AUTOMATED ANALYSIS OF PROTECTIVE RELAY DATA

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SUMMARY

Validation and diagnosis of relay operation is very important to protection engineers in fault analysis. This paper presents development of an expert system based automated analysis solution, which performs validation and diagnosis of digital protective relay operation in great detail by analyzing data contained in various relay reports and files. In the system, forward chaining reasoning is used to predict relay behavior while backward chaining reasoning is used to diagnose the reasons for inconsistency between expected and actual relay behavior. An example is given to demonstrate the capability of the prototype system.

Index Terms*—validation, diagnosis, relay operation, relay report, expert system*

I. INTRODUCTION

Protective relays play a very important role in security and reliability of electric power systems. Validation of correct operation and diagnosis of missoperation of relays is a significant concern to protection engineers in post mortem fault analysis [1].

Due to the power of microprocessors, modern digital protective relays can provide users with abundant data which illustrate what relays "see" and how they respond during power system faults. These data include sampled analog currents and voltages, status of input and output contacts, status of protection and control elements and relay settings [2]. They are usually contained in various relay reports and files such as event report, fault report, oscillography file and setting file.

Large volume of data may overwhelm protection engineers when they conduct analysis of protection system operation manually. This problem may be more apparent under complicated event conditions. Since early 90's, expert system has been proposed as a potential tool for protection engineers to develop intelligent analysis of power system protection [3]. Various expert system applications in testing, validation and diagnosis of protection system operation have been reported in literature [4-6].

As reported, because input data to these expert systems mainly come from SERs, DFRs and SCADAs, which contain little information about internal states of relays, only limited analysis of relay behavior is performed. To the best of our knowledge, there is no previous work on detailed validation and diagnosis of digital relay operation at both external and internal level by utilizing data from relay reports and files.

This paper presents our research results related to development of an expert system based automated analysis solution which performs validation and diagnosis of digital protective relay operation in great detail by analyzing data contained in various relay reports and files. Section II introduces the information and data contained in reports and files of modern digital relays. Section III presents the conceptual strategy of analysis. Section IV describes the system implementation. Section V uses an example to demonstrate the capability of the prototype system developed so far. Conclusions of this paper are given in Section VI.

II. REPORTS AND FILES OF DIGITAL RELAYS

The firmware of many modern digital protective relays is designed using the concept of functional elements. These elements usually include inputs, outputs, protection elements, control elements and pilot schemes. The states of each element are represented by a set of predefined logic operands. The status and timing of logic operands which are contained in various relay reports and files reflect both external and internal operation behavior of relays [7], [8]. Although the names and formats of relay reports and files may vary from manufacturer to manufacturer, they generally fall into four categories: event report, fault report, oscillography file and setting file. TABLE I summarizes the information and data contained in these reports and files.

It should be noticed that relay performance specification in user's manuals also provides useful information on element operating parameters to predict expected relay behavior.

III. CONCEPTUAL STRATEGY OF ANALYSIS

Validation and diagnosis of relay operation is fundamentally based on comparison of expected relay

TABLE I
SUMMARY OF INFORMATION AND DATA IN RELAY REPORTS AND FILES

Report & File	Description
Event Report	It contains a list of time-stamped logic operands and relay conditions in chronological order. It provides most of the information through which the external operation and internal states of the relay can be observed.
Fault Report	It contains information on fault type, fault location and voltage and current phasors during pre-fault and fault periods calculated by the relay.
Oscillography File	It contains analog values of three-phase voltages and currents and digital status of logic operands selected to be recorded by users. Digital status data provide complementary information on logic operands if some of them are not reflected in the event record report but are selected to be recorded in the oscillography file by users.
Setting File	It contains configuration information on the relay at three levels: selecting protection and control elements, deciding how the selected elements are logically combined and setting the operating parameters of each selected element. The information is used to predict expected relay behavior.

behavior and actual relay behavior in terms of status and timing of logic operands. If the expected and actual status and timing of an operand is consistent, the correctness of the status and timing of that operand is validated. If not, certain failure or missoperation is identified and diagnosis will be initiated to trace the reasons by logic and cause-effect chain.

Fig. 1 illustrates the conceptual strategy of analysis. The expected behavior of the relay is predicted by an expect system module which simulates relay operation logic. Inputs to this module are disturbance information, relay settings and relay performance specification.

Disturbance information includes fault inception time, fault type, fault location and current interruption time after circuit breaker opening. In the original design of the system, it is supposed to come from other fault analysis applications based on advanced algorithms and techniques [5], [9], [10].

With disturbance information, relay settings and performance specification available, the expected status and timing of each active operand of the relay are inferred by forward chaining rules. The results are regarded as hypothesis of relay behavior. The actual status and timing of relay operands which are obtained from the event record report and the oscillography file are regarded as facts of relay behavior.

With both the hypothesis and facts of relay behavior as inputs, an expert system module will perform validation based on hypothesis-fact matching and diagnosis based on logic and cause-effect chain. Finally a report on the results of validation and diagnosis will be generated.

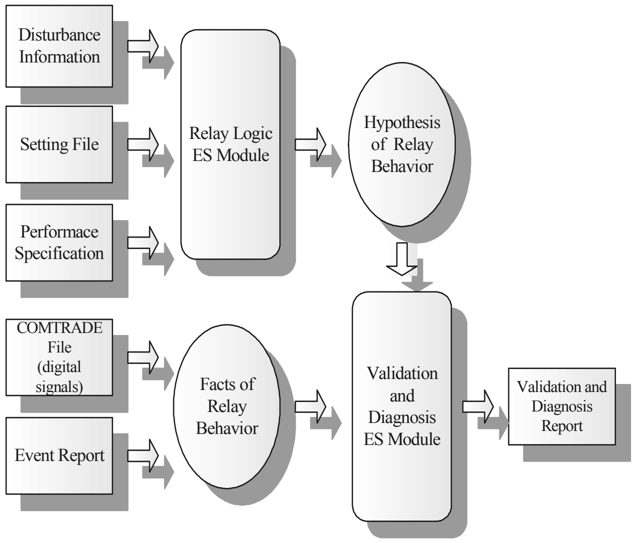

Fig. 1. Block diagram for conceptual strategy of analysis

IV. SYSTEM IMPLEMENTATION

The framework of the automated analysis system is developed under the platform of Visual C++. The expert system core is implemented in CLIPS expert system shell [11]. It is interfaced with the framework by means of Dynamic Link Library (DLL).

A. Fact Input

The initial fact input for expert system reasoning is implemented in the Visual C++ framework. The framework first reads relevant information and data as well as users' manual inputs, converts them into CLIPS language format and then loads them into CLIPS shell.

B. Rule Base

Currently the rule base of the expert system is designed for GE's D60 relay with the following four protection elements enabled [7]: Phase Distance (PHASE DIS), Ground Distance (GROUND DIS), Phase Instantaneous Over Current (PHASE IOC) and Ground Instantaneous Over Current (GROUND IOC).

The rule base includes two parts. One is for building expected relay operation logic. The other is for validation and diagnosis of actual relay operation. The former is developed at five levels: operation of individual phases of an element, operation of an element, relay trip, circuit breaker opening and current interruption by circuit breaker. The latter can be divided into three parts according to their functions. The three functions include validation and diagnosis of status of operands, evaluation of operating speed of protection elements and associated circuit breaker and examination whether the relay is tripped by the expected element. The rule base built in CLIPS language is stored in a text file. When the analysis is initiated, it is loaded into CLIPS shell through the Visual C++ framework.

C. Reasoning Process

The reasoning for building expected relay operation logic is in a bottom-up manner, that is, from operation of individual phases of an element to current interruption by circuit breaker, which is actually a forward chaining process [11]. Fig. 2 illustrates the reasoning process, which only details the logic for GROUND DIS Element. Operation logic for other elements is quite similar. The time delay parameters such as dTSUPN, dTPKP_P_Z, dTOP_P_Z, which are used to infer the timing relations, are obtained from relay performance specification, relay settings and user inputs according to experience.

The reasoning for validation and diagnosis of status of operands is performed in two stages. Fig. 3 illustrates part of the reasoning process. In the first stage, the validation of correctness of status of operands and diagnosis of the direct reason for incorrectness of status of operands is performed at all of the five levels: operation of individual phases of an element, operation of an element, relay trip, circuit breaker opening and current interruption by circuit breaker. The validation is based on the existence and non-existence of hypothesis and fact of an operand status. If both the hypothesis and the fact exist, the correctness of the operand status is validated and there is no diagnosis information. If the hypothesis exists and the fact does not exist or a hypothesis does not exist but a fact exists, a symptom will

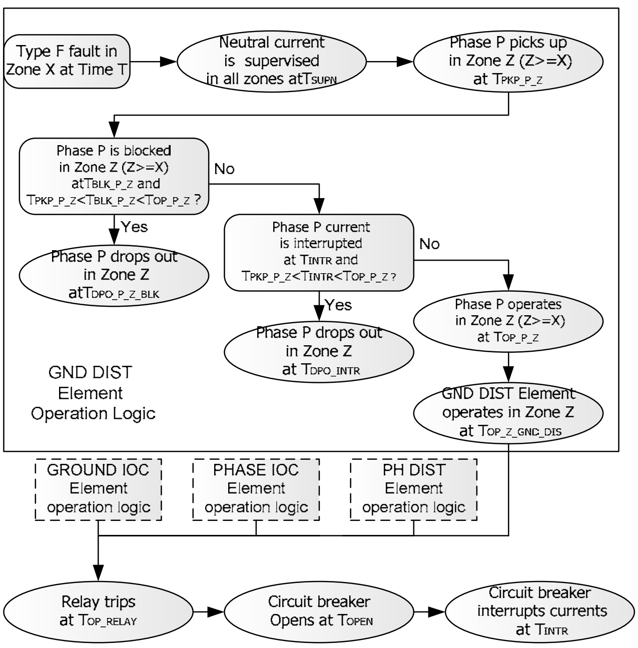

Fig. 2. Reasoning process for building relay operation logic

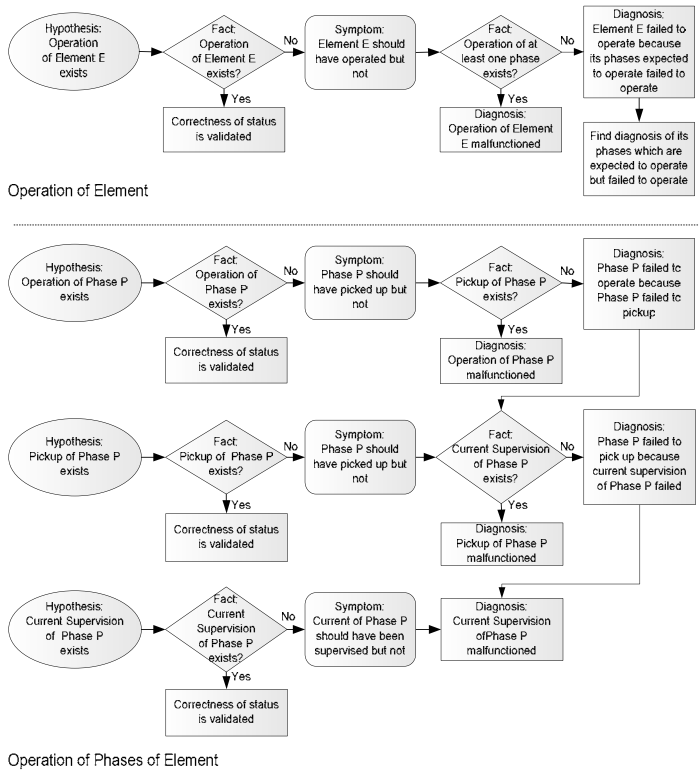

Fig. 3. Part of reasoning process for validation and diagnosis of status of operands

be identified and the direct reason for the symptom will be diagnosed. In the second stage, the final reasons for symptoms identified in the first stage will be traced in top-down manner by relating together the direct reasons for symptoms found in the first stage, which is a backward reasoning process [11].

The operating speed of protection elements and associated circuit breaker is evaluated by examining the timing of status of operands.

With the validation and diagnosis information of status of operands and operating speed of protection elements available, whether the relay is tripped by the expected element is further examined and the diagnosis is performed.

V. EXAMPLE

In this section we use a simplified example to demonstrate the capability of the prototype expert system developed so far.

It is assumed that the relay to be analyzed has generated relay reports and files when it responded to a power system fault. The data and information contained in the reports and files are deliberately manipulated to reflect multiple failures and missoperation so that the diagnosis capability of the expect system can be demonstrate comprehensively.

The disturbance information is assumed to be known. It is shown in TABLE II.

TABLE II
DISTURBANCE INFORMATION

Fault Type	A-B
Fault Location	Zone 1
Fault Inception Time	0 second
CB Currents Interruption	Failed
CB Currents Interruption Time	N/A

The validation and diagnosis results are displayed in the dialog shown in Fig. 4. The validation information section lists the logic operands whose status is as expected and the elements whose operating speed is as expected. It also indicates whether the circuit breaker opens and interrupts currents as expected and whether the operating speed of the circuit breaker is as expected. The diagnosis information section gives detailed diagnosis results in the way of cause-effect chaining. In this case, multiple failures and missoperation have been found and diagnosed.

As indicated in the validation information section, the relay tripped but the circuit breaker failed to open to interrupt currents, because there is validation information of relay trip but there is no validation information of circuit breaker opening and current interruption. This is further confirmed in the diagnosis information section.

As pointed out in the diagnosis information section, the circuit breaker failed to interrupt currents because it failed to open. This is due to malfunction of the circuit breaker but not the failure of relay trip.

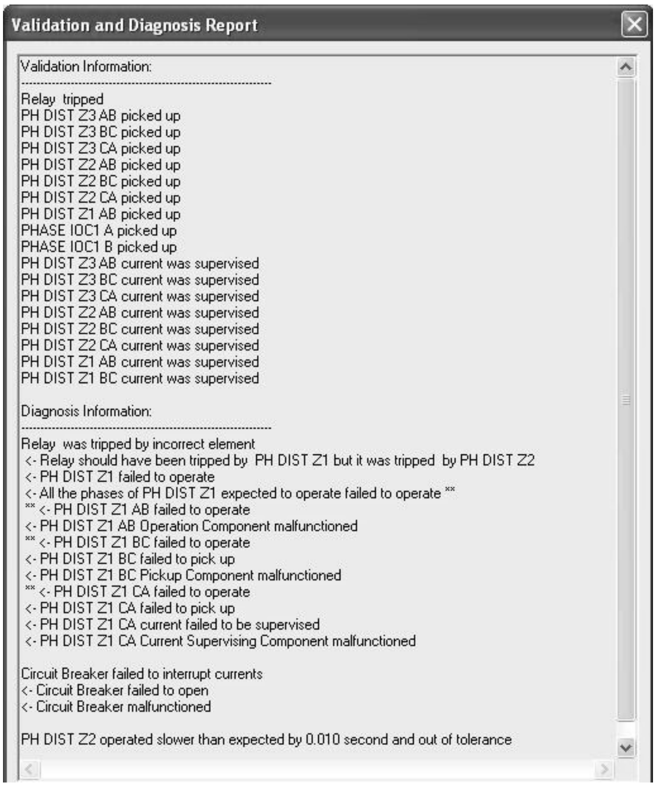

Fig. 4. Validation and diagnosis report

Another diagnosis is that the relay should have been tripped by PH DIST Zone 1 element but it was tripped incorrectly by PH DIST Zone 2 element. This was because PH DIST Zone 1 element failed to operate. The reason of the failure was because all of its phase elements expected to operate failed to operate. The failure of operation of AB element was due to malfunction of its operation component. The failure of operation of BC element was due to failure of pickup, which was caused by malfunction of its pickup component. The reason for failure of operation of CA element was traced down to the malfunction of its current supervision component.

There was also timing diagnosis information. Although PH DIST Zone 2 element operated to trip the relay, its operating speed was slower than expected and out of pre-set tolerance.

All the validation and diagnosis information is as expected, which proves the correctness of the design of the system.

VI. CONCLUSION

Based on the discussion in this paper, conclusions are drawn as follows:

- Various reports and files generated by digital relays provide abundant information for validation and diagnosis of protection system operation.
- Expert system is a powerful tool for protection engineers to develop intelligent applications for analysis of protection system operation.
- Combination of forward chaining reasoning and backward chaining reasoning makes expert systems more flexible and efficient.

The analysis capability of the prototype system has been demonstrated to some extent by a simplified example in this paper. Some future work is proposed. First, the expert system is designed only for analysis of GE's D60 relay so far. The knowledge base will be expanded to make the expert system applicable to more relays. Second, the disturbance information essential for analysis is supposed to come from other fault analysis applications based on advanced algorithms and techniques. It is desirable to integrate one or more of these applications with this digital relay data analysis system to achieve a more automatic and comprehensive fault analysis application.

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