A REVIEW OF ADAPTIVE AUTORECLOSURE TECHNIQUES

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Abstract

Adaptive autoreclosing is a fast emerging technology for improving power system marginal stability during faults. It avoids reclosing unto permanent faults and recloses unto transient faults only after the secondary arc has extinguished. This paper presents a comprehensive review of various adaptive autoreclosure techniques. It aims at providing a broad perspective on adaptive autoreclosing techniques to researchers and application engineers.

Keywords: Adaptive autoreclosing; Adaptive single-pole autoreclosing; Adaptive three-phase autoreclosing; Artificial neural network; Signal processing.

1. Introduction

Electricity providers all over the world have in recent times been confronted with the challenging task of meeting the ever-growing demand for electrical power.

This growing electrical power demand is as a result of the increasing trend of industrialisation and population growth. The massive load centres are concentrated in areas which are often distant from the generating stations, and thus require the building of transmission lines to transport the power. Not only must electricity providers be able to meet the growing need, they must also do so in a reliable, quality, economical, and secure manner.

With regards to the transmission of electric power to these load centres, electric power providers have these options: (a) Construction of new transmission networks, (b) Addition of another circuit to existing single transmission circuits, i.e. double-circuit lines, and (c) Upgrading of existing transmission networks; be it single or double-circuit, in other to operate at higher voltage levels [Bán, *et al.* (1998)]. The option of constructing new transmission networks (a) is however not considered owing to the huge economic and environmental implications; the cost of new conductors, towers, insulators, protection equipments, the difficulty in acquiring new right-of-ways, and the environmental battles that must be fought, deter electricity suppliers from considering this option. Option (b) seems worth considering, however, its implementation also comes with a cost. The cost mainly involves the reconfiguration or replacement of towers, and the acquisition of new conductors and insulators. The reversion to double-circuits will also demand changes in the existing protection system. The last option, (c), of increasing the loading capabilities of existing transmission systems is an option which is adopted by most providers of this utility. The upgrading of existing transmission lines does not require much monetary requirements since the construction will not result in completely new lines and the towers remain the same [Bán, *et al.* (1998)].

Notwithstanding the financial gains in resorting to the upgrading of existing transmission lines, pushing more power through existing transmission systems threatens the marginal stability of the system [Aggarwal, (1998)]. The problem of marginal stability, coupled with the frequent occurrence of faults on power systems poses serious threats to the quality, reliability of supply, and the overall security of the power system.

The advent of autoreclosures has brought a huge sigh of relief to electricity providers [Gardiner and Ramsden, (1997)]. The application of autoreclosures to power systems improves marginal stability, power quality (voltage dips are avoided), security and reliability of supply [Aggarwal, (1998)]. Autoreclosures can be classified into conventional and adaptive autoreclosures.

Conventional autoreclosures reclose a circuit after a fixed (dead) time, following a trip initiated by a fault, and can be single-pole or three-pole [Fitton and Gardiner, (1995)]. This can lead to reclosure unto permanent and transient faults, shock to system, and endangering of system stability. Properly designed adaptive autoreclosures, owing to their being able to adapt reclosure times, overcome the aforementioned disadvantages.

2. Adaptive Autoreclosures

Properly designed adaptive autoreclosures provide a distinction between permanent and transient faults. Reclosure is inhibited when a fault is permanent and in the case of a transient fault, the optimal reclosure time is determined. Adaptive autoreclosures can be classified into Adaptive single-pole or single-phase autoreclosures (AdSPARs) and Adaptive three-phase autoreclosures (AdTPARs).

Adaptive single-pole autoreclosing is the autoreclosing of one phase of a circuit breaker following a single-phase trip for single-phase-to-ground faults, with the autoreclosing time based on existing specific conditions on the transmission line [El-Serafi and Faried, (1994)], [NPPC, (2005)]. Adaptive three-phase autoreclosing involves the autoreclosing of all three phases of a circuit following a three-phase trip. Three-phase autoreclosure failures however have more serious consequences to the power system than sing-phase autoreclosure failures.

Adaptive autoreclosures afford the following advantages [Aggarwal *et al.* (1994)], [Esztergalyos *et al.* (2005)] to a power system:

- Improvements in transient stability.
- Improvements in system reliability and availability, especially where remote generating stations are connected to load centres with one or two transmission lines
- Reduction of switching overvoltages.
- Reduction of shaft torsional oscillation of large thermal units.
- High-speed response to a sympathy trip.
- Minimised unsuccessful reclosing.
- Reduction in system and equipment shock.

The successful development of an excellent adaptive autoreclosing technique is inhibited by factors such as the complex nature of the transmission network (line configuration, source parameters, system loadings, and system voltage), different fault types and locations, fault point on wave, and atmospheric conditions [Aggarwal, (1998)],[Aggarwal *et al.* (1994)].

Properly designed adaptive autoreclosures are expected to meet the following requirements:

- Make a clear distinction between permanent and transient faults.
- Avoid reclosing unto permanent faults.
- Determine the extinction time of a transient fault arc.
- Provide an optimal reclosure time.
- Perform satisfactorily under varying power system operating conditions such as loading, noise and atmospheric conditions.
- Less expensive and easy to implement.

The adaptive single-pole autoreclosure schemes that have been proposed can be classified into four major groups. These groups have been reviewed in sub-sections 2.1 to 2.4. Subsection 2.5 discusses adaptive three-phase autoreclosure schemes.

2.1. *AdSPAR schemes based on the comparison of voltage magnitudes*

In these schemes [Aboreshaid *et al.* (1998)], [Aggarwal *et al.* (1993a)], fault classification is achieved by measuring and comparing the voltage of the tripped phase to that of the energized phases. A fault is considered to be permanent when the magnitude of the faulted phase voltage is zero. The prediction of secondary arc extinction time which is only captured by [Aggarwal et al. (1993a)] is done by identifying the amplitudes and associated frequencies of the post-clearance voltage waveform patterns.

Albeit these techniques are simple to implement, they have the following flaws:

- The voltage of the tripped phase associated with a permanent fault is not always zero. The actual magnitude heavily depends on the type of permanent fault. Example, whether the fault is a high or a low impedance fault. Generally, the voltage increases with increasing fault impedance [Aggarwal et al. (1993a)]. Thus, the method will construe a permanent fault with a small voltage magnitude for a transient fault and therefore reclose.
- It has been admitted in [Aggarwal et al. (1993a)] that owing to the fact that (i) the voltage magnitudes at each end of the isolated conductor can vary substantially with load currents and fault location, (ii) it is very difficult to estimate the actual magnitude of the voltage associated with a permanent fault and (iii) the effect of fault

impedance on the magnitude of voltage, these methods may erroneous in distinguishing a transient fault from a permanent one.

- They are limited by their inability to cope with previously unencountered situations and are also not robust in the presence of noise.
- The many causes of faults and the interplay of several factors such as line construction, fault position, prefault loading, source parameters, and atmospheric conditions which influence the actual waveforms of the secondary arc voltage may hinder the effectiveness of these techniques [Aggarwal *et al.* (1994)].

2.2. ***AdSPAR schemes based on various fault voltage components***

The algorithm in [Park *et al.* (2004)] determines the time of secondary arc extinction by using the Discrete Fourier Transform to compute the total harmonic distortion factor of the voltage signal of faulted and tripped phases. The algorithm derives its backing from the assertion that “the voltage waveform of the faulted phase during the secondary arc is greatly distorted compared with the same voltage after the secondary arc extinction” [Park et al. (2004)]. It is however unable to predict an exact secondary arc extinction time, it only provides a range of ‘safe to reclose time’. The algorithm in [Abouelenin *et al.* (2003)] obtains the difference in value between the present value of the DC component and the value of the DC component ¼ a cycle ago, and then compares the difference to a predetermined threshold value**.** The same procedure is repeated for the fundamental component for the difference between the present value and the value of the fundamental component ¼ a cycle ago with a threshold value. The difference-value of the DC component and the fundamental component should both exceed their threshold values, for a number of samples for the algorithm to determine the extinction time of the secondary arc.

The schemes presented in [Kim *et al.* (200)], [Ahn *et al.* (2001)]- [Ahn *et al.* (2006)] utilizes the rms-value of the faulted voltage waveform. When the difference between the present rms-value and the previous rms-value at each time step is greater than or equal to a certain differential threshold, a certain duration threshold is incremented; arc extinction time is reached when the duration threshold attains a certainty value. The tracked rms-value of a permanent fault however has no sudden increment.

Another AdSPAR scheme that has been proposed in [Yu and Song, (1998a)] employs the Daubechies 4 discrete wavelet transform to analyse fault transients and extracts wavelet levels 1, 5 and 6. A threshold-based decision logic for the wavelet coefficients is used to distinguish between transient and permanent faults, and also predict secondary arc extinction time.

The algorithms in [Abouelenin et al. (2003)], [Ahn *et al.* (2001)] and [Ahn *et al.* (2006)] detect a permanent fault at a time which is equivalent to the time of secondary arc extinction. Thus it takes a longer time to detect a permanent fault.

Ones again, the many causes of faults and the interplay of several factors such as line construction, fault position, prefault loading, source parameters, and atmospheric conditions which influence the actual waveforms of the secondary arc voltage may hinder the effectiveness of these techniques [Aggarwal *et al.* (1994)]. They are also limited by their inability to cope with previously unencountered situations and are also not robust in the presence of noise.

2.3 *AdSPAR schemes based on various fault generated high frequency transient signals*

These schemes utilize high frequency voltage [Bo *et al.* (1997)] or current signals [Youyi *et al.* (2001)], [Aggarwal *et al.* (1997)] and [Chen *et al.* (2003)] to distinguish between permanent and transient faults and also predict optimal reclosure times. While the algorithm in [Bo *et al.* (1997)] makes use of busbar voltages and generator output currents to predict arc extinction times, the technique in [Aggarwal *et al.* (1997)] uses a spectral energy computation to detect the optimal reclosure time. On the other hand, the scheme in [Chen *et al.* (2003)] predicts its optimal reclosure time by computing the transient energy of the power system. The proposed method in [Youyi *et al.* (2001)] however does not have arc extinction time determination capabilities.

The following limitations can be pointed out:

- The high cost of high frequency transient voltage detectors in [Bo *et al.* (1997)].
- Difficulty in calculating the spectral and transient energies of a practical system.
- The many causes of faults and the interplay of several factors such as line construction, fault position, pre-fault loading, source parameters, and atmospheric conditions which influence the actual waveforms of the secondary arc voltage may hinder the effectiveness of these techniques [Aggarwal *et al.* (1994)].
- These schemes are also limited in their ability to cope with previously unencountered situations and are also not robust in the presence of noise.

2.4 *AdSPAR schemes based on artificial neural networks*

Artificial Neural Networks (ANNs) are mathematical tools originally inspired by how the human brain processes information. ANNs are composed of simple elements (neurons) operating in parallel with connections (weights) between them. The network function is determined largely by the weights between neurons. ANNs can be trained to perform a particular function by adjusting the values of the weights between neurons. Fig. 1 illustrates the ANN training concept.

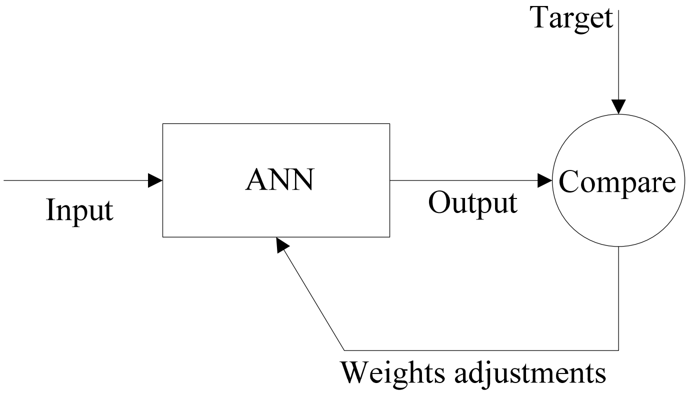

Fig. 1. ANN training concept

Typically, a number of input/target pairs are needed to train a network. A neuron receives numerical information through a number of input nodes, processes it internally, and puts out a response. The processing is usually done in two stages: first, the input values are linearly combined, and then the result is used as the argument of a nonlinear activation function. The combination uses the *weights* attributed to each connection, and a constant bias term. Fig. 2 shows one of the most used schemes for a neuron.

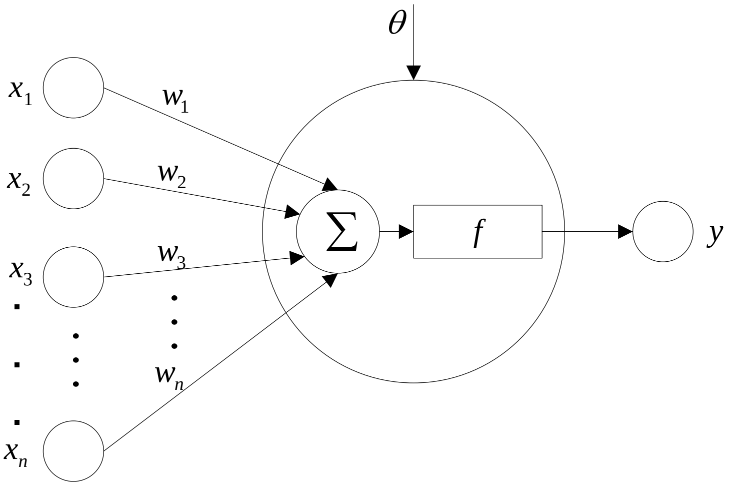

Fig.2. An artificial neuron

The neuron output y is given by:

$$y = f\left[\left(\sum_{i=1}^{n} w_i x_i - \theta\right)\right], \quad i = 1, 2, 3, \ldots, n \tag{1}$$

Where x_i the neuron input; w_i is the weight; θ is the characteristic neuron offset (bias) and f is the activation function [Al-Shareef *et al*. (2008)].

Neural networks are able to derive meaning from complicated or imprecise data and can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques [Gershenson, (2001)].

The schemes based on artificial neural networks employed either Fourier transform[Aggarwal et al. (1994)], short-time fast Fourier transform [Fitton *et al*. (1996)], [Zoric *et al*. (2000)] or wavelet transform [Frimpong *et al*. (2009)], [Frimpong *et al*. (2010)], [Yu and Song, (1998a)], [Yu and Song, (1998b)], [El-Hadidy *et al*. (2004)] and [Chen *et al*. (2004)] to decompose voltage waveforms. Vital features extracted from the decomposed waveforms were then used to train various neural networks to distinction between permanent and transient faults and also predict transient arc extinction times. The trained neural networks can then be used for real-time operations. Recurrent [Lukowicz, (2004)], Multi-layer perceptron [Aggarwal et al. (1994)], [Fitton *et al*. (1996)], [Frimpong *et al*. (2009)], [Frimpong *et al*. (2010)], [Yu and Song, (1998a)], [Yu and Song, (1998b)], [El-Hadidy *et al*. (2004)] and Radial basis function [Chen *et al*. (2004)] are the neural networks that have been employed.

Albeit, the use of neural networks requires extensive off-line preparations, these schemes have the following advantages, albeit with varying degrees:

- These schemes are easy and inexpensive to implement; they make use of existing protection hardware.
- They can cope with previously unencountered situations and are robust in the presence of noise.

A general block diagram of an ANN-based adaptive autoreclosure scheme is shown in fig. 3.

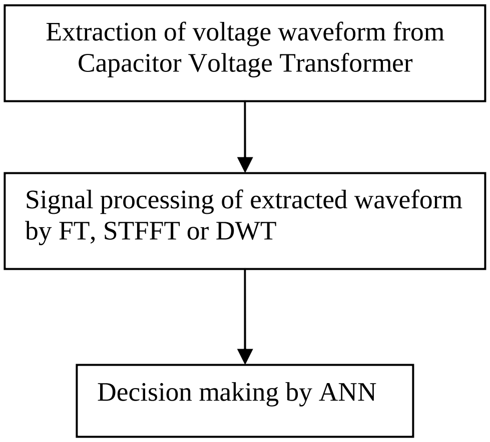

Fig. 3. General block diagram of ANN-based AdSPARs

2.5 *Adaptive three-phase autoreclosures(AdTPARs)*

The method proposed in [Terzija and Radojevic, (2004)] utilises an algorithm which is derived in the time domain and based on the differential equations describing the electromagnetic transients on overhead lines. The method is however only able to classify faults; it cannot determine the secondary arc extinction time.

Another AdTPAR method has been proposed in the paper titled: “A New Adaptive Autoreclosure Scheme to Distinguish Transient Faults from Permanent Faults”[Qiang *et al*. (2002)]. The proposed method is based on the carrier channel protection and modal analysis. However, like the scheme developed in [Terzija and Radojevic, (2004)], this method is only able to distinguish between faults. Likewise, the technique proposed in [Youyi *et al*. (2001)] provides only a partial solution to the three-phase autoreclosure problem.

The method proposed in [Aggarwal *et al*. (1993b)] which employed an artificial neural network has the ability to identify faults (permanent or transient) and also determine the secondary arc extinction time. The method was however developed for double-circuit transmission systems and will not work for single-circuit lines.

3. Conclusions

A number of adaptive autoreclosure schemes have been reviewed in this paper. The schemes were reviewed under the following groups: Adaptive single-pole autoreclosure (AdSPAR) schemes based on the comparison of voltage magnitudes, AdSPAR schemes based on various fault voltage components, AdSPAR schemes based on various fault generated high frequency transient signals, AdSPAR schemes based on artificial neural networks and Adaptive three-phase autoreclosure schemes.

The fast, easy and less expensive to implement nature, as well as the robustness of AdSPARs developed with artificial neural networks put them above the rest of the AdSPAR techniques. Among the signal processing tools that have been employed in the ANN schemes, the discrete wavelet transform has so far been proved to be most effective. This is due to its ability to provide multiple resolutions in time and frequency, and also its robustness to noise.

With the regards to the neural network architecture, the MLP and the RBF have been shown to be most robust and effective for such design. It is therefore the view of the authors that an AdSPAR scheme based on discrete wavelet transform and MLP or RBF will be most ideal. However, the writers are conducting a research which seeks to compare the performance of short-time Fourier transform and Discrete wavelet transform as well as MLP and RBF in the design of adaptive autoreclosure schemes.

As regards Adaptive three-phase autoreclosure(AdTPAR) schemes, no method exits which has the ability to distinguish between faults, and also determine the secondary arc extinguishing time for single-circuit transmission systems. The difficulty in the fulfilment of these tasks is due to the fact that:

- there are lots of fault transient components before tripping which conceal the characteristics of fault arc .
- after three-phase tripping, the transmission line is separated from the power source completely.

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