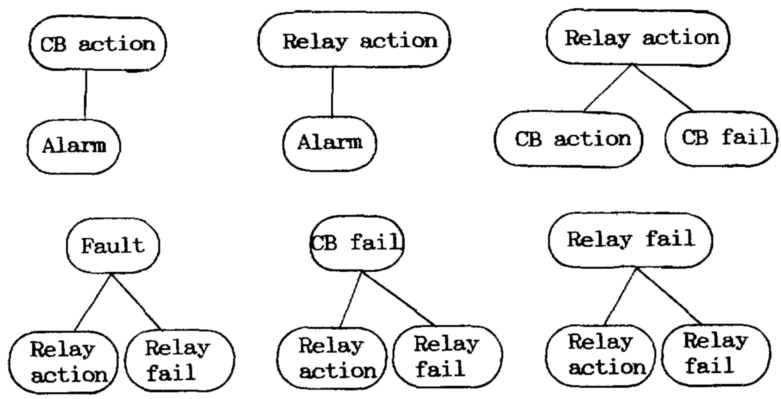

Fig. 3 Detailed relationship

electric values but mechanical 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 using the problem reduction technipue which is shown in Fig. 2.

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 faults 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.

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

2.3 Facts and rules

2.3.1 Facts

network representation

In realization of the expert system, efficiency is seriously dependent upon the reasoning and search strategy. But the structure of represented data is as much as important. The network representation

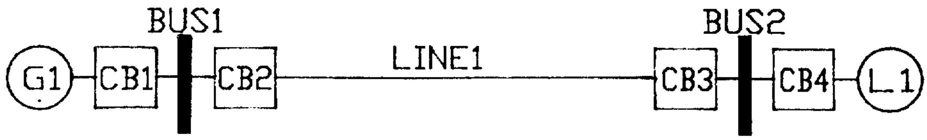

Fig. 4 Sample network

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 for the sample newtwork(see Fig. 4) are as follows and they are stored in static data base.

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

Relay data

As mentioned in section 2.1, four types of reduced relays are considered.

line-relay	(name, cb, zone)
bus-relay	(name, bus No.)
cb-f-relay	(name, cb)
tr-relay	(name, tr. name)

It is unnecessary to express each relay name because we find the positions of relays from the information about the equipment which has the relays. For example the position of a line relay is known by the name of the related CB. Each relay name is not considered. The information about relays is represented by rules and stored in the dynamic data base. Because it is assumed that the whole system has the same kinds of reduced relay models for each bus, line and transformer, reduced models can be produced. Otherwise relay information can be made by the user. Also the on/off status of relay is not required in the data because only the relays which are contained in alarm set, are supposed to be in status "on".

2.3.2 Rules

Although the cause of relay operation is not only fault as shown in Fig. 3, let's assume that only fault activates the relay for simplicity. Then the correct rules in actual power system is as follows.

facts : CB alarm, Relay alarm
rules : Fault⟶Relay operation
Relay operation⟶CB action
Relay⟶Alarm
CB action⟶CB alarm

The goal is to determine 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 can be solved not by deductive reasoning but by inductive reasoning. It is correct in the light of common sense. To solve the problem by inductive reasoning, the premise part and conclusion part must be changed. An example of a rule is as follows.

act(cb(x)) if alarm(cb(x)).

This rule says that any CB may have operated if we have alarm of the CB.

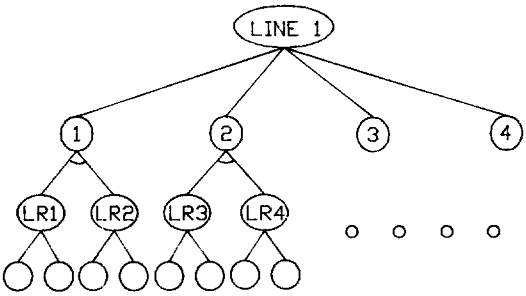

Fig. 5 Second level subproblem for line 1

2.4 Reasoning and Search

2.4.1. Rasoning

As mentioned above, this expert system is written by PROLOG which provides backward reasoning basically. In this problem AND/OR tree is so large, it is necessary to confine the range of fault for efficiency as the experts usually do to find the fault. This can be done by using the given alarm set. In other words, it is a forward reasoning process to get the first level subproblem(which are candidate elements?) in Fig. 2, With these elements backward reasoning process begins.

2.4.2 Search

As shown in Fig. 5, if a line 1 is at fault, four cases are considered. Node 1 means perfect operation of line-relay and node 2, 3, 4 means back up operation. In most cases the probability of non-operation is smaller than that of normal operation. So search begins from the node for which the probability of the relay mis-operation is lower than others. In other words "Best first search strategy" is used. This rule is applied also for solving the lower level subproblems.

3. Case Study

CASE STUDY 1

⟨Received Alarm set⟩

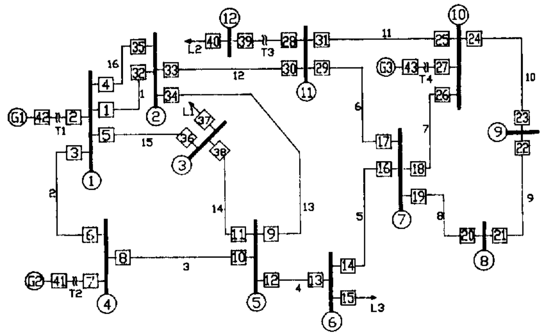

Fig. 6 Sample network for case study

line-relay at CB14 in Line5 with Zone2.
line-relay at CB20 in Line8 with Zone2.
line-relay at CB26 in Line7 with Zone2.
line-relay at CB29 in Line6 with Zone2.
line-relay at CB16 in Line5 with Zone1.

cb(14).
cb(20).
cb(26).
cb(29).

⟨Solution by expert system⟩

Possible solution No. 1
fault occurred at line(5).
Back up relay at CB No. 16 in Line No. 5 failed.
Do you want another solution? yes
there are no more solutions ! !

CASE STUDY 2

⟨Received Alarms set⟩

line-relay at CB14 in Line5 with Zone 2.
bus-relay at Bus7.
cb-failure-relay at CB16.

cb(16).
cb(17).
cb(26).
cb(19).

⟨Solution by expert system⟩

Possible solution No. 1
fault occurred at bus(7).
CB No. 18 failed.
Do you want another solution? yes
there are no more solutions ! !

4. Conclusion

An expert system has been proposed which estimates the faulted element and generates all the possible hypothesis from the received alarm set. For the good efficiency, bi-directional reasoning and best-first search technique has been used.

Acknowledgement :

This work was supported by Korea Science and Engineering Foundation.

REFERENCES

[1] B.G. Buchanan, E.H. Shortliffe, "Rule-Based Expert Systems," Addison-Wesley, 1984.
[2] "TURBO PROLOG," BORLAND, 1986.
[3] D. d. Wolfgram, T.J. Dear, C.S. Galb-raith, "Expert Systems for the Technical Professional," JOHN WILEY & SONS, 1987.
[4] N.J. Nilsson, "Principles of Artificial Intelligence," Springer-Verlag, 1980.
[5] Ivan Bratko, "Prolog Programming for Artificial Intelligence," Addison-Wesley, 1986.
[6] L. Brownston, R. Farrell, E. Kant, N. Martin, "Programming Expert System in OPS5," Addison-Wesley, 1985.
[7] F. Hayes-Roth, D.A. Waterman, d.B. Lenat, "Building Expert Systems," Addison-Wesley, 1983.
[8] R. Davis, D.B. Lenat, "Knowledge-Based Systems in Artificial Intelligence," McGraw-Hill, 1982.
[9] J.R. Hobbs, R.C. Moore, "Formal Theories of The Commonsense World," Ablex Publishing Corporation, 1985.