DIAGNOSTICS OF HIGH VOLTAGE METAL OXIDE ARRESTERS PROCEDURE ERRORS

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Abstract

A technique has been described which can determine ac resistive current directly or by obtaining the watt loss of the test specimen and dividing by the true rms (trms) value of the applied voltage. The procedure errors with standard voltage dividers and digital systems have been calculated. Special attention was paid to the voltage shift. A new method for the direct resistive current measurement was proposed. The effect of small amount of harmonics was shown.

INTRODUCTION

Diagnostics of gapless arresters is based on internal current measurements which flows through varistor elements. Under normal conditions and phase voltage, the capacitive current component (in the range 0.5 - 3 mA) is about then times greater than the resistive one (10 - 250 μA) [1]. Because the resistive component is the best marker of ageing it should be measured. The best known methods of resistive component measurement are: the measurement of the total current at the moment of voltage peak, the compensation of capacitive component using no lossy high voltage condenser and active power measurement. In the first method the resistive current peak is estimated, the second one enables to show the signal as a time function, in the third one the rms value of resistive component is estimated [2].

The current measurement is simple and cheap (current shunt or current transformer). For the voltage measurement or compensation, the voltage divider or no lossy condenser is needed. These methods can be used principally in the lab or using the special mobile high voltage source [3]. The total current can be measured simply in the on line mode. Unfortunately its peak, rms or average value are only the auxiliary parameters. Even considerable increase of resistive current component causes initially only small increase of peak, rms and average value of total current. Therefore these parameters can not detect the initial ageing of varistor elements.

Because of the non-linear varistor elements even under ideally sinusoidal voltage the internal current contains harmonics. Diagnostics methods based on total current analysis utilise nearly linear dependence between the current third harmonic peak and resistive current component peak [4]. In reality the supply voltage contains the harmonics.. They cause also harmonics in the varistor total current. To reject these noisy harmonics the special field probe can be applied [1]. Diagnostics based on the total current harmonics analysis without harmonics elimination caused by non-ideal sinusoidal supply voltage is characterized by considerable errors.

PHASE ERRORS

During arrester diagnostics the voltage and current measurements are made with errors. As in each measurement we have here the important amplitude errors but we have here also the phase errors. The amplitude errors are not the subject of the presented paper. The phase errors cause that measured signal gets ahead of real signal or is late in the time. The effect is caused by cable capacitance, input resistance and capacitance of measuring equipment. The influence of inductance due to low frequency can be not taken into account.

voltage divider

The voltage divider consists of the HV capacitance C_1 and the capacitance C_2 (low voltage capacitance and input capacitance of the measuring equipment). The phase shift between signals U_1 and U_2 results from the finite input resistance R (fig. 1).

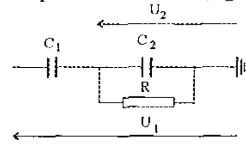

Figure 1. Capacitive voltage devider

$$\underline{Z} = \frac{1}{j\omega C_1} + \frac{\frac{1}{j\omega C_2}R}{\frac{1}{j\omega C_2}+R} = \frac{R}{1+j\omega C_2 R} + \frac{1}{j\omega C_1} \quad (1)$$

$$\overline{I} = \frac{\overline{U_1}}{\underline{Z}} = \frac{\overline{U_1}}{\frac{1}{j\omega C_1} + \frac{R}{1+j\omega C_2 R}} \quad (2)$$

$$\overline{U_2} = \frac{\overline{U_1}\cdot\frac{R}{1+j\omega C_2 R}}{\frac{1}{j\omega C_1} + \frac{R}{1+j\omega C_2 R}} = \frac{\overline{U_1}\cdot j\omega C_1 R}{1+j\omega R(C_1+C_2)} \quad (3)$$

High Voltage Engineering Symposium, 22–27 August 1999
Conference Publication No. 467, © IEE, 1999

$$\eta = \frac{\overline{U}_1}{\overline{U}_2} = \frac{\overline{U}_1[1+j\omega R(C_1+C_2)]}{\overline{U}_1 j\omega C_1 R} \quad (4)$$

$$\eta = \frac{C_1+C_2}{C_1} - j\frac{1}{\omega C_1 R} = A - jB \quad (5)$$

The voltage ratio is therefore complex number with the modules

$$|\eta| = \sqrt{A^2+B^2} \quad (6)$$

The high voltage U_1 lags behind the low voltage U_2 by the angle α and the time Δt

$$\alpha = arctg\frac{B}{A} \qquad \Delta t = \frac{\alpha \cdot 20ms}{360} \quad (7)$$

20 ms at the frequency 50 Hz, 16.6 ms at 60 Hz

The angle α is inverse proportional to the product of C_1 R. The increase of capacitance C_2 (increasing of voltage ratio) and increase of input resistance R causes decrease of phase error. The increase of HV capacitance C_1 is possible in limited cases only.

Typically the HV capacitance is in the order of 100 pF and the input resistance 1 MΩ. In the tab. 1 the voltage ratio and voltage shift calculations for the three input resistances and for two low voltage capacitances are listed. At the R = 1 MΩ and the voltage ratio modules η = 10 001 the voltage shift amounts to 7.3 μs. The increase of the resistance R to 10 MΩ (e.g. by using standard oscilloscope probe) decreases this time to 0.73 μs. Using the R=0.1 MΩ and the voltage ratio of 1027 we obtain the voltage shift of 721 μs, which makes the set up totally useless for the aim of arresters diagnostics.

Similar calculations were made for simple, non-compensated resistive voltage devider with HV resistor 100 MΩ. The low voltage part of the divider consists of low voltage resistor R_{2A}, input resistance R_{2B}, the cable and input capacitance of measuring equipment C.

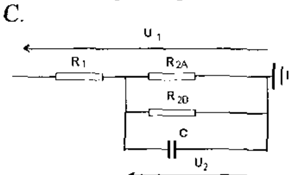

Figure 2. Resistance voltage divider

The voltage ratio η for this divider equals:

$$\eta = \frac{R_1+R_2}{R_2} + j\omega CR_1 = A + jB \quad (8)$$

where R_2 is the resistance of the parallel connection of R_{2A} and R_{2B}.

The voltage U_1 is getting ahead of low voltage U_2 by the angle α proportional to the capacitance C. It consist of cable capacitance (about 100 pF/m) and input capacitance of the measurer. The input capacitance of the oscilloscope is usually small, in the range of 25 pF but it can be greater due to overvoltage protection (varistors). The calculation results for the resistive divider 100 MΩ with R_{2A}= 85 kΩ and

1. the relatively small input resistance of 100 kΩ and input capacitance of 3,6 nF (recorder ARPE)
2. the R_{2B}= 1 MΩ and C= 395 nF (oscilloscope Kikusui) are shown in the table 2.

current shunt

It is convenient to consider the measurement of the current flowing through the no-lossy condenser. The compressed gas condenser which is the simplest model of the MOA in the low leakage current range has the power dissipation factor tgδ in the range of $10^{-5} \cong 0$. The current is measured by means of serial resistance e.g. 1 kΩ. Because of input capacitance of the recorder and cable C_2 (fig. 1) the measured current gets ahead the current which would flow through the current shunt without C_2. (If C_2 did not exist). The caused by C_2 current shift error amounts to:

$$\beta = arctg\frac{A}{B} \qquad \Delta t = \frac{\beta \cdot 20ms}{360} \quad (9)$$

$$\frac{C_1+C_2}{C_1} = A \qquad \frac{1}{\omega C_1 R} = B \quad (10)$$

where R is resistance of parallel connected input resistance of the measurer and current shunt.

The calculations were made with C_1 = 138 pF (fig.1, typical capacitance of the 110 kV MOA), C_2 = 375 pF, current shunt 1 kΩ and input resistance of the oscilloscope 1 MΩ. They showed that the current shift error amounts to 0.009 μs and is negligible.

phase errors with ideal sinusoidal voltage

The figure 3 shows computer simulation of high voltage U, total current I and the resistive component I_R. The resistive current changes after the equation I_R= A u ^{n}, where A= 0.2 , n = 2.

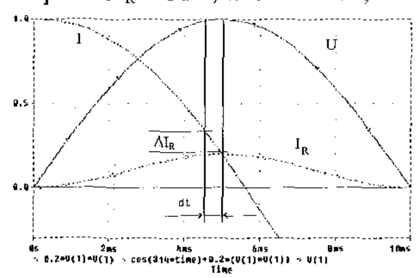

Fig. 3. Shift error during the direct I_R measurement with the capacitive voltage divider

With the capacitive voltage divider the low voltage gets ahead of the high voltage by dt. From this results that the measured value of resistive current is greater than the real value I_R by the Δ I_R.

HARMONICS INFLUENCE

The voltage in the alternating current systems contains only odd harmonics, it is called antisymmetric signal. If in the circuit there are only resistances, then the current has the same shape as the voltage.

$$i(t) = I_1 \cdot (\sin\omega \cdot t + p_3 \cdot \sin 3\omega \cdot t + p_5 \cdot \sin 5\omega \cdot t + ...)$$

P_k - harmonics amplitude

When the circuit contains inductors then the current is less deformed than the voltage. When there are only capacitors the current is more deformed. In this case the reactance for each harmonics is different and in the current flowing through the capacitance, the harmonics amplitude number k is k times greater than in the voltage signal.

$$I_k = k \cdot \omega \cdot C \cdot U_k = k \cdot \omega \cdot C \cdot p_k \cdot U_1 = k \cdot p_k \cdot I_1$$

$$i(t) = I_1 \cdot (\cos\omega \cdot t + 3p_3 \cdot \cos 3\omega \cdot t + 5p_5 \cdot \cos 5\omega \cdot t + ...)$$

The voltage and current rms value of an condenser are as follows:

$$U = \sqrt{1 + (p_3)^2 + (p_5)^2 + ...(p_k)^2}$$

$$I = \sqrt{1 + (3p_3)^2 + (5p_5)^2 + ...(k\,p_k)^2}$$

Even at small voltage deformation, the current flowing through the condenser is distinctly non-sinusoidal. The fig. 4 shows the voltage containing four harmonics with phase shift = 0: 100 kV 50 Hz; 5 kV 150 Hz; 3 kV 250 Hz; 2 kV 350 Hz and the current flowing through the 25 pF condenser.

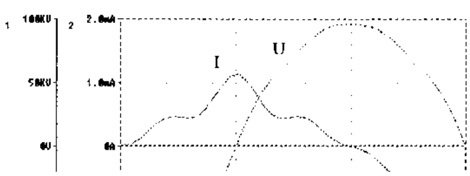

Fig. 4. The deformed voltage and current flowing through a condenser

The both signals on the fig. 4 are symmetrical, the phase shift angle between them = 90°.

Generally the voltage harmonics are shifted against the base harmonics by the different angles, the condenser current has also the same shift.

$$u(t) = U_1 \cdot [\sin\omega \cdot t + p_3 \sin(3\omega \cdot t + \psi_3) + p_5 \sin(5\omega \cdot t + \psi_5) + ...]$$

$$i(t) = I_1 \cdot [\cos\omega \cdot t + 3p_3 \cdot \cos(3\omega \cdot t + \psi_3) + 5p_5 \cdot \cos(5\omega \cdot t + \psi_5) + ...]$$

Again, the voltage shape can be changed by this only insignificantly, otherwise it is with the capacitive current. The fig. 5 shows the same voltage as in the fig. 4, the only difference consists in the fact that the fhird harmonics is shifted by the angle of + 90°. It is very interesting that the current gets ahead the voltage not 5 ms but only 4,37 ms. The smaller phase shift between voltage and current is caused by the non-symmetric voltage shape. It is worth underlining that in the case of nonsinusoidal signals we can not determine the receiver type (capacitive or inductive) on the base of current - voltage shift.

The voltage devider moves all harmonics. Because the imaginary part of the voltage ratio is a frequency function (see eq. 5 and 8), therefore the shift angle of harmonics at the measured low

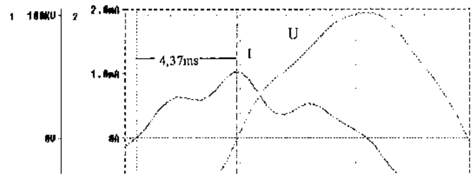

Fig. 5. Non-sinusoidal voltage with the third harmonics shifted by 90° and the condenser current.

voltage signal is a bit different than that in the high voltage signal.

LIMITS OF DIGITAL ACQUISITION

According to the direct method the resistive current is determined by the total current measurement at the instant of voltage peak. This instant can be fixed with an error because the changes of the sinus function near its peak are small. The sinus function changes were found at the sampling rate 100 and 1000 during one halfperiod. It is evident (tab. 3) that at the sampling rate 100 for the time 4.9 , 5.0 and 5.1 ms the sinus values are equal each other with the accuracy of ± 0,0001. The 10 bit A/D converter will treat the sinus values at these three times as the same. At the measurement resolution 1/1024 the time error for determination of voltage peak instant equals 0.1 ms = 100 μs.

Tab. 3. Sinus value near its peak at the sampling rate 100 and 1000 times per halfperiod

Δt=0,1ms	4,8	4,9	5,0	5,1
sinωt	0,99798	0,99948	0,99999	0,99953
Δt=0,01ms	4,98	4,99	5,00	5,01
sinωt	0,999975	0,999992	0,999999	0,999997

Sampling the sinus function 1000 times per halfperiod, each 10 μs, we need the 17 bit A/D converter with the resolution of 1/100 000. With the standard 12 bit converter the time error for determination of peak voltage instant is much greater than phase error of voltage devider with the voltage=ró ratio 1 : 10 000 and with 1 MΩ input resistance of oscilloscope which equals only 7 μs.

NEW METHOD PROPOSAL

For the voltage measurement we use often the capacitance devider consisting of no-lossy HV condenser. When we use this condenser with serial current shunt, we can determine the resistive current peak by the total arrester current measurement at the instant when the condenser current equals zero. At this time the both currents changes are great.

The time error for determination of the condenser current zero is smaller than for determination of voltage peak. Because the phase shift error for the current measurement is negligible therefore such method accuracy is very high. Fig. 6. compares the old method for resistive current determination to the new one.

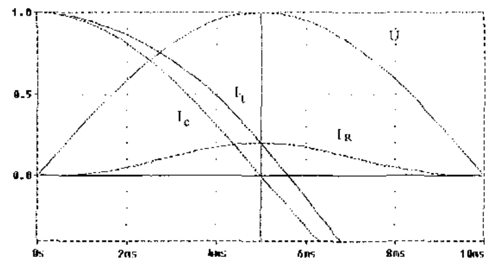

Fig. 6. Possibilities for determination of resistive current peak

When the voltage contains higher harmonics its top can be more flat than the top of ideal sinus function. The problems with precise determination of voltage peak instant can be therefore bigger. One of many possible cases is shown in fig. 7 which compares the pure sinus shape with the voltage containing four harmonics.

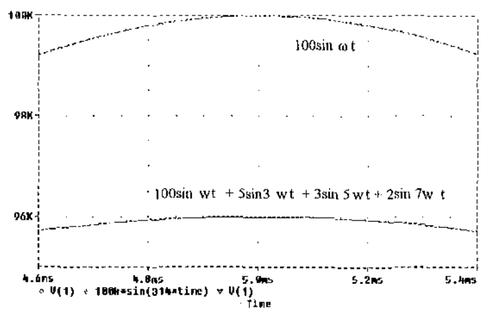

Fig. 7. Pure sinus shape and the voltage with four harmonics

conclusions

The voltage shift caused by capacitance devider can be reduced significantly by choosing high voltage ratio of 10 000. The current shift caused by a 1 kΩ shunt is negligible.

Harmonics in the voltage affect considerably the capacitive current and therefore the total arrester current. The voltage shape can be more flat at the top which increases the digital acquisition limitations.

New method proposed enables the resistive current measurement with a greater accuracy.

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Authors would like to thank the polish Research Committee KBN and German Academical Foundation DAAD for the financial support.

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Table 1. The voltage ratio and voltage shift of the capacitance devider

C_1	C_2	R	A	B	η	α	Δt
pF	μF	MΩ	-	-	-	stopnie	μs
138,2	1,3820	0,1	10001,00	230,7	10003,7	1,32	73
138,2	1,3820	1	10001,00	23,04	10001,03	0,132	7,3
138,2	1,3820	10	10001,00	2,304	10000,00	0,013	0,73
138,2	0,13820	0,1	1001,00	230,7	1027,08	12,98	721

Table 2. The voltage ratio and voltage shift of the resistance devider

R1	R2a	R2b	R2	C	A	B	η	α	Δt
MΩ	MΩ	MΩ	MΩ	pF	-	-	-	stopnie	μs
100	0,085	0,1	0,046	3600	2152	113	2155	3,005	166
100	0,085	1	0,078	395	1283	12,4	1283	0,554	31