ISSN 2229-5518

Modified Shifted Current Method for Extraction the Resistive Leakage Current of Metal Oxide Surge Arrester

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Abstract— Surge arresters are installed on transmission and distribution lines and in substations between phase and earth to reduce the failure rates of system. To monitor the degradation of surge arrester measurement of total leakage current is used. The gapless zinc oxide surge arresters enable the utility personnel to measure the leakage current due to its gapless physical configuration. The resistive leakage current is extracted from total leakage current to determine the health of surge arrester. As the resistive current increases the life of surge arrester gets decreases. In conventional method total leakage current is measured by using current shunts or current transformers with addition of applied voltage which is difficult to measure in online condition. Modified Shifted Current Method (MSCM) is used to extract the resistive current from the total leakage current without the need of the voltage signal. In this paper the extraction of resistive leakage component from the total leakage current of Metal-oxide Surge Arresters (MOSA) is done by using the technique Modified Shifted Current Method (MSCM) and simulated in MATLAB.

Index Terms— Metal-oxide surge arresters, Resistive leakage current, Modified shifted current method

1. NOMENCLATURE

It	**Total Leakage Current (mA)**
Ir	Resistive Leakage Current (µA/mA)
Ic	Capacitive Leakage Current (mA)
G	Amplifier gain
Vsh	Applied voltage (kV)
$\varphi 1$	Power angle
Uk	*k* order harmonics voltage
θk	*k* order harmonics voltage phase angle
fk	Harmonic component of capacitive leakage current
*Ir*3	Third harmonics of the resistive current
*It*3	Third harmonics of total leakage current
*Ip*1	Fundamental probe current
*Ip*3	Third harmonic probe current

2. INTRODUCTION

LIGHTING strikes are the main reason for outages in overhead transmission lines, distribution lines and in substations. To avoid these problems surge arresters are widely used in electrical substations for power equipment protection. During a surge, the arrester provides a safe path for the surge to flow to the grounding system. The surge arrester has a very high resistance at its power frequency operating voltage, but then the resistance becomes very low when a surge voltage is applied across its terminals. Under normal operation, surge arrester has very high impedance up to several mega ohms and it can be considered as open circuit. Therefore, all of the current in circuit will flow through the equipment and bypassing surge arrester [1] [2]. When overvoltage occurs instantly, the impedance of the surge arrester reduces to a few ohms or less for severe surges to avoid large current flows through equipment. The resistive current, third harmonic of resistive current have been shown to be good indicators of the arrester's health condition.

Various types of surge arrester are rod gap, horn gap, multi gap, Expulsion type, valve type, gapped silicon carbide (SiC), gapless metal-oxide (MO). Operating principle is same for all the types only difference is that MOSA have highly nonlinear V-I characteristic [2]. Metal Oxide Surge Arresters (MOSA) experience some kind of degradation due to factors such as repeated discharging of impulse current, high temperature and high moisture environment, and continuous operating voltage. Various methods are there for extracting the resistive current from total leakage current by online as well as offline condition. The compensation method have problem with applied voltage measurement which is main component for extracting resistive component as explained in [3]. Variable coefficient method and multi coefficient method have problem with higher order harmonic voltage which is difficult to measure [3][4]. The probe-based method have problems with error due to the fact that the magnitude and phase angle of harmonic voltages influence the third harmonic component of the resistive current. The MSCM technique is used to obtain linear relationship which exists between the peak value of the fundamental component of the resistive current and the phase shift between the fundamental components of the capacitive current and the total arrester current [5][6][7].

This paper describes the stepwise Modified Shifted Current algorithm to extract the resistive current from total leakage current without need of measuring applied voltage and implemented in MATLAB. The Comparison between conventional probe method which requires the voltage signal measurements and MSCM is carried out.

2. Monitoring Techniques To Measure Resistive Leakage Current

The different methods are used to extract the resistive leakage current from total leakage current in normal operating conditions. Following are some of monitoring techniques [3][4].

2.1 Compensation Method

Compensation method is the conventional monitoring method for separating the resistive leakage current of ZnO surge arrester. [3]. Measuring principle is based on the orthogonally between the resistive current and the capacitive leakage current. It satisfies the following equation,

$$i_r = i_t - i_c \tag{1}$$

If the applied voltage is a pure sine wave, the capacitive current component can be written as,

$$i_c = G v_{sh} \tag{2}$$

The resistive current is in phase with the voltage and the capacitive component is orthogonal to the voltage. Therefore, these currents satisfy,

$$\int_0^{2\pi} i_c i_r \, d\omega t = 0 \tag{3}$$

Combining equation (1), (2), (3)

$$\int_0^{2\pi} v_{sh}(i_t - G v_{sh}) d\omega t = 0 \tag{4}$$

So the capacitive component of the leakage current is set completely to get the resistive component. This method is most desirable method to check the condition of MOSA. Actual measurement of applied voltage is necessary so it is not suitable for online application.

2.2 Variable Coefficient Compensation

This method imports the harmonics analysis to reform compensation method, which adopts the variable compensating coefficient to balance the capacitive portion of every order harmonics current [3]. Using phase vector diagram, the resistive current is

$$i_r = i_t - \frac{i_t \sin \varphi_1}{v_{sh}} \sum_{k=1}^{n} k \times U_k \cos(k\omega t + \theta_k) \tag{5}$$

where I_{t1}, φ_1, U_{sh} are amplitude of the principal wave current of the arrester, the power angle (angle difference between the principal wave voltage and the corresponding current), and the amplitude of the principal wave voltage.

2.3 Multi-coefficient Compensation

As regards the influence of the high order harmonic voltages, the multi-coefficient compensating factor f_k is used to offset every order harmonic component of capacitive leakage current in this method. Then the resistive current is extracted.

$$i_r = i_t - \sum_{k=1}^{n} f_k \cos(k\omega t + \theta k) \tag{6}$$

$$f_k = \frac{\int_0^{2\pi} i_x \times \cos(k\omega t + \theta_k) \times d\omega t}{\int_0^{2\pi} \cos(k\omega t + \theta_k) \times d\omega t} \quad () \qquad (((7)$$

The capacitive current is removed completely from the total leakage current the remaining is the resistive leakage current.

2.4 Probe Current Method

ISSN 2229-5518

This method for harmonics analysis of the leakage current is based on a probe current. During the measurement, a field probe is set on the arrester which produces the current. A relation between the resistive current and its third harmonic component is calculated [4].

$$I_{r3} = I_{t3} - k * \frac{I_{t1}}{I_{p1}} * I_{p3} \quad (8)$$

I_{r3}, I_{t3} is the third harmonics of the resistive current and the total leakage current respectively and I_{p3}, I_{p1} is the third harmonic induced current though field probe. I_t is principle wave current, k is compensation coefficient which is constant and its value is between 0.7 to 1.0

2.5 Modified Shifted Current Method Current Method

The MO surge arrester is represented as a simplified equivalent circuit model includes a capacitance branch in parallel with a non-linear resistive branch as shown in Fig. 1 [7] [8] [9]. The total leakage current I_X of the arrester is given by a vector sum of a capacitive component I_C which does not vary with the degradation of the arrester and the resistive component I_R which varies with the degradation of the MO surge arrester as shown Figure 2.

All currents are time dependent, so $I_X, I_C, and\ I_R$ Can be written as;

$$I_X(t) = I_C(t) + I_R(t) \quad (10)$$

The resistive component can be obtained by,

$$I_R(t) = I_X(t) - I_C(t) \quad (11)$$

The subtraction in (2) can be implemented as below;

$$I_X(t) = I_C \cos \omega t + [I_R] \quad (12)$$

where $[I_R]$ is the resistive current component with harmonics.

Shifted the total leakage current by quarter period

$$I_{x\,Shifted}(t) = I_x \cos[\omega(t - \frac{1}{4f})] \quad (13)$$

Summation equation (12) and (13)

$$I_{sum}(t) = I_x[\cos(\omega t) + \cos\{\omega(t - \frac{1}{4f})\}] \quad (14)$$

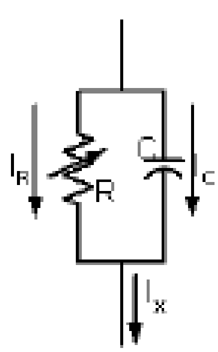

Fig.1. Simplified model representation of Metal Oxide Surge Arrester

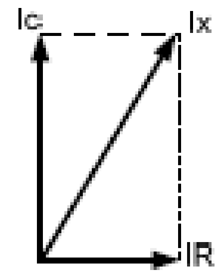

Fig.2 Vector diagram of $I_X, I_C, and\ I_R$

3. ALGORITHM OF MODIFIED SHIFTED CURRENT METHOD (MSCM):

The algorithm for calculating resistive leakage current using the modified shifted current method is described as follows. [8]

1. Firstly the actual leakage current data is given to the low pass filter and ADC.
2. The digital form of the input data is analyzed and by using phase locked loop the frequency of the signal is determined. A new waveform formed by introducing a quarter period delays to original total leakage current.
3. The total leakage current waveform is added to the delayed waveform.
4. Peak time of the summation waveform is observed. This peak is used to determine the peak time of capacitive current which is a quarter period delayed from the total leakage current.
5. Based on the information from 3 and 4, generate a sinusoidal waveform to represent the capacitive leakage current based on peak time, peak value and frequency detected.
6. The resistive leakage current can be obtained by subtracting capacitive leakage current from total leakage current.

The block diagram for the algorithm is shown in Fig.4.

ISSN 2229-5518

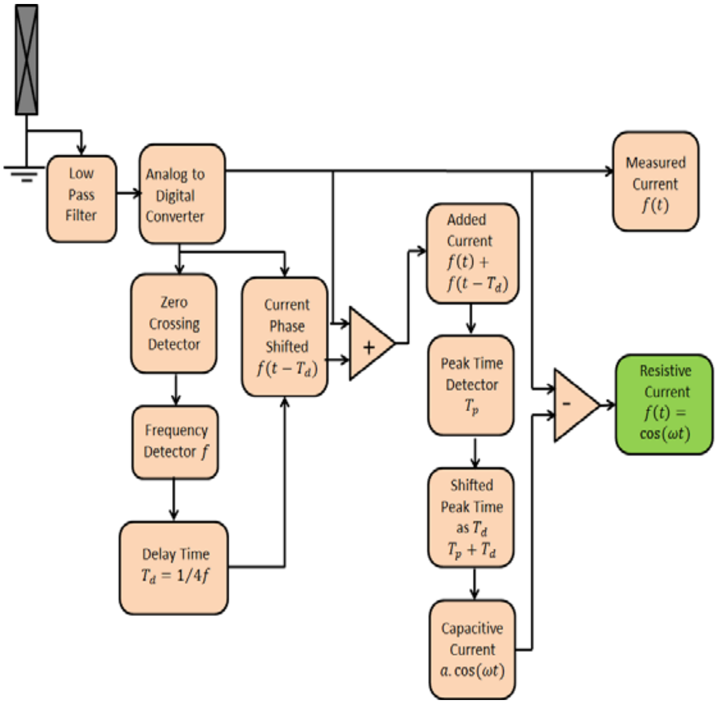

Fig.3 Block diagram of the MSCM algorithm

4. IMPLEMENTATION OF MSCM IN MATLAB

The MSCM is simulated in MATLAB. The leakage current is obtained by adding resistive and capacitive leakage currents and simulating the MSCM technique. The resistive leakage current waveform is generated which have fundamental, 3rd, 5th, 7th, 9th, 11th, order harmonics. The capacitive leakage current is represented by a sinusoidal waveform having a frequency of 50 Hz and leading the resistive leakage current by 90°. Then the resistive and capacitive current waveform superimposed with each other to get the MO total leakage current.

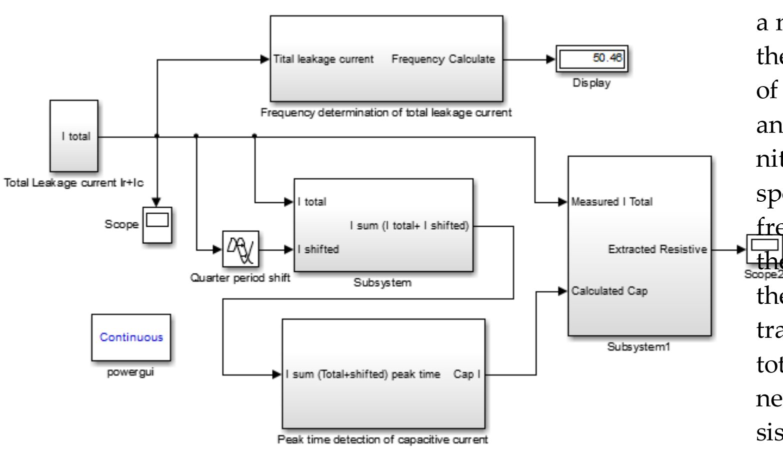

Fig 5: Simulink model for MSCM Technique

The MSCM algorithm is then applied to the generated total leakage current. The result of the simulation, namely the extracted resistive component is then compared to the originally generated resistive component.

5. RESULTS AND DISCUSSIONS:

The results obtained from simulation shows that the proposed new method to extract the resistive component of the leakage current is easy.

Figure 6 shows the MATLAB generated waveforms of the resistive, capacitive and total leakage currents respectively. Fig.6 (a) shows the resistive leakage current component containing the 1st, 3rd, 5th, 7th, 9th and 11th harmonics while Fig.6 (b) shows the capacitive leakage current. The total leakage current, which is the summation of the resistive and capacitive leakage currents, is shown in Fig.6 (c).

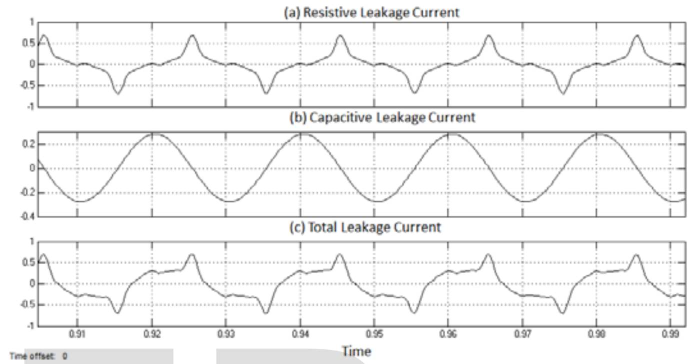

Figure 6 MATLAB simulated current waveforms (a) resistive component, (b) capacitive component, and (c) total leakage

After generating the total leakage current, the MSCM is used to extract the resistive leakage current component. To extract the resistive component, firstly, shift the total leakage current by 90° as shown in (Fig. 7a).

The shifted current has same magnitude with phase difference of 90° is then added to the original total leakage current to give a new waveform as shown in (Fig.7b). Note the times at which the new waveform has its maximum values. The peak values of the capacitive component occur at quarter periods before and after these resistive peak times. Determine the peak magnitude of the capacitive component by reading the corresponding value of the original total leakage current. Using the frequency, peak time and peak value information generated the capacitive current component as shown in Fig.7d. Finally, the resistive current component (Fig.7d) is obtained by subtracting the capacitive component (Fig.7d) from the original total leakage current. The extracted resistive current component as shown in (Fig.7d) is exactly the same as generated resistive current in (Fig.6a).

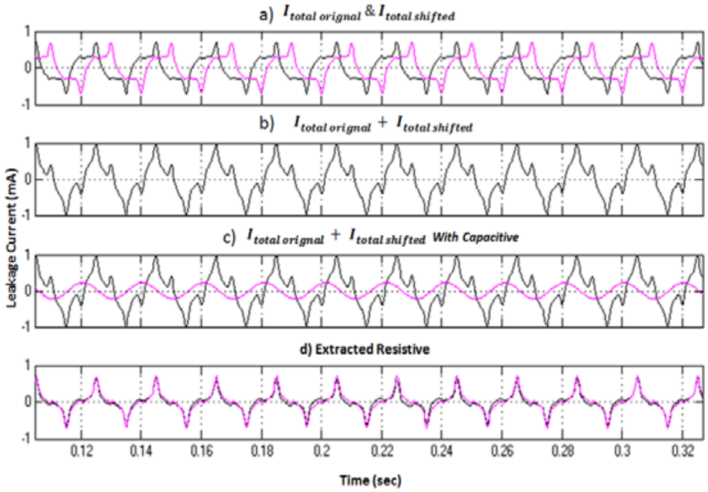

Figure 7 Illustration of shifted current method (a) total leakage current and it's shifted, (b) summation of waveforms, (c) generated capacitive current component, and (d) extracted resistive current component

This shows that the modified shifted current method works well without the need of voltage measurements at all as in conventional method. The rating of Metal Oxide Surge Arrester is 12kV, 5KA. The MSCM technique is applied to extract resistive currents from total leakage current. The advantages of this method are reduced cost and safe working procedure.

REFERENCES

[1] Xianglian Yan, Yuanfang Wen, Xiaoyu Yi, *"Study on the Resistive Leakage Current Characteristic of MOV Surge Arresters"*, IEEE conference, 2002

[2] T.K. Gupta *"Application of Zinc Oxide Varistors"*, Journal of the American Ceramic Society", Vol. 73, No. 7. 1990, pp.1817-1840

[3] J. Lundquist, L. Stenstorm, A. Schei, B. Hansen, *"New Method for Measurement of the Resistive Leakage Current of Metal Oxide Surge Arrester in Service"*, IEEE power Engineering Society Conference, California, July 9-14 1989.

[4] Chandana Karawita and M. R. Raghuveer, *"Onsite MOSA Condition Assessment—A New Approach"*, IEEE Transactions on Power Delivery, Vol. 21, No. 3, July 2006

[5] Christian Heinrich and Volker Hinrichsen, *"Diagnostics and Monitoring of Metal-Oxide Surge Arresters in High-Voltage Networks—Comparison of Existing And Newly Developed Procedures"*, IEEE Transactions on Power Delivery, Vol. 16, No. 1, January 2001

[6] Zulkurnain Abdul-Malek, Novizon, Aulia, *"A New Method to Extract the Resistive Component of the Metal Oxide Surge Arrester Leakage Current"* , 2nd IEEE International Conference on Power and Energy (PECon 08), December 1-3, 2008, Johor Baharu, Malaysia

[7] Zulkurnain Abdul-Malek, Novizon Yusoff and Mohd Fairouz Mohd Yousof, *"Performance Analysis of Modified Shifted Current Method for Surge Arrester Condition Monitoring"*, IEEE Conference, 2010

[8] Zulkurnain, Abdul-Malek, Novizon, Aulia, *"Portable Device to Extract Resistive Component of the Metal Oxide Surge Arrester Leakage Current"*, Australasian Universities Power Engineering Conference, 2008

[9] Jurnal Teknologi, *"A Technique for Extracting the Resistive Leakage Current of Metal Oxide Surge Arrester"*, ISSN 0127–9696, 2012 Penerbit UTM Press