An Expert System (ES) to Evaluate and Characterize Faults in Transmission Lines Using Case-Based Reasoning (CBR)

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***Abstract* - This paper describes an Expert System (ES) centered on Case-Based Reasoning (CBR) that defines and characterizes faults that have occurred in the largest Colombian transmission company's grid, ISA's power network. This expert system helps to process information quickly for power system disturbance analysis, which is necessary to determine the possible causes for a fault. The expert system is based on the construction of rules that characterize faults, which are created by disturbance analysis experts, taking advantage of their experience and knowledge in this field. The expert system's rules were created taking only fault oscillographic records into account and not the operation of protection relays or CB operations. This methodology also enables the expert system to be easily transplanted into other networks. This study is part of the *Diagnóstico Automático de Eventos* (DAE), which is software for automated fault analysis developed by ISA.**

Key words: Expert System, Case-Based Reasoning, Rules, Fault, Power System.

I. INTRODUCTION

In Colombia, the electric power transmission companies have transmission control centers from which they remotely operate all substation equipment. When a fault occurs, transmission control center dispatchers have to analyze power system faults and restore the transmission network as soon as possible, using information from protection relays, fault recorders, sequence of events analyzers (SOE), and operational guidelines. Also, Transmission Control Center Dispatchers must rely heavily on past experiences with faults in order characterize new faults [1].

Expert systems are powerful tools of Artificial Intelligence (AI) that emulates human reasoning to solve problems [1] [14]. Therefore, this methodology was used in this project because expert systems perform similarly to a transmission control center dispatcher in real time. Recently, expert systems have taken on relevance in some fields of electric power engineering [14]. One of the most common fields studied has been the fault diagnosis of power systems [8]. Many of these studies related to expert systems are used in power systems control centers to aid control center dispatchers in recognizing and characterizing faults in real time. The dispatcher´s responses are complicated by the large amount of information that must be analyzed at one time. This difficulty is called "human cognitive barrier" [16].

Commonly, these studies have taken into account expert systems for fault analysis power system using the signal operation from relay´s information and CB´s operation [10][15]. However, in many transmission control centers, complete information is not available or time-download information can to take a long time, because this activity is done manually by the dispatcher.

ISA has been developing a project to automatize the fault diagnosis of power systems called "*Diagnostico Automatico de Eventos* (DAE)" since 2007 [6][7]. To complete this project, it was necessary to create an expert system to find the fault source. Therefore, this paper presents an expert system using Case-Based Reasoning (CBR) to evaluate and characterize faults in Transmission Lines. This CBR is represented by rules, which were created by taking only fault oscillographic records into account; these fault records come from relays or fault recorder devices installed in substations.

To avoid problems in relation to downloading the fault recorders in real time, ISA has developed an additional software to download records automatically in real time called "*Sistema Automatico de Gestión de Equipos de Subestaciones*" (SAGES). This software allows the control center dispatcher to concentrate only on fault analyses and not on retrieving data systems from computer storage.

The expert system rules were created based on real faults that occurred in ISA's power transmission system. Initially, the expert system had been tested with cases of transmission lines' faults caused by open conductors. The rules for this case were created by expert engineers with many years of experience in power system fault analysis [1].

II. THEORY OF EXPERT SYSTEMS AND CASE-BASE REASONING

Expert systems are part of a general category of computer applications in the Artificial Intelligence (AI) like genetic algorithms, molecular computation, and neural networks, among others, which simulate the human reasoning in order to solve problems [12][13]. However, expert systems are different because they are based on knowledge associated with previous experiences and not on a usual deductive program. An expert system contains knowledge, which must be obtained through an interview with a person who has recognized expertise in the problem area.

Expert systems can be developed using different methodologies. The most common methodologies used are Bayesian Networks, diffuse networks, and Case-Based Reasoning. For this study, Case-Base Reasoning was selected to develop the expert system, because this methodology is more similar to the behavior of transmission control center dispatchers in real time than the others. "A case is a contextualized piece of the knowledge representing an experience that teaches a lesson fundamental to achieving the goal of the reasoned," Kolodner (1993). Case-Based Reasoning is a methodology conceived in four sequential parts. (Fig. 1).

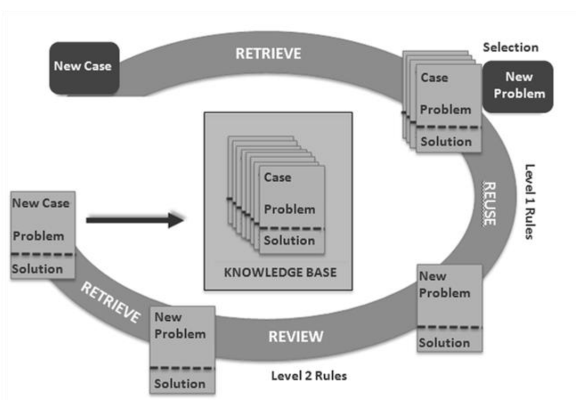

Fig. 1. Case-Based Reasoning (RBC).

Retrieve

This part of the process recovers similar cases from a knowledge base using expert rules, which permit the system to find the candidate cases most appropriate to characterize the new problem.

Reuse

To recycle knowledge and information from retrieved cases in the knowledge base in order to characterize the new case. Detailed information about previous cases is used to try to identify the new case´s source and to create a reasonable solution to a new problem.

Review

The objective of this process is to analyze the proposed solution and to evaluate whether the information in the knowledge base is useful and if the solution has a high level of accuracy.

Retrieve

The new solution is characterized by the expert system rules. The complete information is reviewed to identify new information in the case that can feedback the knowledge base.

All Artificial Intelligence's tools have advantages and limitations, which are shown below in Table 1.

EXPERT SYSTEMS	
Advantages	Limitations
Knowledge Management	Time-consuming
Auto-knowledge	Difficult programming
Flexibility	Objective knowledge
Active memory	
Permanency	
Reliability	

Table 1. RBC Advantages and Limitations.

III. PROPOSED EXPERT SYSTEM

The proposed expert system is based on Case-Base reasoning. The input variables for this expert system are only oscillographic records, which are generated at the substation when a fault occurs. First, these oscillographic records are considered new cases to be analyzed. Next, the expert system applies first level rules to the new case and then it selects various candidates from the knowledge base using a selection process. Thereafter, the expert system reuses the selected candidates and the new case and applies second level rules to identify the best candidate to describe the new cases. The next step is to review the process in order to check for a solution. Finally, the new case is evaluated to decide whether it provides new information to feedback the knowledge base. (Fig. 2)

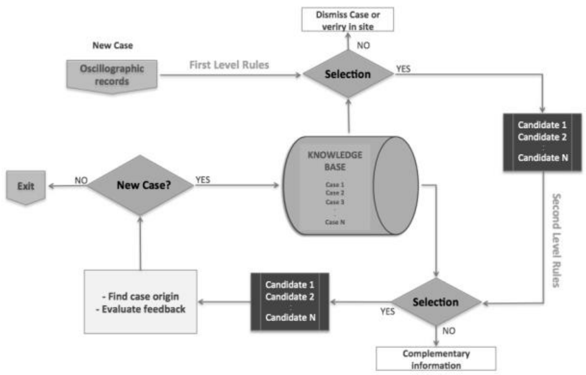

Fig. 2. Proposed Expert System.

The most important parts of this expert system are the following:

Oscillographic records

The SAGES software automatically downloads these. It`s necessary that all files are in COMTRADE format. The expert system only requires one correct file per substation. Generally, this task is not difficult because in each substation, there are normally three devices that generate oscillographic records when a fault occurs. All oscillographic records are divided into four main stages: Pre-fault, fault, death time, and steady state (Fig. 3). The DAE software has a neural red train to characterize oscillographic records that identify analog signals and translate them into logical values. [6][7].

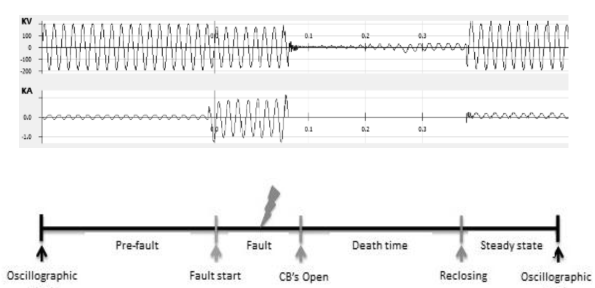

Fig. 3. Main Fault Stages.

Knowledge base:

The knowledge base was created by taking into account many years of experience by the transmission control system dispatchers. The knowledge base has many characterized faults that occur in real time in the Colombian transmission grid. The knowledge base is growing continuously because each case analyzed by the expert system represents an opportunity to feedback it.

Expert system's rules:

A detailed analysis using logic gates was developed by transmission control center fault analysis experts to create rules and meta-rules for the expert system (Fig. 4). The variables employed to create the rules were the following:

- Phases voltage ground.
- Neutral and phases conductor current.
- Angular difference between phases voltages, ∠Va–Vb, ∠Vb–Vc, ∠Vc–Va.
- Angular difference between phases currents, ∠Ia–Ib, ∠Ib–Ic, ∠Ic–Ia.
- Fault type.
- Residual Voltage.
- Residual Currents.
- Fault duration.
- Angular difference between phases voltages and phases currents.
- Reclosing type.
- Trip time

These variables were analyzed in the four main stages: Pre-fault, fault, death time and steady state.

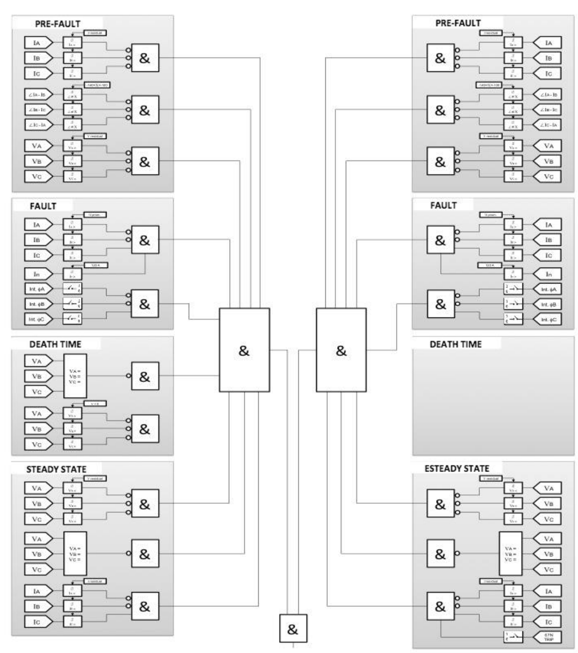

Fig. 4. Logic Gates to Create Rules.

IV. CASE STUDY

For this case study, we used real faults related to open or broken conductor faults that occurred in ISA's power transmission system. The expert system is not implemented in real time yet. However, this case study has been tested using DAE software to ensure its reliability. A detailed description of the main parts of the case study is explained below.

Knowledge base cases:

Initially, the engineers looked for all faults related to open or broken conductor faults in the last 12 years in ISA's database. Twenty-two cases were found where the source of the fault was an open or broken conductor. This type of fault was selected because of the economic impact, not because of the frequency of occurrence. This is because it can be very time consuming to find the source of these faults, which in turn directly reduces ISA's profits because of penalties. Fig. 5 shows more common faults that have been found.

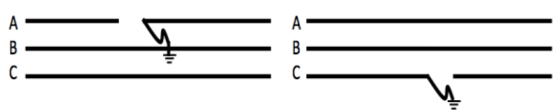

Fig. 5. Open Conductor Faults.

Inference engine:

The inference engine is the brain of the expert system. It contains the rules and meta-rules that permit the expert system to characterize fault sources. In this study, the software selected to program the expert system was CLIPS because of its flexibility. Additionally, it is free software developed by NASA in 1984 and is periodically updated. When a new case occurs, it is uploaded into the system and the appropriate rule is activated in order to select the candidate cases from the base knowledge to characterize it.

To construct the inference engine, the engineers studied the details of only open conductor faults and designed the interaction between rules and the different fault stages (Fig. 6).

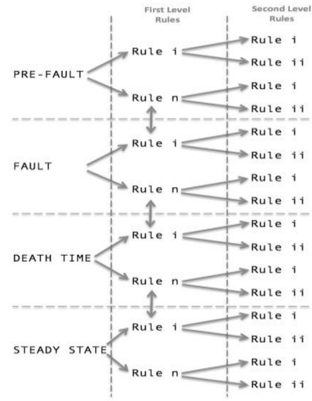

Fig. 6. Inference Engine.

Creation of rules:

To explain the creation of rules inside the inference engine, it is best to look at this specific example. In the pre-fault stage, residual current (Ix) can be found in one of the three phases of the transmission power line (Fig. 7). The pre-fault wave could suggest the possibility of an open conductor fault in the power system. When this occurs, a rule called resid_curr is activated by the expert system and this rule, in turn, actives an additional rule called ang_dif to evaluate the angular difference between the three currents of the transmission power system. In addition, the rule ang_dif can activate one or more rules or meta-rules to identify similar cases inside the knowledge base to characterize the new case (Fig. 8). This process continues until the best candidate is found inside the knowledge base.

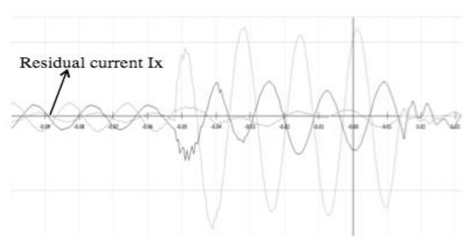

Fig. 7. Pre-Fault Oscillographic Records.

```
(deffacts current_phases
    (current (rms "ia")  (inoma))
    (current (rms "ib")  (inomb))
    (current (rms "ic")  (inomc)))

(defrule  capacitive
(current ( rms ?n)( inom ?m)
       (test (< ?m icap))
    =>
    (assert (resid_curr))
    (assert (ang_dif))
```

Fig. 8. Rule.

V. ARTIFICIAL RETRAINING OF EXPERT SYSTEMS

Obviously, the more cases the knowledge base contains, the larger and more suitable it will be for the expert system because the large amount of knowledge in the active memory allows the system to identify the fault source in new cases more efficiently. It is not always convenient to wait for more cases to naturally occur in real time in order to improve the knowledge base. Therefore, it is necessary to create artificial cases in the knowledge base using power system simulation software and validate them using the rules previously applied within the expert system. (Fig. 9).

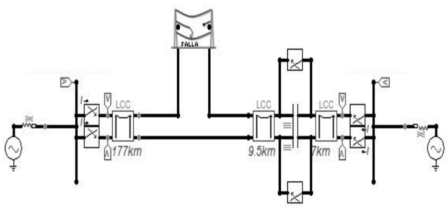

Fig. 9. Artificial Retraining of Expert Systems.

VI. FUTURE DEVELOPMENTS

As a result of this project, the engineers will be able to create an expert system to evaluate the performance of protection relays when a fault occurs in ISA's power transmission system. It is possible that this expert system will have similar software architecture to the one presented in this project.

VII. CONCLUSIONS

Currently, there are many studies over expert systems for fault diagnosis in transmission lines, focusing on finding the fault location, protection analysis, and detection of alarm signals. A large advantage of this project is that this expert system can locate the source of the fault and identify the situation that caused the fault.

This expert system has proved to be a powerful tool in real time to help transmission control center dispatchers in fault analysis. Dispatchers are highly interested in the development of expert systems because with its support, they can dedicate all their cognitive resources towards the restoration procedures, resulting in a minimization of the duration of customer outage.

An additional advantage of this tool is that it inputs solely oscillographic records in order to characterize a new fault (case), allowing the expert system to be transplanted into other networks, without many new requirements.

This expert system will allow ISA to achieve a higher level of knowledge management [17], taking into account the high turnover rate of employees in the company, which could result in the loss of the knowledge and experience in fault analyses.

VIII. REFERENCES

[1] AMAYA Jaime y Jaramillo Vélez Rodrigo, Metodología para la Identificación y Caracterización de Eventos por Desprendimiento o Rompimiento de Conductor en Líneas de Transmisión de ISA. Universidad Pontificia Bolivariana, Medellín 2012.

[2] R. C. G. Teive, J. Coelho, C. C. B. Camargo, P. C. Charles, T. Lange and L. Cimino Jr, Bayesian Network Approach to Fault Diagnosis and Prognosis in Power Transmission Systems, Intelligent System Application to Power Systems (ISAP), International Conference 2011.

[3] MONTERROSA Gaitán Farmer Osvaldo, Metodología Conceptual para la Evaluación y Diagnóstico de Fenómenos Transitorios en la Red De Transmisión de Energía Eléctrica a partir de Eventos Reales, Universidad Pontificia Bolivariana, Medellín 2011.

[4] HENAO López Fernando, Modelo para el Desarrollo de un Sistema Inteligente en la Identificación Y Caracterización de Registros de Eventos de Fallas de las Líneas de Transmisión de ISA, Universidad Pontificia Bolivariana, Medellín 2010.

[5] M. Batiba, AMIT. Jain, M.B Srinivas, A web based Expert System Shell for Fault Diagnosis and Control of Power Equipment, International Conference on Condition Monitoring and Diagnosis, Beijin, April 2008.

[6] LLANO Zuleta Luis Everley, Diagnostico Automático de Eventos en Tiempo Real en un Sistema de Transporte de Energía a través del SOE y SCADA usando Técnicas de Inteligencia Artificial, Universidad Nacional de Colombia, Medellín. 2007.

[7] CALDERÓN Serna Jhon Albeiro, Modelo Adaptativo de Inteligencia Artificial para el Diagnóstico Automático de Fallas a partir de Registros de Osciloperturbografía, Universidad Nacional de Colombia, Medellín. 2007.

[8] ALI Hamzeh, K. Zaidan. Dvelopment of an Expert System for Off and On Line Faults Diagnosis in Electric Power System. Damasco University P.O Box 5115. Syria 2004.

[9] HEUNG-JAE Lee, Deung-Yong Park, A Fuzzy Expert System for the Integrated Fault Diagnosis, IEEE Transactions on Power Delivery, VOL. 15, NO. 2, APRIL 2000.

[10] ZHU Yongli, Y.H. Yang*, An Expefct System for Power Systems Fault Analysis, IEEE Transactions on Power Systems, Vol. 9, No. 1, February 1994.

[11] WENGIN Zhang, GENDING Fan, An Expert System to Help Dispatchers Deal with Faults in Northeast Electric Network. IEE International Conference on Advances in Power System Control. Hong Kong, November 1991.

[12] A. Kusiak, Expert Systems and Optimization, Software

Engineering, IEEE Transactions on, Volume 15, Issue 8, Aug 1989.

[13] C.L Ramsey, An Evaluation of Expert Systems for Software Engineering Management, Software Engineering, IEEE Transactions on, Volume 15, Issue 6, Jun 1989.

[14] Z.Z. Zhang, G.S Hope, O.P Malik, Expert Systems in Electric Power Systems a Bibliographical Survey. IEEE Transactions on Power Systems, Vol 4, No 4, October 1989.

[15] KEVIN Tomsovic, PAUL Ackerman, An Expert System as a Dispatchers Aid for the Isolation of Line Section Faults, IEEE Transactions on Power Delivery, Vol PDRD-2, No 3, July 1987.

[16] B.F Wollenberg, Artificial Intelligence in Power System Operations, Procedings of the IEEE, Vol 75, No 12, December 1987.

[17] D. M. Robert, Organizational Culture and Knowledge Management in the Electric Power Generation Industry, A Dissertation Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Management in Organizational Leadership, University of Phoenix, 2008.

IX. BIOGRAPHIES

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