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Influence of pollution of surge arrester housing on the leakage current

Streszczenie. (Wpływ zanieczyszczeń na osłonie ogranicznika przepięć na prąd upływu). *Artykuł opisuje wyniki badań związanych z pomiarami całkowitego prądu upływu oraz prądu upływu powierzchniowego na zanieczyszczonej osłonie tlenkowego ogranicznika przepięć średniego napięcia. Były badane korelacje pomiędzy wewnętrznym/powierzchniowym prądem upływu i warstwą zanieczyszczeń a harmonicznymi całkowitego prądu upływu.*

Abstract*. The total leakage current and the external leakage current on the polluted housing of MV metal oxide surge arrester was measured. Correlation between the internal/external leakage current and pollution layer on the harmonics of total leakage current was investigated.*

Słowa kluczowe: ogranicznik przepięć, prąd upływu, harmoniczne.
Keywords: surge arrester, pollution, leakage current, harmonics.

Introduction

The pollution of the porcelain housing of the surge arrester due to ambient conditions in the installation site has negative influence on the ZnO varistors. When the surface of the porcelain housing is locally unevenly contaminated, an excessive electrical stress is applied to a part of the ZnO varistors. If the pollution lasts for a long period of time the ZnO varistors are generated in heat which finally result in the thermal runaway – the leakage current flowing through the ZnO varistor blocks abnormally increases resulting in higher and higher temperature. The external leakage current sears unevenly the wet surface resulting in increasing of the electric field between wet and dry zones on the porcelain housing. This relatively slow thermal process is influenced by ambient temperature and conditions (winter, summer, day, night, foggy, rain, sunshine, snow, coastal region, inland area etc.) and temporary overvoltages in the system. In coastal regions the contaminant consist of sodium chloride (NaCl) while inland areas are contaminated by industrial pollutants such as paper pulp, fly-ash, cement dust etc. Cold climates are contaminated with the salts used for deicing the streets (brine, calcium chloride). These contaminants can include a mixture of soluble and insoluble materials.

Another problem related to the external pollution of the surge arrester housing is related to the generation of the partial discharges. They are internal through capacitive coupling between internal and external area of the ZnO varistor column, and external – surface due to non-uniform voltage distribution along ZnO varistor elements. Internal partial discharges may damage varistor elements which are not adequately coated and may cause the total destruction of the arrester [1–4].

Application of pollution test

Most pollution tests on surge arresters are carried out according to the test procedures given in IEC 507. The test procedures are suitable to test the pollution performance of standard insulators. Authors in [1] carried out test procedures according to different standards and found out that test procedures performed according to ANSI are reproducible while by application of the salt layer the dispersion of temperature growth on surge arrester is high. Furthermore, the creation of dry zone on the polluted surge arrester under alternating voltage result in:

1. quad increase in the internal leakage current due to capacitive coupling between contaminated layer and ZnO varistor column when the dry zone occurs close to the flange (for two or more units surge arresters),
2. local temperature increase in the varistor column depending on the location and size of the dry zone,
3. generation of the partial discharges within the surge arrester due to excessive radial electrical stress.

As the results mentioned that with procedures according to standards extreme conditions was not reached for contaminated surge arrester, the authors have proposed new test procedure to realize pollution test. The proposed test procedure consists of the thermal stability control and partial discharge detection under extreme conditions.

Overheat testing of the varistors in laboratory conditions is realized according to different test procedures as the salt fog test by IEC 507, the solid layer test method, test according to ANSI/IEEE C62.11-1987 and some alternative of the mentioned test procedures. Results obtained from above mentioned procedures were compared and some results were controversial.

Experiments

In order to find out the influence of the porcelain housing contamination of the surge arrester on the total leakage current magnitude and on the external leakage current magnitude flowing on the surface of the porcelain housing an experiment on MV surge arrester with rated voltage U_r=27 kV and maximal continuous operating voltage U_c=22 kV was performed. The internal diameter of the porcelain housing was 56 mm and the diameter of the ZnO varistor blocks was 47 mm.

The experiment was planed to six stages. Following electric parameters during the experiment was measured:

- the total leakage current under line-to-ground voltage,
- the external leakage current under line-to-ground voltage,
- the total leakage current under line voltage,
- the external leakage current under line voltage.

During the past stage of experiment the total leakage current under line-to-ground and line voltage was measured. The leakage current magnitude according to the Ohms law was calculated. The shape of the leakage current in time domain by digital scope was measured. The external leakage current flowing on the surface of the porcelain housing by auxiliary electrode was measured. The auxiliary electrode was made from copper strip with 1 mm thickness and 10 mm width. On the figure 1 the simple equivalent circuit is shown.

Before each measurement the noise voltage magnitude in the electric circuit was measured. Then the magnitude of the voltage drop on resistors R_1 and R_2 with digital scope was measured. The peak-to-peak voltage drop on resistors R_1 and R_2 as a result of average value from ten was registered and sampled data archived. Using FFT the frequency analysis of the archived data (total leakage current and external leakage current) was realized.

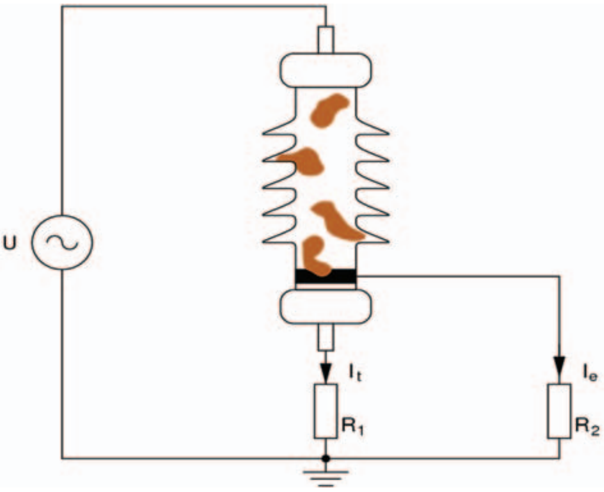

Fig.1. Equivalent circuit for the measurement of the leakage current

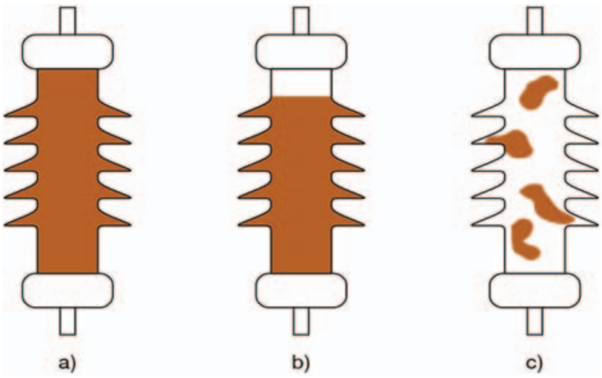

Fig.2. Using of the solid layer test: a) – solid layer covers all surface, b) – creation of the non-conducting zone, c) – non-uniform creation of the non-conducting zones

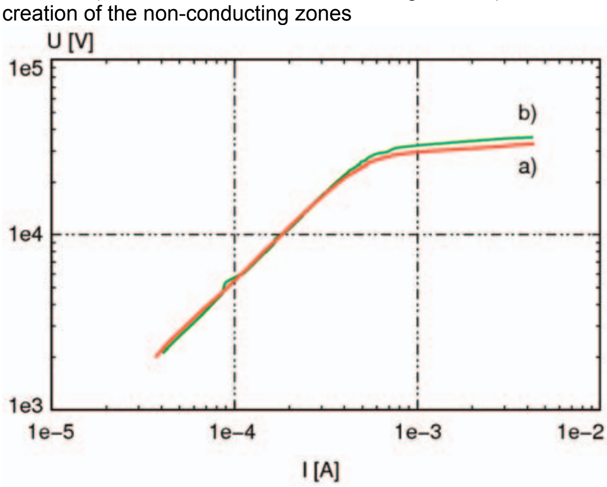

Fig.3. Current-voltage characteristic of the surge arrester

For the experiment purpose the solution was prepared. The solution consists of 4 g Aerosil, 0,2 g Fomapon (detergent), 1 g NaCl and 200 ml distilled water. Prepared solution on the porcelain housing (its surface) of the surge arrester was applied. After while the surface was naturally dried. The dried contaminated layer does not cover equally all the surface; some parts of the surface of porcelain housing remain clean (see fig. 2c).

The porcelain housing contamination during experiment stages was planned as follows:

- porcelain housing contaminated with dust in the place of storage; total duration – one year (stage A),
- clean porcelain housing (stage B),
- clean porcelain housing moistened with hot steam (stage C),
- porcelain housing contaminated with prepared solution and dry ambient (stage D),
- porcelain housing contaminated with prepared solution and moistened with hot steam (stage E).

The experiments with hot steam was not realized in the closed system with constant relative humidity. The hot steam only for increasing of the contaminated layer conductivity was applied.

Experiment evaluation

The data obtained during the experiment was evaluated from three points of view:

1. amplitude analysis of the leakage current,
2. frequency analysis of the leakage current,
3. using of the modified solid layer test method.

In the amplitude analysis the maximal magnitude of the leakage current depending on the contamination and conductance of the contaminated layer was investigated. In the frequency analysis the FFT on the registered data at each stage of the experiment was applied. In the experiment the modified solid layer test method was used.

Amplitude analysis

On the figure 3 the current-voltage characteristic of the investigated surge arrester is shown. The current-voltage characteristic with digital equipment was measured (a). As the leakage current has higher harmonic components the root-mean-square was additionally computed (b), see equation. 1. Likewise the root-mean-square of the high voltage source was computed:

$$I_{\mathrm{rms}} = \sqrt{\sum_{i=1}^{n} I_{(i)}^2} \qquad (1)$$

where: I_{rms} – root-mean-square of the measured leakage current, $I_{(i)}$ – root-mean-square of the harmonics.

On the figure 4 the total I_t and external I_e leakage current measured on the clean surge arrester is shown. On the figure 5 the total and external leakage current measured on the contaminated surge arrester moistened with hot steam is shown.

From the figure 4 it can be seen that on the clean surge arrester flows external leakage current with only small magnitude. The phase shift between the total and the external leakage current is very small. It comes to this, that the external leakage current has almost capacitive character.

The magnitude of the external leakage current flowing on the contaminated porcelain housing moistened with hot steam depends mainly on the conductance of the contaminated layer.

From the figure 5 it is clear the phase shift between the total and external leakage current. The external leakage current has resistive and capacitive characteristic. The measured time between zero crossing of the total and external leakage current is 2.1 ms which correspond the phase angle 37.8 degree. The capacitive component of the leakage current is superimposed through the capacitive coupling.

Near the maximal amplitude of the external leakage current the current impulses were registered. These current impulses originated in generation of the partial discharges due to non-uniform voltage distribution along the surface of the porcelain housing of the surge arrester and were superimposed to the measured external leakage current.

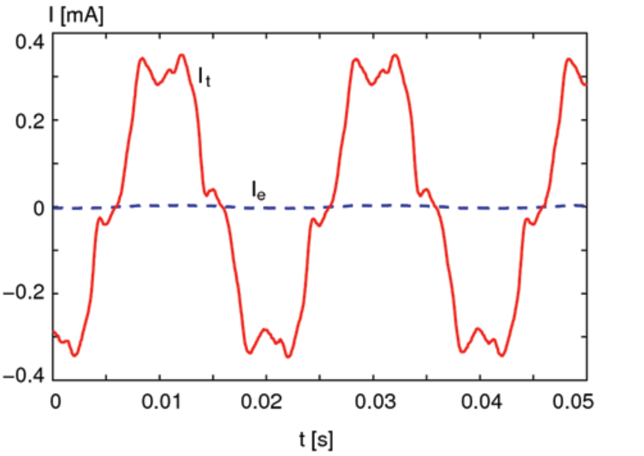

Fig.4. The total and external leakage current on the clean surge arrester

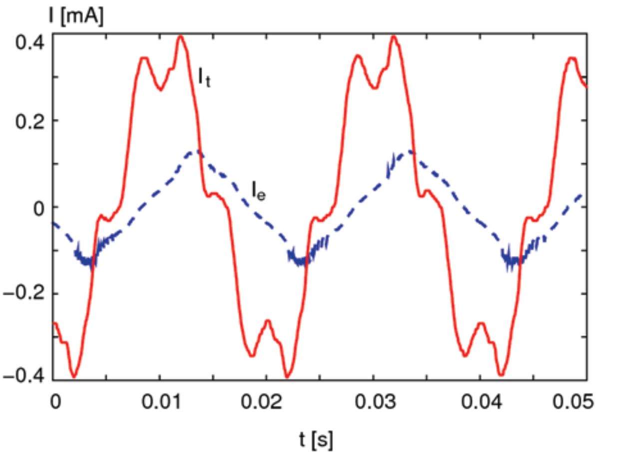

Fig.5. The total and external leakage current on the contaminated surge arrester

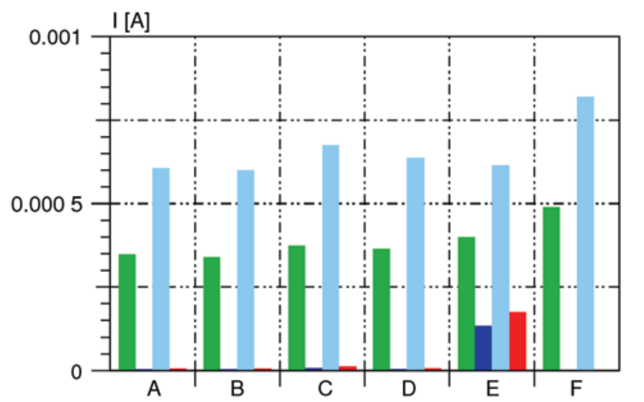

Fig.6. The maximal magnitudes of the leakage current during experiment stages A–F

On the figure 6 the maximal magnitudes of the leakage currents during experiment stages are shown. In the figure four values of the leakage currents for experiment stages from A to E are presented. They are: the total leakage current under line-to-ground voltage, the external leakage current under line-to-ground voltage, the total leakage current under line voltage and the external leakage current under line voltage. The ratio of the total leakage current for contaminated and clean surge arrester under line-to-ground voltage is 1.18; for external leakage current the ratio is 36.8; under line voltage the ratios are: 1.025 and 26.9.

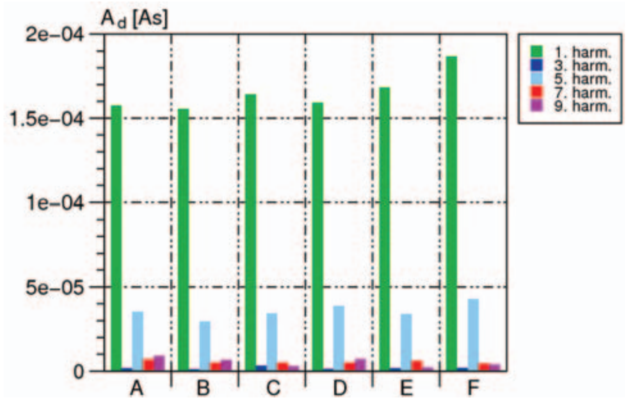

Fig.7. The frequency analysis (amplitude density) of the total leakage current under line-to-ground voltage

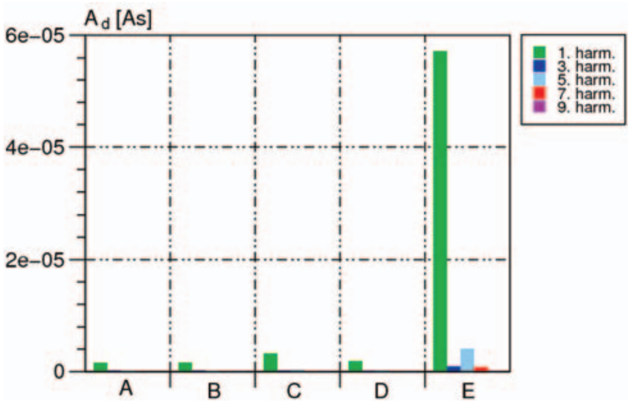

Fig.8. The frequency analysis (amplitude density) of the external leakage current under line-to-ground voltage

The experiment stage F was modified and similar to experiment stage E – only the total leakage current under line-to-ground voltage and line voltage without auxiliary electrode was measured.

Frequency analysis

The frequency analysis of the leakage current during all experiment stages using FFT was realized. On the figure 7 the harmonics from 1st to 7th are presented. From the figure it is clear that except 1. harmonic (50 Hz) the 5. harmonic dominates. By analysis of the external leakage current it was find out that the 1. harmonic dominates. During the experiment stage E the 5. harmonic of the external leakage current increases.

Under line voltage the total leakage current of the surge arrester is increased. Except 1. harmonic again the 5. harmonic dominates. The 3. harmonic is higher in comparison with that under line-to-ground voltage.

Using of the modified solid layer test method

During the experiment the modified solid layer test method was applied. The conducting layer was formed in stages by deposition of the solution on the porcelain housing in order to achieve non-uniform distribution of the contaminated layer. The humidification with hot steam in open place was realized. In this arrangement the conductivity of the contaminated layer was varying. The generation of the partial discharges on the porcelain housing was not always equal. They arise in the top of the surge arrester near the flange connected to the high voltage.

Conclusion

For the on-line diagnostics purposes the leakage current measurements and its harmonic analysis is recommended. By installation of the surge arresters in polluted regions the creation of the contaminated layer occurs which changes its conductance in accordance to atmospheric moisture. The increased external leakage current is superimposed to the internal leakage current.

In order to find out the influence of the contaminated layer on the total leakage current magnitude the experiment with six stages was realized. The data obtained from experiment were analyzed and it was find out that:

1. in the laboratory conditions the external leakage current flowing on the surge arrester surface which is polluted but not moistened has small magnitude and has capacitive characteristic,
2. humidification of the contaminated layer results in increase of the external leakage current 36.8 times under line-to-ground voltage and the external leakage current has resistive-capacitive characteristic,
3. the maximal amplitude of the total leakage current under line-to-ground voltage is higher on the contaminated layer which is moistened 1.44 times in comparison with clean surge arrester; under line voltage the ratio is 1.37,
4. using FFT it was find out that the leakage current ratio of the first harmonic on the contaminated layer which is moistened and clean surge arrester is 1.19 under line-to-ground voltage and 1.14 under line voltage,
5. the leakage current ratio of the fifth harmonic on the contaminated layer which is moistened and clean surge arrester is 1.21 under line-to-ground voltage and 1.25 under line voltage.

Using of the modified solid layer test method results in increase of the external and total leakage current. In the further experiments the influence of the contaminated layer conductance on the total leakage current of the surge arrester will be realized.

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