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Non-intrusive fault identification of power distribution systems in intelligent buildings based on power-spectrum-based wavelet transform

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ABSTRACT

A new approach for protection of power distribution systems in intelligent buildings has been presented in this paper. Directly adopting the wavelet transform coefficients (WTCs) requires longer computation time and larger memory requirements for the non-intrusive fault monitoring (NIFM) identification process. However, the WTCs contain plenty of information needed for the symmetric and asymmetric transient signals of fault events. To effectively reduce the number of WTCs representing fault transient signals without degrading performance, a power spectrum of the WTCs in different scales calculated by Parseval's Theorem is proposed in this paper. In this paper, artificial neural networks (ANNs), in combination with power-spectrum-based wavelet transform, are used to identify fault types and locations in power distribution systems of industrial buildings by using NIFM. The high success rates of fault event recognition for load-bus faults and transmission-line faults from simulations have proved that the proposed algorithm is applicable to fault identifications of non-intrusive monitoring applications.

1. Introduction

In protection analyses of power system, power system fault is one of the most important research topics. These faults which are mainly due to short circuit phenomena can drastically fail the operations of power systems and cause excessively high currents to flow which causes damages to devices and fire accidents to buildings. Types of faults, like a short circuit condition in a power system distribution network, will result in severe economic losses and reduce the reliability of the electrical system. Different types of transient phenomena occur on the transmission line. From these transient phenomena, faults on transmission lines and load buses need to be detected, located, classified accurately, and cleared as fast as possible. In earth fault and short-circuit protections, faulty phase identification and location of fault are the two most important items which need to be addressed in a reliable and accurate manner. In multiple phases system, the faults are basically divided into symmetric (balanced) and asymmetric (un-balanced) types. The type of symmetric fault is only a balanced three-line-to-ground fault (LLLGF). Different types of asymmetric faults are single line-to-ground fault (SLGF), line-to-line fault (LLF), and double line-to-ground fault (DLGF).

1.1. Research background

Due to the serious consequences of fault damages in power systems, many researchers have devoted their efforts to this area and reported their findings in articles. Chunju et al. [1] have proposed a SLGF location method for employing wavelet fuzzy neural network (WFNN) to extract fault characteristics from the fault signals in an industrial distribution power system. However, this method cannot significantly increase the fault location accuracy because it does not use the high frequency information of pre-fault current and voltage. In fact, when fault location changes, the equivalent capacitance will change, the charging and discharging currents will be also changed, namely the high frequency currents are different. The high frequency currents and voltages are related with the distance from the relaying point to the fault location. Borghetti et al. [2] have built specific mother wavelets inferred from the recorded fault-originated voltage transient waveforms to improve the wavelet analysis. In this paper, the authors assumed that the network topology and the traveling wave speeds of the various propagation modes are known. However, as concluded in [2], this method is expected to improve the algorithm accuracy by means of proper integration of time-domain fault location approaches. Reference [3] has used

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Acronyms

ANFIS	Adaptive neuro-fuzzy inference system
ANN	Artificial neural network
BP-ANN	Back-propagation artificial neural network
DLGF	Double line-to-ground fault
DWT	Discrete wavelet transform
EMTP	Electromagnetic transient program
ESE	Electrical service entry
FTED	Fault transient event detection
LLF	Line-to-line fault
LLLGF	Three-line-to-ground fault
MDMS	Meter database management system
MFNN	Multi-layer feed-forward neural network
NIFM	Non-intrusive fault monitoring
NILM	Non-intrusive load monitoring
PSO	Particle swarm optimization
PSs	Power signatures
SCADA	Supervisory control and data acquisition
SE	Spectral envelope
SLGF	Single line-to-ground fault
STFT	Short-time fourier transform
U_T	Turn-on transient energy algorithm
WFNN	Wavelet fuzzy neural network
WMRA	Wavelet multi-resolution analysis
WPT	Wavelet packet transform
WTCs	Wavelet transform coefficients

wavelet energy and entropy criterion of the wavelet packet transform (WPT) coefficients for every faulty current and voltage signal to extract features and reduce the size of data sets for training and testing of artificial neural networks (ANNs). However, this method only implements in SLGF of power systems. Reddy et al. [4] have performed well to use a wavelet multi-resolution analysis (WMRA) technique to extract the features of the transient current signals and employed computational intelligence techniques as an adaptive neuro-fuzzy inference system (ANFIS) and ANN in conjunction with GPS to identify fault location. This paper focuses on amplitudes of the second- and third-order harmonics generated during fault current occurrence to track the fault location. Therefore, among different coefficients pertaining to different decomposition levels, only the summation of the fifth-level detailed coefficients (d5) is considered for the sampling rate of 6 kHz. Bezerra Costa [5] has presented a wavelet-based methodology for real-time detection of fault-induced transients in transmission lines, where the wavelet coefficient energy takes into account the border effects of the sliding windows. As a result, the performance of the proposed energy analysis is not affected by the choice of the mother wavelet and presenting no time delay in real-time fault detection.

The concept of non-intrusive load monitoring (NILM) was originally introduced at MIT by Hart [6] in late 80s. The NILM, in contrast with the traditional supervisory control and data acquisition (SCADA)-based system, can drastically reduce hardware and maintenance costs because only one set of voltage and current sensors is needed at the electrical service entry (ESE) [6]. Although several NILM algorithms were developed during the past two decades, recognition accuracy and computational efficiency have been remaining as challenges. Hart proposed a method for disaggregating electrical loads by examining only the appliance specific power consumption signatures within the aggregated load data [7]. However, the voltage variations of the utility may result in overlapping of loads in the P-Q plane [8], different loads may consume the same real and reactive powers or they are with the simultaneous start and power signatures (PSs) that have non-discrete changes in power consumption may not be adequately measured only from steady-state parameters [6,9]. In addition to the steady-state power draw, Leeb et al. have used the "spectral envelope" (SE) concept [10] for a NILM system. The SE is a vector of the first several coefficients of the short-time Fourier transform (STFT) of the transient current signal. Although this method can detect numerous appliances including the variable loads, it requires extensive training for each appliance before classification and monitoring can be performed. Yang et al. [11] employed a turn-on transient energy algorithm (U_T) in a non-intrusive monitoring of industrial electrical loads. However, this algorithm requires a high sampling rate to accurately capture the detailed variations in the transient energy. Recently, there has been a growing interest in improving the performance of recognition for using artificial intelligence methods such as ANNs. Srinivasan et al. [12] proposed a NN-based approach to identify harmonic sources. However, the method does not incorporate the various operation modes in each load. In [13], the authors have applied particle swarm optimization (PSO) to optimize the parameters of training algorithms in NN for improving the recognition accuracy. Nevertheless, the resulting training time could be quite long.

1.2. Problems and contributions

However, as far as the author is well aware that fault identification for the distribution system of an industrial building by using non-intrusive monitoring techniques is still in the primary stage of development. Based on the concept of the NILM, this paper proposes new fault identification approaches for load-bus faults and transmission-line faults on low-voltage power distribution systems in intelligent buildings by using non-intrusive monitoring techniques. The non-intrusive fault monitoring (NIFM) refers to a method of detecting the current waveforms of a distribution system using a single set of sensors at ESE. Fig. 1 shows a typical NIFM system on power distribution systems in an industrial building. Three-phase three-wire and three-phase four-wire systems are generally used to run a typical power system distribution network. As shown in the figure, the secondary side of the distribution transformer, the voltage and current at ESE are measured and sent to the meter database management system (MDMS). This data is processed by the NIFM algorithms to identify the operation statuses and fault events for the individual feeder.

As in the existing methods mentioned above, the wavelet transform (WT) technology has been often used to capture the time of transient occurrence [14]. Integrating the WT technology with the artificial intelligence method or expert system becomes a promising approach to improve the recognition accuracy of fault events. However, the following issues must be overcome before their practicality can be realized for a non-intrusive classifier in the NIFM system [15].

1) Directly adopting the WT coefficients as inputs of the NNs requires large memory space and long training time;
2) The decomposition level with the number of extraction features must be reduced to enhance computation efficiency of the NIFM system;
3) Not only can symmetric and asymmetric fault events be identified but load-bus faults and transmission-line faults can also be detected.
4) The reliability of the electrical system cannot be reduced even only one set of voltage and current sensors is needed at ESE.

In an effort to overcome some of the above-mentioned problems, a new NIFM system is proposed in this paper. This paper presents a novel classifier consisting of two models as shown in Fig. 2. First, the WMRA technique and Parseval's Theorem are