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Evaluation of MOSA condition using leakage current method

Zoran N. Stojanović *, Zlatan M. Stojković

Faculty of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11120 Belgrade, Serbia

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ABSTRACT

This paper covers the evaluation of metal-oxide surge arrester (MOSA) condition using the method based on the analysis of leakage current at the operating voltage of the network. A comparison is made between the following variants of this method: (1) the method based on harmonic analysis of the total leakage current; (2) the method based on the third order harmonic of the resistive leakage current; (3) the method of power loss; (4) the capacitive current compensation method; and (5) the method based on direct measurement of the amplitude of the resistive leakage current. For these methods the appropriate indicators are introduced for evaluating the MOSA condition. The application of these methods is analyzed depending on fluctuation and the presence of higher harmonics of the MOSA operating voltage. Calculations were conducted using the program MATLAB on a simplified equivalent circuit of a MOSA with a non-linear element modeled using the degree function. Based on the calculation results, a gradation was made for the applicability of individual indicators for evaluating the MOSA condition which indicates a special advantage for using the fundamental harmonic of the resistive component of leakage current and the fundamental harmonic of power loss.

1. Introduction

The reliable and adequate supply of electrical energy is the basic requirement which is expected of an electrical power system (EPS) by consumers of electrical energy. This requirement must be fulfilled by the EPS at all functional levels of production, transmission and distribution of electrical energy. As a result of recent technological trends in power engineering, the important application of monitoring and diagnostics of high voltage equipment has been realized [1–5].

The condition of the MOSA, which today represents the basic device for protection from surges at all voltage levels, has a significant influence on the reliability of EPS operation. The characteristics of the MOSA irreversibly change during exploitation as a result of several factors, of which the most important are: improper selection, aging due to operating voltage, accelerated aging due to current strain, penetration of moisture into the housing, as well as the influence of atmospheric occurrences and chemical reactions.

The evaluation of the MOSA condition can generally be conducted on the basis of the methods which require interrupting operation (off-line methods) and methods which do not require operation to be interrupted (on-line methods). The off-line methods provide better insight into the MOSA condition, but use of these methods results in significant expenses for disassembly, transport and laboratory testing. The most economically acceptable methods for evaluation of the MOSA condition are on-line methods. Despite being less reliable, these methods can provide a preliminary picture of the MOSA condition based on which further steps are taken, i.e., conducting field and/or laboratory testing. The methods based on leakage current at the operating voltage of the network [6–10], MOSA temperature [11,12] and the electromagnetic field around the MOSA [13,14] are the on-line methods for evaluating the MOSA condition.

The oldest and most widely used methods for evaluating the MOSA condition are the methods based on the analysis of leakage current at the operating voltage of the network. While these methods had limited application in classic arresters due to the existence of a spark gap, the inception of the MOSA increased their use and importance. The reason lies in the fact that a MOSA has no spark gap so there is always a low current flowing through this arrester, even at the operating voltage. This current is called MOSA leakage current, considering that it does not exceed a value of 2 mA. The resistive component of leakage current is an excellent indicator for evaluating the MOSA condition. However, it is not immune to external influences or the influence of the network, so it is necessary to take these factors into consideration when evaluating the MOSA condition.

This article presents the evaluation of the MOSA condition using the method based on the leakage current at the operating voltage of the network. The possibility is discussed of applying the following variants of this method: the method based on harmonic analysis of the total leakage current [6], the method based on the

* Corresponding author. Tel.: +381 11 3218341; fax: +381 11 3248681.
E-mail addresses: stojanovic@etf.rs (Z.N. Stojanović), zstojkovic@etf.rs (Z.M. Stojković).

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third order harmonic of the resistive leakage current [7], the method of power loss [8], the capacitive current compensation method [9], and the method based on direct measurement of the maximum amplitude of the resistive leakage current [10].

The effect of fluctuation of the network operating voltage on the applicability of individual methods is considered in detail using a simplified model of a MOSA with a non-linear element modeled through a degree function. All calculations were conducted using the MATLAB technical computing software [15]. Special consideration is given to the influence of the third, fifth and seventh harmonic of voltage on leakage current, and then also to their collective influence. The analysis was conducted for the permitted values of higher harmonics of voltage depending on the voltage level according to relevant standards [16,17] and norms [18].

Based on the calculation results, the appropriate conclusions are derived in relation to the applicability of individual indicators for evaluation of the MOSA condition. Special attention must be dedicated to the fundamental harmonic of the resistive leakage current and the fundamental harmonic of power loss as the best indicators for evaluating the MOSA condition.

2. Methods for evaluation of MOSA condition based on leakage current

A MOSA has an exceptionally non-linear *U–I* characteristic. This characteristic can be explained in three areas. The first area corresponds to a current of up to 2 mA and voltages which are lower than the rated MOSA voltage. Next is the area in which very small voltage changes correspond to exceptionally large changes of current, and finally, the area which corresponds to a larger than rated current and voltages higher than the remaining voltage of the MOSA at the rated leakage current flow [19]. Due to this, depending on the considered operational mode, the MOSA is often modeled for just a single part of the *U–I* characteristic. As the area of poor conductivity is of interest for the methods based on leakage current, within the analysis a simplified MOSA model [20] will be used, displayed in Fig. 1.

The equivalent circuit of a MOSA is the consequence of the granular nature of the varistors from which the arrester is composed. The resistance of the area between grains is of a non-linear nature and due to this is a non-linear resistance R_p. R_s represents the resistance of the grain which is linear and normally very small. Grains with inter-granular layers make a network of capacitances which can be collectively represented by capacitance *C*. Disregarding the effect of resistance R_s, the MOSA leakage current can be explained as a linear capacitive component and a non-linear resistive component.

The methods for evaluating the MOSA condition based on measurement of leakage current are reflected in the measurement of current on the grounding conductor of the arrester. That way, the total leakage current i_t is measured which consists of the dominant capacitive current i_c and the resistive current i_r, and which, by order of magnitude, is smaller in value.

The typical waveforms of voltage $u(t)$, total current $i_t(t)$, capacitive current $i_c(t)$ and resistive current $i_r(t)$ are displayed in Fig. 2, as functions of time.

An aged MOSA is characterized by an increased content of resistive leakage current. For the aforementioned variants of the method based on leakage current at the operating voltage of the network, the following indicators were introduced for evaluating the MOSA condition: rms value of the third harmonic of the total leakage current (I_{t3}), rms value of the third harmonic of the resistive leakage current (I_{r3}), rms value of the resistive leakage current (I_r), amplitude of the resistive leakage current (I_{mr}) and the total power loss (*P*). Along with these indicators, which result from the methods based on leakage current, new indicators were used which these methods had previously not taken into account: rms value of the fundamental harmonic of the resistive leakage current (I_{r1}) and the fundamental harmonic of power loss (P_1).

3. The influence of voltage fluctuation

An analysis of the effect of voltage fluctuation on the indicators was conducted using the simplified MOSA model shown in Fig. 1. The non-linear characteristic of the MOSA is defined by the expression:

$$\frac{i_r}{I_{ref}} = \left(\frac{u}{U_{ref}}\right)^{\alpha}, \qquad (1)$$

where i_r is the instantaneous value of the resistive leakage current, *u* is instantaneous value of the voltage, I_{ref}, U_{ref} is reference current and reference voltage which define one point on the *U–I* characteristic, and α is the coefficient of non-linearness.

The experimentally realized characteristics of a MOSA [21] were used and modeled applying (1) for adopted values of $\alpha_n = 4.7$ for a new MOSA and $\alpha_a = 3.4$ for an aged MOSA. For the purpose of simplicity, the reference values I_{ref} and U_{ref} were assigned as 1 mA and 1 pu, respectively.

The MATLAB technical computing software was used for the realization of the aforementioned model. The operating voltage $u(t)$ is represented by a sinus function and varies within the limits of ±0.7 pu. For each new sample of voltage, on the basis of (1), a sample of the resistive current is calculated. The sampling fre-

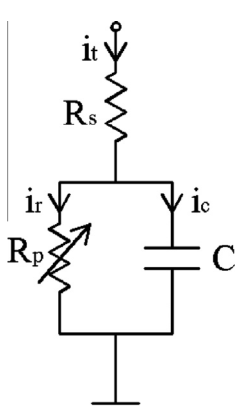

Fig. 1. Simplified MOSA model.

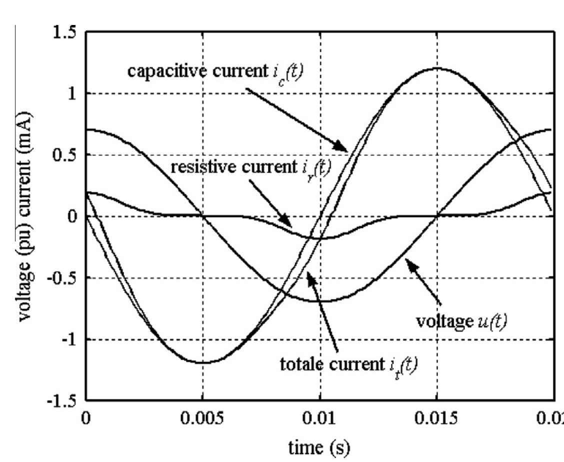

Fig. 2. Typical waveforms of MOSA voltage and current.