Janusz BANDEL
Krzysztof KRASUSKI
Tomasz BŁAŻEJCZYK
Artur HEJDUK
Mariusz MYKOWIECKI
Paweł KROGULEC

A SUPPORT INSULATOR WITH VOLTAGE MEASUREMENT FUNCTION TO MV SWITCHES

ABSTRACT *The article presents construction of a new support insulator with a voltage measurement function for use in indoor switchgears with air insulation, for rated voltage up to 24 kV. Standard requirements for support insulators as well as measuring sensors have been given. The influence of insulating material (epoxy resin) on the measuring sensor accuracy for different voltage frequencies (higher network harmonics) was analyzed. The electric field was analyzed in order to ensure uniform distribution along the low voltage sensor. The newly developed sensor was compared to the sensor but without function of a support insulator.*

1. INTRODUCTION

Due to the tendency to limit the dimensions of switchgears, devices performing several functions simultaneously are designed. An example of such a device is our own solution of the support insulator with the voltage measurement function (Fig. 1). This apparatus replaces a large traditional voltage transformer, by a small-sized support insulator with a built-in voltage measuring sensor (VMS).

Janusz BANDEL, M.Sc.[1), Krzysztof KRASUSKI, Ph.D.[1),
Tomasz BŁAŻEJCZYK, Ph.D., Artur HEJDUK, M.Sc.[1),
Mariusz MYKOWIECKI, M.Sc.[1), Paweł KROGULEC, M.Sc.[2)

e-mail: [j.bandel; k.krasuski; a.hejduk; m.mykowiecki]@iel.pl
pawel.krogulec@elektrometal-energetyka.pl

[1) Łukasiewicz Research Network – Institute of Electrical Engineering,
Mieczysława Pożaryskiego St. 28, 04-703 Warsaw (Poland)

[2) Elektrometal Energetyka S. A., Mazura St. 18A, 02-830 Warsaw, (Poland)

This device has been designed in a consortium with the Elektrometal Energetyka S.A. entitled: "Construction of integrated systems supporting and optimizing the work and safety of the MV switchgear based on automation of control and protection system", founded through Regional Operational Program of the Mazowieckie Province 2014-2020, point 1.2 – "Research and development activities of enterprises – type of projects – Research projects development".

As it is known [1–6], the measurement of network voltages in indoor switchgears with air insulation can be realized not only by means of instruments transformers, but also by using resistive dividers. As mentioned earlier, the project develops a model of a support insulator with the function of measuring the supply voltage Figure 1. Hitherto manufactured universal sensors of this type, i.e. with a voltage indicator function dedicated to switchgears with different rated voltages, for lower values of rated voltages are very imprecise, and in particular for voltages of several kilovolts. There are also high accuracy sensors on the market, but installed as a separate device without an additional support function. The designed VMS sensor has a measurement accuracy of 1.5% ranging from a few hundred volts to several dozen kilovolts.

Fig. 1. The designed sensor VMS

2. STANDARD REQUIREMENTS

Our apparatus is a new technical solution (combining support and measurement functions), therefore, there is no a special standard dedicated for such devices as yet. In this situation, the standards concerning voltage transformers (PN-EN 60044-7: 2003, PN-EN 61869-6: 2017) [7, 9] as well as and support insulators (PN-EN 60660:2002, PN-IEC 60273:2003) [8, 10] should be applied.

The device considered has been tested accordingly to the following requirements of the above standards:

- endurance of alternating and pulse voltage insulation,
- low level of partial discharges (for supporting insulators),
- endurance of required bending moment,
- resistance to lightning strokes,
- endurance of alternating voltage insulation under rain,
- checking the accuracy,
- checking electromagnetic compatibility,
- measurement of partial discharges (for voltage transformers).

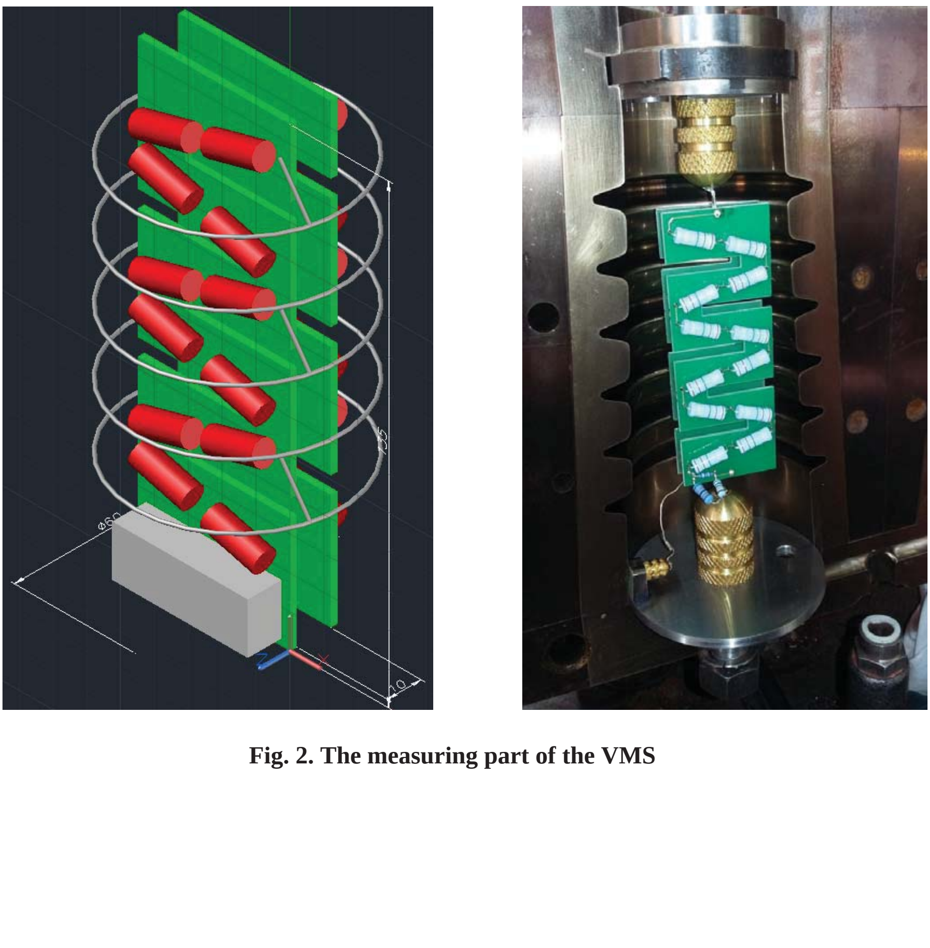

Fig. 2. The measuring part of the VMS

Some requirements of the standards [7, 9] for voltage transformers, cannot be directly applied to voltage dividers. According to the procedure included in these standards, a test voltage should be applied between the HV and LV windings for 60 seconds. In voltage dividers the HV element is directly connected with one end of the LV element. The other end of LV is earthed. Therefore, the test mentioned is not possible.

Declared parameters of our device are as follows:

- rated voltage is 24 kV/√ 3 kV, LV element is set on 3.25/√ 3 V,
- output resistance of the divider is 200 kΩ ± 1%,
- required electrical withstand voltage is 50 kV at 50 Hz,
- lighting withstand voltage is 125 kV at 1.2/50/μs,
- required bending moment is 8 kNm.

The sensor considered consists of several resistors connected in series (Fig. 2) and separated by appropriate slots to increase electrical withstand. The resistors VR37 (Vishay Co.) have been applied in our solution. The slots mentioned (Fig. 2) are filled with an epoxy resin ($\varepsilon_r = 6$) that improves electrical field distribution along measuring sensor and makes stronger mechanical construction.

3. TEST RESULTS

Essential features of VMS as power frequency withstand voltage, lighting withstand voltage, ratio of the voltage divider, accuracy of the voltage measurement, as well as bending moment has been testing according to the earlier mentioned standards. The ratio of the voltage divider has been tested for power frequency as well as for other frequencies from 0 up to 4 kHz.

A change of the voltage divider ratio of the VMS after impregnation with the epoxy resin was also observed (Fig. 3). The biggest difference after filling occurs at 1 kHz, where the ratio changes by 74%. On the other hand, at 50 Hz the difference does not exceed 0.5%. To obtain the divider ratio, k, equal to approximately 7400 for 50 Hz, the appropriate resistivity of resistors has been chosen.

The application of special metal rings located along the resistor has been also investigated to obtain more uniform electric field distribution (along the voltage divider). The finite element method software has been applied for this purpose. Results of computations are presented in Figures 4 and 5. Analyzing these graphs it can be concluded that the *z*-component of the electric field strength in the model with rings is much more uniform then in the case without these rings. The fluctuation of this quantity is about 4 V/m in the first case (Fig. 5) but in the second case is about 140 V/m (Fig. 4.). Nevertheless, this solution (rings) has not been finally applied in VMS configuration because of some technical problems during manufacturing process.

The developed sensor has been checked for mechanical requirements as well. The bending moment withstand required for such supporting insulators (8 kNm) has been met during this test.

Finally, the indications of VMS sensor have been compared to indications of a commercial sensor but without the supporting function. The comparison has been made for the measurement voltage of 800 V for frequencies scope from zero to 500 Hz.

This test has been done in the high voltage laboratory of the Institute of Electrical Engineering. The results of these measurements are shown in Figure 6. One can observe that the discrepancy of results (obtained for these two sensors) does not exceed 5% for whole range of frequencies, however, the maximal discrepancy appears for 500 Hz. On the basis of the obtained results, it can be stated that the accuracy of both sensors satisfies the requirements of the appropriate standards.

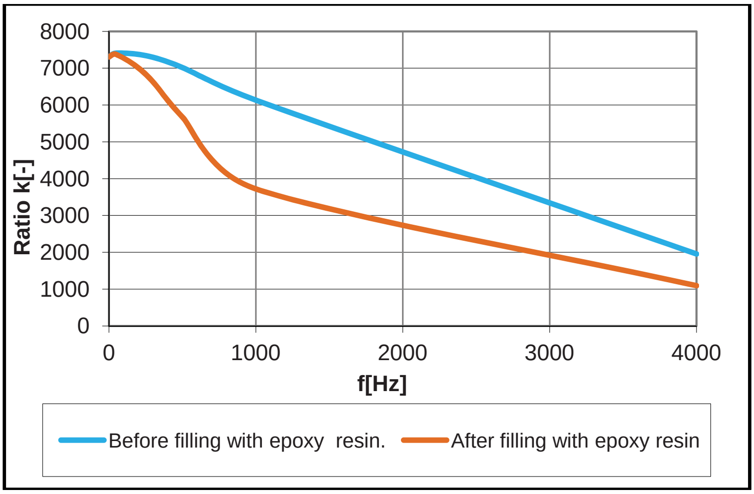

Fig. 3. Ratio of the voltage divider k in the frequency domain

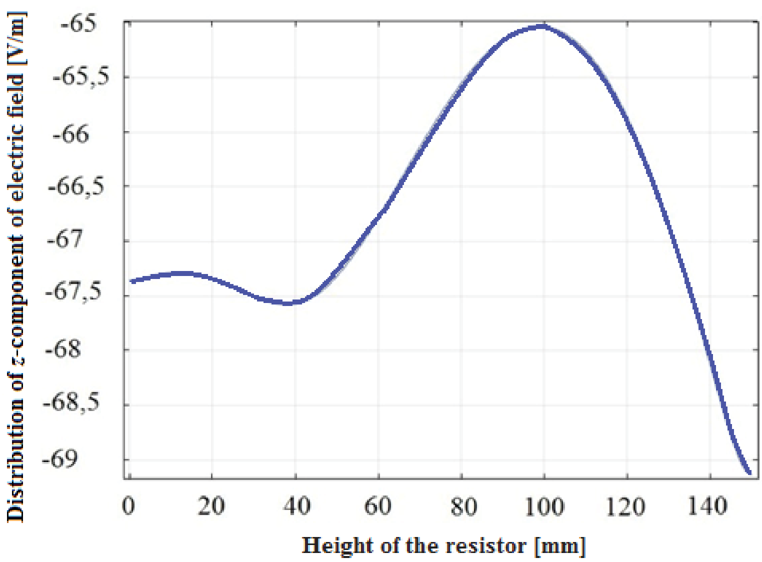

Fig. 4. Distribution of *z*-component along the height of the resistor without rings

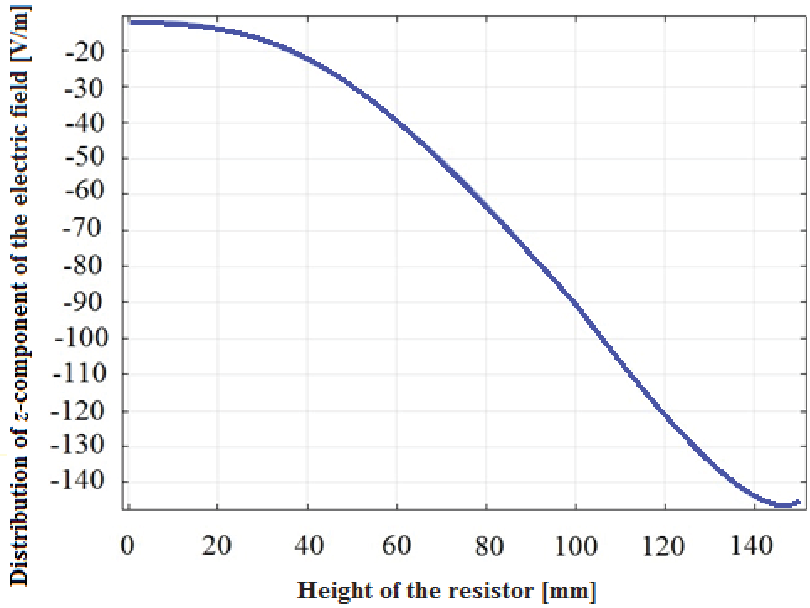

Fig. 5. Distribution of *z*-component along the height of the resistor with rings

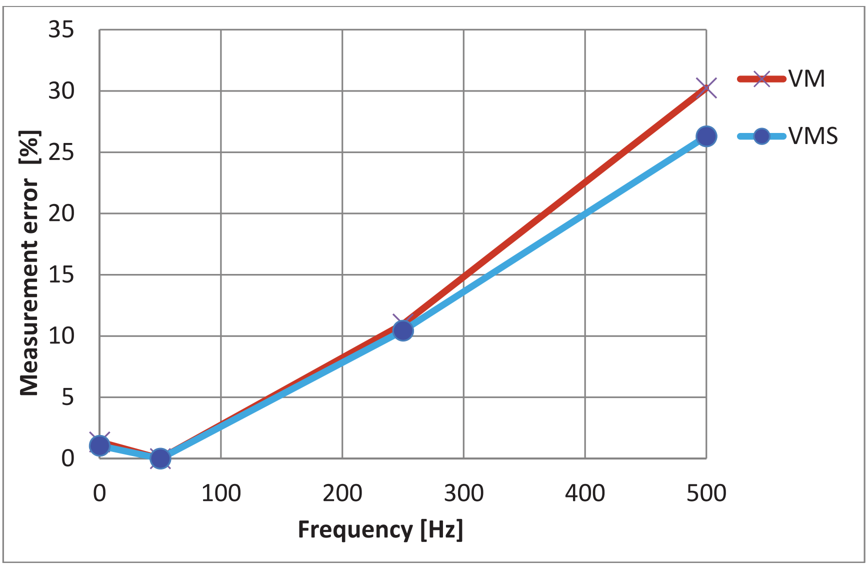

Fig. 6. Comparison of measurement error of the VMS sensor with a commercial sensor (VM)

4. SUMMARY

The publication presents the results of tests for the developed VMS sensor that is mounted in the support insulator of the 24 kV voltage switchgear. The fulfillments of electrical requirements as well as mechanical ones have been found. A change in the frequency response of the measuring element after filling with epoxy resin was observed especially for higher frequencies. These difference is due to the change of the internal distribution of the capacitances along the measuring element. This difference has been compensated by the choice of appropriate resistances. Moreover, the correction of the electric field *z*-component by the application of special metal rings has been analysed; however, these results have not been applied in final apparatus configuration because of some technical problems during manufacturing process. At the end, the developed VMS sensor has been successfully compared to the commercial measuring sensor without the supporting function.

LITERATURE

1. Błajszczak G., Olak J.: Rezystancyjny dzielnik napięcia do pomiarów wyższych harmonicznych w sieciach 400 kV. Konferencja Aktualne problemy w elektroenergetyce (APE '11), Jurata, 8–10 czerwiec 2011, str. 97–104, 2011.
2. Crotti, G., Gallo, D., Giordano, D., Landi, C., Luiso, M., Modarres, M., Zucca M.: Frequency compliance of MV voltage sensors for smart grid application. IEEE Sens. J., vol. 17, No. 23, pp. 7621-7629, 1 Dec.1, 2017.
3. Garnacho F., Khamlichi A., and Rovira J.: The Design and Characterization of a Prototype Wideband Voltage Sensor Based on a Resistive Divider. Sensors (Basel, Switzerland) 17.11 (2017): 2657. PMC. Web. 21, 2018.
4. Kowalski G., Lisowiec A., Kalinowski A., Nowakowski A., Wlazło P.: Rezystancyjny sensor średniego napięcia., Elektro Info, nr 4/2018, str. 1–6, 2018.
5. Olejnik B.: Rezystancyjny sensor średniego napięcia Alternatywne metody pomiaru średniego napięcia w elektroenergetycznej sieci rozdzielczej. Poznan University of Technology Academic Journals: Electrical Engineering, nr 78, str. 97-104, 2014.
6. Pawełek R., Wasiak I. Jurek M.: Pomiary wyższych harmonicznych napięcia w sieci 400 kV. Przegląd Elektrotechniczny, vol. 90, nr 7, str. 230-233, 2014.
7. PN-EN 60044-7:2003 Przekładniki. Cześć 7: Przekładniki napięciowe elektroniczne, 2003
8. PN-EN 60660:2002 Badania izolatorów wsporczych wnętrzowych z tworzyw organicznych do układów na znamionowe napięcie powyżej 1 kV i poniżej 300 kV, 2002
9. PN-EN 61869-6:2017 Przekładniki. Cześć 6: Dodatkowe wymagania ogólne dla przekładników małej mocy, 2017.
10. PN-IEC 60273:2003 Właściwości wnętrzowych i napowietrznych izolatorów wsporczych do sieci o znamionowym napięciu powyżej 1000 V, 2003.

Accepted for publication 05.03.2020

IZOLATOR WSPORCZY Z FUNKCJĄ POMIARU NAPIĘCIA DO ROZDZIELNIC SN

Janusz BANDEL, Krzysztof KRASUSKI,
Tomasz BŁAŻEJCZYK, Artur HEJDUK,
Mariusz MYKOWIECKI, Paweł KROGULEC

STRESZCZENIE *W artykule przedstawiono konstrukcję izolatora wsporczego z funkcją pomiaru napięcia do zastosowania w rozdzielnicach wnętrzowych z izolacją powietrzną, o napięciu znamionowym do 24 kV. Podano wymagania norm stawiane izolatorom wsporczym, jak i sensorom pomiarowym. Przeanalizowano wpływ materiału izolacyjnego (żywicy epoksydowej) na przekładnię sensora pomiarowego dla różnych częstotliwości napięcia (wyższe harmoniczne sieciowe). Wykonano analizę pola elektrycznego wzdłuż członu niskonapięciowego sensora w celu zapewnienia równomiernego jego rozkładu. Porównano nowo opracowany sensor z obecnym już na rynku sensorem pomiarowym bez funkcji wsporczej.*

Słowa kluczowe: *izolator wsporczy, sensor supply voltage, dzielnik rezystancyjny*