The real-time condition monitoring system of gapless arrester based on ZigBee protocol and third harmonic leakage current as indicator parameters

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Abstract. Monitoring the condition of arrester in service have been presented in the past. Several methods of monitoring the condition of surge arrester were introduced by many researchers. Some and almost all the methods are based on measuring the leakage current. The goal of this study is to design a portable arrester condition monitoring system which is capable of performing arrester health analysis without the need for a voltage source reference — the design based on the previous research which introduces the new method to discriminant the resistive leakage current from total leakage current. The method for diagnosing arrester health is only with the leakage current waveform. The advantage of not needing the voltage reference is that the system can ultimately be used in the field where access a voltage reference about 150 kV is not practical. The design employs a ZigBee wireless protocol as well as a microprocessing based system utilizing an Arduino microcontroller. The ground side current from the arrester is fed through a resistor, which can then be used as a read voltage. The LabVIEW based graphical user interface was prepared to analyze an arrester’s data. The user connects the GUI to the Arduino via ZigBee, samples the waveform from an arrester and then additional data processing is executed. The main part of this processing involves the modified shifted current method on the sampled waveform. Upon conclusion, the user is left with only the resistive component of the arrester leakage current, which is displayed in both the time and frequency domains for analysis.

1. Introduction

In the last decades metal oxide (ZnO) surge arresters become more important in high voltage protection. The ZnO arrester has some advantages such as reducing of size, quick response for steep discharge current and high protective performance compare to the old type Silicon Carbide (SiC) surge arrester. Although it has some advantages, caused by gapless type arrester some leakage current always flows through arrester blocks to ground. Due to this leakage current can be laid overheating and can be caused degradation on arresters. So it is very important to monitor the amount of leakage current of ZnO arrester.

Monitoring the condition of ZnO arrester in service has been presented in the past. Several methods of monitoring the condition of ZnO surge arrester were introduced by many researchers. Some and almost all the methods are based on measuring the leakage current in the ground connection of the
arrester [1-8] caused the leakage current is well known that the resistive component of the continuous leakage current is a good indicator of the surge arrester condition. The increasing of the continuous resistive current may be caused either by moisture ingress due to sealing problems, or by premature degradation of the ZnO arresters, increase in arrester temperature. These all kind of monitoring devices were installed near at arresters ground wire and regularly recorded by operators [9]. This condition is wasting time and money and also facing difficulty in transmission line arrester monitoring.

To overcome the difficulty, wasting time, and also money, the need for online and real-time monitoring of ZnO arrester is very necessary today. This monitoring is useful to know the current condition of arresters quickly and easy [10-13]. The preventive maintenance is a hot issue as current maintenance type today. Preventive maintenance needs real-time data, and it should be easy to get. With preventive maintenance, the failure of the electrical system due to high voltage impulse can be reduced [14]. This encourages utilities to install on-line condition monitoring system in high voltage substations and transmission line arrester, as well as arrester monitoring system to get real-time data.

This paper describes, proposes, and develops the design of wireless data acquisition system for the monitoring leakage current of ZnO arresters using Arduino microcontroller and Zigbee protocol wireless data communication. A prototype was initially tested in the high voltage laboratory with some distance between transmitter and receiver. This design is built to introducing improvements in data acquisition algorithm and also demonstrating its transmission performance of ZigBee protocol based data communication. The results obtained using the proposed system is compared with those recorded directly through a wired data acquisition system.

2. Data acquisition and wireless communication

The Arduino microprocessor is employed for data acquisition. It has a 6-channel successive approximation analog to digital converter available on board. The ADC is capable of measuring within 10 bits of resolution with an overall absolute error of less than 2 LSB. This is done while operating at a sampling rate of up to 15-kilo samples-per-second. For data communication, the ZigBee series 2 is used. It communicates between arrester and station-based and also operator gadget for online communication.

2.1. Data acquisition

The Arduino microcontroller board is used which has inbuilt ADC and other peripheral circuitry necessary for operation. The physical parameter is sensed by the current sensors and is converted into an analog signal. This analog signal is fed to the Arduino board which is then converted into an equivalent digital quantity and is further processed in the microcontroller [15]. The raw digital signal or processed signal out of microcontroller may be displayed on the LCD, and at the same time, this data is sent station base through the ZigBee data communication. The data is then accessed and is imported in Excel for computation and graphical representation. This developed product can be readily implemented in the industry for logging of any physical quantity such as temperature, humidity or pressure.

2.2. ZigBee based data communication

Propose ZigBee for data communication has many advantages. ZigBee is the ZigBee Alliance developed a specification of a network and security services layer technology application and based on the IEEE 802.15.4 standard. The main applications for 802.15.4 are aimed at control and monitoring applications where relatively low levels of data throughput are needed, and with the possibility of remote, battery-powered sensors, low power consumption is a key requirement [16]. It is primarily intended for domestic and commercial applications, e.g., home and building automation, PC peripherals, toys, and games but also finds application in other contexts, e.g., medical sensors and industrial control.
The distances that can be achieved transmitting from one station to the next extend up to about 3-kilometers, although very much greater distances may be reached by relaying data from one node to the next in a network. The system is specified to operate in one of the three licenses free bands at 2.4 GHz, 915 MHz for North America and 868 MHz for Europe. In this way, the standard can operate around the globe, although the exact specifications for each of the bands are slightly different. At 2.4 GHz there are a total of sixteen different channels available, and the maximum data rate is 250 kbps. For 915 MHz there are ten channels, and the standard supports a maximum data rate of 40 kbps, while at 868 MHz there is only one channel and this can support data transfer at up to 20 kbps [17].

The data is transferred in packets. These have a maximum size of 128 bytes, allowing for a maximum payload of 104 bytes. Although this may appear low when compared to other systems, the applications in which 802.15.4 and ZigBee are likely to be used should not require very high data rates. The standard supports 64 bit IEEE addresses as well as 16 bit short addresses. The 64 bit addresses uniquely identify every device in the same way that devices have a unique IP address. Once a network is set up, the short addresses can be used, and this enables over 65000 nodes to be supported. Figure 1 shows the configuration of data communication using ZigBee and microprocessor.

![Figure 1. Data communication configuration.](image-url)

As can be seen in Figure 1, the leakage current sensor was connected to the Arduino microprocessor through the analog-digital converter. Leakage current signal is converted to digital before sent by Zigbee transmitter. The regulated 5 volt DC power supply is employed for Arduino microcontroller source and 3.3 volt DC for Zigbee communication. At and using digital signal is converted to analog and saved in data logger in excel file. The excel data next used by data processing...
to extract the resistive part of leakage current and obtain the harmonic spectrum which displays in frequency based.

A wireless system for condition-based monitoring arrester is using ZigBee 802.15.4 protocol. A simple operational block diagram of the proposed system is shown in Figure 2. The continuously-measured current signals obtained from sensors installed at the equipment to be monitored are fed into a WLAN-IEEE 802.11b/g transmitter/receiver block (WLAN Tx/Rx). The measured signals are pre-conditioned as described in section 3 before they are transmitted to a remote access point and a control station (personal computer). The LabVIEW platform is used for real-time continuous monitoring and data processing. The system features two-way communication capability which enables synchronized data processing.

![Figure 2. Wireless condition monitoring arrester using ZigBee protocol.](image)

2.3. Data processing
The leakage current data which is stored in data logger is processed using shifted leakage current method (SCM). The SCM was developed by Novizon, 2008 [1]. The resistive component of leakage current which is responsible for degradation of the arrester is obtained by just subtracting the capacitive component from the total leakage current. The method is based on the leakage current signal and processes to obtain the resistive current.

3. Methodology
On-line condition monitoring system designed using ZigBee, Arduino-Uno, ZigBee shield, ZigBee adapter, and leakage current sensor. The setting for ZigBee was done with X-CTU software. This setting is to define ZigBee as the coordinator, router or end device. Leakage current sensor mounted on the end device then ZigBee as the coordinator was installed on the computer to receive data from the router and end device. The processing software was used to create user interfaces with the user so that easy monitoring the condition of arrester based on the third harmonic leakage current.
4. Results
Measurements were carried out at several voltage levels up to the arrester rated voltage. Examples of the current waveforms recorded with a 12 kV rms applied voltage using the WLAN sensor and directly through the DAQ card are shown in Figures 5. This behavior is well reproduced by the WLAN sensor which shows signals very close in magnitude and shape to those measured with the DAQ card. The phase difference between the current signals was also accurately measured. The phase shift between the DAQ signal and WLAN signal is due to transmission delay incurred in the WLAN module and access point.
4.1. Excel database

The leakage current arresters data were stored in Excel format due to storing data in specific cells seemed to be a very simplistic process. As research was conducted online about doing so, and the data acquisition LabView based package was employed. This package allows one to utilize an Excel spreadsheet with a wide array of capabilities fully.

Initially, the layout of this database system was created about how the data would be stored and organized. The first page of the database includes the name of each stored arrester and the number of data readings each one has taken in the past. The variable, so-called “dataSetAmount” are used for importing or exporting the precise amount of data readings for each arrester. Each page in the database is used for a specific arrester and includes all of its associated information and data. If LCM is run on an arrester data reading, four values are produced which are time, resistive current, frequency and a third harmonic of the resistive leakage current. Another array class variable was created called “dataDateEntry” to organize all data readings for an arrester by data and time. An image of the excel database for one arrester can be seen below in Figure 6.

Figure 5. Example of leakage current, sending and receiving.

Figure 6. Example of Excel database
4.2. Graphic user interface

The main purpose of the graphical user interface (GUI) is to provide a user-friendly method to interact with the device, as well as monitor and store information on lightning arresters over time. When a data reading is initiated, the arrester waveform will be displayed to the user. If the waveform is not acceptable, meaning that errors occurred which have affected the data in some way, the user can decide not to utilize this waveform data and can try again. However, if the reading is successful, our LCM code will then be run on the data sample. Once complete, both the resistive component of the leakage current and its FFT will be and also the magnitude of the waveform displayed to the user. The user can then monitor and evaluate these waveforms over time and decide if a specific arrester needs to be replaced due to degradation.

Figure 7 presents the GUI of condition monitoring arrester builds in the LabView environment. The GUI consists of leakage current, resistive leakage current, and the Fast Fourier Transform of the resistive leakage current waveform is displayed. Also, the magnitude of all waveform is displayed for easy to read by the operator.

![GUI of on-line condition monitoring arrester](image)

**Figure 7.** GUI of on-line condition monitoring arrester

4.3. Signal Processing

Continuously monitored leakage current for 10 mins was processed to give the leakage current signal as can be seen in Figure 8(a). The signal processing part was discriminated the total leakage current in the capacitive and resistive current. The resistive part was used for monitoring indicator and further process using fast Fourier transform to obtain the harmonic spectrum. The third harmonic of the resistive current also become an indicator of degradation. The resistive leakage current obtained is shown in figure 8(b) and 8(c) respectively.
Figure 8. Results of signal processing using LCM (a) total leakage current, (b) resistive leakage current, and (c) harmonic spectrum of resistive leakage current.

5. Conclusion
The feasibility of real-time wireless condition monitoring system for application in arrester has demonstrated in this work. The system can be used as a standalone device as well as part of a multi-sensor network to measure leakage current and other parameters in a variety of equipment. The continuous data acquisition at some sampling rate is configured to monitor specific quantities such as leakage current peak and r.m.s values, the sinusoidal signal at regular time intervals.

It has been successfully tested in monitoring applications such as for monitoring the leakage current of a surge arrester. The measured results were validated against those measured directly using a wired data acquisition card and showed excellent agreement: the total leakage current, resistive leakage current and harmonic spectrum of resistive leakage current presented in LabView GUI. The third harmonic and maximum of resistive current was used for an indicator of condition arrester. Further work is required to improve accuracy, account for transmission delays, and extend the application currently on multiple sensors.

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References

[1] Z Abdul-Malek, Novizon and Aulia 2008 A new method to extract the resistive component of the metal oxide surge arrester leakage current in Power and Energy Conference PECon. IEEE 2nd International pp. 399-402.

[2] L Huijia and H Hammei 2010 Development of Tester of the Resistive Leakage Current of MOA in Power and Energy Engineering Conference (APPEEC) pp. 1-4.

[3] C Moldoveanu, V Brezoianu, A Vasile, V Ursianu, F Goni, C Radu 2010 Intelligent system for the online real-time monitoring of high voltage substations in Innovative Smart Grid Technologies Conference Europe (ISGT Europe), IEEE PES pp. 1-8.

[4] P Yan, W Zhan and L Qiyang 2012 A New Monitoring System for Metal-Oxide Arresters in Computer Science & Service System (CSSS) International Conference pp. 1030-1033.

[5] Z N Stošanović and Z M Stojković 2013 Evaluation of MOSA condition using leakage current method, International Journal of Electrical Power & Energy Systems, vol 52, pp. 87-95.

[6] X Zhi-niu, Z Li-Juan, D Ao and L Fang-cheng 2013 A Current Orthogonality Method to Extract Resistive Leakage Current of MOSA Power Delivery, IEEE Transactions vol 28, pp. 93-101.

[7] A G Kanashiro, M Zanotti, P F Obase and W R Bacega 2011 Diagnostic of silicon carbide surge arresters using leakage current measurements Latin American Transactions, IEEE (Revista IEEE America Latina), vol 9, pp. 761-766.

[8] T Luo, S Yang, X Li, W Zhou, J Yu and L Qiu 2010 A Life-Time Monitoring Device of Surge Arrester with Series Gap in E-Product E-Service and E-Entertainment (ICEEE) International Conference pp. 1-4.

[9] N A A Rahman, N Abdullah and M F Ariffin 2010 Influence of earthling resistance on the performance of distribution line lightning arrester in Electromagnetic Compatibility (APEMC) Asia-Pacific Symposium pp. 1538-1541.

[10] L Lifeng, S Caixin, Z Quan, G Leguan and D Qun 2001 A novel electrical equipment on-line monitoring system based on the geographic information system in Electrical Insulating Materials (ISEIM) Proceedings of 2001 International Symposium on pp. 205-208.

[11] J L Velasquez, R Villafafila, P Lloret, Molas, A Sumper, S Galceran 2007 Development and implementation of a condition monitoring system in a substation in Electrical Power Quality and Utilisation EPQU 9th International Conference on pp. 1-5.

[12] M Hai-Bao, G Yi-Xin, D Ming, Z Guan-Jun and S Wei 2008 On-line monitoring technology for MOA on HV transmission line in Condition Monitoring and Diagnosis CMD International Conference on pp. 448-451.

[13] M-C Pan, P-C Li and Y-R Cheng 2008 Remote online machine condition monitoring system Measurement vol 41, pp. 912-921.

[14] J Jun and W Yu 2010 Research on online monitoring of arrester in Electricity Distribution (CICED) China International Conference on pp. 1-6.

[15] P A Beddows and E K Mallon 2018 Cave Pearl Data Logger: A Flexible Arduino-Based Logging Platform for Long-Term Monitoring in Harsh Environments Sensors, vol 18, pp. 530.

[16] R R Patil, T N Date and B E Kushare 2014 ZigBee based parameters monitoring system for an induction motor in IEEE Students' Conference on Electrical, Electronics and Computer Science pp. 1-6.

[17] Z Zhiquiang, W Yunling and Y Lei 2017 Approaches and simulation for receiver sensitivity test of ZigBee module in IEEE International Conference on Electronic Measurement & Instruments (ICEMI) pp. 98-102.