

A Review on Artificial Intelligence Applied For Sophistication of Relay Protection

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ABSTRACT: Artificial intelligence (AI) is the ‘attempt’ of man to make the machines able to act and live like other living beings to make life of the human beings easier. One of the wide applications of the AI is in the protection of the electrical systems. The different technologies in the field of AI are used for the improvement in the relay protection system, so as to increase the power system stability and integrity. The paper reviews the different ways, expert systems, artificial neural network (ANN), fuzzy logic (FL), and wavelet transform fuzzy-neural logic in which the AI can be applied in the different fields of protection of the power system. Also, the concerns of some thinkers about the use of AI are discussed.

KEYWORDS: AI, protection, expert systems, ANN, FL, Wavelet transform, fuzzy-neural logic

I. INTRODUCTION

In electrical power systems a large number of messages and alarms are transmitted to the control center in case of disturbances. These disturbances are associated with faults that may be of different types and can occur anywhere in the system. An important objective of all the power systems is to maintain a very high level of continuity of service, and when abnormal conditions occur, to minimize the outage times. Abnormal conditions can cause short circuits i.e. faults which can either be single phase to ground, phase to phase, phase to phase to ground, or a three phase fault. The microprocessor technology brings unquestionable improvements of the protection relays- criteria signals are estimated in a shorter time; input signals are filtered-out more precisely; it is easy to apply sophisticated corrections; the hardware is standardized and may communicate with other protection and control systems; relays are capable of self-monitoring. All this, however, did not make a major breakthrough in power system protection as far as security, dependability and speed of operation are considered. The key reason behind this is that the principles used by digital relays blindly reproduce the criteria known for decades. The relaying task, however, may be approached as a *pattern recognition* problem - by monitoring its inputs, the relay classifies on-going transients between internal faults and all the other conditions. Or, the protective relaying may be considered as a *decision making* problem - the relay should decide whether to trip or retrain itself from tripping. This observation directly leads to AI application in power system protection. Practically, it includes the artificial neural network approach (pattern recognition), as well as the expert system and fuzzy logic methods (decision making). The paper includes the problems encountered while protecting the power system during abnormal conditions and various AI methods for solving the problems.

II. LITERATURE SURVEY

The problems result mainly from the trade-off between the security demand (no false tripping), and the speed of operation and the dependability (no missing operations) requirements. The more secure is the relay (both the algorithm and its particular settings), the more it tends to misoperate or operate slowly. And vice versa, the faster is

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the relay, the more it tends to operate falsely. The problems listed reflect the current practice in power system protection. There are basically two ways to mitigate the problem of limited recognition power of the classical relaying principles. One of them is to improve and extend the measurements available to a given relay (for example, optical CTs for improvement and substation integration for extension). The second way is to improve the recognition process itself based on what is already available and either:

- search for the new relaying principles, or
- apply several of known principles in one relay to improve the recognition, or
- apply correction of the CT and CVT transient error, or
- improve a type of fault determination by using of the ANNs classifier, or
- use self-organizing algorithms such as ANNs to find out automatically a protection principle.

It always takes certain time to estimate the criteria signals accurately enough to base the tripping decision on them. Either they are measured fast or accurately. There is no perfect digital measuring algorithm that solves this well-known conflict between the speed and the accuracy. Either certain pre-filtering is applied, or the basic algorithm uses longer data window; or certain post-filtering is employed (or even a combination of these three means). There is always a level of uncertainty in the estimate of the criteria signal at the beginning of a disturbance when the relay operation is mostly wanted. In some situations, although imprecise, the value of the criteria signal enables solid decision, but in other cases, such as a fault at the end of the protection zone, the relay must wait for more precise estimate of the criteria signals.

III. ARTIFICIAL INTELLEGEENCE METHODS

AI is a subfield of computer science that investigates how the thought and action of human beings can be mimicked by machines. Both the numeric, non-numeric and symbolic computations are included in the area of AI. The mimicking of intelligence includes not only the ability to make rational decisions, but also to deal with missing data, adapt to existing situations and improve itself in the long time horizon based on the accumulated experience. Three major families of AI techniques are considered to be applied in modern power system protection:

- Expert System Techniques (XPSs),
- Artificial Neural Networks (ANNs),
- Fuzzy Logic systems (FL),
- Wavelet Approach

A. Expert systems

The first expert systems included a few heuristic rules based on the expert's experience. In such systems, the knowledge takes the form of so called production rules written using the If... then... syntax (knowledge base). The system includes also the facts which generally describe the domain and the state of the problem to be solved (data base). A generic inference engine uses the facts and the rules to deduce new facts which allow the firing of other rules. The knowledge base is a collection of domain-specific knowledge and the inference system is the logic component for processing the knowledge base to solve the problem. This process continues until the base of facts is saturated and a conclusion has been reached (Fig.1). To guide the reasoning and to be more efficient, these systems may incorporate some strategies known as metaknowledge. Rule based systems represent still the majority of the existing expert systems. There are few applications of XPS to power system protection reported, but all of them solve the off-line tasks such as settings coordination, post-fault analysis and fault diagnosis. As yet there is no application reported of the XPS technique employed as a decision making tool in an on-line operating protective relay. The basic reason for this is that there is no extensive rule base that describes the reasoning process applicable to protective relaying. Instead, only a few rules or criteria are collected.

B. Artificial Neural Network

The ANNs are very different from expert systems since they do not need a knowledge base to work. Instead, they have to be trained with numerous actual cases. The reach accuracy of an electromechanical, static or a microprocessor based distance relay is affected by different fault conditions and network configuration changes. So ANN techniques, which can adapt dynamically to the system operating conditions at a high speed, can provide a required solution to

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great extent. The ability of ANN to learn by training any complex input/output mapping and recognize the noisy patterns (those with desired segments missing and/or undesired segments added) gives them the powerful property of pattern recognition and classification. An ANN is a set of elementary neurons which are connected together in different architectures organized in layers what is biologically inspired (Fig.2). An elementary neuron can be seen like a processor which makes a simple non linear operation of its inputs producing its single output. A weight (synapse) is attached to each neuron and the training enables adjusting of different weights according to the training set. The ANN techniques are attractive because they do not require tedious knowledge acquisition, representation and writing stages and, therefore, can be successfully applied for tasks not fully described in advance. The ANN are not programmed or supported by a knowledge base as are Expert Systems. Instead they learn a response based on given inputs and a required output by adjusting the node weights and biases accordingly. The speed of processing, allowing real time applications, is also an advantage.

Since ANNs can provide excellent pattern recognition, they are proposed by many researchers to perform different tasks in power system relaying for signal processing and decision making. The common application of the ANN technique assumes:

- The ANN is fed either with non-processed samples of the input signals, or by features of those signals extracted using certain measuring algorithms (or by a combination).
- The sliding data window consisting of the recent and a few historical samples of the signals is fed to the ANN.
- The output from the ANN encodes the output decision such as tripping command, type of fault, direction of fault, etc.
- The training patterns exposed to the ANN cover the most important operating conditions both internal faults and other disturbances. Typically, only the selected window positions are used for training.
- Additional pre- and post-processing may be applied. The most widespread application of ANNs is in pattern classification and associative memory where they can learn to distinguish between classes of inputs and, therefore, they can be successively used for decision making and phenomena classification. A major problem with ANNs is that no exact guide exists for the choice to the number of hidden layers and neurons per hidden layer. On the other hand, the ability to generalize is one of the main advantages of using ANNs.

C. Fuzzy Logic

With reference to Fig.3 the fuzzy logic approach to protective relaying assumes [6]:

- The criteria signals are fuzzified in order to account for dynamic errors of the measuring algorithms. Thus, instead of real numbers, the signals are represented by fuzzy numbers. Since the fuzzification process provides a special kind of flexible filtering, faster measuring algorithms that speed up the relays may be used.
- The thresholds for the criteria signals are also represented by fuzzy numbers to account for the lack of precision in dividing the space of the criteria signals between the tripping and blocking regions.
- The fuzzy signals are compared with the fuzzy settings. The comparison result is a fuzzy logic variable between the Boolean absolute levels of truth and false.
- Several relaying criteria are used in parallel. The criteria are aggregated by means of formal multi-criteria decision-making algorithms that allow the criteria to be weighted according to their reasoning ability.
- The tripping decision depends on multi-criteria evaluation of the status of a protected element. Additional decision factors may include the amount of available information, or the expected costs of relay mal-operation. The XPS, ANN and FL approaches have their own advantages and limitations. Table I compares the basic features of these AI methods.

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Table I. Compares of AI methods that are used for various functions that are important with relevance to the power system protection. It compares the functions of the methods that are or can be used for the protection purpose in electrical power systems.

FEATURES	Approach		
	XPS	ANNs	FL
Knowledge Used	Expert knowledge in the form of rules, objects, frames, etc.	Information extracted from the training set of cases.	Expert knowledge in the form of protection criteria.
Troubleshooting and improving a relay	Change of rules required	Difficult- the internal signals are almost impossible to interpret	Convenient- internal signals are understandable and analyzable
Self-learning	Possible	Natural	Possible
Handling unclear Cases	Possible	Natural	Possible
Robustness	Not critical and easy to ensure	Difficult to ensure	Not critical and easy to ensure
Setting a Relay	Convenient	Large no. of simulation required	Convenient both knowledge and simulation are used
Computations	Extensive	Dedicated hardware	Moderate

D. Wavelet Approach

The fundamental frequency components of the post fault voltages and currents need to be extracted as quickly and accurately as possible for the quick response of a digital relay. Wavelet approach is one of the new tools in this direction which is useful for power system transient analysis, since the conventional signal processing techniques have the inherent disadvantages of long discrimination time, errors in impedance calculations and misclassifications (during CT saturation and in presence of fault resistance). Wavelet transform (WT) has the ability to perform local analysis of relaying signals without losing the time-frequency information. WT in conjunction with AI/Fuzzy/Expert system/SVM based techniques have the advantage of fast response and increased accuracy in fault type and location identification.

A preprocessing module based on discrete wavelet transform (DWTs) considerably simplifies the input signal, reducing the volume of input data fed into an ANN that classifies the fault events. An example of WT, solution for protection of parallel transmission lines by decomposing fault current signals using WT and by comparing the magnitudes of line currents in the corresponding phases is presented by Osman et al., (2004).

The ability of wavelets to decompose the signal into different frequency bands using multi resolution analysis (MRA) allows detecting and classifying faults as well as extracting the voltage and current fundamental phasors needed to calculate the impedance to the fault point in distance protection and with filtering algorithms, fast relay operating times are obtained. Discrete wavelet transform based MRA is used for feature extraction and the features extracted from fault current signals are used to train and test the support vector machine (SVM) for fault classification and the

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fault location from the relaying point is computed by RBFNN. A solution to the complexities of the protection of series compensated transmission lines, is proposed, which is a combination of wavelet-SVM technique for fault zone identification. In a Fuzzy-logic-wavelet based technique the wavelet transform of current signal provides hidden information of a fault situation to FLS, to classify the fault. These fuzzy procedures solve the problem with simple computational procedures rather than using more complex algorithms in the deterministic way.

The combined techniques of WT with ANN and WT with Fuzzy Logic depend on huge samples and trainings for knowledge representation, leading to an excessively complicated job. Wavelet singular entropy (WSE) technique which indicates the uncertainty of the energy distribution in the time-frequency domain is used to extract features from fault transients for the fault diagnosis in EHV transmission lines. The capabilities of wavelets are affected owing to the existence of noises riding high on the signal and the problem lies in identification of the most suitable wavelet family that is more approximate for use in estimating fault location. Most of the wavelet based techniques employ multi-level wavelet decomposition, which requires multi-level filtering followed by complex computations. Wavelet transform can help as a powerful tool in protection of electrical system provided further work is done in reducing the algorithm complexity, computational burden and response time.

IV. APPLICATIONS

The discussed AI methods can be applied to various schemes of protection of power system. The various applications are listed below. Most of the following applications utilize the combination of the different AI methods.

- a) Protection of different electrical equipments such as transformers, transmission lines, generators and generating stations, etc.
- b) Measurement of various electrical quantities
- c) Fault location, fault type identification and diagnosis
- d) Analysis of the fault data acquired
- e) CT and CVT correction
- f) Advanced features like directional on over-current devices, breaker co-ordination, etc.

The AI can also be used for the protection of the recently trending smart grid and the distributed generation. The above mentioned applications of the artificial intelligence reduce the errors in the measurement of the electrical quantities during normal as well as faulty conditions, thereby helping us to monitor the power system accurately and efficiently.

V. THE DEBATE

We are trying our best to 'create' humans; however, some people think the idea of intelligent protection as a danger to the system integrity and even to the human race. The reason behind their thinking is the events causing failure of the energy system of different countries of America and Europe; those were the results of unpredictable response of the protection relay during complex emergency modes due to disabling wrong sectors of network.

There is sense of danger of excessive concentration of protective functions in a single terminal, additional relay protection functions, extrinsic to the protection itself, not only lead to the physical complication of the device, consequently reducing its reliability, but also to the complication of its software and user interface.

The main concern is that the protection system may become self-aware may lead to the different actions that will not be in the favour of the system health defined by humans. Therefore, even though there is significant progress in the development of artificial intelligence, there is difference in opinion about its intentions and result as well.

VI. CONCLUSION

The artificial intelligence proves very important in a way so as to increase the accuracy and efficiency of the power system protection. Combining the various methods discussed the power system protection integrity the different advantages of the methods can be exploited while overcoming their disadvantages, thereby making the system more robust and reliable.

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