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Protection of smart substation based on WLAN complies with IEC 61850 using traveling wave analysis

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ABSTRACT

Fast protection of distribution substation based on traveling wave is becoming a reality today. The transient traveling wave is mostly used in protection to determine the faulted line and the fault location. The advantages of signal of traveling wave includes immunity to system oscillation, transition resistance, CT saturation, and neutral point operation modes. In this article, a detailed study for analyzing the performance of using WLAN for real time protection based on the transient traveling wave. The high sampling frequency needed for traveling wave causes blockage in communication in the process bus. Now a packing of multi samples with suitable compression techniques in Merging Unit (MU), or using feature extraction with Hilbert–Huang transform with WLAN compliance with IEC 61850 has been tested. Further, this article presents the modeling and simulation of a WLAN communication network for an automation system using the precepts of IEC 61850, which is currently becoming a trend in Substation Automation System (SAS) specification. This article also investigates the impact of impulsive and interface noise on WLAN performance. Finally, the article advocates the wide application of traveling waves in the digital substations based on the IEC 61850 protocol.

1. Introduction

The IEC 61850 is considered a powerful protocol used in substation automation. It has an advantage being international standard, it permits cross border transmission of data through electrical installations. The most important element is to define data in the form of objects with a unique name and definite behavior. This ensures interoperability of devices devised by distinct manufacturers. The IEC 61850 standard is the result of cooperation among the manufacturers and users to create a uniform and futuristic approach for the protection, communication, and control of substations [1].

GOOSE is an acronym for “Generic Object-Oriented Substation Event” which is a particular fast communication service that functions independently between the server (bay control unit) and client (centralized station controller). According to IEC 61850-8-1, GOOSE, a swift communication must occur directly among protection devices and bay control units. GOOSE can also be used to implement switchgear interlocking across bays (substation interlocking) [2–7].

Smart Grid electricity production and distribution system network uses various modern digital technologies like smart meters and smart appliances in order to enable proper and reliable production and distribution of the electrical energy. Based on the state of the system, the various changes can be done automatically to eliminate the disturbances and to go back to the normal working state. Smart Grid offers affordability, sustainable power, improves reliability and stability of the network, reduces CO_2 emission, improve energy efficiency, connect the renewable energy to the grid, and connect the DERs (Distribution Energy Resources) to the energy system. These demands create new challenges. Smart grid can provide the entire, by installing digital equipment in our existing infrastructure, our generator and electrical utilities can interconnect all as us in optimized the control their network.

WLAN has been widely used in smart grid. Numerous researches in the field of WLAN have been employing it in industrial

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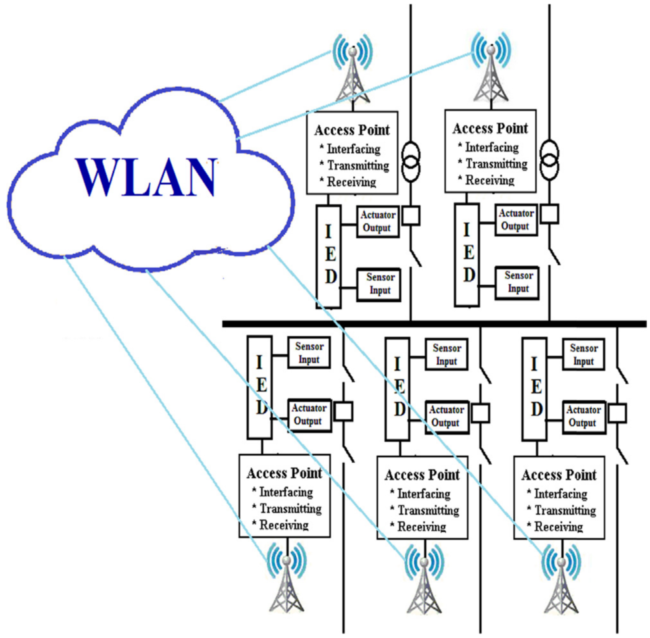

Fig. 1. Schematic diagram of the proposed protection system for smart substations.

applications. The infrastructure needed to implement WLAN is quite simple and it can also be used for protection application, monitoring, and control. There are a few manufacturers that have developed WLAN for automation and protection purposes. The time delay of WLAN used for protection and control was tested by the authors and noted that it must satisfy the requirement specified in IEC 61850 part 5. There have been several researches that suggest the use of WLAN in substation for protection, fault location, and fault line selection. These applications can be divided into two groups; they are respectively, real time protection relays and non-real time fault location and fault line selection [8–16].

IEC 61850 is a data management protocol, and the channel bandwidth does not represent any issue. In spite of that IEC 61850 have not used traveling wave technique for fast protection, this is because the output model type of SV (Sample Value) message is periodic, and since the traveling wave sampling frequency is very high between 200 KHz and 1 MHz, this leads to network blocking. Furthermore, expensive but high data-rate fiber-based Ethernet networks may not be a feasible solution for the MV/LV (Medium voltage/Low voltage) distribution network. Extensive work is carried out to assess wireless LAN technologies for various IEC 61850 based smart distribution substation applications: control and monitoring; automation and metering; and over-current protection.

The fast protection system based on traveling wave for smart substation proposed in this article consists of intelligent relays, located at each line terminal connected to the substation. The Intelligent Electronic Devices (IED) record the measurements of the traveling wave during fault condition using COMTRADE recorder. The measured data is processed using Digital Signal Processing algorithms to determine the Faulted line and initiate a tripping signal to the circuit breaker. All the measured data using IED are exchanged to make an accurate decision. Furthermore, the delay is calculated using second generation, more modern IEEE 802.11n technology, which resolves the issue of three limit actions including capacity, channel inefficiency, and inability of handling multipath. Fig. 1 shows the schematic diagram of the proposed protection technique for smart substations.

The article also presents an assessment of WLAN performance for IEC 61850 based on smart distribution substation applications.

The rest of the article is organized as follows. In section II, the application of traveling wave signals in Smart Substation is described. Section III shows the traveling wave compression using wavelet transform. Section IV presents the communication Data Flow analysis. The communication data delay is described in section V. The protection through featured extraction is described in section VI. Finally, the conclusion of the article is given in section VII.

2. Application of traveling wave signals in smart substation

The substations are connected as shown in Fig. 1 with a power transmission line from their end. The transmission lines are the most frequently faulted element of the electrical power system. There are many causes of the faults; phase and ground faults, human mishandling and lightning. Faults result in short to long-term power outages for customers and may lead to considerable losses. Thus, determination of fault location in high voltage power transmission lines is absolutely essential. Fault location can be determined using traveling wave detectors located at the substation line end. Accurate fault location can aid in the fast restoration of power [17,18].

The traveling wave detectors at substation lines ends require a high sampling rate >200 kHz. The traveling wave for real time application, such as protection, cannot be supported by the 54 Mbps WLAN due to unacceptable time delays. There have been many solutions that have been proposed to overcome this shortcoming. In this article, we proposed pre-processing of the traveling wave Sampled Analog Value (SAV) in the Merging Unit (MU) using modern digital signal processing algorithm. It is worth mentioning here that the ideal sampling frequency should be 1 MHz, however, using less than the recommended sampling frequency can result in lower precision. The second solution proposed in this article is known as feature extraction based on Hilbert–Huang transform.

3. Traveling wave compression using wavelet transform

There are many types of signal compression algorithms are mainly used in power system protection and control. The First algorithm is the Fast Fourier Transform (FFT). This algorithm compresses the data in frequency spectrum, which is calculated very fast. Next is the Discrete Cosine Transform (DCT), which is considered simple and fast. And third is the Discrete Wavelet Transform (DWT) that achieves a high compression ratio [19,20].

The wavelet transform introduces new classes of basic functions for the time–frequency signal analysis and have the properties which are suitable for the transient components and discontinuities as evident in power system disturbances. The wavelet analysis provides a method of pre-processing for data compression by preserving feature integrity and removing redundancy to achieve higher compression with controlled degradation in data fidelity [21].

In this article, the voltage signal during fault is obtained from the COMTRADE recorder at a rate of 20 kHz between phase and ground using PSCAD/EMTAC Simulator. This sampling frequency has been chosen due to the limitations of licensing of PSCAD/EMTAC, which is up to a maximum frequency of 20 kHz. This signal is generalized to other high frequency signals. The purpose of this step is to implement the lossless compression using wavelet transform. In order to evaluate the compression ratio using level threshold a Matlab1-D wavelet transformation was used. Fig. 2 shows the recorded fault signal by COMTRADE recorder at 20 kHz between phase and ground. Fig. 3 depicts a detailed coefficient of wavelet transformation up to level 5, which represents a high frequency component of wavelet transformation after the decomposition.

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