RESEARCH OF INDIRECT MEASUREMENTS OF BENDING FORCE ON HIGH VOLTAGE INSULATORS BY ACCELEROMETER

Cernaj Lubos
PhD Student[1]
lubos.cernaj@stuba.sk

Kozarik Jozef
PhD Student[1]
jozef.kozarik@stuba.sk

[1]*Faculty of Electrical Engineering and Information Technology*
Slovak University of Technology in Bratislava
3 Ilkovicova str., Bratislava, Slovakia, 812 19

Abstract: The aim of this research is to research and verify possibilities of using the accelerometer to determine mechanical load acting on high voltage insulator. Accelerometer measurements were done on the outdoor post insulator C30 - 850 - II. The insulator was loaded multiple times with various bending force. Vibration induced by external forces was detected by an accelerometer. The insulator features a cable hole, which can be used for optical cables. The accelerometer was glued to the outside surface of insulator's plate. The results of this research will be used to verify the suitability of the chosen method for detecting the mechanical overload of high-voltage insulators. The results will be used in the design of a device that will serve to detect overload early in order to prevent damage to high-voltage lines and increase its reliability and durability.

Keywords: high voltage insulators, bending force measurement, accelerometer, mechanical stress measurement.

1. Introduction

The main purpose of high-voltage insulators is a separation of high-voltage line components from components with other potentials. On the other hand, it also transfers mechanical forces between high-voltage line components, but while mechanical forces are transferred the insulator is stressed and the dielectric material wears out [1]. Therefore, the aim of research is the research of possibilities of detection of mechanical forces which can mechanically overload the high-voltage insulators.

Influence of mechanical forces acting on high-voltage insulators has a direct effect on their durability and reliability. Therefore, overloading of these insulators can cause damage of insulators; these damages can manifest as cracking and failures of the insulators [2–5]. Research of mechanical stresses of high-voltage insulators can be useful in increasing of safety and reliability of high-voltage distribution system. In real-world scenario the usage of electronic-based measurement methods is difficult due to high electrical fields around these insulators, this is the reason we have focused on methods that can be implemented with modern optical devices such as accelerometers [6–8].

2. Methods

Insulator was placed vertically into a bending machine. The accelerometer was glued to the surface of the insulator using epoxy glue (**Fig. 1**). Insulator under test was loaded 21 times with different force and different bending rate. First, two tests were done with 50 % of the minimum bending failing load and bending rate of 10 mm/min. Then let's have loaded insulator ten times with 95 % of load and same bending rate. Next three tests were also done with 95 % load but with a slower bending rate of a 3 mm/min. Let's have continued by increasing load to 100 % and keep bending rate at 3 mm/min. Last three tests were again with 3 mm/min bending rate, but the bending force acting on the insulator was increased above safe limit 105 % of minimum bending failing load. Insulator has withstood our tests without any noticeable changes or damage. During the test, cracking sound was heard caused by high force acting on screws holding insulator in place.

3. Results

A simple data logger was designed to record measured data. The measuring equipment consists of a three-axis accelerometer MEMS LIS2DW12 [10] for detecting bending forces of the insulator, a STM ARM Cortex-M0+microcontroller [11] and a microSD card for storing the measured data. DS3234 RTC with integrated crystal is used to obtain time stamps. Measured 3-axis acceleration forces are logged to SD card in binary format to maximize the sampling rate of the device. Binary encoded data is decoded to CSV format using a python script. Every measurement cycle is turned on and off by a button, the device has to a LED to signalize pending measurement and the battery state. The device has 10 days battery life with measurement powered on, if no pending measurement device is in sleep mode when only consumes 5 µA. The device has rechargeable Lithium polymer battery, which can be charged by a micro USB cable or phone charger. The device is consisting of two parts which are connected by disconnectable cable. One is the main unit, the other one is the sensor board with the only accelerometer which is placed to the measured insulator.

Accelerometers can be used to measure vibrations, direction and magnitude of acceleration and direction of the vector of gravitation acceleration. Let's use MEMS accelerometer LIS2DW12TR from ST Microelectronics [10]. Since insulator was fixed to the ground, it was only able to measure vibrations and gravity acceleration. Measured vibration data were very similar to acoustic data. Most valuable data were obtained from measuring the angle of gravitational acceleration.

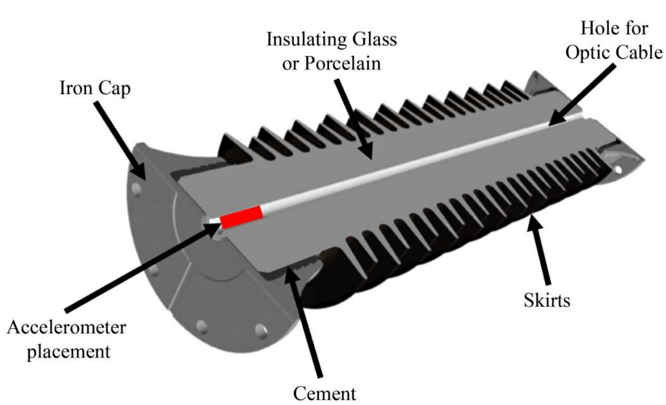

Fig. 1. Turn section of insulator C30-850-II with hole for optic cable

After filtration and processing of data, it was possible to calculate the angle of bend of the insulator. The issue with this method is that accelerometers have natural drift which may change over time [1, 2, 9]. Also, bending of an insulator is not 100 % reversible process and there can by slight residual bend after removing bending force. This can be seen in **Fig. 2** as a change in baseline of data.

Due to the predictable nature of measurement setup, it was possible to filter out accelerometer offset and residual bend. For this particular insulator, it was possible to correlate bending force with bending angle. Due to the nature of the manufacturing process every insulator has a different ratio between bending angle and bending force. Processed measurement data are shown in **Fig. 3** as bending force over time.

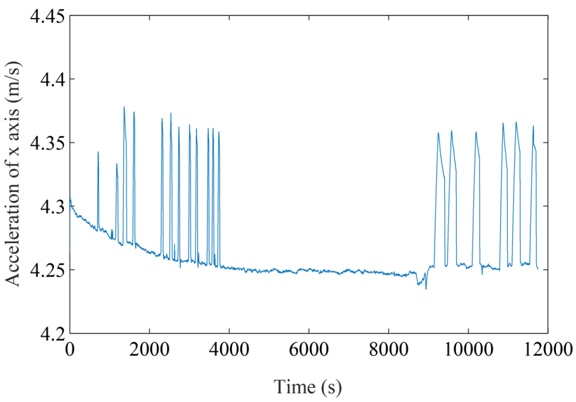

Fig. 2. Acceleration on *x* axis of accelerometer over time

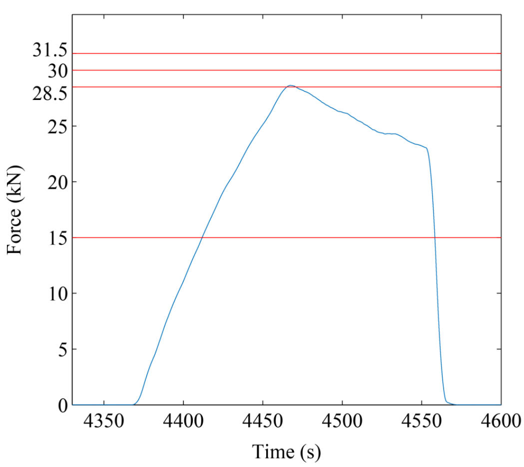

Fig. 3. Bending force over time

Detail of single bending event (**Fig. 4**) shows gradual increase in bending force until it reached chosen maximum force for a particular event. Then let's slowly decrease bending force until the end of bending event where we released bending force completely.

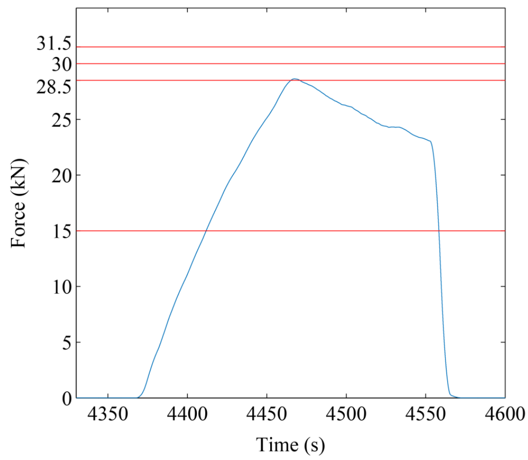

Fig. 4. Single bending event

4. Discussion and conclusions

The aim of this research was to determine the effect of mechanical overload on the high voltage insulator. Due to the mechanical forces between the components of the high voltage lines, the insulator material is stressed and can be overloaded and damaged. Early detection of insulator damage can contribute to increasing the reliability and durability of high voltage lines and minimize the risk of damage. The chosen method of detection of mechanical overload by accelerometer was performed on external insulator C30-850-II. The insulator was placed vertically in the bending machine and was subjected to various bending forces. Measurements were performed on several pieces of insulators to eliminate errors due to differences between samples.

Using accelerometer, it was possible to measure the bending angle of the insulator. This angle was directly proportional to the bending force for this particular insulator. The different insulator may have a different ratio between bending force and angle; thus, it would be required to measure bending ratio for each individual insulator. The bending ratio may be temperature-dependent and also it may change over time. This issue would require further research.

Acknowledgement

This work was supported by the Slovak Research and Development Agency (APVV-16-0626 and APVV-17-0522).

References

1. Mishra, A., Gorur, R., Venkataraman, S. (2008). Evaluation of Porcelain and Toughened Glass Suspension Insulators Removed from Service. IEEE Transactions on Dielectrics and Electrical Insulation, 15 (2), 467–475. doi: https://doi.org/10.1109/tdei.2008.4483466
2. Vaillancourt, G. H., Carignan, S., Jean, C. (1998). Experience with the detection of faulty composite insulators on high-voltage power lines by the electric field measurement method. IEEE Transactions on Power Delivery, 13 (2), 661–666. doi: https://doi.org/10.1109/61.660958
3. Gorur, R. S., Cherney, E., de Tourreil, C., Dumora, D., Harmon, R., Hervig, H. et. al. (1995). Protective coatings for improving contamination performance of outdoor high voltage ceramic insulators. IEEE Transactions on Power Delivery, 10 (2), 924–933. doi: https://doi.org/10.1109/61.400837
4. Cherney, E. A., Baker, A. C., Kuffel, J., Lodi, Z., Phillips, A., Powell, D. G., Stewart, G. A. (2013). Evaluation of Aged and Replacement Strategies for High-Voltage Porcelain Suspension-Type Insulators. IEEE Transactions on Power Delivery, 1–8. doi: https://doi.org/10.1109/tpwrd.2013.2283159

5. Amigó, J. M., Serrano, F. J., Kojdecki, M. A., Bastida, J., Esteve, V., Reventós, M. M., Martí, F. (2005). X-ray diffraction microstructure analysis of mullite, quartz and corundum in porcelain insulators. Journal of the European Ceramic Society, 25 (9), 1479–1486. doi: https://doi.org/10.1016/j.jeurceramsoc.2004.05.019
6. Schneider, H. M., Guidi, W. W., Burnham, J. T., Gorur, R. S., Hall, J. F. (1993). Accelerated aging and flashover tests on 138 kV nonceramic line post insulators. IEEE Transactions on Power Delivery, 8 (1), 325–336. doi: https://doi.org/10.1109/61.180353
7. Meziani, S., Thomas, M., Zarour, D. (2019). Diagnosis of bearing defects by variational modes decomposition from vibratory and acoustic emission measurements. International Journal of Vehicle Noise and Vibration, 15 (1), 21. doi: https://doi.org/10.1504/ijvnv.2019.10023604
8. Contreras, J. E., Rodríguez, E. A. (2017). Nanostructured insulators – A review of nanotechnology concepts for outdoor ceramic insulators. Ceramics International, 43 (12), 8545–8550. doi: https://doi.org/10.1016/j.ceramint.2017.04.105
9. Haas, M., Cihak-Bayr, U., Tomastik, C., Jech, M., Gröschl, M. (2018). Primary calibration by reciprocity method of high-frequency acoustic-emission piezoelectric transducers. The Journal of the Acoustical Society of America, 143 (6), 3557–3562. doi: https://doi.org/10.1121/1.5041266
10. MEMS digital output motion sensor: high-performance ultra-low-power 3-axis "femto" accelerometer (2019). LIS2DW12. STMicroelectronics. Available at: https://www.st.com/resource/en/datasheet/lis2dw12.pdf
11. Ultra-low-power 32-bit MCU Arm®-based Cortex®-M0+, 64KB Flash, 8KB SRAM, 2KB EEPROM, LCD, USB, ADC, DAC, AES. STM32L063C8 STM32L063R8 (2019). STMicroelectronics. Available at: https://www.st.com/resource/en/datasheet/stm32l063c8.pdf

Received date 09.10.2019
Accepted date 07.11.2019
Published date 23.11.2019