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Proceeding Paper

Online Condition Monitoring of 120 kV Zinc Oxide Surge Arresters Using Correlation Method †

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Abstract: The degradation of Zinc Oxide Surge Arresters (ZnOSA) is commonly detected by the resistive component of its leakage current 'I_r'. The methods previously employed to extract the resistive component of the leakage current were intricate and demanded a greater number of computational steps. The objective of this paper is to propose a new technique for the age detection and degradation analysis of ZnOSA, named the 'Correlation Method', which does not require the extraction of the resistive leakage current. The correlation coefficient is calculated between the power factor (pf) and total leakage current (I_t) on the MATLAB software (Version R2018a). The performance of this method is analyzed experimentally by changing the voltage, ranging from 70 to 120 kV, of surge arresters. The proposed research offers improved computational efficiency and provides valuable insights into the relationship between the power factor, leakage current, and the aging process of ZnOSA. Moreover, the results of the proposed methods are compared with those of existing techniques.

Keywords: Zinc Oxide Surge Arresters; total leakage current; resistive current; condition monitoring; correlation coefficient; age detection

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1. Introduction

Zinc Oxide Surge Arresters (ZnOSA) are utilized to protect the system against overpotential [1]. The working of ZnOSA is affected by aging and insulation breakdown inside the arrester. Therefore, it is necessary to protect the ZnOSA from further damage and deterioration, which may cause interruptions in electricity transmission and distribution [2]. Condition monitoring techniques are employed to determine the current health status of ZnOSA in terms of its aging and degradation. These conditions are implemented in two ways: (a) online and (b) offline [3]. Offline condition monitoring requires the disconnection of the surge arrester from the power system [4]. On the contrary, an online technique is capable of monitoring the condition of the arrester during its operation in the grid. Online condition monitoring techniques are most commonly based on the measurement of I_t, which comprises two components, capacitive and resistive currents [5]. The variations in environmental factors have a more noticeable effect on the aging of ZnOSA, particularly in the resistive component of the leakage current [6]. Therefore, it is adopted as the most reliable indicator of an arrester's condition. Researchers have proposed many methods for the extraction of I_r [7,8]. These include the modified shifted current method, capacitive current shifted method, conventional method and others, as described in Table 1 [9–11]. However, a significant number of computation steps are required; moreover, the accuracy and results are inadequate, since it requires the separation of I_r from I_t [12,13]. To reduce the computational steps and improve the age detection process, a new technique is proposed, which is based on the correlation between the power factor and total leakage current at different voltages. It is essential to propose new techniques for the online condition monitoring of ZnOSA, independent of the extraction of I_r.

Table 1. Existing methods for online condition monitoring of surge arresters.

Method		Working Principle
(1)	Conventional Method	To determine I_t, current transformers are used with incorporation of applied voltage.
(2)	Modified Shifted Current Method	I_r is obtained by inserting the observed I_t into the 180-degree phase-shifted I_c.
(3)	Capacitive Current Compensation Method	By modifying a reference signal's magnitude and phase to accommodate I_c and I_r, they are calculated.
(4)	Least Square Method	To determine I_r and I_c, time domain equations are developed.

This paper introduces a new aging indicator-based online condition assessment of ZnOSA, known as the correlation method. The proposed technique is based on the computation of the correlation between the pf and I_t of the arrester. The experimentation is conducted using three samples of ZnOSA by varying the applied voltage levels from 70 to 120 kV, as a prominent variation is observed in the leakage current level by varying the voltage level from 70 to 120 kV [14]. The obtained results are compared with existing methods that require the extraction of I_r from I_t. The results show that the proposed method can easily detect aging, without performing numerous computational steps, more effectively as compared to existing methods.

2. Methodology

The correlation method is proposed in this paper for the online health assessment of ZnOSA. Experiments are carried out in the high-voltage laboratory to measure the total leakage current of three samples of 120-kV rated arresters. All the tested samples of ZnOSA have the same voltage–current characteristics, current age and physical dimensions. The applied voltage is varied from 70 to 120 kV with a step of 10 kV for the classification of the arrester samples. After obtaining the leakage current signal, the modified shifted current method is used to extract the resistive current for the validation of the results, as shown in Figure 1. The obtained current parameters are substituted into Equation (1) to determine the angle of the current. Equation (2) is employed to determine the power factor of the arrester using the angle 'θ'. The correlation coefficient 'Q' between the I_t and pf of each arrester sample is obtained on MATLAB to determine its condition within the voltage range of 70–120 kV.

$$\theta = \sin^{-1}\frac{I_c}{I_t} \tag{1}$$

$$\mathrm{pf} = \cos\theta \tag{2}$$

where I_c = capacitive component of total leakage current.

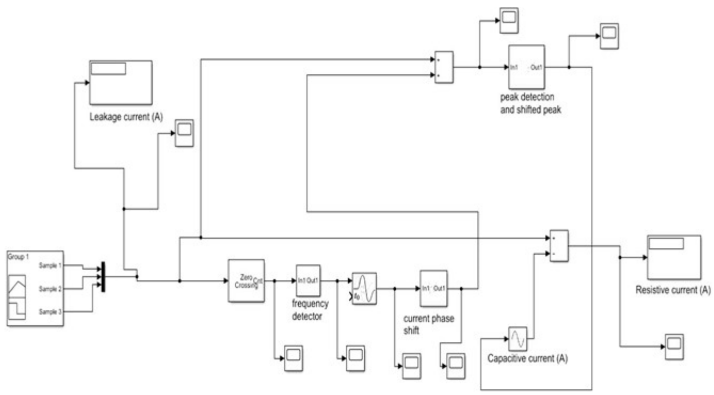

Figure 1. Simulink model for the withdrawal of resistive current component of I_t.

The followed research methodology is shown in Figure 2.

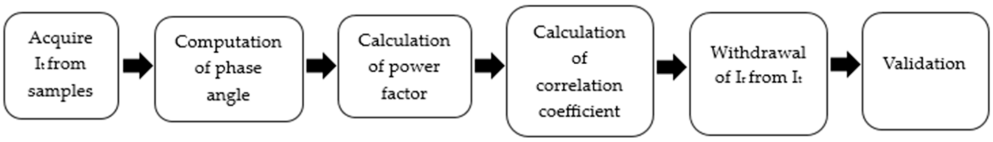

Figure 2. Research flow diagram.

3. Results and Analysis

The experimental results of I_t and I_r for each arrester sample, obtained by varying the voltage levels from 70 to 120 kV, are tabularized in Table 2.

Table 2. Measured values of I_r and I_t for samples 1, 2 and 3.

Vrms	Sample 1		Sample 2		Sample3	
(kV)	I_r (μA)	I_t (μA)	I_r (μA)	I_t (μA)	I_r (μA)	I_t (μA)
70	305.70	821.60	328.20	830.10	316.60	825.90
80	360.60	935.90	412.40	954.89	375.10	942.30
90	489.50	1088.5	575.20	1129.9	503.10	1094.9
93	540.20	1148.1	624.50	1190.0	554.80	1155.1
98	562.20	1205.9	665.20	1257.8	573.10	1210.9
100	637.60	1261.9	714.40	1303.0	653.40	1270.1
110	720.10	1389.5	939.30	1514.0	745.70	1401.0
120	1540.3	2007.9	2155.0	2516.0	1645.4	2092.3

Based on the information obtained from Table 2, it is observed that the resistive current increases as the voltage rises.

Similarly, the obtained results of angle 'θ' and pf are presented in Table 3. It is evident from Table 3 that the angle of the current varies inversely with respect to the applied voltage. This is due to the fact that the increase in I_t with the applied voltage in fact increases the resistive current more significantly as compared to the capacitive current [15].

Table 3. Computed values of pf for samples 1, 2 and 3.

Vrms (kV)	Power Factor		
	Sample 1	Sample 2	Sample 3
70	0.401	0.436	0.392
80	0.412	0.441	0.399
90	0.453	0.513	0.461
93	0.471	0.532	0.491
98	0.466	0.533	0.469
100	0.516	0.559	0.519
110	0.523	0.619	0.531
120	0.772	0.861	0.795

The results of correlation coefficients Q1, Q2 and Q3 of samples 1, 2 and 3, respectively, are shown in Table 4.

Table 4. Results of correlation coefficients.

Correlation Coefficient	Sample	Result
Q1	1	0.9839
Q2	2	0.9966
Q3	3	0.9896

Table 4 shows that sample 2 has the highest correlation coefficient as compared to samples 1 and 3. Hence, Q2 indicates that sample 2 is highly aged amongst the studied samples. It is also inferred that the power factor has a direct relationship with the applied voltage. Furthermore, it is evident from Figure 3 that sample 2 has the highest value of correlation between pf and I_t as indicated by red line which shows that sample 2 is highly aged.

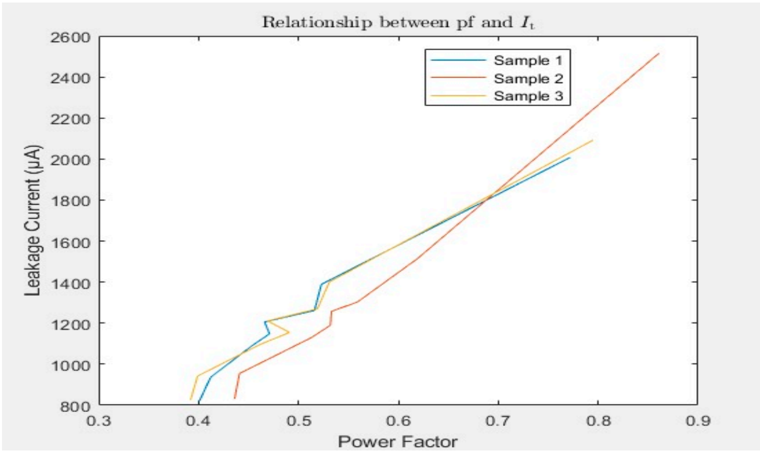

Figure 3. Relationship between power factor and I_t.

The results are validated using the previously applied method that uses I_r as the aging indicator by extracting I_r from the samples. The extracted resistive leakage current components of samples 1, 2 and 3 are presented in Figure 4. The resistive current of sample 2 is more distorted, with a high magnitude as compared to other samples. This is due to the fact that sample 2 is the most aged sample among all arresters.

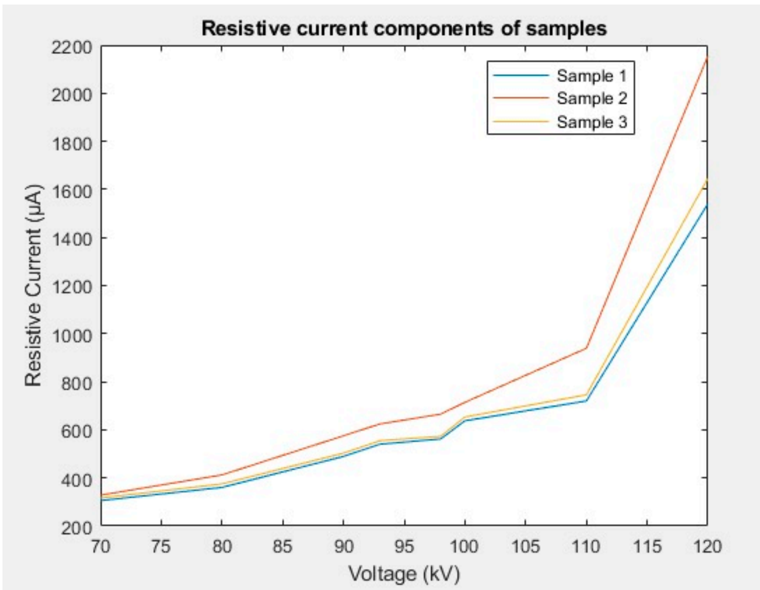

Figure 4. Resistive current component I_r of samples 1, 2 and 3.

The correlation between pf and I_t is determined to be directly related to the aging of ZnOSA. Consequently, utilizing this relationship can serve as a simpler and more effective method to monitor the aging of ZnOSA and assess its overall health.

4. Conclusions

In this paper, a new technique based on the correlation coefficient method is proposed for the online condition monitoring (age detection) of ZnOSA. This technique is executed on the MATLAB software (Version R2018a) with the help of data extracted from a 120 kV rated ZnOSA. To validate the efficiency and accuracy of this proposed method, the I_r of samples 1, 2 and 3 were extracted from I_t, using a Simulink model. A significant reduction in computational steps was observed when employing the new technique compared to previously applied methods. It is concluded that when using the correlation-based technique, fewer computational steps are required as compared to previously used techniques. It is also concluded that the correlation between pf and I_t is directly proportional to the aging of the ZnOSA. Hence, this can be used as a more simple and efficient method to monitor the health of a ZnOSA by detecting its age.

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