Diagnostic appliance for evaluating the operational state of metal oxide arresters

1 Introduction

Evaluation of the operating state of surge arresters with conventional recording spark gaps or discharge counters is possible only with reservations. Starting from published and own investigations on the operating behaviour of surge arresters a diagnostic appliance was developed meeting the following requirements:

- The diagnostic data can be recorded during operation.
- Changes of the existing internal structure of the arrester and additional bushings are not necessary.
- The evaluation of the operating state of the arrester is made exclusively by analysis of leakage current.

2 Criteria for arrester evaluation

A permanently applied voltage causes a continuous leakage current in surge arresters without spark gaps (metal oxide arresters). While capacitive current component is dominating with applied continuous operating voltage, the resistive component (A to kA range) is prevailing in case of temporary overvoltages or discharge processes. Causes a resistive leakage current, due to overload and/or ageing of the metal oxide varistor, such a big amount of heat, which no longer can be dissipated via the arrester surface, the arrester will be destroyed (thermal runaway).

The following problems may occur during the operating time of the arrester:

- Frequent current impulses with high amplitude or energy-rich discharge processes lead to irreversible changes of the varistor characteristic (degradation). The leakage current increases subsequently.
- A change in the voltage distribution caused by external pollution of the arrester housing may result in an increased power dissipation in the metal oxide varistor stack.

A rise of varistor temperature will be the consequence from increased leakage current or increased power dissipation caused by such operating conditions. This temperature increase will be enhanced by the negative temperature coefficient of the metal oxide varistors.

For the aforementioned reasons it is useful to be able to evaluate the state of the arrester during operation. The leakage current with its capacitive and resistive component presents itself as evaluation criterion. The following criteria can be deduced as result of investigations (Fig. 1):

– The 3rd harmonic of leakage current is nearly proportional to its resistive component in the range of interest. So a sufficient evaluation criterion for metal oxide arresters (MOA) is given since the resistive component of the leakage current leads to the heating-up of the metal oxide varistor by voltage load.

– Independent of the evaluation of the 3rd harmonic of leakage current the arrester state also can be evaluated by the ratio between peak value and effective value (crest factor) of the leakage current. Due to the falling segment in the range around continuous operating voltage of the arresters (U_c) this criterion is not so certainly applicable but it is a good supplement to the first mentioned criterion.

– Additional the waveform of the current can be recorded with oscilloscope. So it is possible to evaluate the arrester state visually by comparison with reference pictures.

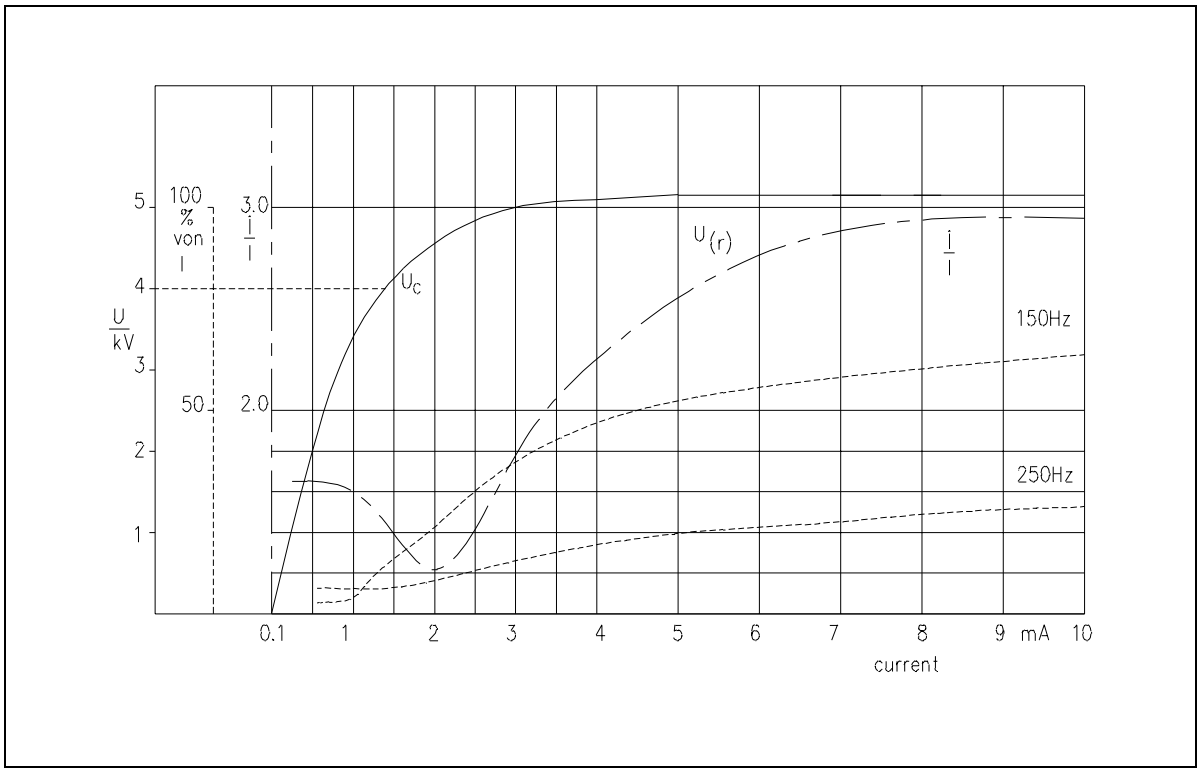


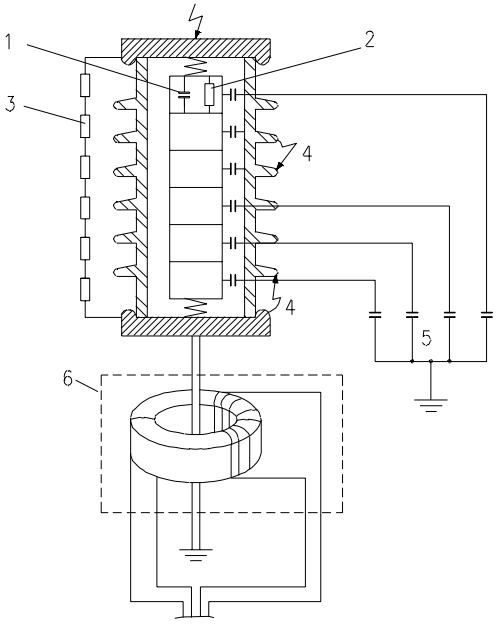
Fig. 1: Leakage current analysis on 2 metal oxide discs

Therefore the diagnostic appliance can determine the following properties of the arrester leakage current:

- Effective value
- Peak value
- 3rd harmonic
- Waveform

To ensure representative information by leakage current analysis consider that the leakage current is influenced essentially by the following influences (Fig. 2):

- Type of arrester (specific design by different arrester manufacturers)
- Relation of residual voltage (at nominal discharge current) to continuous operating voltage
- Ambient temperature and direct solar irradiation
- Pollution of the arrester surface
- Stray capacitance's to earth and to neighbouring phases



1 Varistor capacity
2 Non-linear varistor characteristic
3 Conductive external pollution of housing surface
4 Partial arc
5 Stray capacities
6 Clamp adapter / indicator

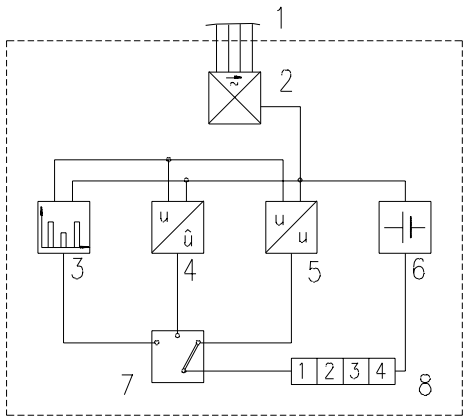
Fig. 2: Influences on leakage current analysis

3 Functional principle of diagnostic appliance

The diagnostic appliance consist of flux compensated current transformer (Fig. 4) and signal processing unit with display (Fig. 3).

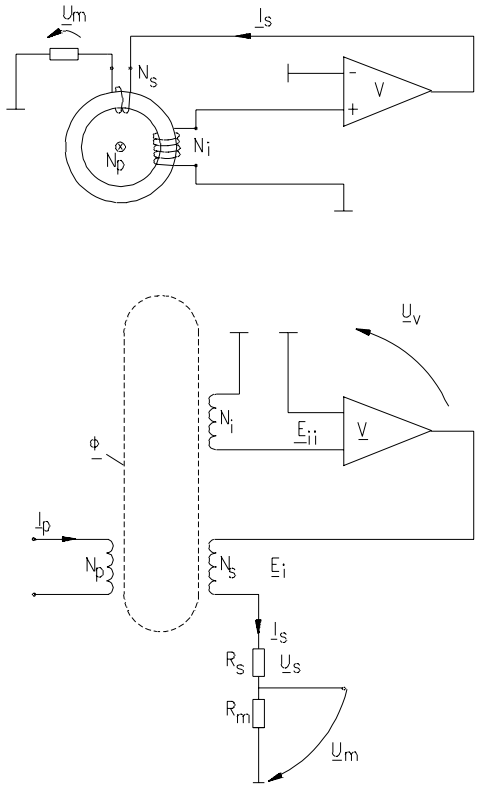
As can be seen from the basic circuit (Fig. 4) the current $\underline{I}_p$ flowing through the primary winding (earth connection with $N_p = 1$) causes a flux $\underline{\Phi}_p$ in the ring core. With help of operational amplifier the current $\underline{I}_s$ is driven through compensating winding N_s which causes a mutual-flux $\underline{\Phi}_s$ in the ring core. The flux difference induces in the indicator winding N_i. a voltage $\underline{E}_{ii}$ which controls the compensating current $\underline{I}_s$ so that the flux difference is minimised.

The voltage drop $\underline{U}_m$ over the sensing resistor R_m which is in value and phase directly proportional to the current $\underline{I}_p$ will be supplied to the signal processing (amplifier, filter, rectifier).



1 Connection to clamp adapter / indicator
2 Amplifier
3 Spectral analysis
4 Measurement of peak value
5 Measurement of effective value
6 Battery
7 Selection switch
8 Display

Fig. 3: Signal processing unit with display



$\underline{V}$	Amplifier
N_p	Primary winding (= earth connection)
N_s	Compensation winding
N_i	Indicator winding
$\underline{E}_{ii}$	Voltage induced in indicator winding
$\underline{U}_v$	Output voltage of amplifier
$\underline{U}_m$	Voltage proportional to primary current
$\underline{\Phi}$	Magnetic flux in the ring core
$\underline{I}_p$	Primary current (leakage current)
$\underline{I}_s$	Compensating current

Mesh equation : $-\underline{E}_i = \underline{U}_v - \underline{U}_m - \underline{U}_s$

with : $\underline{U}_v = \underline{v} \cdot \underline{E}_{ii}$

and : $\underline{E}_{ii} = -j\omega \cdot N_i \left(\underline{\Phi}_p - \underline{\Phi}_s\right)$

and : $\underline{\Phi} = A_L \cdot \underline{I} \cdot N$

and : $\underline{E}_i = 0$ (compensation)

and : $N_p = 1$ (earth connection)

follows : $$\underline{U}_m = \underline{I}_p \frac{R_m}{N_s - \dfrac{R_s + R_m}{j\omega \cdot \underline{v} \cdot N_i \cdot A_L}} = \underline{I}_p \cdot \frac{R_m}{\sigma}$$

Fig. 4: Flux compensated current transformer

4 Technical realisation of the diagnostic appliance

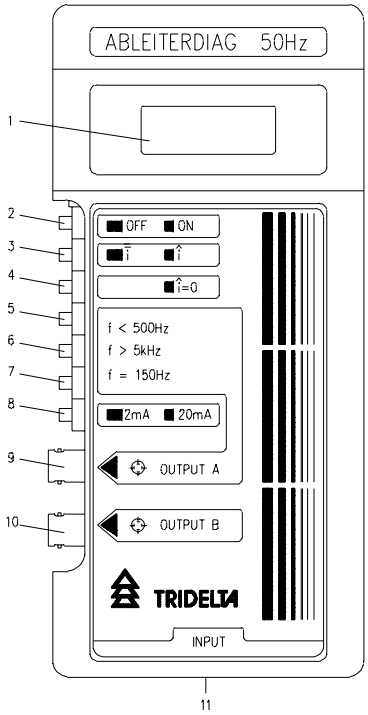
The diagnostic appliance comprises a clamp adapter (indicator device), an interconnection cable and an evaluating appliance (ABLEITERDIAG).

There are three types of the evaluating appliance (designed for rated frequencies of 50 Hz, 60 Hz and $16^2/_3$ Hz).

Two measuring ranges are provided for evaluation of leakage current from 100 µA to 20 mA. An oscilloscopic presentation of the arrester current before and after the selected frequency filter is possible via two separate measuring signal outputs (BNC sockets). All other functions and operating conditions of the appliance are pictured in Tab. 1 and Fig. 5:

Equip the battery box with 6 pieces 1.5 V batteries (size AA) before starting the "ABLEITERDIAG". Make sure that the engraved polarity is considered because wrong polarity may destroy the appliance.

For making measurements connect the "ABLEITERDIAG" to the clamp adapter by means of the interconnection cable. Clip the clamp adapter around the earth connection of the surge arrester.



1 Display
2 Operating switch ON-OFF
3 Mode switch
4 Reset button (peak value)
5, 6, 7 Filter selection switch
8 Scale switch
9 Signals output (after filtering)
10 Signals output (before filtering)
11 Input socket

Fig. 5: Front panel and control elements for rated frequency of 50 Hz

Control element	**Function**
Operating switch (2)	This switch starts/stops the operation.
Mode switch (3)	This switch selects the operation mode (effective value or peak value measurement). Peak value measurement is possible only with selected frequency range 'f < 500 Hz'
Reset button (4)	The peak value is recorded by charging a capacitor. A falsification of the real peak value may be caused by transient processes or extremely strong external field interference's. This button should be used for erasing the measured values for verification purposes.
Filter selection switch (5), (6), (7)	These 3 switches select the frequency ranges. Switch (5) activates the range 'f<500Hz'. A low-pass lowers high frequency interference's caused by main. In this range effective value as well as peak value are measured. Switch (6) activates the range 'f>5kHz'. In this range the effective value of high frequency disturbances (partial discharge phenomena) can be measured. Switch (7) activates the measurement (of effective value) of 3rd harmonic of the arrester leakage current.
Scale switch (8)	This switch selects the measuring range 2 mA or 20 mA
Signals outputs (9), (10) (1 MΩ, < 50 pF) 2 mA range: 100 mV = 1 mA 20 mA range: 1 V = 1 mA	An oscilloscope can be connected on these signal outputs. So an visual checking of waveform of the leakage current is possible. Output 'B' (10) shows the original leakage current (before filtering). Output 'A' (9) shows the output signal of the selected filter.
Input socket (11)	The interconnection cable to the clamp adapter / indicator should be connected in this place.

Tab. 1: Control elements and functions for rated frequency of 50 Hz

5 Hints for measurement

- For measurements follow the standard DIN VDE 0101 "Starkstromanlagen mit Nennwechselspannungen über 1 kV" or conform national standards.
- Do not measure during thunderstorms or switching actions.
- Do not inject external signals to the signal outputs (9) and (10). This could destroy the "ABLEITERDIAG".
- Ensure that only the current through the arrester is evaluated. Do measurements only with dry arrester surface to avoid leakage currents over the housing surface and high frequency influences due to wet pollution layers.
- Position the clamp adapter for each measurement on the same place of the earth connection. Hold the clamp adapter so that the earth connection go perpendicularly through the adapter.
- Convert the measured values according to standard operating conditions according to Fig. 6 and Fig. 7.
- Carry out an initial measurement immediately after installation.
- Record the measured values in a table like Tab. 2.
- Repeat the measurement in case of considerable deviation against the initial measurement. So you can avoid falsifications due to discharge processes immediately before measurement.
- Press reset button before measurement of peak value. So you can avoid errors caused by transient processes or extremely strong external field interference's.
- In case of doubt check the wave form of leakage current on signal output 'B' and compare with reference pictures in Fig. 8.
- An exceed of the measuring range is indicated by a 'l' in the left half of the display during the other digits are blanked out.
- Spent batteries are indicated by a 'B' in the display.

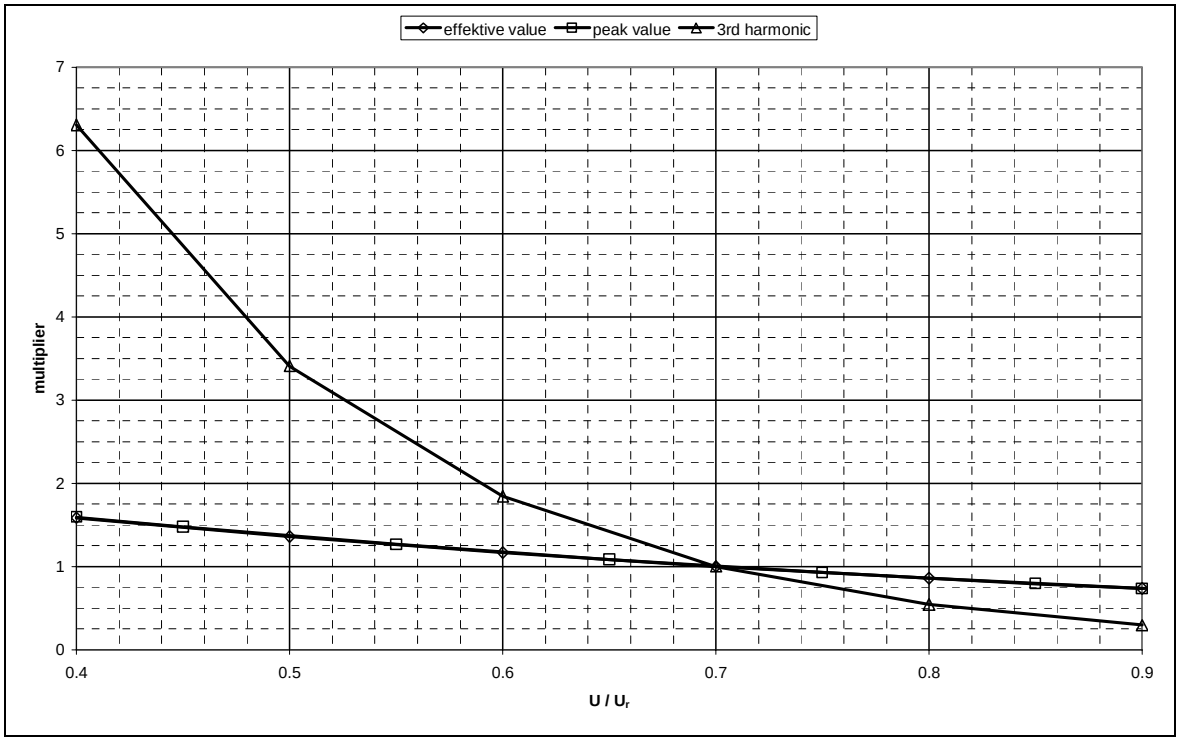


Fig. 6: Conversion to standard operating conditions (voltage)

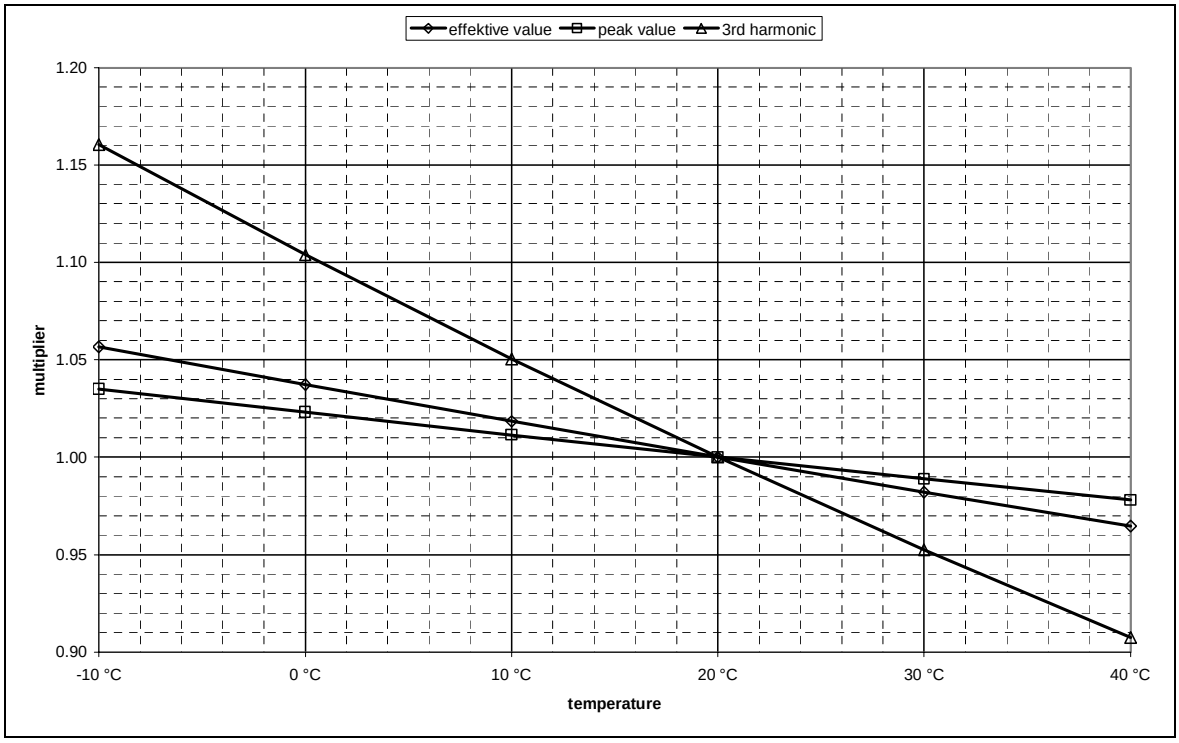


Fig. 7: Conversion to standard operating conditions (temperature)

test report						
location of arrester:_____						
arrester type:_____ arrester no.:_____ year of manufacturer:_____						
date						
temperature	(°C)					
line voltage	(kV)					
air humidity	(%)					
effective value	(mA)					
peak value	(mA)					
3rd harmonic	(mA)					
effective value (corr.)	(mA)					
peak value (corr.)	(mA)					
3rd harmonic (corr.)	(mA)					

Tab. 2: Example for recording of measured values

6 Evaluation of results

The arresters is in normal operation state if corrected values in Tab. 2 fulfil the following conditions simultaneously:

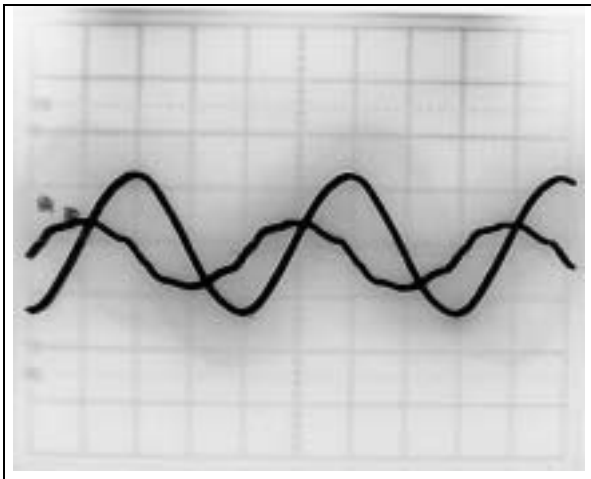
– the peak value do not exceed 4 mA,

– the effective value do not exceed 2 mA and

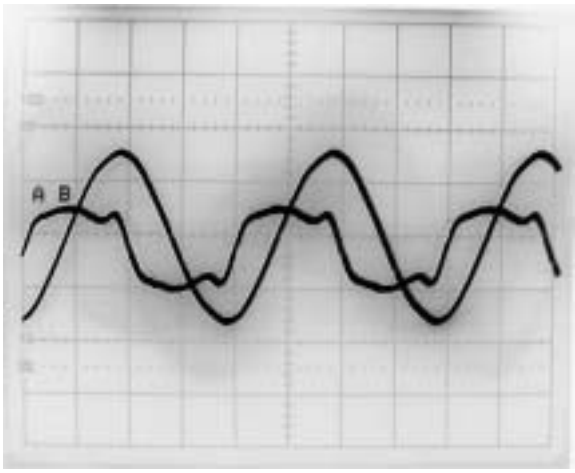
– the 3rd harmonic do not exceed 0.1 mA.

If one of the above given maximum values is exceeded the measurement is to repeat in short periods. So falsification of measured values can be excluded and tendency can be determined.

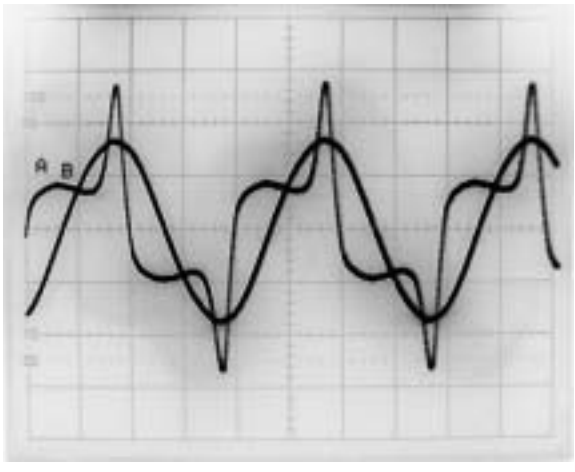
If the above given maximum values are permanently exceeded wave form of leakage current should be recorded by means of oscilloscope on signal output 'B'. Result should be submitted to TRIDELTA.



← Leakage current in normal operation state



← Leakage current in operation state immediately after surge



← Leakage current in abnormal operation state

Fig. 8: Oscillograms of leakage current