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METHOD FOR DETERMINING THE ACTUAL PRESSURE VALUE IN A MV VACUUM INTERRUPTER

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Abstract. *The paper describes the author's method for determining the actual pressure value in a vacuum interrupter of a MV disconnector during high-voltage laboratory tests. The need to develop such a method was due to the lack of possibility to measure the pressure directly in the vacuum interrupter during the tests. There was a risk of damaging the vacuum gauge as a result of an electrical jump. The proposed method consists in measuring, in de-energized conditions, the difference in pressure between a set of vacuum pumps and a prototype vacuum interrupter made for the purpose of implementing this method. Thus, knowing the pressure value at the pumps and having the scaling characteristics of the system determined, it will be possible to determine the actual pressure inside the tested MV disconnecting extinguishing interrupter during high-voltage tests. Measurements of pressure drop in the pumping channel were carried out for air and three electro-negative gases: helium, argon and neon, used in the study by the authors of this paper.*

Keywords: vacuum switchgears, vacuum technology, vacuum systems, pressure measurement

METODA OKREŚLANIA RZECZYWISTEJ WARTOŚCI CIŚNIENIA W PRÓŻNIOWEJ KOMORZE GASZENIOWEJ SN

Streszczenie. *W artykule opisano autorski sposób pozwalający na określenie rzeczywistej wartości ciśnienia w próżniowej komorze rozłącznikowej SN podczas wysokonapięciowych badań laboratoryjnych. Konieczność opracowania metody tego typu wynikła z braku możliwości pomiaru ciśnienia bezpośrednio w komorze próżniowej w trakcie badań. Istniało bowiem ryzyko uszkodzenia próżniomierza w wyniku przeskoku elektrycznego. Proponowana metoda polega na pomiarze w warunkach beznapięciowych różnicy ciśnienia pomiędzy zestawem pomp próżniowych, a prototypem komory próżniowej wykonanym dla potrzeb realizacji tej metody. Dzięki temu znając wartość ciśnienia przy pompach oraz mając wyznaczone charakterystyki skalowania układu, w trakcie badań wysokonapięciowych możliwe będzie określenie rzeczywistego ciśnienia wewnątrz badanej rozłącznikowej komory gaszeniowej SN. Przeprowadzono pomiary spadku ciśnienia w kanale pompowym dla powietrza oraz trzech gazów elektroujemnych: helu, argonu oraz neonu, wykorzystywanych w badaniach przez autorów niniejszego artykułu.*

Słowa kluczowe: próżniowa aparatura łączeniowa, technologia próżniowa, systemy próżniowe, pomiar ciśnienia

Introduction

The continuous increase in demand for electricity determines the development of medium voltage lines, both in terms of their length and technological advancement. Currently, there are over 306 thousand kilometers of medium voltage lines in Poland [6]. For efficient and failure-free operation of power infrastructure, appropriate switching devices are necessary, maintenance-free operation, thus ensuring improved reliability indices, the values of which are billed to Distribution System Operators (DSOs) [1, 5, 7].

Switching devices used as components of medium voltage lines are divided into two types. The first are open-type devices and the continuously gaining in importance closed-type devices. The most common closed devices are SF6 gas and vacuum arc extinguishers. Sulfur hexafluoride is an extremely harmful greenhouse gas, as its GWP100 is 22,000 times greater than that of carbon dioxide. In order to limit the use of this medium, the Kyoto Protocol was signed in December 1997, which obliged the countries of the world to reduce the amount of greenhouse gases produced [2, 8].

An alternative to SF6 gas is apparatus based on vacuum technology. Over the last few years, there has been a definite increase in the number of devices installed based on vacuum technology. This is due to the excellent performance of vacuum for arc extinguishing and its almost neutral environmental impact. Figure 1 shows the percentage of newly designed circuit breakers in medium voltage networks installed in the world power industry over the last decades.

The aforementioned factors have made the switchgear based on vacuum technology become the main development trend dedicated to medium voltage lines, which is perfectly exemplified by the innovative vacuum disconnector EKTOS, developed by a team of scientists from the Lublin University of Technology in cooperation with the EKTO company from Białystok, dedicated to intelligent medium voltage networks of the Smart Grid type [3, 10, 11].

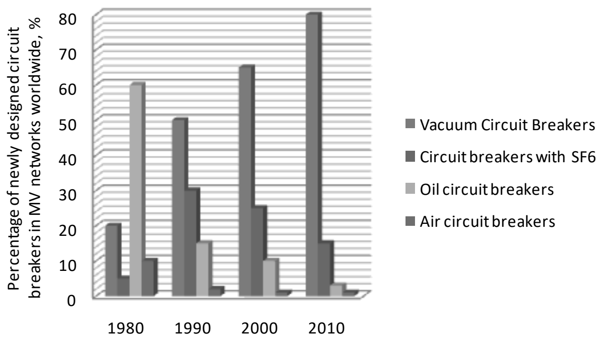

Fig. 1. Percentage share of MV circuit breakers in electric power network in the world between 1980 and 2010 (own elaboration based on [9])

Vacuum switching devices are based on vacuum interrupters used for connecting current circuits of a given device. The construction of MV vacuum interrupter consists of ceramic or glass casing, in which the current track (supply and contact pair) is located. The material and shape of the contacts is selected at the design stage in such a way as to limit the wear and tear of contact pads during switching operations. The possibility of movement of the mobile contact results from the use of a bellows, which ensures the tightness of the system. Inside the interrupter there is also a condensation screen on which conductive particles from the arc discharge occurring between the contacts are deposited. This element is necessary because conductive particles deposited on the interrupter casing could reduce the dielectric strength. A similar shield is located at the spring bellows. The manufacture of vacuum interrupters is a high-tech process and requires the use of special materials to withstand differential pressures and mechanical shocks. The pressure inside SN vacuum extinguishing interrupters oscillates around 10^{-4} Pa.

Figure 2 shows the structure of a typical MV vacuum interrupter used in power switchgear, while Table 1 presents the basic technical parameters of vacuum interrupters from the largest manufacturers.

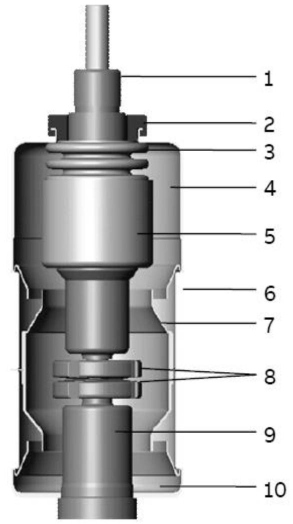

Fig. 2. Construction of the vacuum interrupter (1 – stem / terminal, 2 – twist protection, 3 – metal bellows, 4 – interrupter lid, 5 – shield, 6 – ceramic insulator, 7 – shield, 8 – contacts, 9 – stem / terminal, 10 – interrupter lid)

Table 1. Basic technical parameters of MV vacuum interrupters of the largest manufacturers

Manufacturer	Rated voltage, kV	Rated continuous current	Mechanical durability, thou.
ABB	7.2 – 36	400 ÷ 3150	10 ÷ 1000
EATON	12 – 17.5	630 ÷ 3200	10
SIEMENS	7.2 – 36	630 ÷ 4000	30
ITR (Poland)	≤ 24	400	2

1. Motivation to conduct the study

The growing popularity of vacuum as an insulating medium in power equipment and the need to improve its operating parameters has prompted the authors of this paper to undertake research aimed at developing a method to increase the switching capacity and electrical strength of quenching interrupters dedicated to modern switching equipment. The planned research concerns mainly a comparative analysis of changes in dielectric strength of the contact system of a vacuum interrupter in the open state, depending on the contact material used as well as on the type and pressure of gas in the vacuum interrupter. This pressure is the key physical quantity occurring during the implementation of tests in the Department's Switching and Switchgear Laboratory. It is therefore important to correctly determine this quantity, on which a number of technical parameters depend.

Unfortunately, because testing the dielectric strength of interconnects requires the use of high test voltages, it is not possible to measure the pressure directly in the vacuum interrupter under test. Attempting such measurements would create the possibility of damaging the test head through the possibility of an electrical jump to the vacuum gauge element. Therefore, the authors of this paper developed a method to determine the pressure inside the SN vacuum interrupter under test from the pressure measured at the vacuum pumps. The volume of the whole article should include an even number of pages. The last page should be filled at least 50%. The author should make

2. Test stand

A special version of the vacuum interrupter was designed and constructed for the purpose of this study. It reproduces the geometrical parameters of a real medium-voltage vacuum interrupters used in MV switching devices (Fig. 3). The interrupter is equipped with a vacuum connection ferrule at the height of its contacts, thanks to which it is possible to connect a measuring head there. Obtaining the specified pressure value inside the interrupter was ensured by its adaptation to the connection of the pumping channel.

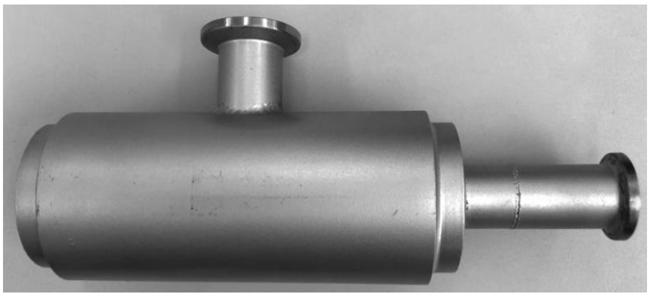

Fig. 3. Vacuum interrupter with special design

A schematic diagram of the test stand developed for the determination of the actual pressure value in the SN disconnecting vacuum interrupter is shown in Figure 4, while a view of the stand is shown in Figure 5.

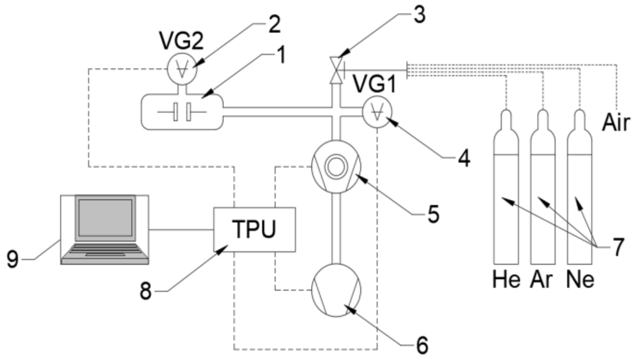

Fig. 4. Scheme of test stand for pressure measurement (1 – prototype of vacuum interrupter in special design, 2 – vacuum gauge no. 2, 3 – vacuum hand valve, 4 – vacuum gauge no. 1, 5 – turbomolecular pump, 6 – rotary pre-pump, 7 – set of technical gases, 8 – TPU control unit, 9 – PC station)

Fig. 5. View of the laboratory station for pressure measurements

The developed test stand consists primarily of a set of vacuum pumps: a rotary pre-pump and a turbomolecular pump. This set operates at a capacity of 90 l/s, thanks to which it is possible to obtain vacuum in the interrupter at the value of the pressure used in currently manufactured SN quenching interrupters. Special vacuum valves used for dosing technical gases or for aeration of the system cooperate with this system. Pressure measurement in the system is carried out using vacuum measuring heads installed at the vacuum pump set (VG1) and at the vacuum interrupter (VG2). The vacuum pumps and measuring heads are operated by a TPU control module connected to the laboratory computer network. The control and reading of the pressure values from the vacuum gauges is done using a computer unit and dedicated software provided by the manufacturer of the vacuum set.

3. Measurement results

The idea of the research conducted was to determine the pressure drop between a vacuum pump and the subject vacuum interrupter prototype.

Measuring the pressure of gases other than air using measuring heads requires correcting the read value by applying calibration factors. Below a certain pressure value, the measuring head operates in the ionization (penning) head mode, where the value read is equal to the actual pressure value. Above this value, the measuring head switches to thermal head mode (Pirani). In this mode, the actual pressure value is linearly dependent on the actual pressure value indicated by the vacuum meter. This is determined by the following relation:

$$p_{eff} = C \times p_{reading} \tag{1}$$

where p_{eff} is the actual pressure value, C denotes the calibration factor and $p_{reading}$ the pressure value read.

The calibration factors for the industrial gases used are shown in Table 2.

Table 2. Calibration factors for test gases [4]

Gas type	Calibration factor	Valid range
He	1.40	$3\times10^{-1} \div 3\times10^{1}$ Pa
Ar	1.57	$3\times10^{-1} \div 1\times10^{2}$ Pa
Ne	1.70	$3\times10^{-1} \div 3\times10^{1}$ Pa
Air	1.00	$3\times10^{-1} \div 3\times10^{1}$ Pa

Above the pressure value specified by the range in Table 2, the actual pressure value should be determined using the characteristics provided by the measuring head manufacturer. However, this pressure range is not of interest to the authors of this paper.

In order to determine the pressure drop across the pumping channel between the vacuum pump set-up and the prototype vacuum interrupter, pressure values were measured at two locations in the system, using vacuum gauges VG1 and VG2. Measurements were made for air and three noble gases: helium, argon and neon, in the pressure range 10^{-4} Pa ÷ 10^{1} Pa.

Based on the obtained measurements, the characteristics $p_{VG2} = f(p_{VG1})$ were developed and are shown in Figures 6–9.

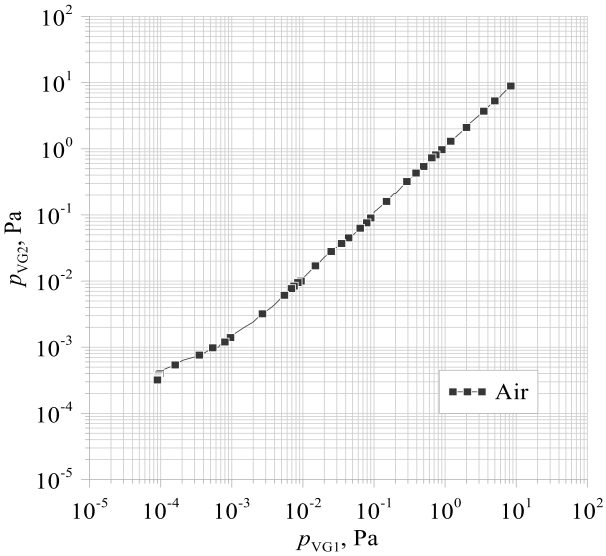

Fig. 6. Characteristics of pressure measured by vacuum gauge VG1 as a function of pressure measured by vacuum gauge VG2 for air

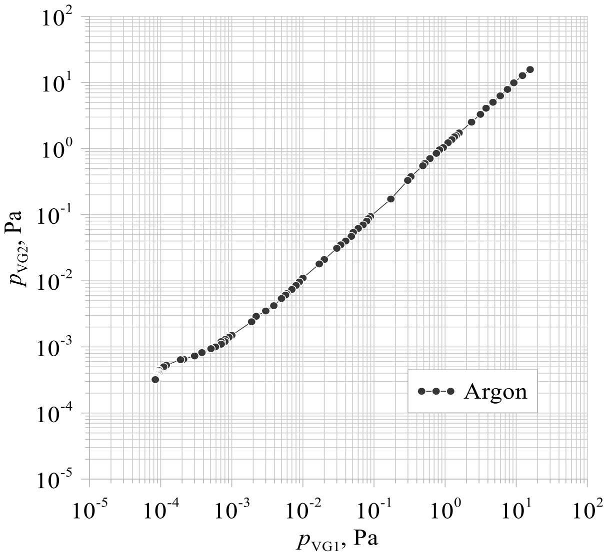

Fig. 7. Characteristics of pressure measured by vacuum gauge VG1 as a function of pressure measured by vacuum gauge VG2 for argon

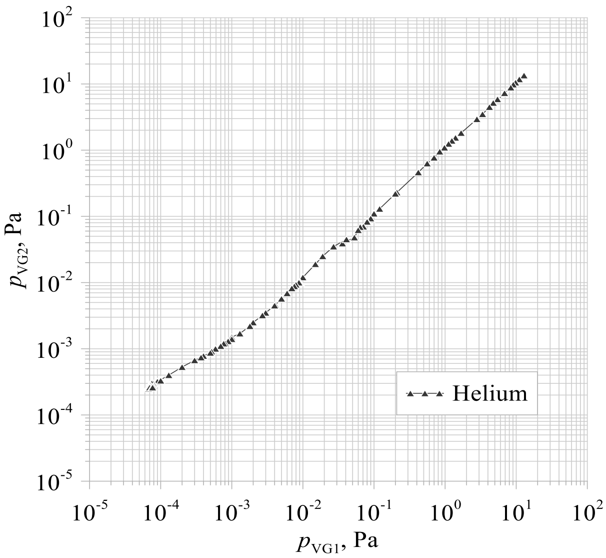

Fig. 8. Characteristics of pressure measured by vacuum gauge VG1 as a function of pressure measured by vacuum gauge VG2 for helium

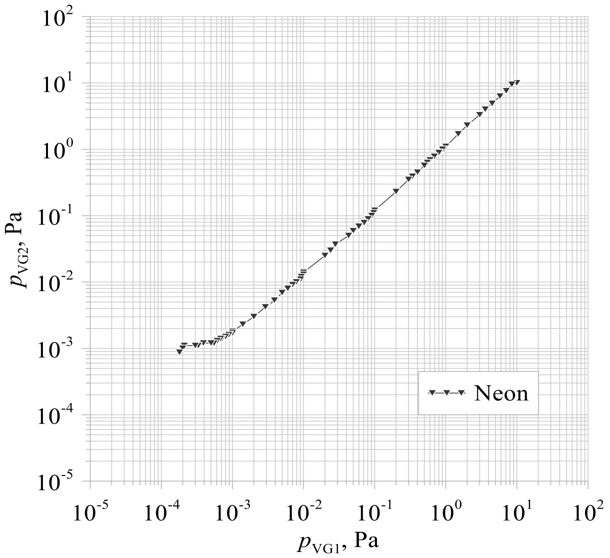

Fig. 9. Characteristics of pressure measured by vacuum gauge VG1 as a function of pressure measured by vacuum gauge VG2 for neon

Analyzing the obtained characteristics, it can be observed that above a pressure value of about 10^{-2} Pa, the pressures indicated by vacuum gauges VG1 and VG2 are approximately equal. Below this value, the pressures indicated by the measuring head VG2 are higher compared to VG1. This is due to the difficulty of maintaining high vacuum along the length of the pump channel, where gaskets and channel diameter changes occur. These locations are highly sensitive and present potential opportunities for air ingress into the system. Therefore, in the pressure range of 10^{-4} Pa ÷ 10^{-2} Pa, the pressure difference between vacuum gauges VG1 and VG2 was determined, which will be used to determine the actual pressure in the tested disconnecting interrupter in the authors' further high-voltage research.

4. Conclusions

The dynamic development seen in the power industry is associated with the need to develop new devices with better performance, while taking into account the trends of miniaturization. This entails a number of works carried out by research teams around the world.

The research team working at the Faculty Laboratory of Switchgear and Distribution Equipment is currently working on widely understood improvement of technical parameters of vacuum interrupters dedicated to modern switchgear used in smart grids.

In the course of high-voltage research work, the necessity arose to determine the actual pressure prevailing in the tested vacuum interrupter in a manner that does not expose the vacuum meter to damage associated with direct pressure measurement near the contact system. A measurement method was developed based on the use of two measuring heads and a prototype of a vacuum SN extinguishing interrupter. Based on the measurement of the pressure values at two locations in the system, the difference in the readings of the vacuum gauges was determined, which will be used to determine the residual gas pressure in further high-voltage tests of the disconnecting interrupters based on the pressure prevailing at the vacuum pump set.

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