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CHECKING OF THE CONDITION OF TRANSFORMERS AND THE EFFICENCY OF OIL REGENERATION WITH RVM (RETURN VOLTAGE MEASUREMENT)

SUMMARY

Up to now the insulation in HV power transformers has been made from oil/paper therefore the diagnosis of this kind of insulation will be also important in the next forty-fifty years. The lifetime of this equipment strongly depends on the condition of the insulation system. The ageing process of oil/paper insulating systems is a very complex and complicated phenomenon. In order to get a well-supported decision on the further operation of aged transformers, relevant information would be necessary on the condition of the oil-paper insulation. We also know that the oil-paper insulation has almost always inhomogeneous condition considering the temperature, moistening and ageing processes. The classical methods (insulation resistance, loss tangent, etc.) characterise the insulation by single measured value. This single value is not sufficient for relevant characterisation and diagnosis of such a complex system with lots of tons of insulation and with almost always inhomogeneous distribution of temperature, moisture and ageing product. If we measure the polarization spectra in three states (new insulation in equilibrium and uniform polarization spectrum, new insulation with not uniform distribution of polarization spectrum, later reaching again the uniform distributions) the shape of three polarization spectra will be different. Comparing the polarization and classical methods of this three case we can realize that sometimes the “classical single values” are almost the same but the polarization spectra are different.

The three response methods provide very practical information about the insulation system (e.g. moisture, ageing). The moistening and accumulation of ageing by-products change the distribution of interfacial polarisation in the range of long time-constants. These promising response methods measure the polarisation distribution in the range of long time-constant (with other words, in the low frequency range). The three test methods were: Return Voltage measurement (RVM), the C and tgδ measurement in range of some tens of mHz to 50 Hz (FDS=Frequency Domain Spectroscopy), and the measurement of DC charging and discharging currents (PDC=polarisation and depolarization currents) up to some thousands of sec. These equivalent methods (RVM, FDS and PDC) are able to follow the changing of condition of insulation contrary to classical methods. Therefore a little bit surprising that until now the convenient standards is missing considering the polarization methods. In an earlier Hungarian research work (Budapest University of Technology) almost all the necessary measurements have been realized, consequently we are in possession of fundamental data considering the polarization methods. This paper would like to show a short review about the RVM technique, the correct interpretation of RVM data and a case study for the checking of the efficiency of the oil reclamation with RVM technique.

Key words: transformers, Dielectric Response Methods, Return Voltage Measurement (RVM), condition assessment, ageing, moistening, life management, oil regeneration

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1. INTRODUCTION

The actual lifetime of transformers strongly depends on the real operating conditions, and so the residual life of these units can spread in a broad scale. The transformer life/ageing is mainly related to the degradation of the insulation, which is caused dominantly by the thermal ageing of the insulating paper, together with the decomposition of the cellulose. The by-products of this process are water and other substances of partly polarisable and ionisable character. The humidity content and the ageing products of the paper have a decisive role in the degradation rate of the cellulose; the higher humidity accelerates very strongly the degradation. It is important to periodically check the internal conditions, diagnose the degree of its deterioration and carry out proper cost-effective preventive/corrective maintenance, refurbishment or on-site oil regeneration taking into consideration its remaining life [8] [9] [10].

The changes of the condition can be caused by certain deterioration effect, most of them can be detected using the classical methods or the polarisation (interfacial and boundary) spectrum techniques. Lots of classical methods (insulation resistance, absorption factor, loss tangent, water content measurements, etc.) have been used for many decades as testing of the solid oil impregnated paper insulation. They intend to qualify the state of inhomogeneous insulation by single measured value. This single value is not proved to be appropriate for relevant characterisation and diagnosis of the complex system of such inhomogeneous insulation considering the temperature, moistening and ageing processes. A good and suitable diagnostics system is able to distinguish the inhomogeneous distribution of the temperature, moisture and ageing product content, the good and wrong condition, the dry and wet state, the changing of condition before and after the oil regeneration, etc. [1] [2] [3] [4] [11].

When we would like to estimate the condition, we had to characterise the oil condition, the ageing phenomena of cellulose insulation (soft and hard cellulose, surface of solid insulation, the ageing product between the paper layers, etc.). Recent attention has been directed to methods of determining moisture content and ageing of the pressboard and paper more directly by measuring the effects of moisture and ageing on electrical properties. Rather than the traditional measurement of power frequency loss angle, measuring various dielectric response parameters, which characterise some known polarisation phenomena, has been in focus [5] [6]. All the three dielectric response methods (RVM, FDS, PDC) reflect the same fundamental polarisation and conduction phenomena in transformer insulation and are able to estimate this complex and complicated insulation system [1] [2] [3] [4].

Unfortunately till now a guide or a standard is still missing in this field, perhaps this is justified that the State of Arts of the polarisation spectrum methods is not well known. The main goal of this paper is to show the good efficiency of one the spectrum methods by means of the RVM (Return Voltage Measurement). For the correct interpretation of the RVM methods first of all we have to offer a brief survey of specific feature of oil-paper insulation with special attention of oil reclamation. Oil reclamation (reclaiming) is the elimination of soluble and insoluble contaminants from an insulating liquid by chemical absorption means, in addition to mechanical means, in order to restore properties as close as possible to the original values [9][11]. The oil reclamation results important and complicated changing in the condition of the oil-paper insulation. One parts of ageing contaminants is in the oil, but important parts are on the surface of the cellulose insulation. With the oil diagnostics we can check the ageing product in the oil but we have not information about the remaining ageing product in the paper insulation. The polarization spectra are able to reflect this complex mechanism, the RVM is able to follow the changing of condition of insulation, and as a consequence, the RVM is able to estimate the effectiveness of oil regeneration. It is well known that the oil regeneration "in a transformer" is far more efficient than simple oil change. In the case of oil change relatively lots of ageing products remain between the paper layers, but the RVM method is able to distinguish the difference between the oil change and the more efficient oil reclamation.

Why are we able to claim that the RVM method is very good tool to diagnose the condition of oil-paper insulation? At the Budapest University of Technology and Economics (BME) a large research work has been carried out to investigate the moistening and ageing of oil-paper insulation in 70s. In the scope of Hungarian research work - among other things – the following processes have been investigated: Return Voltage Measurements (RVM), Dielectric Frequency Domain Spectroscopy (FDS), and Charge/discharge current (measurements of polarisation and depolarization currents (PDC). In the Hungarian research work almost all the possible measurements have been realised. Based on our research work and thirty year's practical experience, we would like to clarify why the interpretation of results seems a little bit difficult. Using the results from the laboratory experiments and from field measurements, an Expert System (ES) was developed for easier interpreting the measurements. In this Expert System distinction is made between good and bad condition, it is showed the relationship between polarisation spectrum of the new and service aged power transformers, actual condition (water content and ageing product), how to extract information from the measurement data [1] [2] [3] [4] [11].

2. BRIEFLY ABOUT THE LIFE EXPECTANCY AND OIL REGENERATION

So far, the main insulation of HV power transformers is still making from oil/paper. Transformers have designed for a 40 years lifetime therefore the management of this kind of insulation will be inevitable in the next forty years or so. The owners are concerned when to replace them and how risk increases with age. In order to minimize the cost of operation of a transformer throughout its life, it is important to periodically check the internal conditions, diagnose the degree of its deterioration and carry out proper cost-effective preventive/corrective maintenance, refurbishment or on-site oil regeneration taking into consideration its remaining life. The owner of the transformer must select - based upon technical, operational and economic considerations - one of the following alternative possibilities: repair or/and refurbishment in factory or on-site, on-site oil regeneration, replacement of damaged unit with a new or spare transformer.

It is well known that the life of the transformer is exclusively determined by the life of the insulating paper. Since the cellulose insulation in a transformer can only be replaced with a rewind and loss of production of the transformer in question, it makes sense to remove the oxidation by-products before they can do any damage to the cellulose. Since any degradation of the cellulose that occurs cannot be reversed, it would be the best to remove the oxidation by-products as quickly as possible. The simple oil purification methods do not remove the oxidation by-products associated with transformer oil aging only oil regeneration methods are capable of removing the sludge found in aged transformer oil and in cellulose insulation found in the transformer.

Regarding the behaviour of oil-paper insulation systems the oil reclamation or regeneration is very cost effective method to improve the condition of transformer insulation. During service life, the oils oxidises forming degradation products as acids and sludge. Untreated oil will attack the paper and drastically cut down on the life of transformers. As it is well known the oil reclamation is effective in removing acid compounds from oils. Knowledge of the general behaviour of an impregnated insulation system and its ageing is the key factor to understanding the possibilities for improving service conditions of insulating paper. Oil regeneration treatment restores oil quality properties, thereby extending the serviceable life of the mineral oil and the reliable life of the transformer. The regeneration will slow the aging rate of the oil, thereby extending the life of paper insulation. We had to mention some words about the simple treatment process of oil. The simple oil treatment is really filtering and drying of oil, but the ageing materials remain in the oil and on the surface of paper insulation. Since there is big difference between the simple oil treatment and the powerful oil regeneration it is essential to use such a diagnostics tool which is able to distinguish the simple and effective process [8] [9] [11].

Considering the ageing of the oil-paper insulation why is it interesting to investigate the efficiency of RVM method and the oil reclamation? The moisture and ageing products increase the dielectric loss, the dielectric loss increases the local temperature and an avalanche processes can start and in the end a dielectric failure can occur. The increased moisture, ageing products and high temperature of the oil-paper insulation accelerate the ageing processes. The evolution of free gas bubble will start with a consequent reduction of dielectric strength and sharp reduction of PD inception voltage. If we would like to specify the risk of dielectric failure of the insulation (when the bubble formation cause breakdown) we have to determine the limiting hot-spot temperature for safe operation of transformers. When free gas bubbles have been observed in transformer conductor heated to overload temperature this phenomenon influences the operation of transformer and inversely, the operation of transformer has an effect on bubble formation [7][10][11]. To avoid premature ageing of the cellulose insulation, the equipment’s water and acid content must be kept to a minimum. If the transformer has a significant water and acid content, drying and oil regeneration may retard ageing of the solid insulation. As we will see below, we have to determine the whole RVM spectrum and each time constants. We had to know the limits of moisture, ageing rate, bubbling temperature, then determining the limit temperature at which the operation of transformer is safe [3] [4].

3. BRIEFLY ABOUT THE RVM TECHNIQUE

3.1. Interfacial and boundary polarisation, polarisation spectrum

Two fundamental dielectric processes, the conduction and polarisation, arise in the dielectrics under the presence of the electric filed. Both processes are very strict connection to the micro-structure of the oil-paper insulation, any change in the insulation lead the changing of fundamental dielectric processes. The magnitudes of dielectric parameters are determined by the intensities of both processes. Therefore it is possible to conclude from the changing of the measured parameters to the development of deterioration of insulation, and indirectly to the decrease of its dielectric strength, as well.

The intensity of conduction can unambiguously be characterised by single quantity, the specific conductivity γ (or by its reciprocal value, specific volume resistivity (ρ)) of oil-paper insulation. The polarisation, however, is more complex process, namely a resultant of several elementary processes of different intensities and relaxation times. It can only be characterised by using the polarisation spectrum (PS) of insulation. The PS is a density function (α(T)) what describes the distribution of the intensity of the polarisation against the time constant (Fig. 1) [3][4].

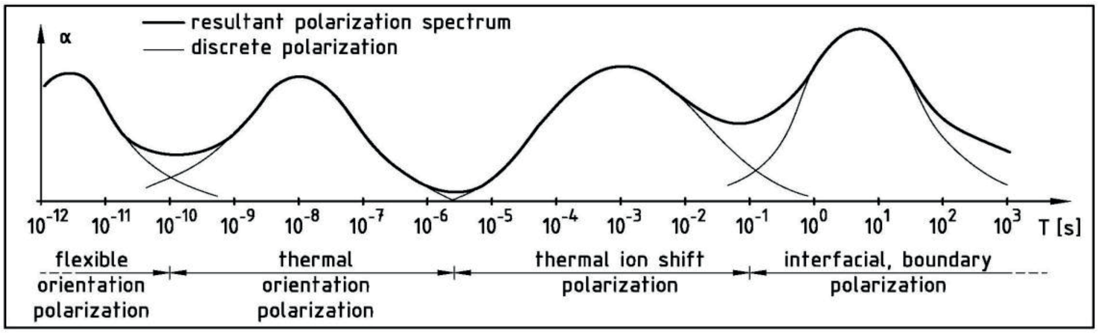


Fig. 1: Polarisation spectrum characterised by the density function of α(T)

The interfacial polarisation spectrums contain lots of information about the insulation systems. As we can see from the technical literature, that the polarization (interfacial and boundary) spectrum techniques are able to access the condition of oil-paper insulation. The interfacial polarisation gets sorted out in the insulation when the following equality is not true: $\varepsilon_1\sigma_2 = \varepsilon_2\sigma_1$ (ε=permittivity, σ or γ=conductivity of insulation material) (Fig. 2).

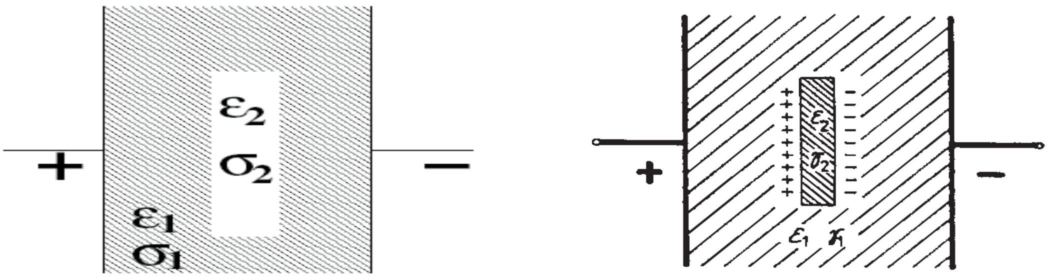


Fig. 2: interfacial and boundary polarisation

This polarisation spectrum characterises not only the material, but - because of the strict relation of the polarisation to the micro-structure - even to the condition of the insulation, as well. Consequently, by investigation this spectrum a conclusion to the deterioration (moistening, ageing, etc.) can be drawn. Regarding the diagnosis of moistening and the ageing processes in oil-paper insulation the interfacial and boundary (volumetric) polarisation is important of the whole polarisation spectra. For the simulation an equivalent circuit can be used, shown in Fig. 3 [3][4]

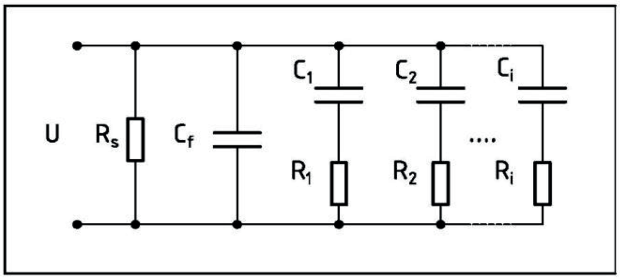


Fig. 3: Equivalent circuit of insulation

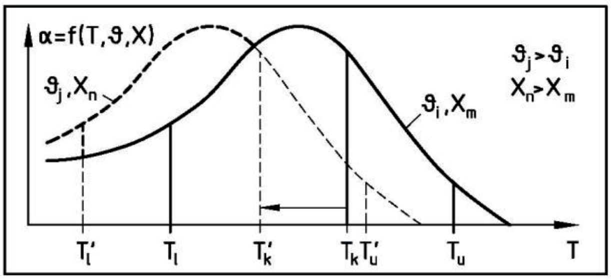


Fig. 4: The polarisation with different time constant

Cf is high frequency capacitance, Rs is the insulation resistance of the test object can. The "slow" polarization processes can be modelled by a parallel connection of series RiCi elements, together with a "high frequency" capacitance Cf. Without going into the details the Figure 4 shows the approximation of polarisation spectrum by "elementary of number n" processes in the related of Tl ...Tu time constant range (αk and Tk are the specific polarisability response the time constant (Ti=RixCi) of the process, parameters: X=moisture, ϑ=temperature) [3][4].

3.2. Technique of the Recovery Voltage Method

The Recovery Voltage Method is a DC method which investigates the slow polarisation processes in the time domain (see Fig. 7). A step voltage (U=) is applied over the electrodes of a completely discharged test object with geometric capacitance. During the charging period the polarisation current flows through the test object. After the charging period, the test object is short-circuited and the depolarisation current flows. After the short-circuiting period is finished, the return voltage is measured under open-circuit conditions. The source of the recovery voltage is the relaxation processes inside the dielectric material, giving rise to an induced charge on the electrodes of the test object. The charging period activates polarisation processes in the object. Depending on how long the test object is charged, different polarisation processes with different time constants become activated. Then during the short-circuiting period, the polarisation processes start to relax. Depending on how long the test object is short-circuited, different numbers of polarisation processes are almost totally relaxed. Then during the open circuit period the polarisation processes, which were not totally relaxed during short-circuit period, relax further and give rise to a recovery voltage over the electrodes of the test object [2][3][5][6].

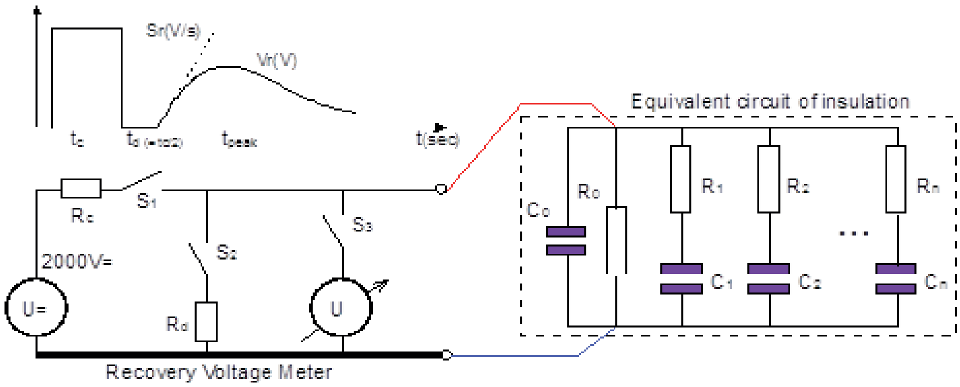
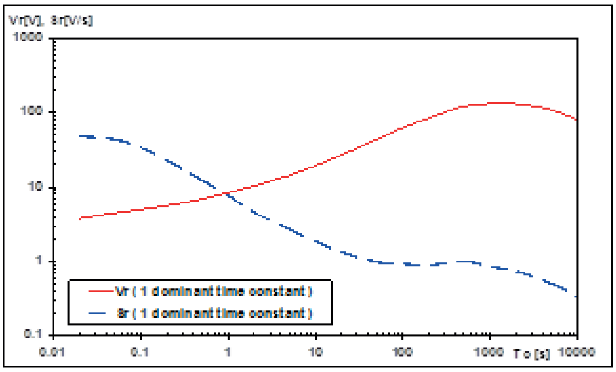


Fig. 7 – RVM measurement cycle and equivalent circuit

The RVM "quasi spectrum" is produced by applying a series of individual charging voltages U= to the test object, followed by a short-circuiting period as explained in Fig. 7, at each cycle increases of the charging period, t = tc as well as the short circuiting period, t = td=tc/2 are made (using a fixed ratio of tc/td=2 for the measuring series). After discharging time (td) has elapsed, the recovery voltage U (t), for a particular cycle, is recorded and from its peak value, the amplitude U is quantified with the charging period tc for that cycle. The resulting curve, Umax as a function of Tc, is called the polarisation spectrum. The initial derivative, dU/dt of the recovery voltage is also found and can be plotted as a function of tc.

The following RVM curves of the Fig. 8 and 9 show such typical cases when the investigated processes have one or two time constant.



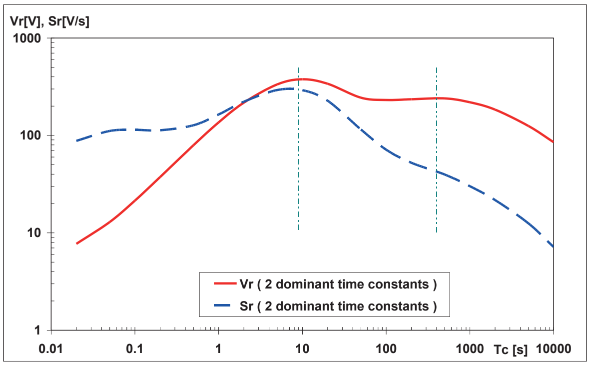


Fig. 8 and 9: typical RVM curves with one and two dominant time constant

The interpretation of an RVM measurement is based on the complete two curves (curves of Vr and Sr), namely the identification of maxima in the polarization spectra, and the estimation of the polarization intensity at the maxima. The analysis becomes much easier if the “initial slope” (Sr) spectrum and ”maximum” (Vr) spectrum are used together.

The curves of Fig. 8 show the shapes of “quasi spectra” (determined by RVM) with one dominant time constants. We have to know that in this case there is only one polarization process which is characterized with single time constant. This is the case, par example, when the oil-paper insulation has a good, dry condition and the system is in equilibrium (the insulation condition is homogenous including the temperature distribution too).

The curves of Fig. 9 show such a case when there are two polarization processes which are characterized with two different time constants. This is when the oil-paper insulation has a good, dry condition and the system is not in equilibrium (the insulation condition is not homogenous), or the paper has good condition (new and dry) but the oil is aged, etc. The "quasi spectrum" is - as can be seen - a continuous curve, with two definitive maxima, at the two time constants, so, that these are well determinable of this curve. If we would like to determine the dominant time constants the “RVM quasi polarisation spectrum” is suitable in practice.

It is well known that the polarization is a more complex phenomenon, a resultant of several elementary processes. Each of the elementary polarization processes are related to a well-defined kind of charge carriers. If the density of a certain kind of charge carriers alters due to some ageing or deteriorating processes of the insulation, the intensity of the elementary polarization will change, as well. The increase in conductivity leads to an increase in dielectric loss and a decrease the time constant of elementary polarization, as well. As an example, since the chemical ageing tends to increase the dielectric loss of both paper and oil, the polarization time constant tends to shift towards lower values for ageing oil-paper insulation. Likewise, moisture in the paper resulting from over-stressing and condition tends to increase the dielectric loss and decrease the polarization time constant.

If the oil-paper insulating system is wet and aged, moisture and the ageing products influence the polarization spectra, as well. This phenomenon is very important when we analyse the condition of insulation system because, as we can see, generally it is possible to distinguish the influence of the water and the ageing. Several papers, which listed in literature, show that the methods measuring the polarization spectrum are extremely useful for assessing the condition of the oil-paper insulation comparing to those classical methods, which use single measured value (as tgδ at 50 Hz) [1][2][3][4][11].

3.3. RVM as diagnostics tool for oil-paper insulation

Fig. 10 and 11 shows curves, drawn with RVM method, measured on oil-paper insulation system models, with exactly pre-set the paper moisture content, and the temperature. Fig. 10 shows the case when the oil and the paper is new, the system is homogenous, the temperature distribution is also homogenous (the temperature was 38°C). We can see that the times constant are in unambiguous relation with the moisture content of the paper: increasing water content shift the time constant to lower value.

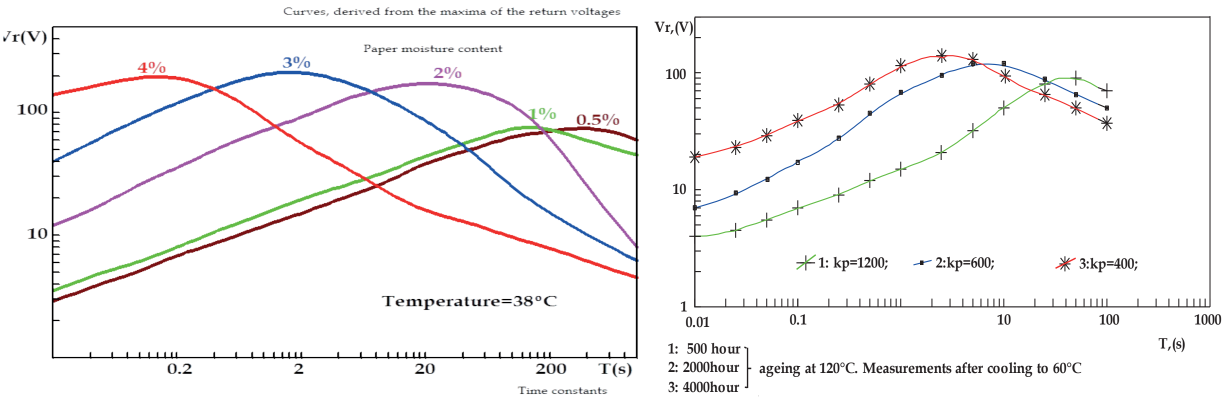


Fig. 10 and 11: Effect of moisture and ageing on the "quasi polarisation spectra" determined by the RVM

Fig. 11 shows spectra on the same oil-paper insulation model, measured on 60°C, after ageing of different time periods, at 120°C beside the determination of the polarisation spectrum with the RVM method. In each case there was also determined the depolymerisation of the paper. All other circumstances were held, or set - as far as it was possible - at, or to the same condition. It can be seen, that with the ageing the dominant time constant of the polarisation shifts - similar as with the increasing of the humidity - "forward", to the smaller values. This means, that with this method, regarding the dominant time constant, it would be theoretically better to speak of a relation to the "equivalent moisture content" of the paper, because of the fact, that the shifting of it is not only caused by H_2O, but by this, and other ageing products together.

In order to use more reliably the diagnostic techniques, it is important to summarise the most important aspects of the oil-paper insulation. The transformer life/ageing is mainly related to the degradation of the insulation, which is caused dominantly by the thermal ageing of the insulating paper, together with the decomposition of the cellulose. The moisture content, the ageing products of oil, etc. have a decisive role in the degradation rate of the cellulose, for example the higher level of humidity, temperature, acid content accelerates very strongly the degradation. Excessive water in transformers is unacceptable because it accelerates the ageing of the solid insulation, increases risk of bubble evolution, and impairs the dielectric properties of main insulation. A good insulation contains a small amount of water, which fact is important to maintain its good mechanical properties. Generally the ageing rate of insulation material is primary influenced by temperature. The water and oxygen have a significant but smaller effect. The effect of water on ageing of paper insulation is directly proportional. It is known that at 3% of moisture content in the paper the polymerization factor decreases ten times faster to its half value, with comparing if the moisture in the paper were 0,3% (dry and new paper insulation).

3.4. Interpretation of RVM results (limit values for large power transformers)

Before interpreting the RVM result we have to speak about the "safe transformer". Considering the literature we can realise that the high temperature, the high moisture content and ageing product is dangerous for transformer. If this three parameters are high, it is risky for transformer because the inception temperature of bubbling must be far higher than the „hot spot" temperature of the transformer. It is proved that inception temperature of bubbling is water content and ageing dependent. What is the meaning of this word of „safe"? The reduced moisture and acid content allows higher reliability and overload capability (no bubbling). Until yet, the judgement of the general state of a transformer insulation could be made only by concerning the results of oil sample tests, tgδ and PD measurements. None of these can give basis for a reliable paper moisture content estimation. Thus the different operating and or production rules, standards, and recommendations could not contain regulations for the limit values for this quality determining quantity.

However now, this quantity can be in a reproducible and reliable manner easily estimated with the RVM method, with measurements made with connections at the bushings, and there has gathered meanwhile experience of thirty years of systematically made measurements on net system. So, perhaps the time is here, to recommend such limit values (Fig. 12). Fig. 12 supports the limit value for the reliable operation of MV and HV transformers. This figure shows a "spectrum" measured on a faulty 120/20 kV transformer, after an insulation breakdown. The measuring temperature was 21°C, the dominant time constant of 0,3s refers to 5% of “equivalent moisture content” in the paper. This is the lowest dominant time constant and now not too important what is the origin (high moisture content or ageing products). Now, considering, that the dominant time constant at this moisture content, and at the operating temperature of about 60°C would be shifted forward, down to the value of 3 ms, it can be presumed, that the increased dielectric losses, and perhaps the initiated bubble and partial discharges too, had a significant role in the breakdown of the insulation.

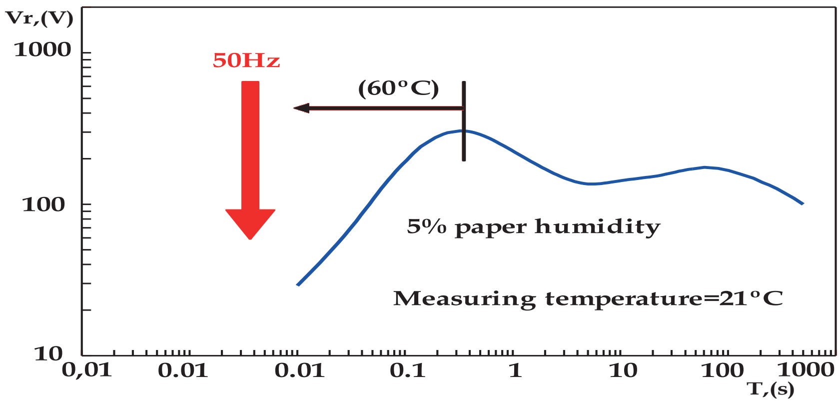


Fig. 12 Spectrum, measured on a transformer after a breakdown

Using the RVM and the “bubbling” curve [3][4][7] we will able to determine the limit temperature at which the operation of transformer is „safe”. For the safe, reliable operation of EHV great transformers (the higher voltage is 220 kV, or higher) a limit of 2-2,5%, and for transformers of the high, and middle voltages (the higher voltage is lower than 220 kV) max. 3,5% could be a good choice, as this recommendable paper moisture content limit. At reaching, or exceeding these values should be made an on-site, or in factory drying treatment on the transformer. The "voltage dependence" of the limit values justifies the fact, which the "allowed electrical stresses" on the insulating paper are in EHV transformers generally higher, than in HV and MV transformers. For new transformers 0,5% could be a good choice for this limit value, and for the limit value after refurbishment, or drying treatment for EHV transformers 1,5%, and for HV and MV transformers 2% limit values could be recommended.

It seems that the RVM technique would be complicated but the moistening and ageing phenomena are complicated and complex and it is lucky that the RVM spectra characterise this complicated processes. If we are in possession of the fundamental database it is not too problematic to analyse these inhomogeneous systems. The RVM Expert System (RVM-ES) has been developed to determine the condition of the oil-paper insulating systems and is based on large research work.

The short recommendation for the interpretation of RVM data measured on oil-paper insulation is the following:

We have to determine the whole RVM spectrum and each time constants. We have to know the „shifting rules” of time constants determined by the temperature, the moisture content and ageing products (see the Hungarian RVM Expert System). The case of new paper/new oil we can use the „nomogram” publish in literature [1][3][4], otherwise it is recommended using the RVM Expert System based on Hungarian research work. We had to know the limits of moisture, ageing rate, bubbling temperature, then determining the limit temperature at which the operation of transformer is safe.

4. CHECKING OF EFFICIENCY OF OIL RECLAMATION WITH RVM TECHNIQUE

Some of the by-products of this degradation, mostly acids and sludge attack the chemical bonds which hold the cellulose insulation together (measured by polymerization). The main goal of the oil regeneration is to remove water and acids being formed and/or getting into the cellulose insulation from the cellulose insulation once there. Transformer oil will discolour as oxidation of the oil takes place. Colour, by itself, is not a reliable test in evaluating the condition of the oil for further use. It is a strong indication that something is happening within the transformer that requires investigation. Once transformer oil changes from the yellow colour range into the orange and red colour range, it has degraded to the point where the vital parts of the transformer are being seriously affected. As the colour of the oil changes, sludge is forming in solution with the oil due to oxidation. This causes a drop in interfacial tension and an increase in the acid (neutralization) number. When transformer oil deteriorates to the red colour ranges, deposited sludge continues to oxidize and harden, blocking vents and insulating cooling fins, causing higher operating temperatures. Insulation shrinkage may take place, and premature failure is possible.

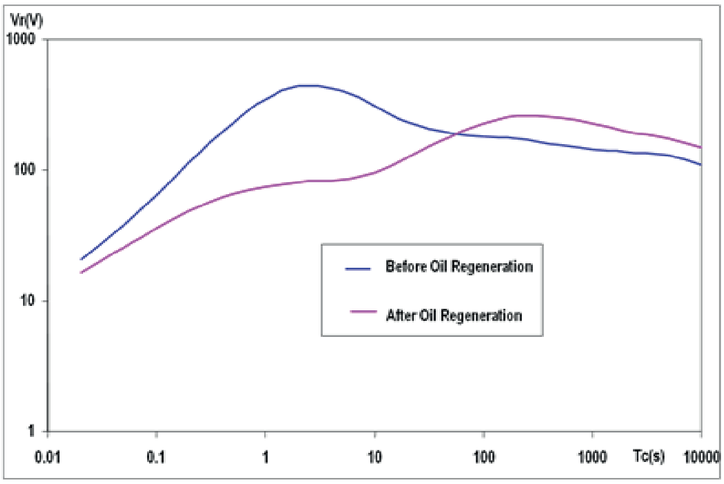


Fig. 13: RVM curves before and after the oil regeneration.

In Fig. 13 it can be seen the effectiveness of oil reclamation. The RVM curves show that the changing the polarisation spectra was important between before and after the oil regeneration, with others words, considerable quantity of ageing by-products were moved [3] [4] [11].

The case of Fig. 13 is very frequent, so it is very important the correct interpretation of RVM curves and the phenomena. In this case the transformer has the following condition: the paper insulation is medium dry and aged, the oil and the surface of the cellulose contains lots of ageing products. It is very important to recognise this condition because if the other repairing works allow us, we can repair it on-site and we will able to save lots of money. The Fig. 13 shows the influence of moisture and ageing products on RVM curves measured in real transformer (220 kV, 160 MVA, which was about 30 year old).

It can be seen that before the oil regeneration the RVM curves have at least two dominant time constants. The lower dominant time constant was mostly influenced by the ageing products, we can check this fact with using of the result of oil screen. The higher dominant time constant characterises the water content in the paper, namely the dryness of the paper insulation. At the first moment it is not too easy to observe this time constant because this part of curve is rather flat. But we can see the polarisation is very strong in the range of 100 and 1000 s. When we carried out the oil regeneration, the influence of ageing products could not totally disappear because the paper during the long service time was able adsorb lots of ageing products. The water content in the paper did not change significantly, so the time constant which characterises the moisture content of the paper remain at almost the same value. With oil regeneration, the parallel insulation resistance increased, so the peak of return voltage also increased. The polarisation which was influenced by the aging products significantly decreased, as it can be seen.

Comparing the RVM curves before and after the oil regeneration we can determine the effectiveness of oil reclamation. These RVM curves show that considerable quantities of ageing products were moved. It is very important to remark that live oil regeneration has much more benefits in comparison to replacing the oil in the transformer or just filtering the oil. Firstly, by doing it on energised transformer, from the consumer's perspective, they will not face any load shedding or supply disruption. Secondly, from the transformer's perspective, apart from reclaiming or regenerating the oil to its original condition, the transformer is also removed of sludge and other impurities from its windings. This is possible as the oil is circulated a number of times through the transformer and the process is only stopped when the oil condition at the bottom of the transformer has reached the acceptable condition and the transformer is rid of sludge, moisture and impurities. The total volume of oil is re-circulated a number of times thorough the regeneration plant and "flushing effect" of a transformer is achieved. In the case of oil change relatively lots of ageing products remain between the paper layers. Regeneration is the complete treatment of oil to like new condition.

Oil regeneration “in a transformer" is far more efficient than simple oil change. It is obvious that regeneration as a complete oil treatment method is the best technical solution to aged transformer oil. Apart from this it is also highly cost effective in comparison to an old procedure of oil change. Using the RVM technique we can check the efficiency the oil reclamation. RVM characterises the condition of the insulation with a spectrum. The traditional methods use a single parameter to characterise the condition. The RVM method is able to distinguish the changing when we remove the ageing products from the oil or from the whole solid insulation system. When we use the RVM method we measure the composite oil-paper insulation. The polarisation response influenced by the interface forming the oil and macro molecules of paper. There is big difference between the RVM spectrum if we remove the ageing product from the oil or we remove the ageing products from the layers of the paper insulation, too (oil regeneration has a flushing effect). Very important remark: the life of the transformer is determined by the life of the paper, oil regeneration is effective if we remove the acid compounds from oils and from the paper layers, too. RVM is very efficient tool to check the condition of paper after regeneration.

5. CONCLUSION

The RVM is a very good tool for getting information of insulating paper in oil - paper insulation systems. For transformers this method is applicable as an acceptance test, as a test which approves that the transport, eventually the storage, and the installation was made properly, as a periodical test, for aiding the decision whether and which transformer needs a refurbishment, a drying process on site, and last but not least, with this method the effectiveness of these renewing operations can be tested. It is also proved that the RVM provides much more information than the classical dielectric methods (insulation resistance, tgδ at power frequency, etc.) but in lack of the real guide line there are some misunderstanding using this method. This paper would like to show some selected case stories to improve the interpretation of results measured with RVM technique. The several thousand of Hungarian experimental and on-site measurements have showed that there is good correlation among the dielectric condition, the equivalent circuit and the measured results. Considering the Hungarian database these methods are useful for evaluating the uniformity of aging and/or moisture distribution and allow observation of progress of ageing moistening processes.

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