

INFLUENCE OF STANDARD CAPACITORS ON THE QUALITY OF HIGH VOLTAGE TESTS ON ELECTRICAL ENERGY TRANSMISSION EQUIPMENTS

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Abstract: This article proposes and implements actions for guarantee of metrological reliability and safe conformity assessment of tested equipments when using standard capacitors. It is presented: a review on standard capacitor typical behavior and the description of an experiment for reduction the contribution on uncertainty.

Keywords: standard capacitor, high-voltage test, metrological reliability.

1. INTRODUCTION

The guarantee on continuity of the electric energy supply goes through equipment and installations with high levels of availability and operative reliability.

Activities of maintenance on electrical energy transmission equipments are characterized by two distinct processes: the equipment restoration; the tests (electric, chemical or mechanical) responsible to verify the conformity to them specifications.

The use of reliable test results and historical data assure safe evaluation of equipment state. This safety contributes directly to the desired levels of availability and operative reliability [1].

The traditional metrological reliability assurance tasks have as the one of its requirements the traceability of the results. This, in turn, is based on calibrations and intermediate checks [2].

Into the high-voltage tests area some measurement equipment characteristics make difficult or even impracticable the accomplishment of these calibrations. Large equipments imply difficult, delayed and expensive transport. Usually the laboratories own only one equipment – due its high cost – disabling the execution of services while it's out of the laboratory.

Another critical issue is the non-availability of calibration services in the market for some types of equipment and voltage levels.

In Brazil, the availability of calibration services for high alternated voltage is up to 200 kV, but the voltage levels of energy transmission systems go up to 750 kV [1].

The present work fits in the context of the reliability assurance of high-voltage tests. It resulted from analysis of vast bibliography - in areas such metrology, certification systems and high-voltage equipment technology - and daily activities of a high-voltage laboratory.

This article investigates alternative ways for metrological reliability guarantee suppressing the necessity of typical calibration in accredited laboratories.

The impossibility of traceability assurance in its strict way is treated in ISO/IEC 17025 [2]. That document foresees the use of specified methods and/or agreed standards since clearly described and approved by all the involved parts.

A detailed research about standard capacitors was developed with focus on constructive aspects and influence factors.

Another approach was the use of available equipments to implement an experiment to attribute an adequate maximum permissible error to the standard capacitor.

The aim of this work was not reduce as much as possible the measurement uncertainty but appropriate it to necessities.

2. HIGH-VOLTAGE STANDARD CAPACITORS ANALYSIS

Pressurized gas capacitors can be used in high-voltage tests as: standards in bridge circuits for capacitance and loss factor measurement; part of potential dividers for high-voltage measurement; part of reference transforming dividers for calibration for instrument transformers [3][4][5].

This article deals with the capacitor as part of a voltage instrument transformers calibration system.

For the related calibration uncertainty evaluation the manufacturer tolerance was used as a prior estimation for maximum permissible error. This is justified by inexistence of historical information about the capacitor behavior as well as any manufacturer data that could be used as a better estimation. However, the use of this tolerance makes inadequate the conformity assessment of voltage transformers ratio error.

In order to reduce the capacitor contribution on calibration uncertainty were developed two activities:

- behavior analysis of similar capacitor by scientific articles research. The aim of this activity was search for evidences that such high-voltage capacitors are much better than the prior tolerance used;

- implement an experiment using an standard inductive potential transformer to estimate a compatible uncertainty contribution for ratio error conformity assessment task.

2.1. Characterization of the capacitor behavior

This type of capacitors are based on the one proposed by Schering and Vieweg in 1928. Basically, they are constituted of two concentric and cylinder electrodes, which the outer one connected to high-voltage and inner one to low voltage and measurement equipments [4][5].

The capacitor under analysis on this article uses sulfur hexafluoride (SF₆) at pressure of 0,35 MPa as dielectric. The nominal capacitance value is 50 pF and was adjusted during its assembling for tolerance of 0,5 %. The conditions for use are: nominal voltage 600 kV under maximum relative humidity of 75 %; temperature range from -5 °C to +45 °C; voltage frequency of 50 Hz or 60 Hz [6][7].

Next paragraphs show that the manufacturer tolerance does not draw the real capacitor behavior.

The capacitor technical specification [7] presents some quantitative data related to influence factors, which are: temperature relative deviation 30 μF/F.°C; internal pressure relative deviation 2,2 pF/MPa; maximum deviation for nominal voltage is less than 30 μF/F.

It's shielded against proximity effects generated by energized apparatus. This feature is achieved using a guard electrode that protects the low voltage electrode from stray electric fields [3][4].

The articles research revealed some characteristics related to the behavior of these capacitors. Those are shown in the following paragraphs where some influence factors - temperature, applied voltage, internal and external pressure, frequency and capacitor positioning - are described and analyzed.

The main cause of capacitance variations due to temperature is related to changes of electrodes and their supports dimensions. Capacitance can decrease or increase depending on dilatation coefficients of these components. This temperature dependence can be widely reduced with optimum electrodes shapes and using materials with adequate thermal characteristics [3][4][8].

The capacitance variation dynamics due ambient temperature is slow because capacitors volume. References [4] and [9] present times to reach steady-state condition of (3 to 20) hours depending on the capacitor size.

In this way, the use of corrections in environments with fast temperature variations is difficult due unknown internal temperature [3][9].

In applications of capacitive dividers formed by different equipments, one suggests that these must be under the same temperature conditions [3]. And the comparison of capacitance values presented before and after the test can help to minimize its effects [8][9].

The capacitance variation related to chamber pressure assumes two basic aspects: in the occurrence of gas leakage; in the change of the internal volume of the capacitor due temperature variations.

For the authors of researched articles, the capacitance should not be corrected by the pressure coefficient if the

variation pressure is caused by the temperature changes. This is justified by the fact that the number of gas molecules inside the capacitor remains constant and the reduction of gas density due increased volume is insignificant. On this way, internal pressure variation should be compensated only in presence of gas leakage [3][4][8][9].

For references [3], [4] and [8] is unanimous the opinion that environment pressure does not significantly affects the capacitance.

With reference to the influence of the applied voltage, it is justified on unbalanced electrostatic forces generated by eccentricity in the alignment of the electrodes. The eccentricity increases until balance between electrostatic and mechanical forces applied to the electrodes supports. This balance adjustment makes capacitance increase behaves like a quadratic function related to applied voltage [3][5][8][9].

The articles [10] and [11] refer to capacitance variation when high-voltage is applied for long periods. Evidences are shown and relate these variations to internal heating due electrical energy being dissipated inside the capacitor.

Variations related to voltage frequency are analyzed in article [4] which evidences that the capacitor is a mechanical system and can be excited on its natural frequency f_0 . However, high-voltage tests are usually executed using 50 Hz or 60 Hz and capacitors with nominal voltage above 100 kV present critical frequencies ($f_0/2$) much lower than those frequencies.

The articles [3][4][9][11] relate capacitor angle tilts to capacitance variations. Experimental results revealed capacitance variations below 5 μF/F for tilt angles less than 12 o. On this way, if the correct capacitor position is assured than its influence can be neglected.

The articles analysis reveals that compressed gas capacitors behavior is much better than the manufacturer tolerance presented of 0,5 %. Then, one can justify the possibility of uncertainty reduction using the experiment presented in following section.

2.2. Reducing capacitor contribution to measurement uncertainty

The uncertainty reduction uses data from a standard voltage transformer calibration that is available in the laboratory.

The standard voltage transformer used is the 4820 model from Tettex Instruments with nominal characteristics as shown: primary nominal voltages of 50 kV and 100 kV; ratio maximum permissible error of ±0,02 %; phase maximum permissible error of ±1 minute [12].

This transformer has a test certificate, dated from July of 2001, which is used as evidence of its behavior despite there is no uncertainty evaluation presented [12].

The calibration circuit used is presented in figure 1, in which the transformer under calibration is the standard voltage transformer 4820. C₁ is the capacitor under evaluation, C₂ is composed of low voltage standard capacitors. The electronic voltage divider standard [14] composes with capacitors C₁ and C₂ a multi-ratio standard voltage divider.

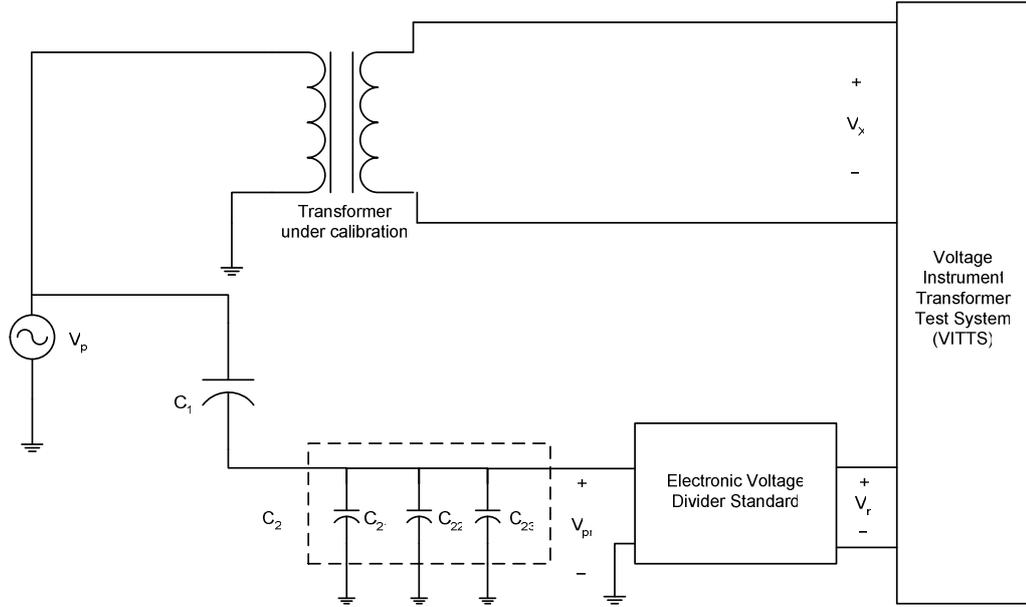


Figure 1 – Calibration circuit

The outputs of transformer under calibration and the multi-ratio standard voltage divider are compared in the voltage instrument transformer test system (VITTS) [15].

The transforming ratio of capacitive divider (k_C), composed of C_1 and C_2 , is given by equation (1).

$$k_C = \left(\frac{k_{TP}}{k_E \cdot (\mathcal{E} + 1)} \right) \quad (1)$$

Where:

k_{TP} is the transformer under calibration ratio;

k_E is the electronic divider transformation ratio;

\mathcal{E} is the ratio error between the transformer under calibration and the voltage divider composed of k_C and k_E presented by the VITTS.

The k_C standard uncertainty is given by equation (2) which is obtained from traditional uncertainty evaluation method presented in ISO GUM [13].

$$u^2(k_C) = u^2(k_{TP}) \cdot \left(\frac{\partial k_C}{\partial k_{TP}} \right)^2 + u^2(k_E) \cdot \left(\frac{\partial k_C}{\partial k_E} \right)^2 + u^2(\mathcal{E}) \cdot \left(\frac{\partial k_C}{\partial \mathcal{E}} \right)^2 \quad (2)$$

Uncertainty contributions related to k_E and k_{TP} are the maximum permissible errors given in manufacturer's specifications. For the electronic comparator the uncertainty contributions are maximum permissible error, instrument resolution and Type A evaluation obtained from the calibration data presented in figure 2.

Applied voltage	Measure #	Ratio error (%)	Phase error (minute)
100 kV	1	0,0015	0.05
	2	0,0017	0.05
	3	0,0016	0.04
	4	0,0016	0.05
	5	0,0016	0.05
	6	0,0016	0.05
	7	0,0016	0.05
	8	0,0016	0.05
	9	0,0014	0.04
	10	0,0016	0.04
	Mean	0,00158	0,05
	Standard deviation	$7,88811 \cdot 10^{-5}$	$4,83 \cdot 10^{-3}$

Figure 2 – Electronic comparator ratio and phase indicated errors

Table presented in figure 3 shows the k_C standard uncertainty.

The capacitance C_1 is defined by equation (3). On the same way done for k_C in equation (2) one can state C_1 standard uncertainty as presented in equation (4).

$$C_1 = \frac{C_2}{k_C - 1} \quad (03)$$

$$u^2(C_1) = u^2(k_C) \cdot \left(\frac{\partial C_1}{\partial k_C} \right)^2 + u^2(C_2) \cdot \left(\frac{\partial C_1}{\partial C_2} \right)^2 \quad (04)$$

Figure 4 presents the new uncertainty estimation for C_1 to be used in the tests.

Uncertainty Source	Sensitivity Coefficients	Contribution	Probability Distribution	Standard Uncertainty
Maximum Permissible Error VITTS	$\left(\frac{\partial k_C}{\partial \varepsilon}\right)^2 = 159989,76$	$5,1 \cdot 10^{-4}$	Uniform	$2,9 \cdot 10^{-4}$
Resolution VITTS	$\left(\frac{\partial k_C}{\partial \varepsilon}\right)^2 = 159989,76$	0,0001%	Uniform	$2,9 \cdot 10^{-5}$
Type A Contribution	$\left(\frac{\partial k_C}{\partial \varepsilon}\right)^2 = 159989,76$	$7,9 \cdot 10^{-5}$	Normal	$7,9 \cdot 10^{-5}$
Maximum Permissible Error Electronic Divider	$\left(\frac{\partial k_C}{\partial k_E}\right)^2 = 25599,18$	0,005%-2,5	Uniform	$7,3 \cdot 10^{-5}$
Maximum Permissible Error Standard Transformer	$\left(\frac{\partial k_C}{\partial k_{TP}}\right)^2 = 0,16$	0.02%-1000	Uniform	0,12
Applying equation (02), $u(k_C) = 0,13$ with $v_{\text{eff}} = 10^{16}$				

Figure 3 – k_C standard uncertainty estimation

Uncertainty Source	Sensitivity Coefficients	Contribution	Probability Distribution	Standard Uncertainty
k_C - Standard Uncertainty	$\left(\frac{\partial C_1}{\partial k_C}\right)^2 = 0,016$	0,13	Normal	0,13
Maximum Permissible Error - C_2	$\left(\frac{\partial C_1}{\partial C_2}\right)^2 = 6,3 \cdot 10^{-6}$	0,02%-19950	Uniform	2,31
Applying equation (04), $u(C_1) = 0,018$ pF				

Figure 4 – C_1 standard uncertainty estimation

The evaluation of degrees of freedom of $u(C_1)$ presented in figure 4 implies $v_{\text{eff}} \rightarrow \infty$ then the coverage factor tends to 2. The expanded uncertainty of C_1 is $2 \cdot u(C_1) = 0,036$ pF. Relating 0,036 pF to the nominal capacitance C_1 one finds 0,072 %.

From the experiment resulted a reduction from 0,5 % to 0,072 % on C_1 uncertainty contribution, allowing a secure conformity assessment of voltage transformers.

3. CONCLUSIONS

The main conclusions of this article are presented:

- the actions executed for metrological reliability assurance presented satisfactory results;
- the laboratory's practical experience was shown as an important factor on metrological reliability assurance. That importance increased when one thinks about situations of unavailability of calibration services for some measurement equipments;

- the high susceptibility on environment conditions and costs for control them, implies to laboratories improve knowledge on dealing with those conditions foreseeing metrological reliability assurance;
- the development and application of analysis as those presented in this article strongly contribute on the knowledge of the behavior of electrical energy transmission equipments. With those type of analysis, small deviations on equipments parameters can be identified with assured uncertainty and used for lifetime evaluation;
- use of available apparatus in the high-voltage laboratory made possible the metrological reliability assurance without necessity of external calibration services;
- the reduction of standard capacitor uncertainty contribution was only possible because the standard transformer and all other equipments used present uncertainties much lower than the standard capacitor acceptable uncertainty value.

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