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Metal-oxide surge arrester monitoring and diagnosis by self-organizing maps

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ABSTRACT

The main metal-oxide surge arrester are usually monitored by measuring the total leakage current and decomposing it into a capacitive component and a resistive component. However, these techniques present some limitations which make their implementation in the field quite difficult. This paper describes a monitoring technique based on classifying the harmonic characteristics of the leakage current. Self-organizing maps have been used in the classification process. Several station classes arresters were tested in the laboratory and their leakage current signals were recorded. Six different types of artificial imperfections were created in the arresters in order to assess the technical capability to discriminate arresters operating under different field conditions. The self-organizing maps are able to identify defective arresters with certainty of almost 98%. The results show that the technique is feasible for monitoring the condition of metal-oxide surge arresters.

1. Introduction

Metal-oxide surge arresters are used to protect electrical power systems against overvoltages. Thus, they contribute decisively to the increase in reliability and continuity of power system operation. Due to the importance of arresters, it is necessary to develop and improve techniques and procedures to monitor and diagnose surge arresters operation conditions correctly and accurately. Since surge arrester failure leads to non-programmed power supply interruption, damage to other substation equipment and risks to technical personnel may happen.

Arresters monitoring and diagnosis is normally based on the measurement and decomposition of the total leakage current of the surge arrester during the steady state operation. The leakage current is usually decomposed into its capacitive and resistive components, since the resistive component and its third harmonic present significant variations on the magnitude and waveshape proportional to the arrester degradation level [1–4]. The analysis and interpretation of the variations of the resistive component are the basis of most of the common monitoring techniques described in the literature.

The main problem of the methods based on total leakage current decomposition is the need to measure the applied voltage on the surge arrester or estimating phase angle difference between the leakage current and the applied voltage. To measure the applied voltage on site is a difficult task, that requires accessing and connecting data acquisition systems to measurement devices (such as potential transformers). The influence of neighboring transmission lines on the measurement and the influence of parasite capacitances are additional problems to reckon with [4]. These problems can impair the condition monitoring of the arrester. There are some methods [2] that claim to overcome the above mentioned difficulties; yet they make use of a series of simplifications and approximations that could comprise the accuracy of the results. A technique developed recently is able to consistently monitor and diagnose the arresters condition, but it requires off-line processing and a database of known surge arrester operation conditions [5].

Consequently, it is quite evident that there is a need to develop a condition monitoring and diagnosis technique that can be applied to arresters in service effortlessly, showing reliable results which will help the technical substation personnel with their predictive and preventive maintenance activities. In this paper, a technique is proposed for surge arrester monitoring and diagnosis, that is based on the analysis of the features extracted from the total leakage current. The implementation can be made on embedded systems; besides previous arresters operation conditions database are unnecessary. The voltage measurement is not necessary, either.

2. Proposed technique

The harmonic distortion level and the total current magnitude (especially, its resistive component) are important indicators of

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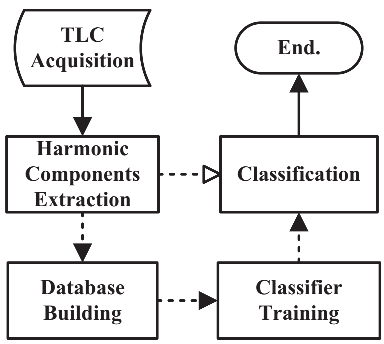

Fig. 1. Proposed technique diagram.

the arrester degradation level [3,4]. Thus, it seems reasonable to extract features of the total current in order to develop a classifier of defects or failures. However, it is noteworthy that the approach proposed here differs from those commonly used in the literature, i.e., approaches based on the decomposition of the capacitive and resistive components of the leakage current. In the proposed technique the characteristics used for monitoring and diagnosis are extracted from the total leakage current and not from the resistive component. A number of practical and technical restrictions are consequently avoided.

In Fig. 1, an overview of the proposed technique is presented. Initially, total leakage current of arresters are obtained either in the laboratory or in the field. Then the signal feature extraction (i.e., relevant amplitude harmonic components) is carried out. Subsequently, the extracted features are organized in patterns to be applied to the classification system, which is based on self-organizing maps (SOM).

3. Total leakage current acquisition

The total leakage current was obtained from maximum continuous operating voltage (MCOV) tests carried out in the laboratory for station class surge arresters. This voltage is the maximum designated root-mean-square (rms) value of power-frequency voltage that may be applied continuously between the terminals of the arrester [6]. The diagram of the experimental arrangement used in the tests is shown in Fig. 2. It consists of an adjustable voltage source, a voltage regulator, a step-up transformer, a protective resistor, a capacitive voltage divider and the test object (the surge arresters) in series with a shunt resistor. The voltage divider was used only to monitor the applied voltage. The current signal was obtained from the shunt resistor and it was stored in a data acquisition system.

3.1. Evaluated samples

It was tested surge arrester samples with distinct physical, electrical and operational characteristics with the purpose of evaluate the generalization capability of the proposed monitoring and diagnosis technique. Some electrical data of the evaluated surge arresters are shown in Table 1.

The operational characteristics were evaluated by the creation of seven different types of artificial imperfections in the tested samples. Typical failures were caused in order to reproduce critical conditions in the field and during transportation [3,5,7–10]. As described in [5,7,8], imperfection types were: sealing loss, superficial pollution, varistors degradation, internal humidity, displacement along the active column, and non-uniform voltage distribution.

Table 1
Characteristics of the evaluated surge arresters.

Surge arrester	Rated voltage (kV)	MCOV (kV)
Type A	96	76
Type B	72	42

The evaluated surge arresters operating conditions are described below.

3.2. Simulated arresters operating conditions

The first condition considered in the testing of surge arresters was its ideal condition. In this case, the tested surge arresters presented characteristics and behaviors similar to the nominal ones. Then, typical failures found in surge arresters were artificially created in the tested samples. The faulty conditions are [5,7,8]:

- *Sealing loss*: characterized by the loss of physical isolation between the environment and the interior of the surge arrester, allowing the exchange of gases. The loss of sealing was created artificially in the laboratory by opening channels between the environment and the interior of the arrester and allowing the exchange of heat and gas;
- *Internal humidity*: can occur in surge arresters due to failures in the manufacturing process at the moment of sealing, or by sealing losses caused by the natural aging process of the equipment. To simulate this defect, the arresters were opened and water was sprayed on the varistor column. Then, the arrester was re-assembled;
- *Superficial pollution*: occurs due to the presence of pollution on the surge arrester housing. To simulate this defect, a salt suspension was sprayed on the entire porcelain housing of the surge arrester;
- *Varistor degradation*: can occur due to natural or precocious varistor aging. To simulate this failure in laboratory, damaged varistors were inserted into the arrester active column. The varistors were damaged by the electrical stress produced by the application of current impulses and overvoltages;
- *Displacement along the active column*: generally occurs due to inadequate transportation or storage of surge arresters. However, this kind of problem may be caused by the manufacturing process as a result of assembly errors. In the simulation, displacements in the active column were performed;
- *Non-uniform voltage distribution*: occurs due to failures in the arrester project or to superficial pollution on the arresters. In the simulation of this kind of failure, several assemblies were used with internal short-circuited varistors; therefore, modifying the electrical field distribution along the arrester.

4. Harmonic components extraction

The methodology consisted in extracting relevant information from current signal to identify the traces that allow the proposed classification system to determine the surge arrester operating conditions. The harmonic level distortion and the magnitude of the total current in surge arresters bring out the significant characteristics of the surge arrester degradation level [1–4].

Generally, the harmonic components of a signal is obtained from the application of Discrete Fourier Transform (DFT), more specifically, the suitable and numerically efficient algorithm, FFT (Fast Fourier Transform). Although, this algorithm is hard to implement, especially, on embedded systems, it does present some limitations like the ones observed in [11]. Thus, in this paper, another implementation of the DFT was used. This implementation is called Goertzel algorithm, which presents some of the FFT limitations;