Electrical Power and Energy Systems 66 (2015) 188–193

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Metal oxide surge arrester condition monitoring based on analysis of leakage current components

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ARTICLE INFO

Article history:
Received 28 December 2013
Received in revised form 30 September 2014
Accepted 27 October 2014
Available online 21 November 2014

Keywords:
Metal oxide surge arrester
Condition monitoring
Indicator
Leakage current

ABSTRACT

This paper presents proper indicators for evaluation of the surge arrester condition based on the leakage current analysis. Maximum amplitude of fundamental harmonic of the resistive leakage current (I_{mr1}), maximum amplitude of third harmonic of the resistive leakage current (I_{mr3}) and maximum amplitude of fundamental harmonic of the capacitive leakage current have been used as indicators for surge arrester condition monitoring. The effects of operating voltage fluctuation, third order of voltage harmonic, over-voltage and varistor aging have been investigated to show the ability of introduced indicators for accurate diagnostic of arrester's conditions. In order to have accurate values of stray capacitors, 3D-FEM has been used. Moreover, surge arrester model for calculating leakage current has been performed in ATP–EMTP. In addition, the signal processing has been done using MATLAB software. This study shows that the introduced indicators are proper criteria for surge arrester condition monitoring.

Introduction

The reliable and adequate energy transmit is an essential concern of customers which must be supply via electrical power system. This requirement should be satisfied by reliable electrical power system at all functional levels of production, transmission and distribution [1,2]. According to the most recent studies, equipment monitoring is the best way to increase the reliability and equipments failure diagnostic [3,4].

Metal oxide surge arresters (MOSAs) are one of the most important equipments for power system protection against switching and lightning over-voltages. Protection of transmission and distribution components is the major function of surge arresters; therefore, their condition monitoring has significant influence on the reliability of power network.

The MOSAs characteristics change during utilization due to the several factors, of which the most important factors are: aging due to operating voltage and impulse current, penetration of moisture into the housing, chemical reaction with the surrounding atmosphere. Degradation of MOSAs due to these destructive factors leads to increase leakage currents.

For condition monitoring of surge arresters, many offline and online approaches have been presented in literature such as: leakage current measurement under operating voltage system [5–10], temperature measurement [11,12], and electro-magnetic field measurement [13,14]. Thermo-vision and electromagnetic tests are non-destructive monitoring methods which are used for surge arresters condition monitoring. The advantages of these methods are that there is no need to disconnect the equipment and secure distance from test object. However, difficulty of data analysis and requirement of expensive equipments for these experiments are drawbacks of the methods.

The most popular methods in literature are based on total leakage current analysis, especially its resistive component, which has been obtained from the decomposition process. The main purpose of most diagnosis techniques are calculation and analysis of the third harmonic of resistive current, power loss measurement, amplitude measurement of resistive leakage current and Fundamental harmonic measurement of the resistive leakage current [5–10].

In this paper, new indicators based on Maximum amplitude of fundamental harmonic of the resistive leakage current (I_{mr1}), Maximum amplitude of third harmonic of the resistive leakage current (I_{mr3}) and Maximum amplitude of fundamental harmonic of the capacitive leakage current (I_{mc1}, it is a new indicator which this method had previously not taken into account) have been proposed to identify surge arresters conditions. To evaluate the performance of the new monitoring criteria, a harmonic components database of total current signals and their components (resistive and capacitive currents) have been produced. This database was

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http://dx.doi.org/10.1016/j.ijepes.2014.10.052
0142-0615/

obtained from medium voltage (MV) and high voltage (HV) surge arresters with different operating conditions, which include operating voltage fluctuation, third harmonic of voltage, over-voltage and varistor aging. According to the obtained results, there are obvious differences between extracted features of aforementioned conditions, which show the significant performance of proposed indicators for different condition monitoring of surge arresters. In this work, in order to have accurate values of stray capacitors, 3D-FEM has been used. Moreover, surge arrester model for calculating leakage current has been performed in ATP–EMTP. In addition, the signal processing has been done using MATLAB software.

MV surge arrester characteristic

The nonlinear *V–I* characteristic of MOSAs divide to three regions. Voltage is lower than nominal voltage and small leakage current flows through surge arresters in first region. Next is the region that very small voltage changes correspond to exceptionally large changes of current. In recent region not only voltage is higher than residual voltage but also current is bigger than rated current.

Under normal operating conditions, a small leakage current goes through surge arrester. This current contains two components: a nonlinear resistive component, due to the nonlinear resistivity of ZnO varistor and a capacitive component, due to the capacitive element. Capacitive component of total leakage current appears at the fundamental frequency of the applied voltage and the resistive component is a non-sinusoidal waveform, which has the fundamental frequency and odd orders of harmonics components.

To study different operating conditions of surge arrester and leakage current variation, medium voltage surge arrester has been used. Table 1 shows the surge arrester characteristics.

MV surge arrester modeling

Surge arrester equivalent circuit has been modeled in EMTP–ATP software as shown in Fig. 1. This model has been used to investigate surge arresters behavior under different situations such as fluctuation, third harmonic of voltage, system overvoltage and varistor aging with the purpose of achieving the new indicators to distinguish different operating conditions of surge arresters.

Where, C_{FF} is capacitance between upper and lower flanges, C_{FUSi} ($i = 1, 2\ldots4$) are stray capacitances of upper flange with spacer and aluminums sheets, C_{FDSi} ($i = 1, 2\ldots4$) are stray capacitances of lower flange with spacer and aluminums sheets and C_{Si} ($i = 1, 2$) are capacitances between spacer and aluminum sheets.

To model nonlinear resistance, *V–I* characteristics of valve elements are needed, which must be valid for the range of voltages considered in the simulation. So a data file representing peak values of applied voltage and resistive current has been used to achieve *V–I* nonlinear characteristic. Experimental setup has been arranged to obtain required *V–I* characteristics which is shown in Fig. 2. According to Fig. 2, experimental setup consists of a high voltage transformer with adjustable voltage between 0–220 V and 0–100 kV, capacitive divider and data acquisition system. Data

Table 1
Technical characteristics of tested surge arresters.

Surge arrester type	1
Rated voltage (kv)	25
Continuous operating voltage (kv)	20
Lightning impulse current with 8/20 microsecond (kA)	10
Maximum residual voltage (kv)	70
Total external creepage distance (mm)	800
Shed numbers	8
Varistor numbers	6

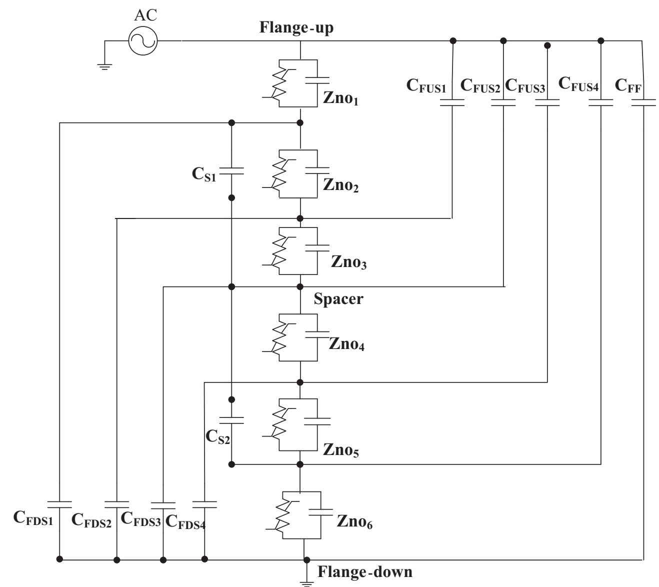

Fig. 1. Medium voltage surge arrester equivalent circuit.

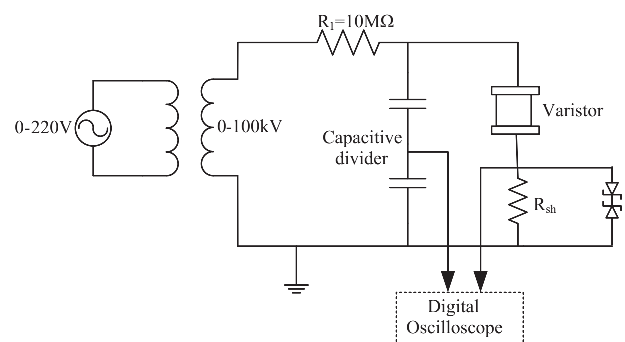

Fig. 2. The experimental set-up for voltage and current measurement.

acquisition system, which uses for leakage current measurement, comprises a digital oscilloscope, back to back connected Zener diodes for overvoltage protection and a 470 Ω shunt resistor (R_{sh}) for measuring leakage current. Capacitive divider is used for measuring applied voltage. The leakage current through the varistor and total applied voltage have been captured using two channel digital storage oscilloscope.

The time-delay addition method [15] has been used to separate the resistive current and capacitive current components from the

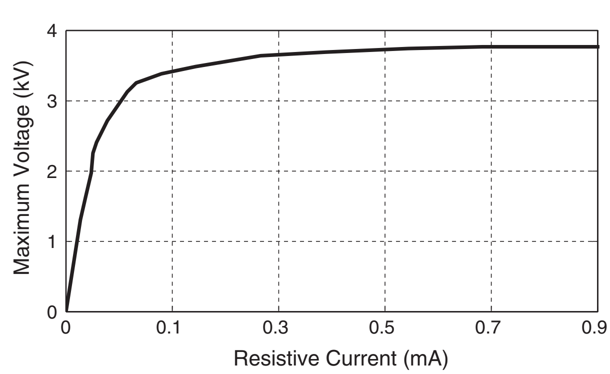

Fig. 3. Varistor *V–I* characteristic.