XXVIII Seminarium

ZASTOSOWANIE KOMPUTERÓW W NAUCE I TECHNICE 2018

Oddział Gdański PTETiS

doi: 10.32016/1.60.24

APPLICATION OF MATLAB SOFTWARE FOR DETERMINATION OF THE ENERGY ABSORPTION CAPACITY OF MODERN SURGE ARRESTERS DEPENDING ON THE NUMBER OF ABSORBED CURRENT PULSES

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Abstract: Metal-oxide surge arresters (MOSA) used in power networks for limiting of the electrical surges are exposed for many stresses in operating conditions. Electrical and thermal factors cause degradation of arresters internal structure being result of absorbed energy and aging processes cumulative effects. As result, changes of its nominal parameters are observed and significant reduction of the devices lifetime is noticed as well.

For MOSA diagnosis and endurance estimation, large number of tests is usually needed. It results in great volume of gathered measurement results. Number of collected data as the effect of experiments, needs effective methods for fast extraction of the specific parameters evaluated in post-processing procedures. In this paper Matlab script for improvement and accelerating of analysis process is presented. Developed software, allowed determination of the surge energies dissipated in arresters, valuation the accumulated energy, as well as averages of voltage, current and surges energy.

Keywords: metal-oxide varistors, degradation processes, surge stresses, diagnostics.

1. PROBLEM DEFINITION AND OBJECT UNDER RESEARCH DESCRIPTION

The Metal-Oxide Varistors (MOV), as protective devices, are commonly used as system limiting the surges occurring in electrical power networks and affecting theirs components insulating systems [1-3]. Modern protective devices based on ZnO varistors are characterized by features variability in function of time, volume of accumulated energy (number and magnitude of stresses) internal structure temperature increase and character of applied stresses [4, 5]. Energy dissipation in the varistors structures causes a device structure changes. Generally, the highest volume of absorbed summary energy, the highest risk of MOV device structure permanent change is noted [6-8].

The paper presents studies on the impact of large number of pulsed electrical stresses influence, i.e. high-current normalized surges 8/20 μs on low-voltage (LV) arresters mitigation effectiveness. An additionally tests scope comprised temperature recorded on metal base of MOVs contacts.

MOVs having form of cylindrical disks (Fig. 1) fabricated of ZnO ceramics combined with various additives (e.g. Bi, Mg, Co, Cr oxides) allow during fabrication process desired parameters adjustment (Table 1).

Table 1. Tested MOV selected parameters

Continuous operating voltage U_c [V]	280
Nominal discharge current (8/20 μs pulse) at I_n [kA]	5
Protection level U_{pn} at I_n [V]	1100
Max. voltage protection level U (I_{max}) [V]	1700
Energy absorption capability (1*8/20 μs; I_{max}) W_{max} [J]	2200

The mechanism of current conduction in varistors is complex, due to the influence of material properties and nonlinear phenomena occurring on a polycrystalline grains [9]. The summary current flowing through the varistor is the result of the partial currents randomly flowing through the volume of the entire polycrystalline structure.

In consequence, the shape of the *I–U* static characteristics of the varistor is strongly non-linear:

$$I = k \cdot U^{\alpha} \tag{1}$$

where: I – current of the MOV, U – voltage at the MOV terminals, k, α – constants dependent on the material and technological process.

Equation (1) determines non-linear characteristic consisting of specific ranges:

- pre-breakdown range with a high resistance and low leakage current of varistor,
- breakdown range with voltage stabilization,
- saturation range with current limited by external circuit.

Degradation of the internal varistor structure caused by high-current pulses and thermal stresses affects the characteristic distortion of the graphs, leakage current growth triggering power losses increase and energy absorption capability reduction.

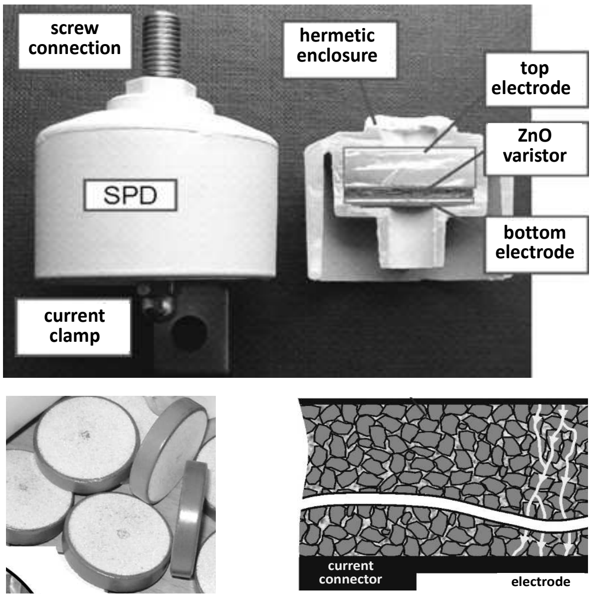

Fig. 1. A low-voltage MOV: SPD design, disk varistors, and the internal polycrystalline structure of varistor [12, 13]

The results presented in the paper are the part of broader studies on the cumulative impact of a number of energetic stresses (high current pulses) on the properties and parameters of MOVs of gapless surge arresters, e.g. changes in current-voltage characteristics and dielectric parameters.

Basis on conclusions found in literature, it is expected the significant decrease of MOVs energy absorption capacity. Permanent change in the internal structure of the varistors modifying their electrical characteristics, described by the varistors response, both – for low and high signal excitation. The question is: what is the influence of frequent surges application on tested objects energy absorption.

However experiments results can be predictable, new technology development incline to perform wide range tests [9-11] on new products appeared in the market to determine the degree of aging of their varistors structures.

2. DIAGNOSIS METHOD SPECIFICATION

The main purpose of the research was the analysis of the influence of number of current surges applied at the tested arresters terminals on its energy absorption capacity.

Because of specific research character, number of tested objects and experiment conditions variations, huge number of collected data was obtained, what is labor consuming process. Therefore, taking into account comprehensive range of the research, dedicated software tool for analysis procedure improvement was needed. It was realized by means of MATLAB software application and dedicated script development.

2.1. Tests set-up and testing procedure

Measurements were performed using testing stand installed in High Voltage Laboratory at AGH University of Science and Technology in Krakow. Testing circuit comprised the following elements presented in figure 2.

As tested objects commercially available surge arresters were used (Tab. 1). During the experiments current flowing through the tested object (the voltage drop at R_p) and voltage (the voltage divider) signals at the arresters terminals were recorded.

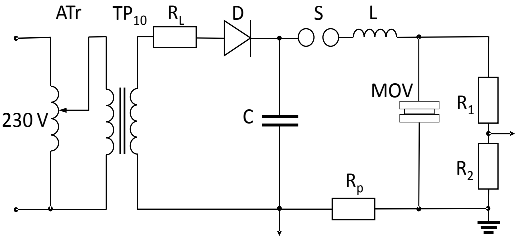

Fig. 2. Testing circuit diagram

where:
ATr – Autotransformer 0-220, 2.5 kVA,
R_L – Resistance 100 kΩ
L - Inductance – 6.7 µH
C – Capacitance – 5.25 µF / 12 kV
R_p – Resistance – 0.37 mΩ
TP_{I0} – Isolating transformer 15 kV
D – Diode 30 kV, I=0.13 A

A current pulse generator responsible for standardized surge application and exposure time programmer were used for tested MOVs stressing. Exemplary current impulse flowing through the arrester and voltage waveform recorded at his terminals are presented in figure 3. For presented case t_1 and t_2 moments given in formula (2) in figure 4b are 0 µs and 100 µs respectively (entire recorded data range).

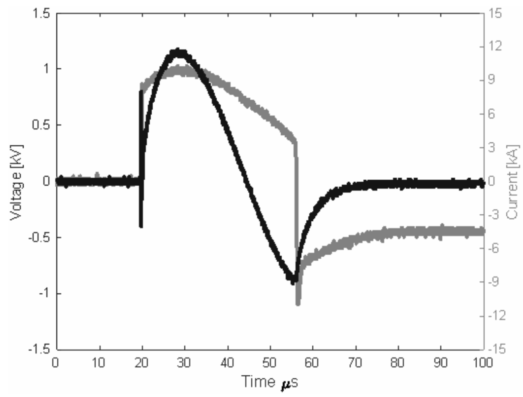

Fig. 3. Exemplary voltage at the varistor terminals and its current waveform recorded during tests

During the experiments tested objects were exposed to 10 energetic stresses characterized by: 10 kA 8/20 µs current pulses in successive 20 series. The pulses were applied every 60 seconds in series of 10 shots (single tests pocket).

At the first stage for the experiment, current and voltage waveforms were recorded and saved in separate *.csv files. All tests were performed using the same scope time base. In consequence in case of any measurement error occurrence, its influence on all obtained results was the same.

This process, together with scope triggering, voltage adjustment and number of performed tests control, was realized by means of first software module presented in figure 4a. Voltages and currents waveforms were recorded for calculation the value of energy absorbed by the each tested MOV. Calculation and output files saving was realized in second software module presented in figure 4b.

Due to measurements stochastic in nature, the average values of pocket of ten measurements were obtained and taken into account successively for future analysis. Mainly energy absorbed by the object were calculated.

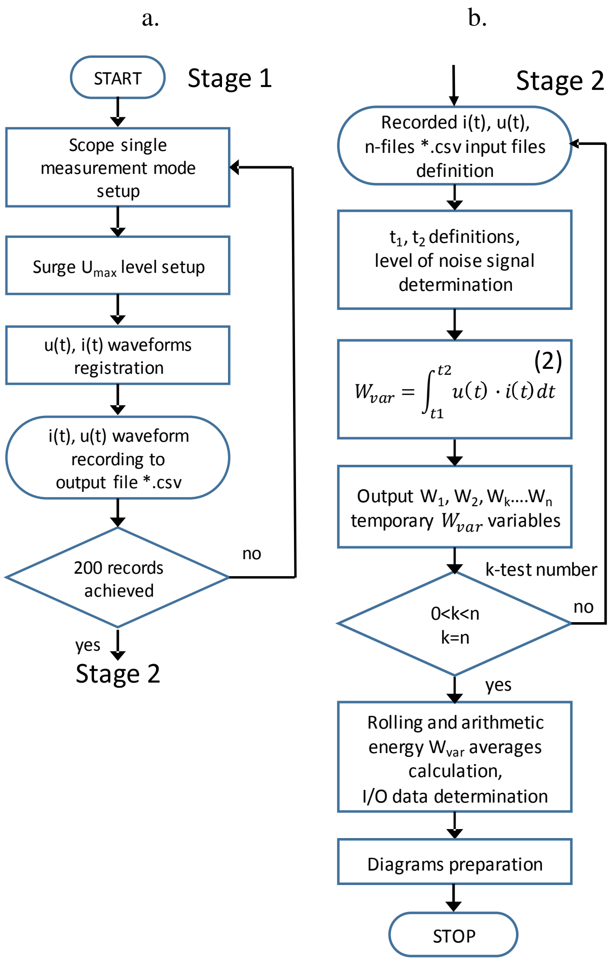

Fig. 4. Matlab software modules diagrams:
a) data collecting stage b) post-processing stage

After each series of energetic stresses temperatures at the bottom clamp and enclosure were recorded. Whole testing procedure for single object contained 20 series of 10 measurements. Every next measurements series were performed in 24 hour time interval to allow varistors cooling and theirs nominal parameters restoration.

2.2. Experimental data post-processing

Due to labor consuming research character, significant number of collected data was obtained. Detailed analysis of achieved results required study of 200 recorded waveforms for the single tests series. Summary over the 600 recorded waveforms were analyzed. For post-processing needs and gathered data processing, Matlab programming environment was utilized for activities of the experiment automation and software script development.

It was realized by means of developed Matlab script module which diagram was presented in figure 4. Script, basis on scope recorded diagrams data, permitted for fast determination the starting and ending moments of surges application, energy of applied surges and energy absorbed by surge arresters.

Elaborated software permitted for major post-processing procedure improvement combined with automatic resultant data calculation, results graphical representation and output file composition. Recorded diagrams, having graphic form (*.jpg) - for quick inspection and numerical form (*.csv) – for mathematical post-processing, were utilized for output data determination.

Basis on surge duration determined by starting t_1 and ending t_2 point of recorded data, surge voltages and currents levels ($u(t)$, $i(t)$), surge energy was calculated according to equation (2) in diagram in figure 4b. At the next step, average values of energy for each of 10 shots were obtained. Next, using integration procedure (formula (2) in figure 4b), energy absorbed by surge arrester was calculated. At the final stage graphical interpretation of obtained results using Matlab graphic engine was performed and files containing resultant data were created and stored.

3. ANALYSIS RESULTS

Graphical interpretation of selected experiments results present figure 5, figure 6 and figure 7. Figure 5 presents energy calculated for each of the performed test shot during entire laboratory experiment. Each tests series containing 200 shots were performed on the same MOV sample with an interval of 24 hours.

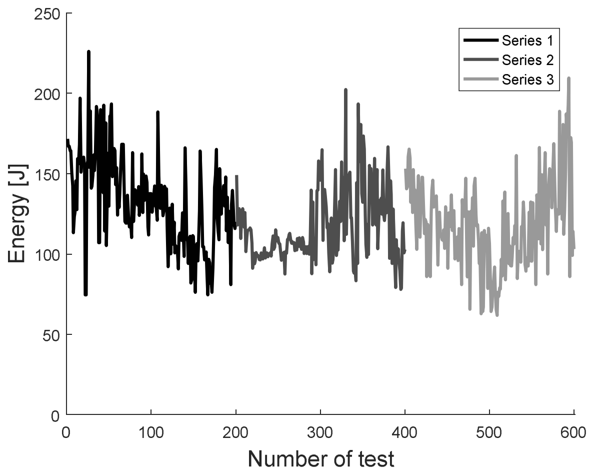

Fig. 5. Energy absorbed during each shot during entire experiment

Figure 6 contains average energy of each pocket of 10 shots obtained during entire experiment divided into three measurements series.

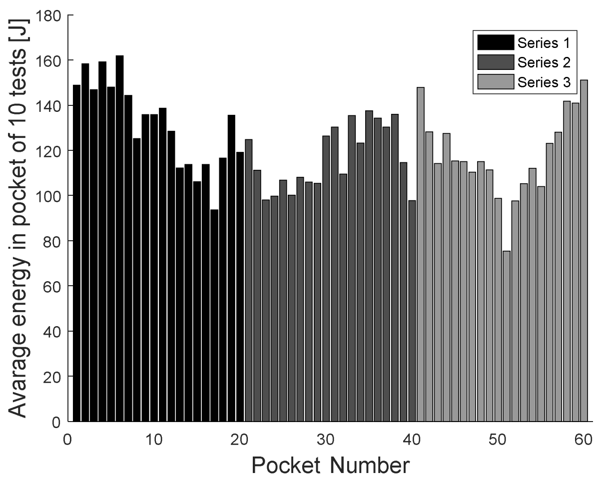

Fig. 6. Summary energy absorbed in each pocket of 10 shots for each tests series

Figure 7 presents summary of energy absorbed during entire experiment.

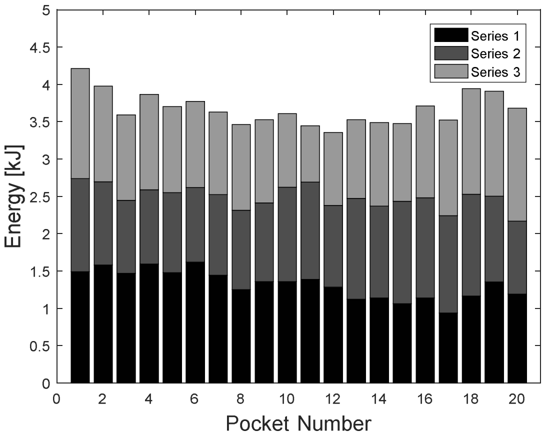

Fig. 7. Average summary energy absorbed for each tests series

4. SUMMARY

Experiment results indicated noticeable effect of high current pulses on the varistor parameters and influence on arrester applied surges suppression capacity. In the long term, due to repeated environmental loads and exposures the degradation processes can be observed and electrical parameters of arresters change. Analysis of the performed experiments indicate that repeated application of the 8/20μs surges in a time interval not shorter than 60 seconds does not cause a significant thermal load of surge arresters at the 18°C to 26°C temperature. The highest recorded temperature occurs in the upper, conical part of the arrester housing.

Due to huge number of data which had to be analyzed, achieved results processing, automation process were required. Developed software script permitted for significant improvement of recorded output data post-processing analysis. Applied procedure significantly reduced time consumption required for calculation, data analysis and graphical representation. It allowed automatic processing the large number of resultant data files. Taking into account software structure, script can be utilized for various type of input numerical data. After minor modification it can also be adapted for different quantities analysis.

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ZASTOSOWANIE OPROGRAMOWANIA MATLAB DO SZYBKIEGO WYZNACZANIA ZDOLNOŚCI ABSORBCJI ENERGII UDARÓW PRĄDOWYCH PRZEZ NOWOCZESNE OGRANICZNIKI PRZEPIĘĆ W ZALEŻNOŚCI OD LICZBY UDARÓW

Aparatura ochronna używana w sieciach energetycznych jest narażona podczas pracy na dużą liczbę udarów napięciowych. Naprężenia elektryczne i termiczne, którym poddawane są ograniczniki przepięć, powodują degradację ich struktury. Związane z tym zmiany wartości parametrów, są skutkiem procesów starzeniowych, będących rezultatem absorbowanej energii. Oszacowanie trwałości ograniczników może odbywać się przez określenie zmian ich stanu w efekcie dużej liczby udarów, jakim w warunkach laboratoryjnych poddane zostały egzemplarze testowe. W wyniku badań uzyskuje się dużą liczbę danych pomiarowych. W artykule przedstawiono oprogramowanie służące skróceniu czasu wykonania analiz oraz umożliwiające szybkie wyznaczenie sumarycznej energii udarów oraz całkowitej energii absorbowanej przez ograniczniki. Dzięki temu możliwe jest oszacowanie zmiany zdolności ogranicznika do absorbcji energii w zależności od liczby, częstości aplikowania i sumarycznej wartości zaabsorbowanej energii wszystkich udarów.

Słowa kluczowe: warystory tlenkowe, procesy degradacyjne, narażenia udarowe, diagnostyka.