An Expert System for DFR File Classification and Analysis

M. Kezunović P. Spasojević
Texas A&M University
College Station, Texas 77843-3128
U. S. A.

ABSTRACT

This paper summarizes results of a research project aimed at developing a prototype expert system for classification and analysis of files recorded in substations using digital fault recorders (DFRs). The main goal of the project was to automate the process of using DFR files to explain various fault events. The utility personnel have pointed out that this process is presently time consuming and automating this process would be a major improvement. An expert system based on a signal processing software and an expert system shell has been developed and tested using actual field data.

Keywords: Expert System Shell, Fault Analysis, Signal Processing, CLIPS

1. INTRODUCTION

The use of expert systems for substation event analysis has been investigated for the last 10 years and a number of different approaches were suggested [1,2]. These approaches are based on the use of various substation devices and systems such as Remote Terminal Units (RTUs) of Supervisory Control and Data Acquisition (SCADA) System, Sequence of Event (SOE) recorders, Digital Relays and Digital Fault Recorders (DFRs) [3]. The events were analyzed based on alarms [4], circuit breaker and relay contacts [5], and analog current and voltage signals [6]. In most of the cases a unique implementation approach was taken regarding selection of expert system rules, programming language and computer system [7].

This paper concentrates on the use of Digital Fault Recorder (DFR) files for substation event analysis. Records captured in a substation by DFRs are quite often numerous and their classification and analysis may take a tremendous amount of time. The protection engineers responsible for explaining various power system events have identified a need to automate the classification and the analysis process. As a result, an expert system was built to assist operators in this time consuming task.

The implementation approach taken in this paper is somewhat unique since both the analog signals and contacts as well as their time relation are used as input data. A signal processing software is used to calculate relevant signal parameters and a CLIPS expert system shell is utilized to implement the rules. The software also includes custom routines for conversion of DFR file formats to the formats required for processing. The prototype is developed using PC configuration and DFR files may be entered from diskettes in the protection engineer's or dispatcher's offices.

The first part of the paper gives basic design characteristics. The following section gives a description of the rules. Implementation details are given next. System performance demonstration is discussed after that. Conclusions and references are given at the end.

2. BASIC DESIGN CHARACTERISTICS

Fault detection and analysis expert system is a rule based system that performs fault classification, event analysis and protection system operation analysis.

In order to obtain these analyses, the expert system processes analog signal samples and contact status data recorded with a digital fault recorder in a substation. Analog signal data consists of voltage and current samples recorded on the substation lines and buses. Contact status data consists of the recorded positions of the substation breaker, relay and communication contacts.

The reasoning required to perform classification and analysis of the event is implemented by using a set of rules. The reasoning process is separated into two stages. In the first stage, the system reasons on the basis of the analog signal parameters, and in the second step, it reasons by using the protection system parameters. Analog signal and protection system parameters are obtained by processing the recorded samples and extracting the relevant features of the signals recorded on the line that had experienced the largest disturbance.

Analog waveforms and protection signals are divided into three time intervals, the predisturbance, disturbance and post disturbance interval. The predisturbance time interval consists of data samples recorded before the instant of the disturbance that activated the recording. The disturbance time interval consists of data samples recorded in the time frame when the signal showed a significant disturbance. The significance of a disturbance is determined by using an experimentally obtained threshold. The post-disturbance interval consists of data samples recorded in the steady-state after the disturbance.

Analog signal parameters are calculated voltage and current RMS-values for the three characteristic intervals described above.

The relevant features of the protection system parameters describe the breaker, relay, and communication system operation. Breaker and relay parameters determine their status in the event time frame. Breakers can be either open or closed all this time or they can change status. The breaker parameters include the contact status information and the time instant of the status change if there is one. Relays may trip or not. The relay parameters include the tripping interval times if there is a trip and an indication if there is no trip. Communication signal parameters provide information on whether and when the relay was blocked and whether it blocked the relay on the other side of the line. The blocking signal may be present all the time, may be present only during the disturbance period, may be on and off, and may not be present at all.

3. DESCRIPTION OF EXPERT SYSTEM RULES

Figures 1, 2, and 3 summarize, in flowcharts, the system rules. As mentioned earlier, these rules are based on analog signal and protection system parameters.

Terminal boxes in flowcharts are final conclusions of the expert system. The reasoning process consists of several intermediate conclusions and a set of decision boxes. Decision boxes check the voltage and current thresholds as well as the breaker and relay operation and their operation times to make relevant conclusions about the event.

Some examples of the corresponding CLIPS rules are given in Figures 4 to 7. They provide an insight in to the rule implementation.

Reasoning based on analog signal parameters (Figures 1 and 2) consists of rules for fault detection, fault classification, and event analysis. Fault detection (Step 1) determines whether there was a fault. Fault classification (Step 2) determines the fault type. Both of these steps are solely based on analog signal parameters. These two steps are further elaborated on in Figure 3. Event analysis (Step 3) is based on checking whether the current RMS values are below certain thresholds. It is also comparing current RMS values for different event time intervals (Step 4) and uses the fault detection information (Step 1). In case of a fault, this analysis makes at least one of the following conclusions:

- The fault was cleared at this substation (Step 5)
- The fault was cleared elsewhere (Step 6)
- The protection system failed and the fault was not cleared at all (Step 7)
- The attempt to perform the breaker reclosing failed (Step 8)

In case of a "no fault" disturbance, the event analysis makes at least one of the following conclusions:

- Correct operation of the protection system (Step 9)
- Misoperation of the protection system (Step 10)
- The attempt to perform breaker reclosing succeeded (Step 11)

Figures 4, 5 and 6 provide implementation rules for Steps 7, 5 and 10, respectively. For example, the rule in Figure 4 states that the protection system failed since the fault was not cleared.

To elaborate on fault detection and classification, the rules are summarized in more detail in Figure 2.

These rules compare phase A, B, C, and zero sequence RMS values of voltages and currents to thresholds to conclude whether there was a fault (Step 12), or what type of fault it was. This example flowchart provides a threshold comparison for detecting the following faults:

- Phase A-to-ground fault (step 13)
- Phase A to phase B-to-ground fault (Step 14)
- Three phase-to-ground fault (Step 15)
- Phase A to phase B fault (Step 16)
- Three phase fault (Step 17)

The phase A-to-ground fault rule implemented using CLIPS is given in Figure 7. Here, voltage and current disturbance and predisturbance values are compared to thresholds to determine this type of fault.

The reasoning based on protection system parameters provides the protection system operation analysis. Figure 3 consists of a flowchart that describes the execution of the rules that perform this analysis. These rules also use the fault detection information to make conclusions about the correct relay operation.

Protection system operation analysis results in:

- Breaker opening and closing times
- Relay tripping time interval
- Breaker failure conclusion (Step 1)
- Relay misoperation conclusion (Step 2)
- Relay failure conclusion

Breaker failure is in effect if:

- The breaker did not operate and the relay had tripped.
- The breaker did not open after the relay had tripped.
- The breaker opening delay is too big.

The relay misoperation is in effect if the relay had tripped and there was no fault.

The relay had failed if it did not trip on a fault even though it was not blocked.

All the above conclusions are made for primary and backup relays and for both breakers that guard the line.

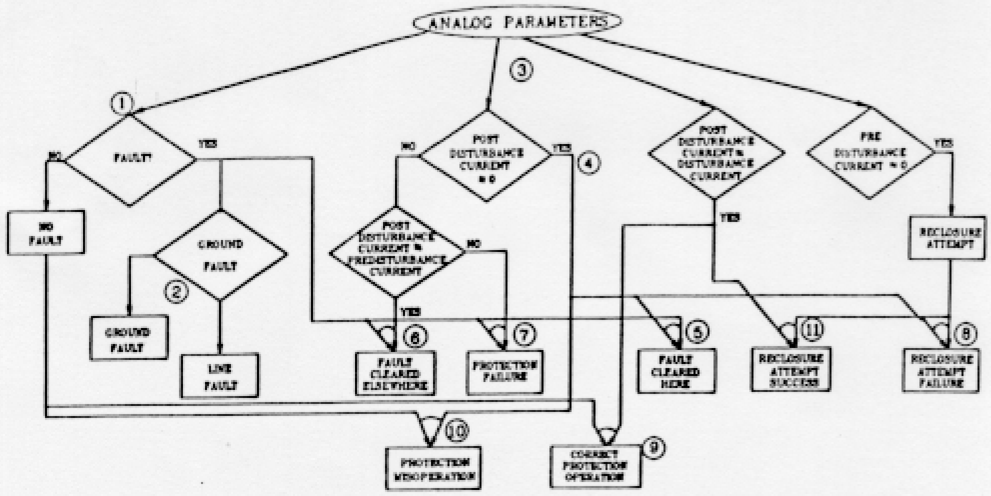
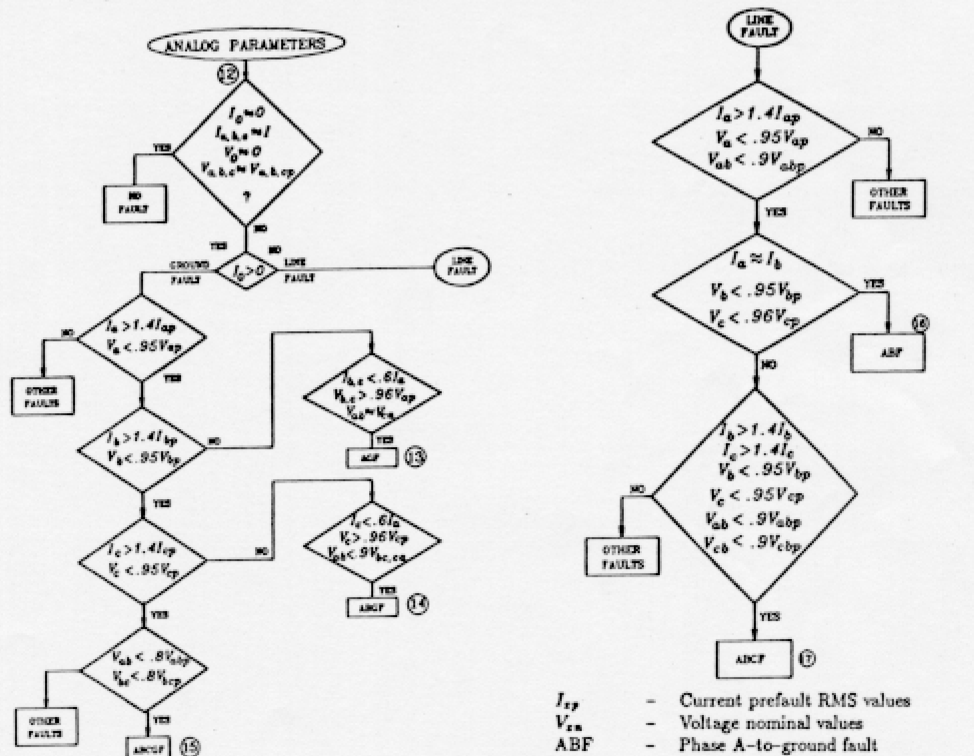


Fig. 1. Rules for Fault Detection, Classification, and General Event Analysis using Analog Parameters



$X_{a,b,c,o}$	-	Phases A, B and C and Zero sequence
$X_{ab,bc,ca}$	-	Line voltage disturbance RMS values disturbance RMS values

I_{xp}	-	Current prefault RMS values
V_{xn}	-	Voltage nominal values
ABF	-	Phase A-to-ground fault
ABGF	-	Phase A to Phase B-to-ground fault
ABCGF	-	Three phase-to-ground fault
ABF	-	Phase A to Phase B line fault
ABCF	-	Three phase line fault
I, V	-	Current and voltage RMS values

Fig. 2. A Conceptual Representation of the Fault Detection and Classification Subtree

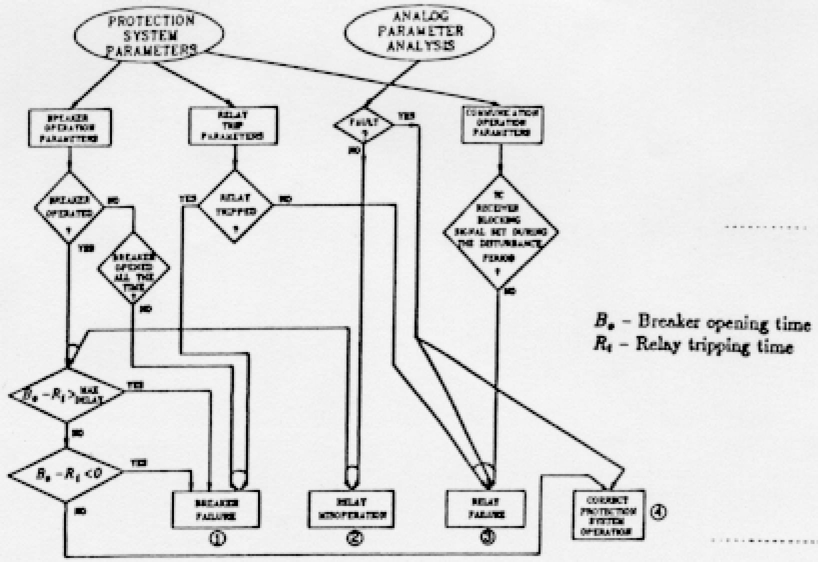


Fig. 3. Protection System Operation Analysis Rules

```
(defrule protection_failure
          (declare (salience 20))
          (fault $?)
          (no clearance)
 =>
          (assert (protection failure))
          (fprintout t crlf "There is a protection failure,
                             the fault was not cleared." crlf)
 )
```

Fig. 4. Protection System Failure Rule

```
(defrule fault_clearance_here
        (declare (salience 40))
        (fault $/)
        (breaker open postdisturbance)
 =>
        (assert ( clearance here))
        (fprintout t crlf " The fault is cleared by the protection " crlf
        "system at this substation." crlf )
 )
```

Fig. 5. Fault Clearance Rule

```
(defrule protection_misop
     (declare (salience 40))
        (Ip ?IOp ?Iap ?Ibp ?Icp)
        (I ?IO ?Ia ?Ib ?Ic)
        (Vp ?Vap ?Vbp ?Vcp ?VOp)

;       (test (< (max ?Ia ?Ib ?Ic) .05))
        (breaker open disturbance)
        (test (< (max (/ ?Ia ?Iap (/ ?Ib ?Ibp) (/ ?Ic ?Icp) ) .1))
        (test (< (max (/ (abs (- :Ibp ?Iap)) ?Iap) (/ (abs (- ?Icp ?Ibp))
            ?Ibp) (/ (abs (- ?Iap ?Icp)) ?Icp)) .2))
        (test (< (max (/ (abs (- ?Vbp ?Vap)) ?Vap) (/ (abs (- ?Vcp ?vbp))
            ?Vbp) (/ (abs (- ?Vap ?Vcp)) ?Vcp)) .02))
 =>
     (assert (protection misoperation))
```

Fig. 6. Protection System Misoperation Rule

```
(defrule phase_A_ground_fault
     (ground fault)

        (test (> ?Ia (* 1.3 ?Iap)))
        (test (< ?Ib (* .5 ?Ia)))
        (test (< ?Ic (* .5 ?Ia)))
        (test (< (abs (- ?Ia ?IO)) (* .96 ?Ia)))
        (test (> ?V0 (* 10 ?V0p)))
        (test (?Va (* .95 ?Vap)))
        (test (> ?Vb (* .95 ?Vbp)))
        (test (> ?Vc (* .95 ?Vcp)))
        (test (< (abs (- ?Vb ?Vc)) (* .05 ?Vbp)))
        (test (< (abs (- ¿Vab ?Vca) (* .2 ?Vabp)))
        (< (abs (- ?Vbc ?Vbcp)) (* .2 ?Vbcp)))

 =>
     (assert (phase_A ground fault))
     (fprintout t "Single line to ground fault, phase A" crlf))
```

Fig. 7. Phase A-to-Ground Fault Rule

Expert System's diagnosis is followed by a display of significant event signals. This display aids operators to quickly verify system's detection and diagnosis performance.

6. CONCLUSIONS

Based on the developments reported in this paper, the following can be concluded:

- Fault detection and diagnosis are time consuming activities that require expertise specific to given system operation practices and equipment characteristics
- Expert system technology can be utilized to automate fault detection and diagnosis process
- Major benefits of the expert system application to this problem are savings in processing time and improvements in the overall analysis.

ACKNOWLEDGEMENTS

The activities reported in this paper were funded by Houston Lighting and Power (HL&P) Company of Houston, Texas, U. S. A. Special thanks are due to HL&P's protection engineers Messrs. C. W. Fromen and D. R. Sevcik for sharing their expertise incorporated in the expert system rules.

REFERENCES

[1] B. F. Wollenberg, T. Sakaguchi, "Artificial Intelligence in Power System Operations," *Proceedings of the IEEE*, Vol. 75, No. 12, December 1987.

[2] *Proceedings of the Symposia on Expert System Applications for Power Systems*; First–Stocholm/Helsinki, 1988; Second–Seattle, 1989; Third–Tokyo/ Kobe, 1991.

[3] M. Kezunović, "Implementation Framework of an Expert System for Fault Analysis," *Third Symposium on Expert System Applications to Power Systems*, Tokyo/Kobe, Japan, April 1991.

[4] T. S. Dillon, "Survey on Expert Systems in Alarm Handling," *CIGRE* W. G. 38–06 Report, Electra, No. 139, December 1991.

[5] S. N. Talukdar, et.al., " The Operator's Assistant – An Intelligent, Expandable Program for Power System Trouble Analysis," *IEEE Trans. on Power Systems*, Vol. PWRS–1, No. 3, August 1986.

[6] H. M. Sendula, et.al., "Automated Interpretation of Digital Fault Recorder Data," *Proc. of Fault Disturbance Conference*, New Orleans, U. S. A. 1989.

[7] M. Kezunovic, et.al., "Expert System Applications to Protection, Substation Control and Related Monitoring Functions," *Electrical Power Systems Research Journal*, pp. 71–78, 1991.