INTELLIGENT SYSTEMS IN PROTECTION ENGINEERING

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Abstract: This paper represents an informal overview of the work performed by the working group C-4 of the Power System Relaying Committee (PSRC) of the IEEE Power Engineering Society. The paper is not formally endorsed or approved by PSRC. The author prepared the paper to promote the WG report. The working group C-4 on Applications of Intelligent Systems in Protection Engineering was formed to continue the activity initiated by the previous working group related to the potential application of Expert Systems to power system protection [1]. The assignment of the working group C-4 is: "Collect information and review, relative to power system Protection, existing applications of Intelligent Systems. Prepare a report on world-wide applications and their development status." The complete report approved by the IEEE PSRC can be found on the PSRC web site http://www.pes-psrc.org/c/.

Key Words: Protective Relaying, Intelligent Systems, Expert Systems, Neural Nets, Fuzzy Logic

I. INTRODUCTION

The application of intelligent systems to power system problems has been an area of strong research interest in the past decade. The most emphasis has been on applications that relate to overall monitoring, operation, and planning of the power system. Less emphasis has been placed on protective relaying, substation control, and related monitoring functions, at least as far as the number of published papers would indicate. It is felt that one of the major reasons for this is due to the real-time constraints imposed by the applications that require most of the functions to be executed automatically in a relatively short time frame. However, with increasing requirements on utility electrical systems for improvements in efficiency, reliability, and quality of service, along with significant technology development toward increased processing speeds and memory storage, there has been an increased impetus to research applications of intelligent systems in protection engineering.

Most AI applications to protection engineering are ancillary functions related to relaying, rather than the relaying functions themselves [2]. For example, one area of interest is the use, selection, setting, and coordination of relays and fuses. Another application is to aid selection of appropriate algorithms for fault location. AI has also been applied for fault data analysis by utilizing digital fault recorder (DFR) signals. It is seen that some of the applications have stringent time-response requirements. With recent computing technology, it seems that AI systems are limited by the boundaries of computer resources and execution times compared to conventional deterministic computer programs. New hardware and software that addresses the constraints of AI implementation are continuing to be developed. As the demand for these tools rise, their availability and cost will become more practical for application to protection engineering, especially for real-time functions.

There are several categories of AI that have certain characteristics and implement different intelligence processes. The main categories introduced in the following sections are: expert systems, neural nets and fuzzy logic.

The paper follows the organization of the WG report and first gives a general review of the application trends. Specific applications reported in the literature are surveyed next. After that a discussion of advantages and disadvantages when using different intelligent techniques is provided. An extensive bibliography is given at the end.

2. GENERAL OVERVIEW OF EXISITNG APPLICATIONS

The number of papers dealing with the application of AI techniques to power system protection problems is growing very fast [3]. In [4], a bibliography of more than 300 papers in the application of AI to power system protection, most of them published in the last five years, is cited. An analysis of the AI techniques used in the published papers is summarized in Figure 1.

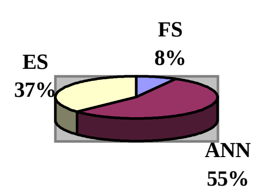

Figure 1. Classification by Methodology
(ANN – Artificial Neural Networks, ES – Expert Systems, FS – Fuzzy Sets) [4]

The ANN approach dominates (majority of papers), followed by Expert System (ES) techniques, and then by Fuzzy Set (FS) theory. As far as the primary protective devices are considered, the domination of ANNs over ESs is even much more evident. The ES technique is mainly used for off-line tasks (settings coordination and post-fault analysis). Also the FS technique is mostly used for post-fault analysis, but there are certain publications advocating its on-line application to primary protective functions.

Figure 2 summarizes the domain of AI applications from the bibliography of papers in [4]. Fault diagnosis is the largest application field of AI techniques in power system protection. This is mainly due to earlier applications of the ES techniques, and recent application of the ANN methods.

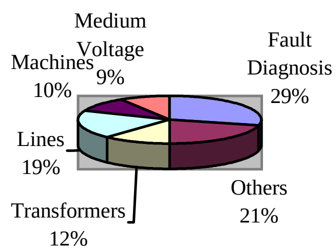

Figure 2. Classification by the Application Domain [4]

Line protection is the next largest application domain. Detection of arcing faults, adaptive autoreclosure, and directional element protection are the topics dominating this category.

Transformer issues are next in the order. The majority of papers in this category address post-fault analysis using the ES-techniques. The primary protection functions are based on the ANN techniques or the FS theory.

Diagnosis of electrical machines is the next category. Rotor/stator winding fault detection is the main issue addressed in this domain.

Medium voltage networks are the least common of application domains. Fault location and analysis are the main topics addressed in this domain.

3. SURVEY OF REPORTED APPLICATIONS

The applications mentioned in the WG C-4 report fall into the following application categories [5]:

- Individual Devices and Functions
- Substation Functions
- System-Wide Functions

The application and related references for individual devices and functions are outlined in Table I. Table II gives an outline of applications and related references for both the substation and system-wide functions.

TABLE I. Individual Devices and Functions

Application Area	**References**
Transmission Line Protection	
• Fault Detection and Classification	6,7
• Fault Direction Discrimination	8,9
• Adaptive Protection	10-12
Distribution Feeder High Impedance Fault Detection	
• Expert Systems	13,14
• ANN	15-18
• Fuzzy Logic	No Papers
Power Transformer Monitoring and Protection	
• Transformer Monitoring and Fault Diagnosis	
a) Expert Systems	19
b) ANN	20-25
c) Fuzzy Logic	26
• Transformer Protection	
a) Expert Systems	No Papers
b) ANN	27-33
c) Fuzzy Logic	34-36

TABLE II. Substation and System Functions

Application Area	**References**
Substation	
• Digital Fault Recorder Data Analysis	37-39
• Sequence of Events Data Analysis	40,41
System Functions	
• Relay Setting Coordination	42,43
• System Level Monitoring and Protection	44
• Alarm Processing and Diagnosis	
a) Expert Systems	45-51
b) ANN	52-55
c) Abductive Inference	56
d) Fuzzy Logic	

4. ADVANTAGES AND DISADVANTAGES

The use of Artificial Intelligence in protection engineering is necessary where uncertainty and incomplete data is involved, and where the application is considered an ‘art’ more than a science. Most of protection engineering is considered an ‘art’ and humans are relied upon to provide experience and expertise that is combined with heuristic reasoning. If a set of explicit rules and accurate data could be found to practice protection engineering then there would be no need for AI, or perhaps human protection engineers. The Fuzzy logic area of AI is meant to model inaccurate information and heuristic reasoning, while ANNS can model applications that are difficult to define mathematically. The ANNs require prior training to do these tasks. Expert systems allow the use of explicit rules to build a knowledge base, but these rules and the output decision may rely on Fuzzy Logic for interpretation of the data.

4.1 Expert Systems

Expert systems are well suited to smaller problem domains that have narrow fields of expertise. The rules in the knowledge base of an Expert System form a large inference net that can be extended and manipulated at any time simply by adding new rules to the knowledge base when required. In this sense, the knowledge of the system is increased. Neither the inference engine, nor the original structure of the knowledge base needs to be altered when adding new rules. However, infinite chaining, contradictions, and other rules concerning multiple paths cannot be processed in an Expert system and have to be avoided. A disadvantage of Expert systems is that some tasks are more successful at being handled than others depending on the population of the knowledge base. Therefore, it is necessary that the domain of the Expert System be as narrow as possible to produce good results.

Expert Systems cannot replace the need for human experts who must study power system problems apply past experience, and learn new solutions. However, real-time application of human expertise to protection can be aided by Expert Systems. Often, the application of expertise is limited to the experts themselves, and this puts a limitation on the availability and efficiency of applying a solution. Human experts are not always available 24 hours a day, and even when available, a human expert may not be able to study all relevant real-time data fast enough when a problem occurs. The extensive use of memory for program storage and execution space, and the vast number of memory accesses for searches and symbolic comparisons are burdens on processing software and hardware. Some special computer architectures have been designed to alleviate some of these restrictions, but the demand for these special architectures has not been high enough to manufacture them at a cost comparable with conventional computer architectures.

4.2 Artificial Neural Networks

Neural networks can operate on multi-dimensional data that humans may not be able to recognize due to our limited three-dimensional view of the world. However, this self-learning ability gives rise to the problem that ANNs can not explain to the user how they arrived at their conclusions. AMMs are especially appropriate and powerful when used to find relationships that re difficult to describe explicitly. Neural networks are good in interpolation, but not in extrapolation. This means that the training sets need to encompass the complete solution space. Preparation of training sets is a complex task, and preprocessing of data is usually required. Since Neural Networks exhibit some of the same properties that biological systems exhibit, they also suffer the same limitations. For some tasks, sequential computing is better than using a Neural Network. On the other hand, Neural Networks provide excellent pattern and trend classification and matching power with fast response, reliability and efficiency [57]. Neural networks do not require explicitly stated rules as in Expert systems and probabilities of rule accuracy and data membership as in Fuzzy Logic. A Neural Network forms its own logic and stores the knowledge in its weights, and instead of being given rules, the neural network learns them by training with examples.

4.3 Fuzzy Logic

Fuzzy sets and Fuzzy Logic possess far greater capabilities than their classical counterparts to capture uncertainties and bridge between mathematical models and associated physical reality [58]. It is appropriate to use Fuzzy Logic when one or more of the control variables are continuous and when a mathematical model of the process does not exist, or exists, but is too complex to be evaluated fast enough for real-time operation [59]. Fuzzy logic can deal with a broader class of problems since it is capable of capturing the vagueness of input description. This, in turn, enables the modeling of human common-sense reasoning, diagnosis, decision making, and other aspects of human cognition.

The Fuzzy Logic based scheme, although very simple and fully traceable, may require off-line pre-installation self-setting [60,61]. As a consequence, the Fuzzy Logic based relaying technique lies between the classical Boolean founded approach (only expert knowledge is used) and the ANN methods (only knowledge extracted from examples is used). Table III compares the ANN and Fuzzy Logic based approaches.

5. CONCLUSIONS

The reported applications reveal significant differences in the number and maturity of applications in the area of power system protection. The differences exist between in-service and simulation applications as well as different intelligent system methodologies. Majority of reported applications are related to the theoretical concepts tested, evaluated and justified by the way of digital simulation. Only a few in-service applications were identified.

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TABLE III. Similarities and Differences between the Fuzzy Logic and ANN Approaches to Power System Production

Feature	Approach	
	Fuzzy Logic	Neural Networks
Knowledge used	Expert knowledge in the form of protection criteria.	Information extracted from the training cases. Expert knowledge also possible.
Troubleshooting and improving relay performance.	Easy-the internal signals are understandable and traceable.	Difficult-the internal signals are almost impossible to interpret. Re-learning seems the only method for troubleshooting.
Self-learning	Possible and efficient [60,61].	Natural.
Capability of handling uncertainty.	Natural.	Natural.
Robustness	Not-critical and easy to ensure since large amount of expert (analytical) knowledge used.	Difficult to ensure.
Setting a relay	Easy-both analytical knowledge and simulations data may be used.	Large number of simulations required. Generalization difficult to ensure.
Computational complexity	Moderate.	Dedicated hardware usually required.

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