Ubiquitous Sensor for Supervision of Lightning Arresters

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Abstract: With the trend of joining IT technology to electric power industry, this paper describes a ubiquitous sensor to monitor condition of lightning arresters installed in overhead power distribution lines. The main technology in designing the sensor is a circuit that detects small leakage current and consumes low power. The prototype sensor measures leakage currents in ranges from 100 uA to 1 mA, and consumes 8.47 mA in active mode and 110 uA in sleep mode. Power duty cycle of the sensor is set at 0.07 %, consuming average 116 uA. By the design, it is expected that the sensor can be operated over a year by a 2-AAA dry battery having a capacity of 1,200 mAh

Key-Words: Ubiquitous, sensor, condition monitoring, lightning arrester, overhead power distribution lines, leakage current, power consumption

1 Introduction

Lightning arresters are the best effective protector against transient overvoltages produced by lightning discharges and switching operations [1]. However, arresters are deteriorated due to the absorption of moistures in environments of its use, repetition in the protective operation to overvoltages, and some defects at the time of manufacturing [2]. Deteriorated arresters could lead power failures, such as line to ground fault by a thermal runaway resulting from the increases in leakage current even in a nominal system voltage [1~3].

Studies on online monitoring techniques of electric power systems have been issued more than ever as the power demand increases rapidly and uninterrupted power delivery requires. Government is leading the joint of IT technologies to high voltage (HV) power systems.

With this background, many researchers focus on the development of ubiquitous sensor networks (USN) to manage power facilities such as transformers, circuit breakers, and lightning arresters installed in overhead power distribution lines effectively [1], [2]. Likewise, ubiquitous sensors for the power facilities are more important than other devices in construction of USN.

Therefore, it is necessary to supervise the lightning arresters in online state and replace the deteriorated one beforehand to ensure the reliability of power delivery [4].

There are about 1.8 millions of lightning arresters in overhead HV distribution lines in KOREA as shown in Fig.1, and the failures caused by them have occupied over 18 %.



Fig.1 Relations between the applied voltage and the leakage current components

Nevertheless they are managed by a direct analysis one by one in the place on a regular basis. This makes us need to introduce USN techniques to lightning arrester management [5], [6]. The sensor to monitor lightning arresters is especially difficult to design because it has to detect uA-leakage currents and to keep its performance under high voltage and large current environments. In this paper, we studied the development of a leakage current sensor consuming low-power to monitor lightning arresters on electrical poles of 22.9 kV-y distribution lines in online state.

Also, the sensor is equipped with a low rate wireless transceiver, Zigbee, to build a USN and can run over a year with a dry battery having a current capacity of 1,200 mAh.

2 Characteristics of Lightning Arrester

Zinc oxide (ZNO) lightning arresters have the excellent non-linear I-V characteristic, and act like a capacitor in normal operation. The electrical equivalent circuit of ZnO lightning arresters is shown in Fig. 2, where the resistive leakage current is presented by Ir, and the capacitive leakage current is given by Ic. The resistive leakage current is produced due to the changes of schottky barrier formed between ZnO grains, and varies according to the electric field intensity applied to the boundaries [7].



Fig.2 Electrical equivalent circuit of ZnO elements

Figure 3 shows the relations among leakage current components when normal operating voltage is applied to arresters. As well known, the total leakage current includes capacitive leakage current with 90° ahead of the system voltage and resistive leakage current with the same phase of the system voltage [8]. Lightning arresters gradually ages, and this results in increase of leakage currents components such as RMS and peak value of the total leakage currents, and its third harmonic leakage currents. Magnitudes of these leakage current components range from 150 uA to 300 uA.



Fig.3 Relations between the applied voltage and the leakage current components

3 Sensor Design and Experiment

Small leakage current flows through lightning arresters in normal operation and the surge current up to 10 kA can flow during protective operation against overvoltages.

Therefore the following matters in the sensor design should be considered.

- ① Leakage current detection: indirect measurement by a zero-phase current transformer (ZCT).
- ② Measurement ranges: 100 uA ~ 1 mA.
- ③ Power consumption: as low as possible for the construction of USN.
- ④ Electrical surge current immunity of the ZCT: no changes in the magnetization characteristics against large surge currents up to 10 kA

To satisfy above conditions, we used a Mn-ZCT and designed a low-noise amplifier with a sensitivity of 1 V/mA at a gain of 60 dB, which measures leakage currents in ranges of 100 uA \sim 1 mA.

Figure 4 shows the frequency response of the sensor. The high cut-off frequency estimated by sine wave is 1.24 kHz at -3 dB, and the sensor measures not only 60 Hz but also the third harmonic component without attenuation. In addition, magnetization characteristic of the sensor against large surge currents is very important to keep its sensitivity and frequency response. For the experiment, we applied 20 times of a surge currents with 8/20 us and 10 kA. The results showed no changes in the sensitivity and the frequency response.



Fig.4 Frequency response of the leakage current detecting circuit

Figure 5 shows the configuration and the photograph of the prototype sensor. The sensor is installed in the ground-terminal of the lighting arrester. In normal operation, leakage current of lightning arresters is ranges from 150 uA to 300 uA. The leakage current is amplified and transmitted to a peak-hold, a band pass filter (BPF) having a center frequency of 180 Hz, and a RMS-DC converter for readout in the microprocessor unit (MPU). We can get the peak- and RMS- value of the leakage current, and the peak value of its third harmonic with the circuit configuration.



(a) Configuration



(b) Photograph Fig.5 Prototype leakage current sensor

An application experiment is conducted to estimate the measurement performance of the sensor in the same condition where the lightning arresters are installed. The experimental set-up consists of a HV transformer and a lightning arrester used in a power distribution lines as shown in Fig. 6. AC 13.2 kV is applied to the lightning arrester, and the sensor is installed at its ground- terminal.



Fig.6 Experimental set-up

Figure 7 shows leakage current waveforms, the total and its third harmonic leakage current, measured by the sensor. These waveforms are converted to DC level in the peak/hold and the RMS/DC circuit for readout in the MPU.



Fig.7 Typical leakage current waveforms

The power consumption of the sensor is managed by the MPU, and is shown in Table 1. The MPU, the SMPS, and the Zigbee are in a sleep mode to receive an interruption and the rest are in a power down mode consuming 110 uA to minimize power consumption for the period of no-measurement.

In case of an interruption and/or a regular measurement, all of the parts except the Zigbee change into an active mode consuming 8.47 mA. The Zigbee changes to the active mode only in an alarming condition of the lightning arrester and beacon status consuming 58.47 mA, maximum power consumption.

The sensor is programmed to check the leakage currents for 5 seconds every 2 hours because the leakage current of the lightning arrester increases slowly in actual state. As shown in Table 1, the main and standby power consumption of the sensor is 8.47 mA and 110 uA, respectively in case of no communication. The duty cycle of power control is 0.07 % so the average power consumption comes about 116 uA. If the sensor would be driven by a dry battery having the capacity of 1,200 mAh, the expected life span of the battery is about 10,300 hours, 1.18 years.

	Table 1	Power	consum	ption	of	the sensor
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Device	Power Consumption					
Device	Active mode	Com. mode	Idle mode			
MPU	3.20 mA	3.20 mA	100 uA			
Op-Amp	600 uA	600 uA	-			
Peak/hold	1.00 mA	1.00 mA	-			
RMS/DC	170 uA	170 uA	-			
BPF	1.50 mA	1.50 mA	-			
SMPS	2.00 mA	2.00 mA	50 uA			
Zigbee		50.00 mA	10 uA			
Total	8.47 mA	58.47 mA	110 uA			

Figure 8 shows a transmitted data on a PC monitor from the sensor. The data consists of 16 byte; peakand RMS-value of leakage current, and peak-value of its third harmonic component.

💋 Arrester Monito	ring				
Connect Disconnect Se	ttings Save	c Quit		DownLoad	
Date 2006/05/15 2006/05/15 2006/05/16 2006/05/16 2006/05/16 2006/05/16 2006/05/16	Time 17:20:00 18:55:14 23:20:00 05:20:00 11:20:00 12:36:56 17:18:56	le 350 355 346 377 349 352 350	lp 495 504 490 530 490 500 500	13 50 39 40 45 40 44 50	
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Fig.8 Example of a transmitted data on a PC

4 Conclusions

A ubiquitous sensor that can diagnose the soundness of lightning arresters installed in overhead HV distribution lines is studied and developed. The prototype sensor has the high cut-off frequency of 1.24 kHz and the sensitivity of 1 V/mA at 60 dB gain. It measures leakage currents in ranges from 100 uA to 1 mA. The power consumption of the sensor is 8.47 mA in the active mode and 110 uA in the sleep mode. Power duty cycle is set at 0.07 % considering the deterioration characteristics of lightning arresters. Average power consumption of the sensor is 116 uA and the sensor can work for 10,300 hours, 1.18 years with a 2-AAA battery having capacity of 1,200 mAh

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References:

- S.Tominaga, Y.Shibuya, T.Fujiwara, M.Imataki, T.Nitta, Stability and Long Term Degradation of Metal Oxide Surge Arresters, *IEEE Trans. on PAS.*, Vol. PAS-99, No. 4, 1980, pp. 1548–1556.
- [2] Y.Yamashita, S.Yoshikado, Evaluation of factors in the degradation of ZnO varistor, *IEEJ*, Vol. 119-B, No. 6, 1999, pp. 652–657.
- [3] K. Goto, T. sakakibara, I. Kamata, S. Ikeda, On-line monitoring and diagnostics of gas circuit breakers, *IEEE Trans. on Power Delivery*, Vol. 4, No. 1, 1989, pp. 375–381.
- [4] J. Lundquist et al., New Method for Measurement of the Resistive Leakage Currents of Metal-Oxide Surge Arrester in Service, *IEEE Trans. on Power Delivery*, Vol. 5, No. 4, 1990, pp. 1811–1822.
- [5] Adedeji B. Badir, Expert Systems Applications in Engineering and Manufacturing, Prentice-Hall, 1992
- [6] Howitt, I., Gutierrez, J. A, *IEEE 802.15.4 low rate wireless personal area network coexistence issues*, Proceedings of the WCNC, 2003
- [7] K. Eda, A. Iga, M. Matsuoka, Degradation Mechanism of Non-ohmic Zinc Oxide Ceramics, *Journal of Applied Physics*, Vol. 51, No. 5, 1980, pp. 2678–2684.
- [8] S. Shirakawa et al., Maintenance of surge arrester by a portable arrester leakage current detector, *IEEE Trans. on Power Delivery*, Vol. 3, No. 3, 1988, pp. 998–1003.