# THE RECORDING OF THE LOSS CURRENT (BRIDGE OUT-OF-BALANCE-CURRENT) WITH A CRO AS A POSSIBLE METHOD FOR THE QUALITY CONTROL OF FINISHED INSULATIONS

By

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## 1. Introduction

It is a well-known fact that the curve of the loss current has a characteristic shape for different kinds of insulating materials as well as for combinations of them [1, 2]. The r.m.s. value of the fundamental harmonic of the loss current is proportional with the dielectric loss of the insulation for the given voltage and is interrelated with the loss factor tg $\delta$ of the insulation (to be taken for the given voltage, if it is voltage-dependent),

$$\operatorname{tg} \delta = \frac{I_l}{I_c} \tag{1}$$

where $I_l$ is the r.m.s. value of the loss current and $I_c$ the capacitance current. The value of the latter is

$$I_c = U\omega C \tag{2}$$

($U$ voltage in $V$, $C$ capacitance in $F$, $\omega$ angular frequency in 1/sec.). The sum of the dielectric loss is

$$W = U^2 C \omega \operatorname{tg} \delta = U I_l \quad (\text{in } W) \tag{3}$$

At present perhaps the most widely used method for quality control of finished insulations at industrial frequencies is the measuring of tg $\delta$ as a function of voltage, temperature or the time, by using a Schering-bridge or some modification of it. If this value is known, then the voltage and the capacitance being known, we may calculate the loss by using Equ. 3.

However, in many cases we were interested in the value of tg $\delta$ only, because it seemed to have the character of a specific value of the same kind as e.g. a specific resistance.

Later it turned out that tg $\delta$ may be e.g. voltage-dependent, a quality which is now widely used in insulation testing technique considering the voltage-dependency of tg $\delta$, and not its magnitude, as a characteristic of the insulation.

It is also well-known now that in many cases the value of the specific loss

$$p = \frac{\varepsilon \operatorname{tg} \delta f}{18 \cdot 10^{11}} \left( \frac{(W/cm^3)}{(V/cm)^2} \right) \tag{4}$$

(where $\varepsilon$ is the relative permittivity and $f$ the frequency) is far more interesting than tg $\delta$ itself (e.g. for the possibility of thermal breakdown).

The exclusive use of tg $\delta$ or its voltage-dependency as a characteristic for a given finished insulation often brings about further difficulties but of a different kind.

As has already been mentioned tg $\delta$ in most cases will be determined by using the Schering bridge, where tg $\delta$ itself is not seen, but is obtained by balancing the bridge. Now, if tg $\delta$ changes with time during the measurement, the balancing of the bridge is tried again. If the change of tg $\delta$ with time is important, the balancing of the bridge may be impossible altogether and the developing of a fault is not visible, or else a very expensive self-balancing bridge must be used. Another deficiency of the exclusive use of tg $\delta$ as a characteristic value lies in the fact that the same big tg $\delta$ might be obtained for an insulation which contains much moisture, as for another one of the same kind which is dry, but in which an internal ionization is present. Therefore, tg $\delta$ is not characteristic enough for comparing two insulations built up of the same material and having the same structure. It seems to be obvious that this value may be far more inadequate for comparing two different kinds of insulations.

It is often required e.g. also, for prophylactic testing, to demonstrate the changes in the properties of an insulation which had occurred since the last testing. As a matter of course the change of tg $\delta$ shows that the condition of the insulation is changed, but one cannot always tell what kind of change this is.

As a consequence of these deficiencies of the tg $\delta$ method it seemed desirable to introduce new methods for the quality control of a finished insulation which could give more information.

It is also well known that besides tg $\delta$-voltage characteristics already other methods are used for this purpose: absorption measurements, ionization measurements etc.

But for the purpose of quality control of finished insulations those methods would be preferable which are as simple as possible and needing the minimum extra time and apparatus.

According to the very valuable information, which have been obtained by the tg $\delta$ concept, in spite of its deficiencies, the idea seems to be obvious not to substitute it by another method but, if possible, to perfection it.

As a possible completion of the tg $\delta$ method one may propose the recording of the loss current for finished insulations too, a method proposed and already used by others for this purpose [3]. With this paper the author's purpose is to popularize this method which is, as he feels, not recognized and used as much as it deserves. However, there also exists a special purpose for which this procedure also seems to be very useful. This purpose is, as the author wished to establish in a recent paper [4], the control of the power-frequency test of the main insulation of power transformers, instrument transformers, generators, cables etc. In the mentioned paper he proposed that this test should be carried out using a method of control in order to show whether the condition of the insulation is not altered during the test. It is true that for this purpose a self-balancing bridge seems to be adequate enough, or instead of the CRO an electronic voltmeter could be used, but in both cases the shape of the loss-current curve is not visible which according to already cited earlier measurements and also according to our experience seems to be characteristic for the condition of the insulation.

The use of the oscilloscope (CRO) has also a particular advantage as compared with all other methods: it makes possible the recording of the upper harmonics of the loss current separately, which may be even more characteristic of the changes in the condition of the insulation as the loss current itself.

This kind of measurement, if it might at all be applied, requires a personnel having great experience in the evaluation of the curves, because reference values themselves are not characteristic enough. This evaluation is an operation something like the evaluation of an electrocardiogram in medical science as compared with the measurement of a reference value, e.g. the blood pressure.

This is the main reason why the author would be very grateful to have the opinion of his colleagues about his proposals, because only then would it be hopeful of using these methods effectively if many measurements are carried out and the results are compared with experience on the service performance of the insulations tested in this manner.

Now the author will try to recommend this method by giving a few details and some very modest results.

## 2. Measuring apparatus

It is so well known from the literature that a brief description will be satisfactory here.

A Schering bridge was used earthed into that point of the diagonal (4) to which the earthed terminal of the CRO is connected (Fig. 1). A vibration galvanometer (ZI) was used as indicator which could be disconnected after the balancing.

The use of this connection is advantageous for two reasons.

One of these is, that in service one electrode of a finished insulation is always earthed, and therefore, if the Schering bridge normally earthed in point 3 were used one would have to isolate both poles of the tested insulation from the ground which would be inconvenient in most cases.

The second reason is that the CRO-s have an asymmetrical input, one terminal being connected to the casing (enclosure).

As is well known, however, that in this connection the stray capacitance causes an error in the measured value of tg $\delta$ which ought to be determined by a separate measurement. Therefore, if the CRO is used the loss current recorded contains this error. It is possible to compensate it, but in most cases it is unnecessary when using the same apparatus, because only comparative values are obtained.

The upper harmonics of the feed voltage can also give considerable errors as was pointed out e.g. by LIEBSCHER [2]. In most cases, however, the measure-

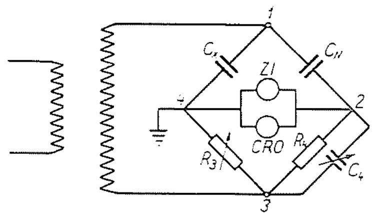


*Fig. 1*

ment is to be carried out in testing plants which have for voltage sources separate sine generators for testing purposes. For the measurements published in this paper the supply network with a not quite sinusoidal voltage was used, and in spite of this, quite appreciable differences in the shape of the upper harmonics were obtained for different insulations.

Another possibility or error on determining the ionization inception voltage from the loss current curve or from its upper harmonics lies in the fact that the testing transformer, the connections and the terminals may ionize, too. This error can also be avoided by the known methods (by using a band-pass filter, tubes as connections instead of wires etc.).

It turned out, however, that avoiding such an amount of external ionization which would falsify the measurements is not as complicated as would be assumed.

It is perhaps worth while to mention that according to other authors and also our own experience it is possible to discern between ionization occurring in oil, in internal voids or in air.

The ionization in oil shows considerable remanence (hysteresis). If e.g. the ionization starts at a certain voltage $U_i$ and disappears at another one $U_d < U_i$, then, if occurring in oil, it always disappears at the same voltage, but after seconds or perhaps after minutes. If the ionization occurs in air, then, on the contrary, it always disappears at once when a certain voltage $U_d$ is reached.

Perhaps it should be mentioned that the balancing of the bridge ought to be carried out with as great as possible resistances, because then the voltage recorded by the CRO which is proportional with the loss current or with its upper harmonics will be greater, being proportional with $I_l R_3$ (see Fig. 1).

The zero-indicator used should be such that it does not influence the record of the CRO.

With a certain experience the balancing of the bridge is possible with the CRO only.

## 3. Method of measurement

After connecting the bridge in the manner indicated in Fig. 1 and adjusting the voltage to the required value, tg $\delta$ is obtained and at the same time the curve of the upper harmonics of the loss current, by balancing the bridge with the resistances $R_3$, $R_4$ and the capacitance $C_4$. As has been mentioned, the balancing should be carried out so that the resistance $R_3$ is as great as possible. Therefore, the normal capacitance $C_N$ being in most cases smaller than $C_x$ (the latter being the capacitance of a transformer, a generator, a cable etc.) and the relation between these quantities being

$$C_x = \frac{R_4}{R_3} C_N$$

$R_4$ should also be as great as possible. Therefore, if $R_4$ is e.g. $\frac{100}{\pi}$, $\frac{1000}{\pi}$, $\frac{10\,000}{\pi}$ we should use, if possible, the greatest value among them. If the bridge is balanced, the upper harmonics of the loss current appear on the screen of the CRO. In Fig. 2 these upper harmonics are shown for several different voltages and for several different kinds of insulations. The amplification for a given kind of insulation remained the same.

If after this the shape of the loss current itself is wanted, the capacitance $C_4$ is disconnected. In this case the Schering bridge becomes a Wheatstone bridge for capacitance measurements. Naturally this is also possible, if tg $\delta$ and the upper harmonics of the loss current are of no interest, to balance the bridge only partially or to use a Wheatstone bridge.

On the screen of the CRO appears in this case the curve of the loss current itself, containing the fundamental harmonic and the upper harmonics. The inception of the ionization can be seen on both curves.

On Fig. 3 this loss current of the same insulations is shown at the same voltages as in Fig. 2, and with the same amplification as used for recording

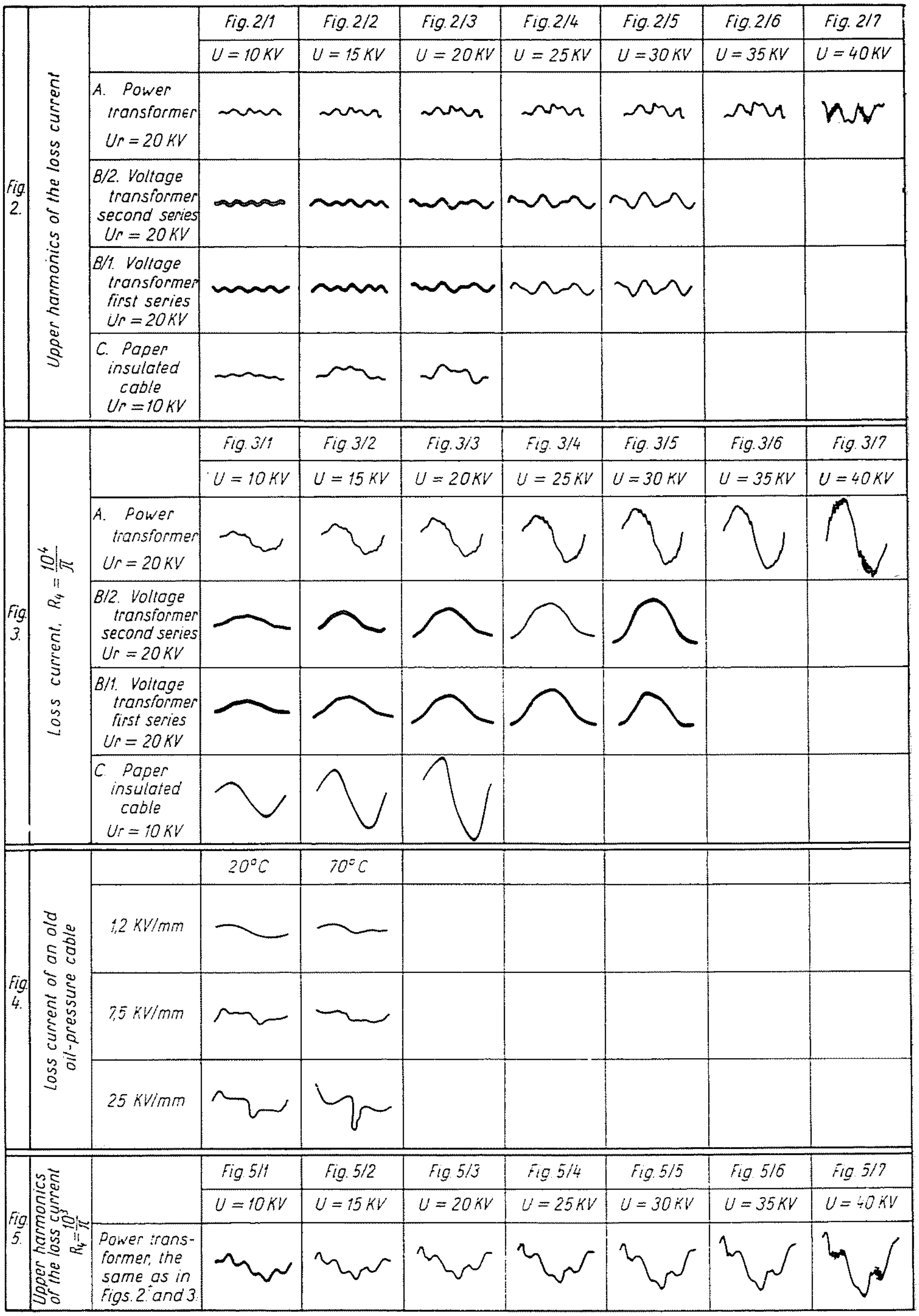
Fig. 2.
Upper harmonics of the loss current
Fig. 2/1
Fig. 2/2
Fig. 2/3
Fig. 2/4
Fig. 2/5
Fig. 2/6
Fig. 2/7
U = 10 KV
U = 15 KV
U = 20 KV
U = 25 KV
U = 30 KV
U = 35 KV
U = 40 KV
A. Power transformer Ur = 20 KV
B/2. Voltage transformer second series Ur = 20 KV
B/1. Voltage transformer first series Ur = 20 KV
C. Paper insulated cable Ur = 10 KV
Fig. 3.
Loss current, R4 = 10^4/π
Fig. 3/1
Fig. 3/2
Fig. 3/3
Fig. 3/4
Fig. 3/5
Fig. 3/6
Fig. 3/7
U = 10 KV
U = 15 KV
U = 20 KV
U = 25 KV
U = 30 KV
U = 35 KV
U = 40 KV
A. Power transformer Ur = 20 KV
B/2. Voltage transformer second series Ur = 20 KV
B/1. Voltage transformer first series Ur = 20 KV
C. Paper insulated cable Ur = 10 KV
Fig. 4.
Loss current of an old oil-pressure cable
20° C
70° C
1,2 KV/mm
7,5 KV/mm
25 KV/mm
Fig. 5.
Upper harmonics of the loss current R4 = 10^3/π
Fig. 5/1
Fig. 5/2
Fig. 5/3
Fig. 5/4
Fig. 5/5
Fig. 5/6
Fig. 5/7
U = 10 KV
U = 15 KV
U = 20 KV
U = 25 KV
U = 30 KV
U = 35 KV
U = 40 KV
Power transformer, the same as in Figs. 2 and 3

the upper harmonics. In case of the instrument transformer No. 1 two series are shown, one for decreasing and another for raising voltages. For this insulation the loss current was appreciably time-dependent for smaller voltages too, showing that the insulation is damaged. The insulation broke down before reaching the testing voltage.

The shape of the loss current for an oil-filled cable with a somewhat deteriorated insulation was shown by GORODEZKY [3] and is reproduced in Fig. 4.

Here it is possible to illustrate the proposals already made as to the use of resistances $R_3$ and $R_4$ as great as possible.

For the sake of comparison, in Fig. 5 are shown the upper harmonics from the same objects as in Fig. 2, but recorded with a resistance $R_4 = \frac{1000}{\pi}$ instead of $\frac{10\,000}{\pi}$ as used previously.

$I_l$ remained very nearly the same, therefore the voltage $I_l R_3$ was one-tenth of the value previously obtained. On the curves of the upper harmonics one can see that they contain some amount of fundamental harmonics too, because the balancing cannot be so accurate with the lower value of $I_l R_3$ as with the higher one.

As the author has pointed out earlier, the recording of the loss current seems to be a useful tool for the control of the voltage test. For this purpose the most suitable method seemed to be the following:

*a)* The bridge is balanced with a voltage about one half of the testing voltage. Then the capacitance $C_4$ is made zero, in order to display on the screen the bridge-out-of-balance voltage which is proportional to the loss current.

*b)* Then the voltage is raised to the value of the testing voltage in the time prescribed in the standards. While doing so there is time to note the voltage at which the ionization (if present) occurs. In most cases it is very probable that the shape and the magnitude of the loss current recorded in this way are not greatly influenced by the fact that the values of the resistances used for the balancing of the bridge are not changed, because the permittivity is much less voltage-dependent than tg $\delta$.

*c)* During testing time one may see whether the shape or the magnitude of the loss current curve remains the same or whether it shows fluctuations or, what is far worse, the magnitude is monotonously growing. According to our very modest experience the insulation can be regarded as safe if the loss-current curve remains the same. For the time being it cannot be accurately judged what amount of fluctuations or asymmetry should be regarded as a criterion for declaring the insulation as not safe enough for putting into service. For this purpose far more experience is needed which can be collected only by carrying out many more such measurements.

## 4. Some conclusions

4.1. It seems that the recording of the loss current and of his upper harmonics may be a useful tool for the quality control of finished insulations. For the time being our proposal is to carry out this measurement as a by-product of the tg $\delta$ measurement. In this case the required extra time and extra equipment is almost negligible but in spite of this the measurement may give extra information.

Probably the use of this method will be of advantage for purposes of prophylactic testing, where consecutive photographic records can be compared which may show many fine details of the changes of tg $\delta$, e.g. the origin of the changes itself.

4.2. If the point of view can be accepted that the power-frequency test deserves a control as much as the impulse test for which the use of some control is prescribed, then the recording of the loss current could be proposed as a control method. This requires almost no extra time. However, "nothing extra" cannot be said for the apparatus, because at present no Schering bridge and no CRO are used for this test. But, as the author has tried to point out, nowadays these instruments are to be found in every testing plant and so their use requires no extra costs.

It may be hoped that by using this method the development of such deteriorations which do not proceed too quickly, can be followed up.

For the recording of very quick phenomena a rapid photo-recording apparatus would be needed. These instruments are relatively expensive and the author does not believe that their use for routine tests would be economical enough. They can be used in research work and in this way perhaps more evidence could be collected on the development of breakdown by alternating voltage, than is at present available.

If we wish to avoid serious damages by testing a defective insulation, it is also possible to use a comparatively simple electronic device which, if the loss current starts growing rapidly, switches off the testing voltage (or gives a signal). This kind of automatic switching will work far more rapidly than any apparatus used for this purpose now.

4.3. It must be pointed out that in spite of the possibility and necessity of making photographic records, the personal skill of the observer has a decisive rôle in evaluating the oscillographic records, by inspection. Perhaps it would be useful to illustrate by giving an example. In the repeated tests of the instrument transformer already mentioned, it was observed that the curve of the loss current, and its upper harmonics as well, showed fluctuations which were not seen, e.g., in the test of the power transformer. It turned out that the insulation of this instrument transformer had suffered a failure during the impulse test carried out a short time before. A damage to the interturn insulation was suspected, because in the power-frequency test with 70% testing voltage subsequently carried out (but without control), the main insulation showed no failure. It seems that the repeated measurements carried out on this insulation (20 kV rated voltage) with voltages above this value (e.g. 30 kV) helped to develop the originally slight puncture originating from the impulse test. After a number of tests the tg $\delta$ also showed that the insulation was suspect, because the balancing of the bridge became unstable, but the oscillogram showed this much earlier.

The number of specimens tested is far from enough to generalize the results, but the author believes that they correspond well enough to the theoretical considerations to propose the use of this method.

It is perhaps worth while to mention that the method may be used for the induced-voltage test of reduced insulations, too.

The author is quite aware of the fact that it would be more correct to put forward his proposals after getting far more experimental evidence, but he hopes that by this somewhat early publication he will make possible for his colleagues to start a discussion or, if they agree with him, to commence the collecting of experiences with the method proposed or with some better ones. The author expresses his thanks to his co-workers, J. PATKÓ and I. HÁRSKUTI, El. Engs., who with great care and skill carried out the numerous measurements, and also to the Power-Plant Trust and the Institute for Power Research also for the permission to publish some of their results.

## 5. Summary

The oscillographic recording of the loss current (bridge-out-of-balance current) or of its upper harmonics seems to be an useful tool for different kinds of quality control of finished insulation, because it may give more information about its condition than only the value of tg $\delta$.

This method may also be used as a control method in the power-frequency test. It is also possible to use the abnormal growth of the loss current for switching off the testing voltage in order to prevent excessive damages in the case of a failure.

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