RESONANT SOURCE FOR THE SUPPLY OF ELECTRIC FIELD PROBE CALIBRATION SYSTEM AT FREQUENCIES BETWEEN 50Hz AND 50KHz

Andrei MARINESCU

ICMET Craiova, amarin@icmet.ro

Abstract **– Electromagnetic environmental conditions checking and provision regarding long and short time human personal and occupational exposure is regulated by international standards. Generally, the human being is exposed mainly to the field generated by the 50 Hz low, medium and high voltage equipments or transmission lines of the electric power system but in industrial applications also higher frequencies are used in certain technological processes.**
This low and medium frequency electric fields have values in the range 0.5V/m − 100kV/m for frequencies within 5Hz and 400kHz. Modern electric field measuring devices works on one or three axes, with software for measured data acquisition & storage and sometimes with the possibility of GPS source localization.
In Romania, there are no installations for the periodical calibration of the instruments for low and medium frequency electric field measurement. The calibration in accredited foreign laboratories is expensive and the said instruments are used almost exclusively based on the certificates issued by supplier at purchasing.
The paper presents an innovative calibration solution based on a double resonant source which enables field strengths up to 100 kV/m to be achieved in a wide frequency range within 50Hz and 50kHz.

Keywords: *electrical field probes, calibration, double resonant power supply*

1. INTRODUCTION

It is known that the precautionary principle was applied to establish certain limit values for the low and medium frequency electric fields, from the electromagnetic spectrum, influencing the human beings by their long or short term action [1].
The World Health Organization (WHO) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) [2] established the exposure limits that were taken over also in the Romanian legislation [3,4].
Generally, the human being is exposed mainly to the field generated by the 50 Hz low and/or high voltage transmission lines of the electric power system but in industrial applications also higher frequencies are used in certain technological processes or for information transmission.
In Romania, there are many electric field measuring instruments in the range 0.5V/m − 100kV/m for frequencies within 5Hz and 400kHz, possibilities of electric field measurement on one or three axes, software for measured data acquisition and storage and sometimes with the possibility of GPS source localization.
The outcome of the analysis made by ICMET showed that these expensive instruments are not checked periodically as specified in their documentation because their calibration in a foreign laboratory has very high prices, pretty much the same as their acquisition prices sometimes.
Standard IEC/ISO17025:2005 [5] "General requirements for the competence of testing and calibration laboratories" specifies explicitly that the accreditation, in this case for electric field measurements, shall be granted and maintained and test reports certifying the exposure level of the population and technical staff shall be issued only based on procedures and instruments checked/ calibrated periodically.
Therefore ICMET aimed to study and achieve an installation for electric field instruments/ probes calibration which to be nationally and internationally accredited. At the same time, the said installation must have the capability to be used in the fundamental or applied research activity both to study the exposure to electric fields in vitro and in vivo and to develop new measuring methods and instruments.
Hereinafter, the measuring conditions specified by the international standards as well as the technical solution drawn up and achieved by ICMET are presented.

2. ELECTRIC FIELD PROBE CALIBRATION ACCORDING TO IN FORCE STANDARDS

The first international standard establishing the conditions and methods used to calibrate the electric field probes appeared in 1987 under the name of IEC 833 [6]. Then, the American standard ANSI 644 appeared from 1994 [7] and in 1998, IEC updated the standard from 1987 under the name of IEC 61786 [8]. There are no major differences between these standards regarding the calibration device about which it is specified that:
"it is achieved an area defined in space where an uniform electric field of known, computable value can be generated".

Practically this area is the one marked by a parallel plate capacitor with dimensions and distances between armatures great enough that in its geometric center to be a limited volume where the electric field to be practically uniform and where to introduce the instrument or probe to be calibrated.

Generally, at a plate capacitor with infinite dimensions, the electric field is given by the simple relation:

$$E_0 = U_0/d \tag{1}$$

Where E_0 is electric field strength, U_0 and d are the applied voltage and the distance between armatures, respectively.

Due to the finite dimensions of the armatures, an edge effect, leading to an E field different from the theoretical value E_0, appears in certain areas inside the capacitor. The field nonuniformity depends on the armature distance and dimensions and on the way the voltage to ground is applied (symmetrically/ nonsimetrically).

The technical solution recommended by [8] is the one presented in Fig.1.

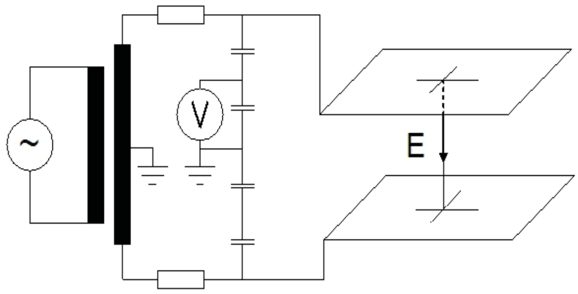

Fig.1 Electric field probe calibration system [8].

The plate capacitor achieved in this way is supplied symmetrically to ground from a step up transformer with the centre tap earthed. In this case, the influence of the adjacent objects on the achieved electric field is reduced. The armatures have a square shape with side a=1.5m and isolation distance d=0.6m or 0.75m.

In order to avoid the edge effect, the electrode edges are achieved as Rogowski type electrodes [9].

The electric circuit provides the use of a symmetric capacitive divider for an exact determination of the applied voltage and possibly R series resistances for circuit current limitation in the case of the plate capacitor breakdown.

As presented in Fig.1, the diagram is intended to achieve calibrations at 50 Hz or up to hundreds of Hz taking into account the limitation owed to internal resonance phenomena in used transformers.

The standards do not mention the circuit use at frequencies other than 50 Hz although relation (1) is used to define the electric field up to frequencies of about 20GHz in GTEM cells [10].

Measurements and numerical simulations [11,12,13,14] of electric field variation, between electrodes at armature surface and on the centre line between electrodes, depending on the ratio between the distance to armature edge (x) and the armature distance (d) lead to the results presented in Fig.2.

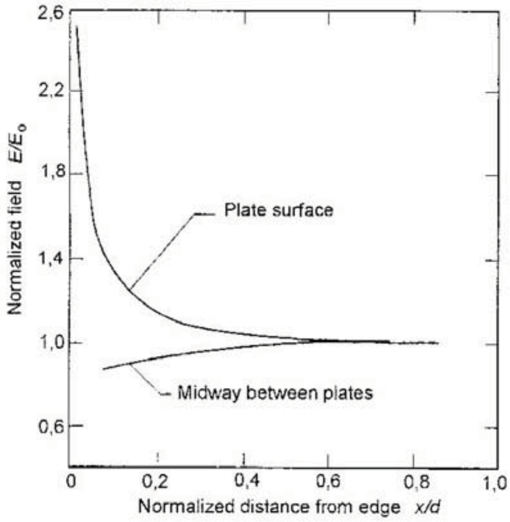

Fig.2 Relative variation E/E_0 at one armature surface (curve 1) and on the centre line between armatures (curve 2) depending on the relative distance to edges (x/d) for d=0.75m [8]. The results obtained without field uniformization pieces at electrode edges.

In an area laying within 0,6d and d (armature distance), electric field strength does not vary with more than 0.1% as compared to the theoretical value E_0.

In these conditions a global measurement uncertainty of maximum 1% for the electric field is possible to be obtained.

In order to avoid field uniformity disturbance due to the presence of the device under calibration (DUC), the largest of its dimensions must not exceed 0.3d [8]. Therefore the dimensions available to place the DUC represent a cube having the side of 0.15m. This volume is greater than the necessary one especially at the instruments with a modern construction.

3. SUPPLY SOURCE FOR LOW AND MEDIUM FREQUENCY FIELD PROBE CALIBRATION.

This development was approached based on the following elements:

- in Romania, at present, there is no reference calibration installation for the electric field probes which to enable a calibration certificate to be issued;
- the standards in force as well as the known publications make no reference to electric field probes calibration at frequencies other than 50Hz.

The supply source for field probe calibration described hereinafter covers in a unitary way the entire domain of interest (50Hz−50kHz) at field strengths up to 100kV/m. The source is based on series resonance phenomenon known from laboratory and on-site testing technique for high voltage equipment as electric cables and GIS (gas insulated substations) [15].

3.1. Operating principle of testing installations based on series resonance

Fig.3 presents this principle where an oscillating LC circuit is excited with variable voltage generated by a transformer (TEX).
Capacitor C represents the test object capacitance and in order to achieve resonance, inductivity L is variable if the excitation frequency is network frequency or is fixed if the excitation frequency can be varied to obtain resonance.

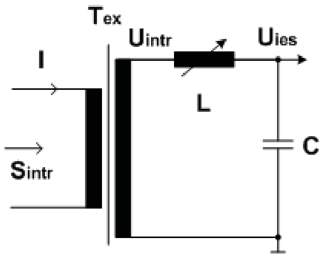

Fig.3 Series resonance testing circuit

The output voltage (test voltage) is given by relationship

$$U_{out} = QU_{in} \quad (2)$$

where Q is the quality factor of the series resonant circuit LC

$$Q = \omega L / R \quad (3)$$

Where R is an ohmic resistance equivalent to the total circuit losses.
Usually, such circuits have Q=20-50 meaning that on the one side the excitation voltage U_{in} has a low value and on the other side that apparent power absorbed from the supply source (Sintr) given by

$$S_{in} = S_C / Q \quad (4)$$

is very close to the reactive power accumulated in the oscillating circuit (S_C).

3.2. Operating principle of the supply source for field probe calibration

Since the calibration supply source has to generate a voltage symmetrical to ground, diagram of Fig.4 containing two identical series resonant circuits (L_e, C_e) was proposed. Symmetry is obtained by connecting to ground the central tap of the excitation transformer.

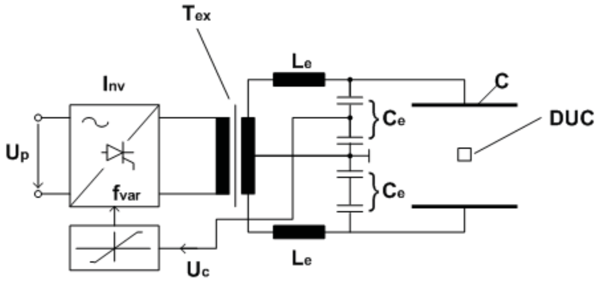

Fig.4 Double resonant source for electric field probe calibration

The diagram is supplied from a static source (I) of variable frequency (f_{var}). The output voltage can have any form because its filtering is made in the two resonant circuits due to their high quality factor. More exactly, according to [16] when the series resonant circuits are excited with periodic rectangular impulses the higher harmonics are nQ times attenuated, where n is the order of the higher harmonics under discussion.
In order to obtain resonance in such a wide frequency range, both L_e and C_e are step variable so that to obtain the desired test frequencies. The capacitance C_e of the divider and the capacitance of the capacitor C are included in the capacitance of the tuning capacitors.
The apparent power absorbed from the network is also in this case Q times lower than the reactive power of the resonant circuits.
Although very simple and having many advantages, the diagram of Fig.4 has not been presented in the specific technical literature so far.

3.3. Supply source computation and practical achievement

The calibration of an instrument EFA300 achieved by Narda [17], one of the most complex instruments existing in Romania, having the following main parameters was proposed:
-Frequency range 5Hz−32kHz
-Field strength range 10V/m −100kV/m
-Three-dimensional measurement
-Fiber optic communication between the field probe and the instrument itself.
The frequency range adopted for the calibration installation starts from 50Hz (the lowest frequency used in Romania) and goes up to 50kHz.
The calculations were performed with a view to achieving a field strength of 100kV/m irrespective of the frequency that is a value higher than the one admitted by the exposure limits with a view to emphasising the possibilities offered by the new resonant testing diagram.

The capacitance of the plate capacitor is:

$$C = \frac{\varepsilon_0 A}{d} \tag{6}$$

and the absorbed current is

$$I_C = \omega CU = \omega CEd \tag{7}$$

where A is armature surface (A=1.5x1.5=2.25m^2), d is the distance between armatures (d=0.6 or 0.75m) and E is the strength of the field to be achieved (max. 100kV/m).

From relations (6) and (7) it follows that

$$I_C = \omega \varepsilon_0 AE \tag{8}$$

Relation (8) shows that in the case of the plate capacitor, the absorbed power does not depend on the distance between armatures but only on the field strength aimed to be achieved for a given frequency and plate area.

The capacitance of the capacitor C is:

C = 33.2pF for d = 0.6m
C = 26.5pF for d = 0.75m

and the voltage necessary to obtain E=100kV/m is

U = 60kV for d = 0.6m
U = 75kV for d =0.75m

In the most general case when all geometrical and electrical parameters are variable and taking into account relations (6) and (8), the ratio of the powers accumulated in the resonant circuit is given by relations:

$$\frac{S_1}{S_2} = \frac{f_1}{f_2} \cdot \frac{A_1}{A_2} \cdot \frac{d_2}{d_1} \left(\frac{U_1}{U_2} \right)^2 \tag{9}$$

or

$$\frac{S_1}{S_2} = \frac{f_1}{f_2} \cdot \frac{A_1}{A_2} \cdot \frac{d_1}{d_2} \left(\frac{E_1}{E_2} \right)^2 \tag{10}$$

The calculation results for the apparent power necessary to supply the calibration capacitor are presented in Table 1.

Table 1: Calculation of the total resonant source power

d=0,6m E=100kV/m U=60kV				
f [Hz]	50	500	5000	50000
I [mA]	0,625	6,25	62,5	625
S [VA]	37,5	375	3750	37500
d=0,6m E=100kV/m U=60kV				
f [Hz]	50	500	5000	50000
I [mA]	0,625	6,25	62,5	625
S [VA]	46,8	468	4680	46800

The dimensioning power of each oscillating circuit L_eC_e is half of the total power and the absorbed power is Q times smaller. If at low frequencies the power is relatively small, at 50kHz powers around 35-50kVA are obtained that is difficult to achieve even with special high voltage and medium frequency transformers.

In these conditions, the advantages offered by the described resonant installation are obvious and the power absorbed from static source inverter, respectively from the mains, is quite small (depending on Q between 1 and 2.5kVA). From the constructive viewpoint, the inductivities of the two resonant circuits are achieved with single layer windings (to reduce the stray capacitance between turns), in air or with open magnetic circuit. Resonant circuit tuning is made adjusting the frequency in certain fixed steps, for example 50, 500(400), 1000Hz, 5, 10, 50kHz as usual. The tuning is made at low applied voltages and it is conserved irrespective of the voltage due to the linearity of the oscillating circuit components.

In order to maintain the quality factor of the resonant circuits the excitation transformer was dimensioned as a medium frequency transformer with low losses using litz wire windings.

The above presented calculations had in view only the reactive power necessary to supply the capacitor C. In practice, the additional capacitors C_e and C_d appear increasing these powers several times.

4. CONCLUSIONS

The paper describes the possibility to use some series resonant circuits to achieve the supply source of a calibration system for electric field probes.

The double resonant source gets a sine output voltage symmetric to ground in a large frequency range (50Hz−50kHz), solution which has not been used so far.

The resonant source supply is made from a static source with variable frequency and with no imposed special conditions for the output voltage form because the resonant circuit reduces nQ times the n-th order harmonics components present in the excitation voltage.

Source achievement is based on ICMET experience in the domain of resonant phenomena application at testing installation construction to supply the high voltage capacitive loads (cables, GIS etc.).

Besides the main goal, setting up of a facility for electric field probe calibration according to the international standards in Romania, the installation can be used for researches on in vivo and in vitro exposure of the biological specimens.

The achieved installation is in the course of testing and validation following to be operational for calibrations at the end of 2010.

References

[1] CENELEC ENV 50166: 1995 “Human Exposures to Electromagnetic Fields”.

[2] ICNIRP “Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and Electromagnetic Fields (up to 300GHz)” In: Health Physics vol.74, 1998, p.494-522.

[3] Ministerul Sanatatii Publice din Romania ”Ordinul nr.1193/2006 pentru aprobarea normelor privind limitarea expunerii populatiei generale la campuri electromagnetice de la 0Hz la 300GHz”. In: Monitorul Oficial nr.985/2006.

[4] Guvernul Romaniei “Hotararea nr.1136/2006 privind cerintele minime de securitate si sanatate referitoare la expunerea lucratorilor la riscuri generate de campuri electromagnetice”. In: Monitorul Oficial nr.769/2006.

[5] ISO/IEC 17025:2005 “General Requirements for the Competence of testing and Calibration Laboratories.

[6] IEC 833: 1987. Measurement of Power Frequency Electric Fields.

[7] ANSI 644: 1994. IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields for AC Power Lines.

[8] IEC 61786: 1998. Measurement of Low Frequency Magnetic and Electric Fields with regard to exposure of human beings-Special requirements for instruments and guidance for measurements.

[9] IEC 60243-1: 9998. Ed.2.0. Cap.18. Electrical Strength of Insulating Materials – Test Methods – Part.1: Tests at Power Frequencies.

[10] IEC 61000-4-20:2003. EMC – Testing and Measurement Techniques Emission and Immunity testing in Transverse Electromagnetic (TEM) waveguides.

[11] A. Braun, E. Brzostek, ,D. Kind, H. Richter, *Development and Calibration of Electric Field Measuring Devices*. In:Proc. of 6-th International Symposium on High Voltage Engineering (ISH), New Orleans, Paper 40.09, 1989.

[12] T. Takuma, T. Kawamoto, Y. Sunaga, Analysis *of Calibration Arangements for AC Field Strength Meters*. In: TIEEE on PAS, PAS-104, nr.2, 1985, p.489-496.

[13] A. Pavic, Z. Stih, *Improvement of Reference Electric Field Generation.* In: Proc. of 16-th IMEKO World Congress, Vienna, 2000.

[14] O. Bottauscio, G. Crotti,S. D′Emilio, ,G. Fasina, A. Mantini, *Generation of Reference Electric and Magnetic Fields for Calibration of Power Frequency Field Meters.* In: TIEEE on IM, vol.IM-42, nr.2, 1993, p.547-552.

[15] A. Marinescu, Gh. Opran, E. Stanescu, D. Popa, *Utilizarea instalațiilor de incercare cu circuit resonant serie in tehnica tensiunilor inalte.* In: EEA Electrotehnica, 30, nr.6. 1982, p.245-250.

[16] A. Marinescu, St. Catana, *Utilizarea excitatiei periodice in impulsuri a circuitelor rezonante RLC la realizarea unor surse de current constant sinusoidal.* In: EEA Electrotehnica, 31, nr.2, 1983, p.56-59.

[17] EFA 300 (available at www.narda-sts.de).