DIGITAL EQUIPMENT FOR MONITORING THE CONDITION OF THE BUSHING RELATED TO THE HIGH POWER TRANSFORMER UNITS

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REZUMAT. Luand in considerare faptul ca trecerea izolata este un element cheie in functionarea transformatorului electric de putere, functionarea sa in conditii de siguranta este o problema speciala, deoarece deteriorarea acesteia duce in multe cazuri la explozii urmate de incendii cu consecinte foarte grave pentru statii si substatii.
Acest articol trece în revistă toate avantajele de monitorizare on-line şi prezintă un echipament numeric de monitorizare continua a starii trecerilor izolate reprezentand contribuţia proprie a autorilor.

Cuvinte cheie: trecere izolata, condensator, izolator, transformator.

ABSTRACT. Because the bushing is a key element in the operation of electric power transformer, its safe operation is a special issue since its damage often leads to explosion followed by fires with very serious consequences for the stations and substations .
This paper reviews all the advantages of the on-line monitoring and presents an equipment for on-line monitoring of bushings, which is the own contribution of the authors.

Keywords: Bushing; capacitor; insulator; Transformer

1. INTRODUCTION

The damage of bushings is one of the main causes leading to the improper operation of the transformers or even to the explosions. The statistics confirmed that 30% of the transformer damages are due to capacitor-type bushings. The European statistics show that 80% of the damaged bushings are between 12 and 20 years old and therefore the monitoring is necessary even before the middle of their life time [1],[2].

The high electric field gradients in the bushing insulation and the high working temperature contribute to the acceleration of insulation ageing.

The explosion of the bushing can damage the transformer tank, can generate an extended fire by transformer oil ignition, and fire in the bundle of cables in the electric switch box or in the control room through the secondary wiring.

A damage of the bushing leads to financial losses (between 1 and 3 million of dollars) to the insurers, both for physical damages and for the disturbances of the affairs in the companies they are serving.. These losses can reach, in exceptional situations, tens million of dollars.

The explosion can generate material damages and human life losses because of the porcelain pieces spread at long distance and with a very high speed.

The traditional diagnosis systems of the bushing insulation are based on periodical measurements of insulation loss factor, once within 2-3 years. In such case, it is necessary to put the transformers out of service and to measure tanδ at an applied voltage of 10 kV.

The disadvantages of this traditional method for monitoring the bushing insulation are the following[3]:
-The testing frequency arbitrarily chosen is not usually correlated with the failure rate development. The practice proved that the period between the measurements must not exceed 100 days to detect 95% from the defective bushings, and this is practically unacceptable;
-The measurements for tanδ performed at an applied voltage of 10 kV are not relevant for the actual condition of the bushing insulation. The measurements at rated voltage, performed on the bushings where partial discharges appear, showed values of 5-8 times

higher than those measured at 10 kV. The oil deterioration at high temperatures generates chemical modifications and sediment accumulations leading to the failures of the bushings. The detection of this type of fault at the voltage of 10 kV can be very difficult, even by tanδ measurement at the rated voltage.
-The traditional testing methods require a lot of work and the putting out of service for a long time.

2. DIGITAL EQUIPMENT FOR ON -LINE MONITORING OF BUSHINGS

For on-line monitoring of bushings it is ideal to monitor the time variation of dielectric losses and of bushings own capacity.

In a quasi-homogeneous dielectric, in homogeneous electric field, the losses in dielectric depend on the electric field strength and temperature. The losses increase proportionally to the square of the electric field strength but they strongly depend also on the temperature θ in dielectric [4], [5].

$$P(\theta) = \frac{1}{2}\varepsilon_0 \varepsilon_r(\theta) \cdot E^2 \cdot \omega \tan\delta(\theta) \quad (1)$$

At high electric fields, the losses have even more accentuated increase related to the electric field strength.

The heat produced by Joule losses from the central conductor of the bushing generates also a temperature rise in the insulating material, which overlaps on that one due to the dielectric losses.

Because of dielectric losses, the alternating current which passes through a bushing is not purely reactive I_r, but it has an active component I_a named leakage current.

$$\tan\delta = \frac{I_a}{I_r} \quad (2)$$

Let us consider an elementary capacitor with the area of the armature S, the thickness d, at the voltage U and the frequency f, which has the losses P:

$$P = p_\theta \cdot v \cdot E^2 \quad (3)$$

where : p_θ are the specific volume losses (v = the volume of dielectric) at the temperature θ and, at the stress with the electric field having the strength E:

$$I_a = \frac{P}{U} = \frac{p_\theta \cdot v \cdot E^2}{E \cdot d} = \frac{p_\theta \cdot S \cdot d \cdot E^2}{E \cdot d} = p_\theta \cdot S \cdot E \quad (4)$$

$$I_r = 2 \cdot \pi \cdot f \cdot U \cdot C = 2 \cdot \pi \cdot f \cdot E \cdot d \cdot \frac{S}{d} \cdot \varepsilon_0 \cdot \varepsilon_r = 2 \cdot \pi \cdot f \cdot \varepsilon_o \cdot \varepsilon_r \cdot S \cdot E \quad (5)$$

$$\tan\delta = \frac{I_a}{I_r} = \frac{p_\theta}{2 \cdot \pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon_r} \quad (6)$$

The phasor diagram is presented in the Figure 1:

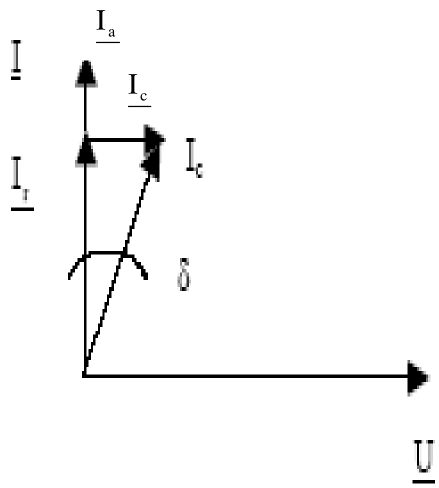

Fig.1 The phasor diagram

The dielectric losses of a bushing are:

$$P = U \cdot I_a = U \cdot I_r \cdot \tan\delta = 2 \cdot \pi \cdot f \cdot U^2 \cdot C \cdot \tan\delta \quad (7)$$

In order to monitor the dielectric loss factor and the own capacity of the bushings, at ICMET Craiova a group of specialists finalized an equipment for on-line monitoring of the bushings.

2.1. Equipment architecture

The equipment presented in the paper is constituted from a signal acquisition and conditioning unit (Fig. 2), by means of which there are taken over the information regarding the leakage current flowing through the bushings dielectric from their test taps, and the information related to the reference voltage corresponding to each bushing from the secondary measuring winding of the voltage measuring voltage transformer; by means of the conditioning blocks IDF-02 this information is applied to the analog inputs ADC0 - ADC5 of two microcontrollers 80C552 related to the electronic modules UCV-02 which perform the signal sampling, storing and transmission, by means of a multiplexer MUX04/232 and a converter RS232/fiber optic, to other converter RS232/fiber optic related to the central processing unit.

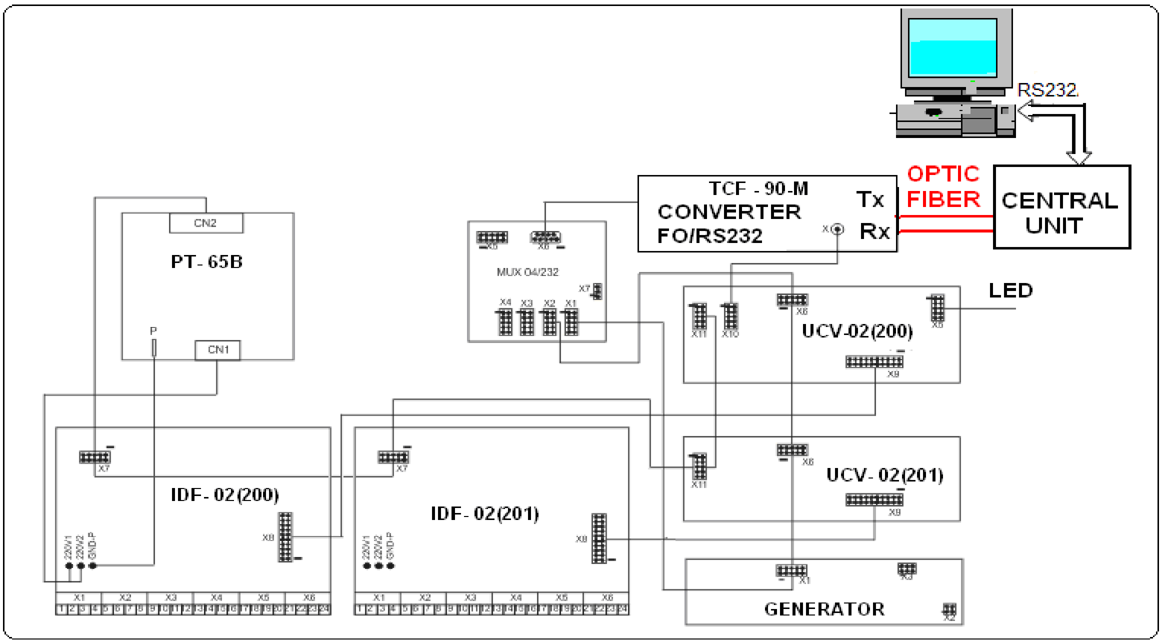

Fig.2. Block diagram of the signal acquisition and conditioning unit

The central unit has the role of processing continuously the received samples, having as functions the continuous measurement of the phase difference between the fundamentals of the voltage and current signals, calculation and continuous monitoring of dielectric dissipation factor $\tan\delta$, by using an algorithm for Fourier series decomposition of the periodical non sinusoidal current and voltage signals and a digital filter for rejecting the disturbances generated by climatic and electric factors, displaying of the dielectric dissipation factor $\tan\delta$ related to the high voltage capacitor type bushings and of the currents measured at terminals on the alphanumeric display, creation of a data base in the external memory of the central unit by means of the modules from the family PC104.

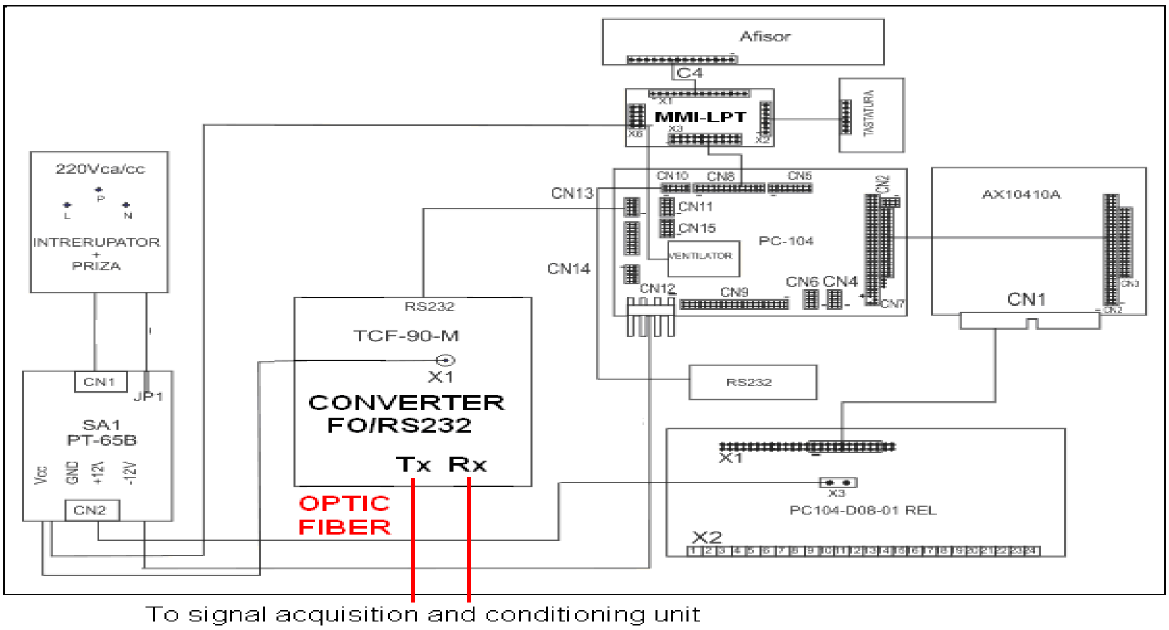

Fig.3. Block diagram of central unit

The central unit enables also the generation of light signals and relay contacts when exceeding the thresholds prescribed for alarming, communication with an IBM PC compatible computer used for visualizing the data, setting the parameters and alarms and downloading the archive

The voltage adapters $A_U(A)$, $A_U(B)$, $A_U(C)$, $A_U(a)$, $A_U(b)$, $A_U(c)$ are step-down transformers especially calculated without phase angle error in the measuring range , supplied in the primary with the voltage from the secondary of voltage measuring transformer, 100/√3 V a.c., and these transformers offer in the secondary the voltage of 1 V eff. The adapter is built on toroidal core with uniformly distributed windings and it is foreseen with protecting screens for the windings.

These ones assure:

- the practical elimination of the phase displacements between the primary and the secondary;
- the elimination of the earth loops;
- the elimination of the disturbing signals.

To eliminate the phase difference on the secondary one mounts a resistive load in order to carry out a constant consumption and to eliminate the time variation of the phase differences.

The current adapters perform the conversion of the bushing leakage current in voltage signal in phase with that one. Their construction is compact and they replace the short-circuiting switch existing at the measuring terminal of the bushing achieving the same protection degree.

The conversion is done by non-inductive resistive elements and very low capacities. Over-voltage protective elements are foreseen.

For each monitored bushing the method presumes the acquisition of two signals: one signal taken over from the test tap of the bushing and the second signal, representing the reference voltage, taken over from the instrument transformer corresponding to the monitored bushing [5].

The taken over signals have non-sinusoidal periodical character and they have the following form:

$$f(t) = A_0 + \sum_{k=1}^{\infty}\left[M_k \cdot \cos(k\omega t) + N_k \cdot \sin(k\omega t)\right] \quad (8)$$

The implemented program performs the calculation of tan δ by the extraction of fundamentals from the sampled signals by a Fourier analysis algorithm.

The calculation algorithm presumes:

- determination of the coefficients M_k and N_k for the fundamentals of the two signals (k=1)

$$M_1 = \frac{2}{T}\int_0^T f(t)\cos(\omega t)dt \quad (9)$$

$$N_1 = \frac{2}{T}\int_0^T f(t)\sin(\omega t)dt \quad (10)$$

The coefficients M_1 and N_1 are determined for each acquired quantity.

- determination of initial phases of the fundamentals

$$\varphi_1 = \arctan\frac{M_1}{N_1} \quad (11)$$

$$\varphi_1^{'} = \arctan\frac{M_1^{'}}{N_1^{'}} \quad (12)$$

where,

φ_1 = the initial phase of the fundamental of the signal taken over from the measuring terminal of the bushing;

$\varphi_1^{'}$ = the initial phase of the fundamental of reference signal taken over from the measuring terminals of the voltage transformer corresponding to the measured bushing.

Noting: $$\delta_1 = \varphi_1 - \varphi_1^{'} \quad (13)$$

The loss dielectric factor is:

$$\tan\delta = \tan\left(90^0 - \delta_1\right) \quad (14)$$

During the experimentations improvements were made in order to reduce the influence of tan δ variation with the load, with the environment factors and with the electromagnetic disturbances, filtering the disturbing influences.

Without any influence, the variation of the dielectric loss factor series would be very slow. Because of the influence of everyday and seasonal variations of the environment temperature and humidity the variation of the dielectric loss factor is cyclic. Besides, for the influence of the random effect of signal and electromagnetic disturbances transmission to a substation, there are many singular points in the data.

Therefore the series of the on-line monitored dielectric loss factor ($\tan\delta_m$) can be decomposed in the following way :

$$\tan\delta_m(t) = \tan\delta(t) + \Delta\tan\delta_w(t) + \Delta\tan\delta_r(t) \quad (18)$$

where:

-$\tan\delta(t)$ is the main component which reflects the actual condition of the insulation which can be considered as the component with slow variation;

-$\Delta\tan\delta_w(t)$ is the component which reflects the everyday and seasonal influences on the environment and of other factors with slow variation (e.g. the load variation) and can be considered as the low frequency component;

-$\Delta\tan\delta_r(t)$ is the component which reflects the influences of the random factors including unusual climatic conditions, electromagnetic disturbances, etc. (its frequency band is wide and in the greatest part it is in the high frequency section).

The dielectric loss factor, tanδ, is filtered according to the relation:

$$\tan\delta_{pa} = \tan\delta_{p-1} + \frac{\tan\delta_{pm} - \tan\delta_{p-1}}{k} \quad (19)$$

where: $\tan\delta_{pa}$ = the present displayed value
$\tan\delta_{p-1}$ = the previous value (measured and displayed)
$\tan\delta_{pm}$ = the present measured value
k = the filtration coefficient

As a result tanδ(t) is obtained when both the high frequency component and the low frequency one are eliminated. The filtration method is useful because it reduces the complexity of the diagnosis since the data can be directly processed, without the need of extended samples.

3. EXPERIMENTAL RESULTS

3.1. Interpretation of tan δ variation in operation

From the literature (report of U.S. Department of Energy, Energy 2005, Long Beach, California, August 14 – 17, 2005.) and records of tan δ variations during operation, it is found that it depends both on the climatic and environment conditions (temperature, moisture, porcelain surface condition) and electric parameters (voltage at bushing terminals, load current etc.)(Figs.4,5), in general not being a fixed value (comparable with the value measured under laboratory conditions).

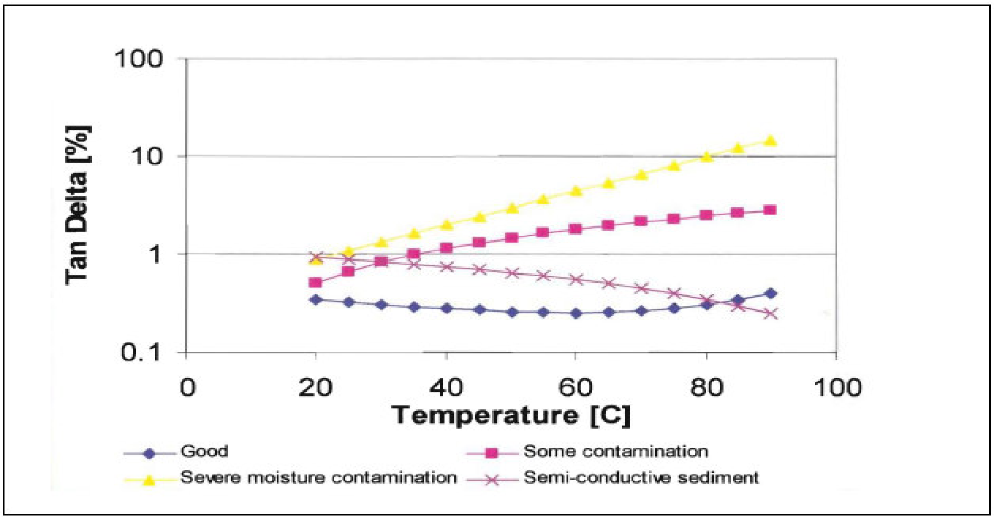

Fig.4. Explanation on the tan δ variation depending on porcelain temperature and surface conditions

Tan δ will change with voltage(fig.5)

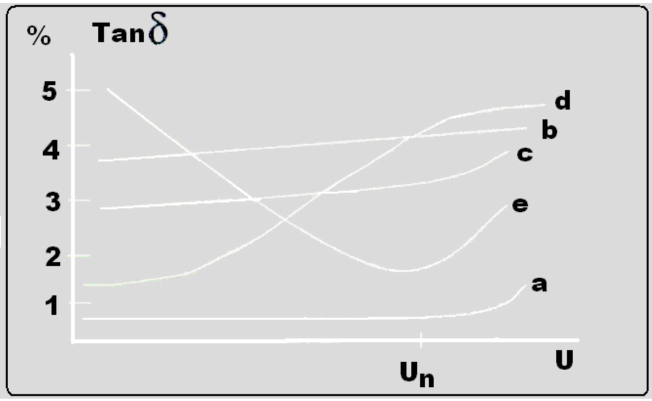

Fig 5. Typical variations of tan δ depending on the operation conditions

a) good condition; b) overall moisture contamination; c) severe local moisture contamination; d) severe PD in the core or core surfaces; e)inner porcelain contaminated with deposits

- At the international conference - CMD2006, papers regarding the on-line monitoring of the bushings were presented. In the paper [8], it is presented a dedicated equipment at which tan δ variations between 0.5% and 4% are noticed.

- The Company AVO New Zealand presents records of tan δ with equipment for on-line monitoring of bushings - PF Live Plus , based on a modified Shering bridge. The presented experimental data indicate tan δ variations which could reach values above 4%.

3.2. Data from operation

For removing the influence of the above mentioned disturbing factors on the monitoring of dielectric dissipation factor tan δ, as a result of some own research and experiments, ICMET provided software filters. By analyzing the tan δ value variations at a 200MVA autotransformer, the following are found:

- for the 220kV bushings, Fig.6.
- for the 110kV bushings, Fig. 7.

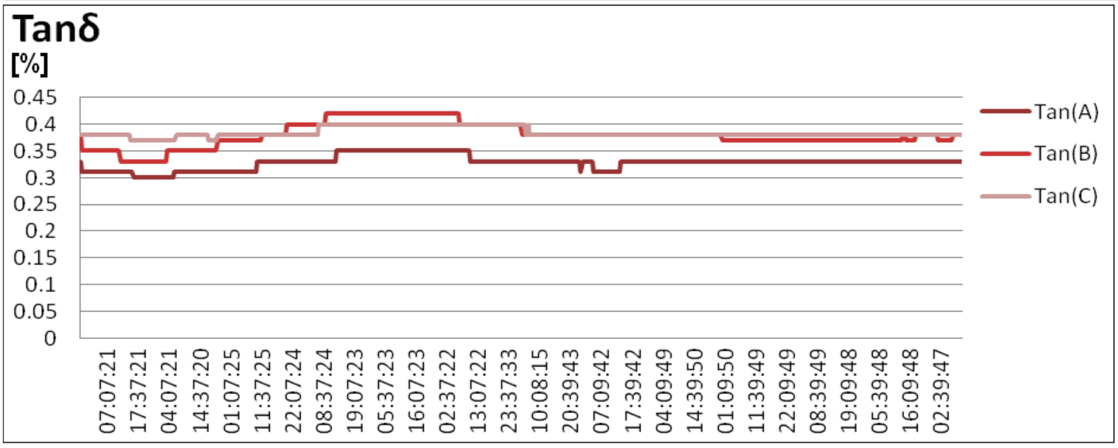

Fig.6. Experimental data on tan δ variation for 220kV bushings, AT 200MVA

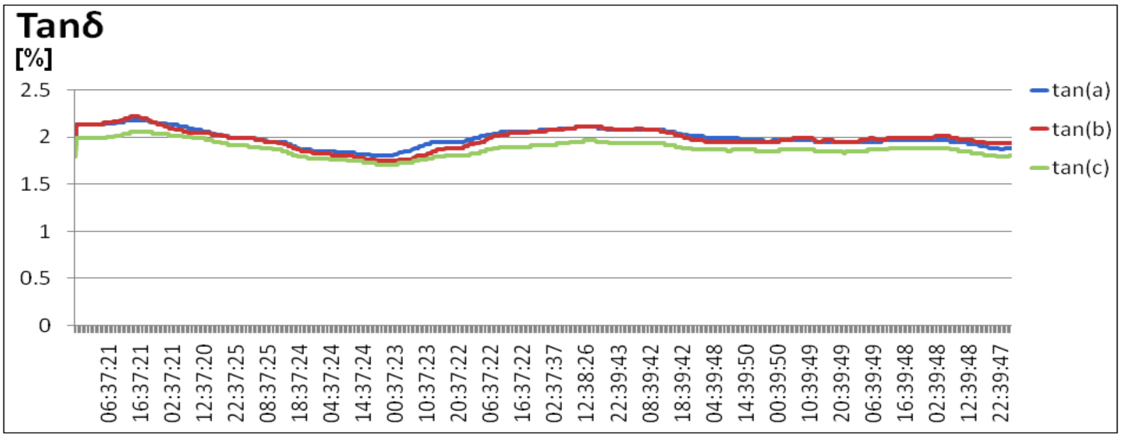

Fig.7. Experimental data on tan δ variation for 110kV bushings, AT 200MVA

When interpreting the results recorded for tan δ, it is taken into account the fact that firstly the tan δ variation tendency is assessed, and not the absolute value which, under the operation conditions, depends on the previously mentioned factors.

The equipment enables also the monitoring of capacitive currents for each bushing (Figs.8, 9).

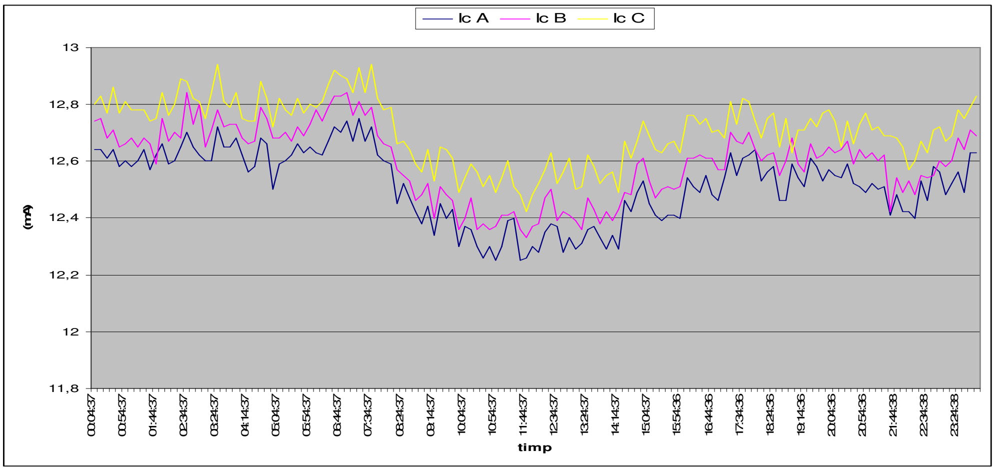

Fig.8. Experimental data on the capacitive current variations for 220kV bushings, AT 200MVA

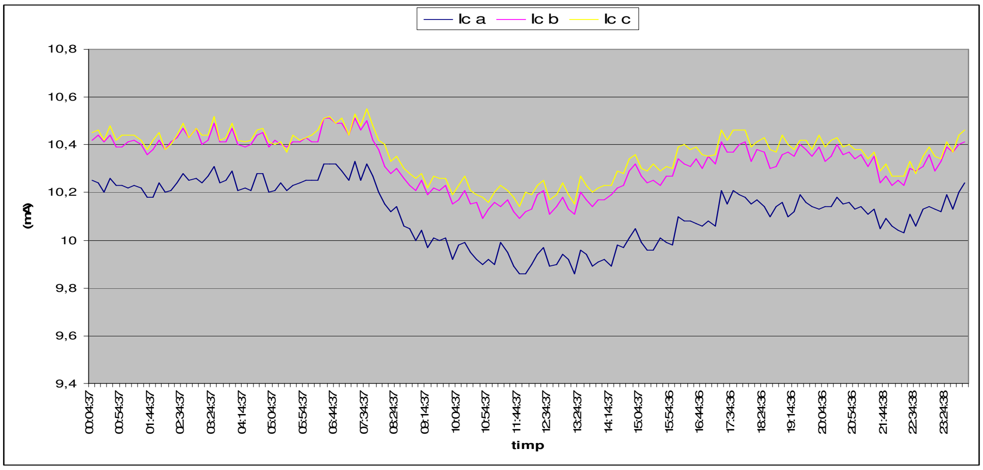

Fig. 9. Experimental data on the capacitive current variations for 110kV bushings, AT 200MVA

If tan δ variation corresponds to a variation above the allowed limit of the capacitive current (i.e. its increase) then the bushing condition is an open question.

The application of this information is very useful because it confirms the accuracy of the measurements performed with the monitoring equipment designed and manufactured by ICMET Craiova, placing confidence in this equipment utilization for protecting the capacitor-type bushings, the high power transformer, key-factors in the good operation of power systems, implicitly.

5. CONCLUSIONS

The method presented in this paper allows the early detection of the faulty bushing and its replacement before the appearance of a failure danger.

This paper presents the advantages of on-line monitoring and especially of on-line continuous monitoring of the bushings on the power transformers.

The proposed solution has the following advantages:

- it solves the problem of monitoring the evolution of loss dielectric factor - tanδ- at the terminals of the bushings afferent to the power transformers;

- it allows the identification of the bushings with dielectric losses by activating the coresponding alarm;
- it carries out the rejection of the disturbances generated by climatic and electric factors, by the implementation of a numerical filter;
- as a result of the experiments, the equipment has been provided with soft filtration enabling to remove the influence of load variation and environmental factors on the variation of dielectric losses, making possible a rigorous monitoring and just-in time alarm in case of a fault occurrence.

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