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Automated Analysis of Digital Relay Data Based on Expert System

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***Abstract:* -- Modern digital protective relays generate variousfiles and reports which contain abundant data regarding fault disturbances and protection system operation. This paper presents an expert system based application for automated analysis of digital relay data. In this application, forward chaining reasoning is used to predict expected protection operation while backward chaining reasoning is employed to validate and diagnosis of actual protection operation. An EMTP/C++ based digital relay model with capability of insertion of user-defined errors and generation of files and reports is developed. The analysis capability of this application is tested using the relay model.**

***Index Terms:*-- relay operation, relay files, data analysis, expertsystem, relay model**

I. INTRODUCTION

With the development of computer and communication technologies, more and more intelligent electronic devices (IEDs) such as digital protective relays (DPRs), digital fault recorders (DFRs), sequence of event recorders (SERs) and remote terminal units (RTUs) of supervisory control and data acquisition systems (SCADAs) are used in power system substations. They supply abundant data related to monitoring, control and protection of power systems

This paper presents research results related to development of an expert system based application for automated analysis of digital relay data. Section II introduces data contained in the files and reports generated by digital relays. Section III presents the conceptual strategy of the analysis. Section IV describes an implementation of the application. Section V introduces an EMTP/C++ based digital relay model and presents a case study to demonstrate the features of the application by analyzing files and reports generated by the relay model..

II. DIGITAL RELAY DATA

Modern digital relays are capable of generating various files and reports, each of which may contain a specific category of data. Generally, oscillography data contain the records of what a relay "sees" during disturbance events. Setting data specifies how the relay is configured. Fault data presents disturbance information and phasor parameters calculated by the relay for its decision making. Sequential event data reveals how the relay and associated protection components actually respond to the disturbance events. These four categories of data are introduced as follows.

A. Oscillography Data

Oscillography data generated by the fault recording function of a digital relay are usually contained in oscillography files in COMTRADE format [6]. Secondary voltages and currents coming into the relay are recorded as analog channels while statuses of both external contacts and internal states of the relay can be recorded as digital channels by users' selection.

B. Setting Data

Setting data contained in a setting file specify configuration parameters of a relay. Usually setting data configures the relay at three levels: selecting protection and control elements, deciding how the selected elements are logically combined, and setting operating parameters of each selected element.

C. Fault Disturbance Data

Fault data contained in a fault report include fault type, fault location and voltage and current phasors during pre-fault and fault periods. They are calculated by a relay and used for its decision making.

D. Sequential Event Data

Sequential Event Data contained in an event report are time-stamped logic operands in chronological order. It contains most of the information through which the external behaviour of a relay and its associated protection system components and the internal states of the relay can be observed.

III. CONCEPTUAL STRATEGY OF THE ANALYSIS

The analysis of relay data is based on comparison of expected and actual protection operation in terms of statuses and corresponding timings of logic operands. If the expected and actual status and timing of an operand are 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 the use of logic and cause-effect chain.

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

Disturbance information includes fault inception time, fault type, fault location and current interruption time after circuit breaker opening. The information may come from several

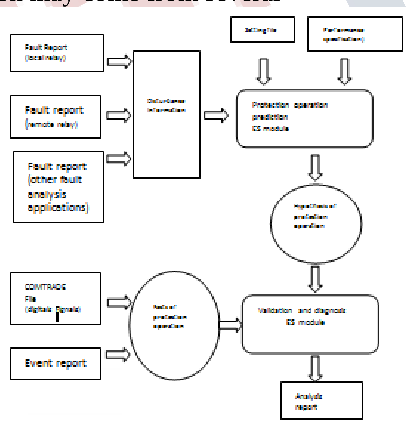

Fig. 1. Block diagram for conceptual strategy of the analysis

Sources: the local relay, remote relays and other fault analysis applications based on advanced algorithms and techniques such as expert systems, Neural Networks and Synchronized Sampling.. To decide the information source to be used in the analysis, we have the following assumptions.

1) The disturbance information obtained from fault analysis applications based on advanced algorithms and techniques is more accurate than that produced by relays.

2) The disturbance information produced by the relay which indicates the fault is in its Zone 1 is more accurate than that produced by the relay which indicates the same fault is in its operation zones other than Zone 1.

Based on above assumptions, the logic for choice of source of disturbance information is illustrated in Fig. 2. Currently this part of logic is not included in our application because we assume the disturbance information is obtained from an expert system based DFR data analysis application With disturbance information, relay settings and performance specification available, the expected statuses and timings of active logic operands are inferred by forward chaining rules. The results are regarded as hypothesis of protection operation. The actual statuses and timings of operands which are obtained from the oscillography file and event report are the facts of protection operation. With both hypothesis and facts of protection operation as inputs, an expert system module will first perform validation of the correctness of statuses and timings of logic operands based on hypothesis-fact matching. Then it will further perform diagnosis of inconsistency of expected and actual statuses as well as timings of logic operands based on the logic and cause-effect chain. Finally an analysis report will be generated.

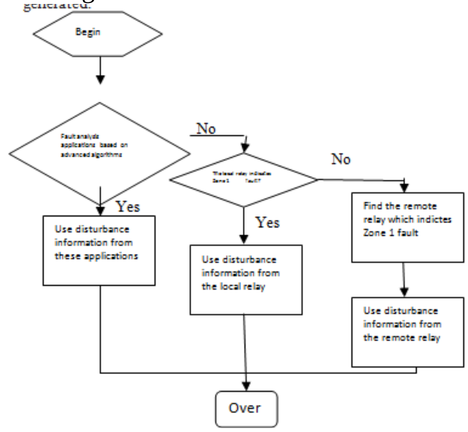

Fig. 2. Logic for choice of source of disturbance information

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IV. APPLICATION IMPLEMENTATION

A windows framework is developed using Visual C++ for the application. Data inputs from relay files and reports and data outputs to analysis reports are implemented through the framework. A CLIPS expert system inference engine is linked with the framework by means of Dynamic Link Library (DLL) [10]. The framework takes care of loading the facts and rules into the inference engine and reading the inference results from the engine.

Data Input

The framework reads the initial facts for the expert system module used for prediction of protection operation from the fault report, the relay setting file and a windows dialog for performance specification input. Then these facts are converted into CLIPS language format. The framework also reads the facts of actual protection operation for the expert system module used for validation and diagnosis of protection operation from the digital signal section of oscillography file and the event report. In order to generate time-stamped logic operands from the oscillography file which are consistent with those contained in event report, several steps of processing are performed.

1) The digital signals in the oscillography file are converted to time-stamped logic operands by examining their status changes and corresponding timings.

2) The time-stamp of a critical logic operand generated from the oscillography file is compared with that contained in the event report to unify the time base for the oscillography file and the event report.

3) The union of the set of time-stamped logic operands generated from the oscillography file and the set of time-stamped logic operands contained in the event report is chosen to observe the actual protection operation.

B. Expert System Rules

Currently the rule base of the expert system is designed for operation of circuit breakers and four protection elements including Phase Distance (PHASE DIST), Ground Distance (GROUND DIST), Phase Instantaneous Over-Current (PHASE IOC) and Ground Instantaneous Over-Current (GROUND IOC).

The rule base includes two parts. One is for prediction of expected protection operation. The other is for validation and diagnosis of actual protection operation. The former is developed according to the protection operation chain which includes seven steps: over-current supervision of individual phases of protection elements, pickup of individual phases of protection elements, operation of individual phases of protection elements, operation of protection elements, relay trip, circuit breaker opening, and current interruption by circuit breakers. The latter are divided into three parts according to their functions. The three functions include validation and diagnosis of statuses of logic operands, evaluation of operating speed of protection elements and associated circuit breakers, and examination whether the relay is tripped by the expected protection element. The rule base built in CLIPS language is stored in a text file. When the analysis is initiated, it is loaded into CLIPS inference engine through the window framework.

VI. CONCLUSIONS

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

1) Files and reports generated by digital relays contain abundant data about the external and internal behavior of relays. They are very useful for detailed diagnosis of protection system operation.

2) Expert systems are powerful tools for protection engineers to develop intelligent applications for data analysis.

3) Forward chaining reasoning and backward chaining reasoning have their own strength. Combination of the two makes expert system applications more efficient.

4) MODELS language of ATP program combined with other high level languages such as C++ can model very complicated logic systems such as multifunctional digital relays.

Future work on the improvement of the relay data analysis application includes two steps. First, the knowledge base of the expert system will be expanded to enable analysis of large quantity of relay data and interactions of several relays if pilot protection schemes are involved. Second, one or more fault analysis applications based on advanced algorithms and techniques will be integrated to provide accurate disturbance information.

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