CORRELATIONS BETWEEN RADIOFREQUENCY DISTURBANCES RADIATED AND INJECTED IN A POWER LINE BY A HIGH VOLTAGE EQUIPMENT

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***Abstract**: Every component of a high voltage overhead transmission or distribution line such as phase conductors or insulator sets can become a radiofrequency disturbance source because of corona discharge or similar phenomena which occur in well known conditions. The radio disturbance level of a power line can be measured in a free space, using adequate antenna and adopting standardized distances from the lateral conductor of the overhead line. The contribution of a single equipment to the overall radio noise produced by a power line, such as insulator string can be evaluate only in the shielded laboratory conditions. The entirely followed procedure and especially the calibration of the measuring circuit in order to determine their attenuation factor are relatively complicate and time onerous tasks. The paper presents a possible alternative method to measure radio disturbances produced by high voltage equipment using a high frequency field probe. Two goals were followed: the first was to determine the correlation between radiated and conducted disturbances produced by high voltage equipment, and the second to propose a simplified method to measure their radio frequency disturbance level.*

Keywords: corona discharge, radio interference voltage, high frequency electromagnetic probe.

1. Introduction

If a critical field on surface conductor of an overhead line - due to its roughness, atmospheric conditions and applied voltage is surpassed - corona discharge occurs. A local high level of electric field strength (above corona inception voltage) or micro sparks between dielectric and metallic parts or due to the bad contacts between different fittings of an insulator set can also produce high-frequency electromagnetic noise. This noise disturb the suitable operation of radio, TV sets or other communication systems located in the vicinity of high voltage overhead line in a wide frequency range, up to 300 MHz [1]. In order to limit this undesired phenomenon, national standards stipulate the maximum radio

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interference voltage (RIV) for high voltage equipment as parts of an overhead line or air insulated substation. The measurement of RIV can be performed only in laboratory conditions in order to ensure a low level of background electromagnetic noise. Even the final effect of high frequency noise produced by a specific equipment affect the environment by radiation, their RIV level is measured based on disturbance currents injected in a calibrated resistor, therefore considering their conducted emissions, or, in other words, evaluating the source of radiated disturbances. To perform this type of measurements in the high voltage laboratory, the specific standards recommend the structure of the circuit and the values of used components, define the quantity to be measured and impose the main characteristics of the measuring receiver. The general conditions are described in the CISPR 18-2 Publication [2] and specific requirements for insulator sets can be found in the product standards IEC 60437 [3] and for conductor and insulator set fittings in EN 61284 [4] respectively.

2. The standardized RIV measuring circuit

Fig. 1 shows the general structure and possible alternatives of RIV measuring circuits according to CISPR 18-2 Publication.

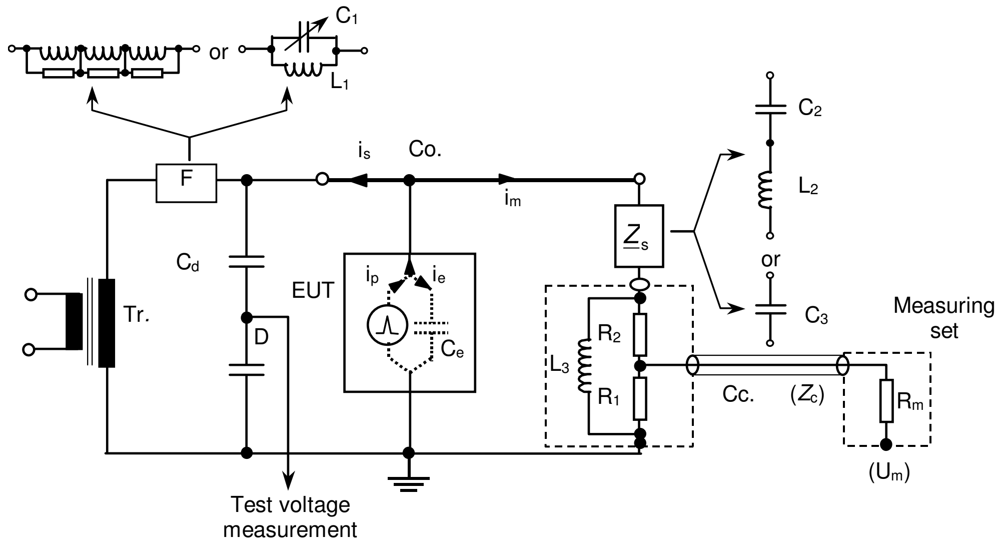

Fig.1. – RIV measuring circuit: EUT – equipment under test, Tr. – high-voltage test transformer, D –a.c. voltage divider, Co. – corona free connection, simulating the line conductor, Cc. – coaxial cable; F – low pass filter; Zs – coupling impedance (high pass filter).

The main requirements for the components of the circuit are:

- The resistive load R_L which simulate the surge impedance of the line must have 300 Ω. In order to adapt the transmission line to the receiver $R_1 = R_m = Z_c$, where R_m is the input resistance of measuring set and Z_c the surge impedance of coaxial cable. Therefore $R_L = R_2 + R_1/2$.;

- The impedance of the high voltage arm of measuring circuit Z_S could be built by an *L–C* series circuit, tuned to f_m ($L_2 - C_2$ in the Fig.1) or a coupling capacitor (C_3 in the Fig.1. f_m is the measurement frequency recommended by the above specified standard). This last solution (a most used one), was adopted in the High Voltage Laboratory of UPB where the following experiments were performed. In this case the standard suggest that a capacitance C_3 at least five times greater than the capacitance to earth of the EUT and its high voltage connections may be satisfactorily for a large range of equipment;
- The requirements for entire measuring circuit impedance are $\left|\underline{Z}_s + R_L\right| = 300 \pm 40\ \Omega$, with the argument of impedance $\varphi \le 20^0$;
- The rejection filter must be an $L_1 - C_1$ parallel circuit, tuned to f_m or an inductor damped by parallel resistors. Its insertion attenuation at f_m must be greater or at least equal to 35 dB, in both direction;
- The inductance $L_3 \geq$ 1mH, measured at 500 kHz. It constitute a final short-circuit path for the residual power frequency component.

Regarding the measurement frequency, CISPR 18-2 Publication stipulates a reference value f_0 of 0.5 MHz or 1 MHz, with a margin of ± 10 % for the actual measurement frequency f_m, in order to find an adequate low noise background.

The measuring set – a receiver with a quasi-peak detector – must comply with the specifications of CISPR 16-1 Publication [5].

The voltage reference value U_r, for which is reported the RIV level at the final of test procedure is equal to $1{,}1 \cdot \mathrm{U_n}/\sqrt{3}$, where U_n is the rated voltage of the equipment under test (EUT).

As can seen in the Figure 1, the high-frequency disturbance currents i_p, generated by corona and micro-gap discharges at the EUT are divided in a current through the measuring impedance, i_m, a current to ground through the own capacitance C_e of the EUT i_e, and a current to the testing voltage transformer, i_s (limited by the rejection filter F). The voltage drop across R_1 resistor is transmitted through a coaxial measuring cable, adapted at both ends, to the measuring set. The circuit characteristics are adequately chosen such as the largest part of disturbance currents i_p to be forced to pass through $\underline{Z}_s$ impedance and therefore through the measuring resistance.

To evaluate the contribution of tested equipment to overall disturbance level engendered by the overhead line, the measurements (V_m) must be reported considering that the disturbance current i_p is injected only in the surge impedance of line, a standard value of 300 Ω being used, and through the own capacitance of tested equipment, C_e to the ground.

The final result of such a test must be calculated using the relation [2]:

$$V_p[\text{dB}/\mu\text{V}/300\Omega] = V_m[\text{dB}/\mu\text{V}] + A[\text{dB}/\mu\text{V}] + R[\text{dB}] \qquad (1)$$

where V_m and V_p reach the values corresponding of the reference voltage U_r, at EUT terminals. A[dB/ µV] represents the attenuation due to the testing circuit because only a part of disturbance current produced by EUT passes through resistive load R_L. Regarding the correction factor R, it expresses the fact that the reading voltage is not the value across resistance R_L = 300 Ω, as stipulate the standard, but across equivalent resistance $R_1/2$:

$$R[\text{dB}] = 20\log_{10}\frac{R_L}{R_1/2}. \qquad (2)$$

The attenuation due to the testing circuit is assessed in two steps, which suppose the built and use of the circuits presented in the Figure 2.

In the first step, keeping the entire testing circuit but without applying the high voltage, the disturbance current produced by corona discharge is simulates by a constant current source of about 50 µA. This source is built by a signal generator (S.G.), tuned at measuring frequency f_m and connected in series with a resistance of about 20 kΩ. In open circuit conditions at its output terminals, the voltage must be about 1V.

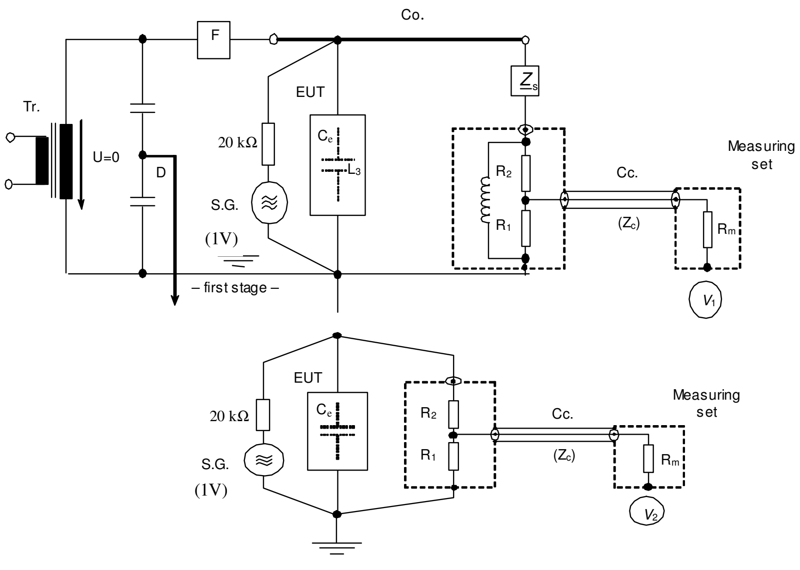

Fig. 2 – The schemas of the calibration circuits. V_1, V_2 – the displayed values at measuring receiver, in dB/µV.

The value recorded at measuring set is V_1. In the second step, all components of high voltage circuit are disconnected and the same current source injects its current only in the measuring resistance. A new value, V_2 is recorded.

The attenuation of the circuit is the difference between the two measurements values displayed by receiver:

$$A[\text{dB/ }\mu\text{V}] = V_2\,[\text{dB/ }\mu\text{V}] - V_1\,[\text{dB/ }\mu\text{V}] \qquad (3)$$

Therefore V_1 correspond of the part of the constant current circuit which flow through resistance R_1, while V_2 of the part of the current which shall injected in the conductor of the overhead line. Generally, the attenuation A reach a value of few dB/μV, depending of the particularities of testing circuit.

Classical testing procedure consists in the following steps, according [2]:

- in the first step, the voltage applied to EUT is increase up to $1{,}1 \cdot U_r$ and this value is kept at least 5 minutes;
- after that, the voltage is decrease in steps of about $0{,}1 \cdot U_r$, up to $0{,}3 \cdot U_r$;
- follow a new increase of the voltage in steps, up to $1{,}1 \cdot U_r$, keeping the high voltage circuit at this value for one minute;
- then a new decrease of the voltage in steps of about $0{,}1 \cdot U_r$, up to $0{,}3 \cdot U_r$ must be ensured;

At each step of the applied voltage must be recorded the V_m value of the radio interference voltage. The diagram of V_p versus applied voltage permits, for the last sequence of the test (when the voltage is decreasing) the characterization of EUT regarding its radio frequency noise level.

3. Alternative method to evaluate radio frequency noise and experimental results

As be described in the previous paragraph, the classical procedure to asses the radio interference voltage of high voltage equipment following CISPR publication is a time onerous one, also the sequence of the measuring circuit calibration. The difficulty to read the values of RIV associated of an applied voltage make this task more difficult, because of instability of corona discharge phenomenon and corresponding recorded values even the measuring circuit is built to display the conventional „cvasi-peak" level.

The alternative proposed method consist in the recording of high frequency electric or magnetic field using an adequate field probe disposed at a specified distance from the high voltage test arrangement. The measurements could be performed at the same measuring frequencies as for classical RIV method. We use a high frequency electric field probe, in a 300 kHz-30 MHz range and parallel records (RIV and radiated electric field) were performed. The radiated field measuring systems with high frequency field probe was adjusting to display the maximum average value of electric field (over 1 sec time interval).

The testing object was a 110 kV composite insulator set. The experimental arrangement was carried out according IEC 60383-2 Publication [6]. The length of the conductor which simulates the line was 6 m length and the clearance from the floor of laboratory was 6.2 m. The field probe was located perpendicular to the axis of conductor, at 5 m lateral distance and 1 m height from the floor. Figure 3 shows the main elements of experimental set-up.

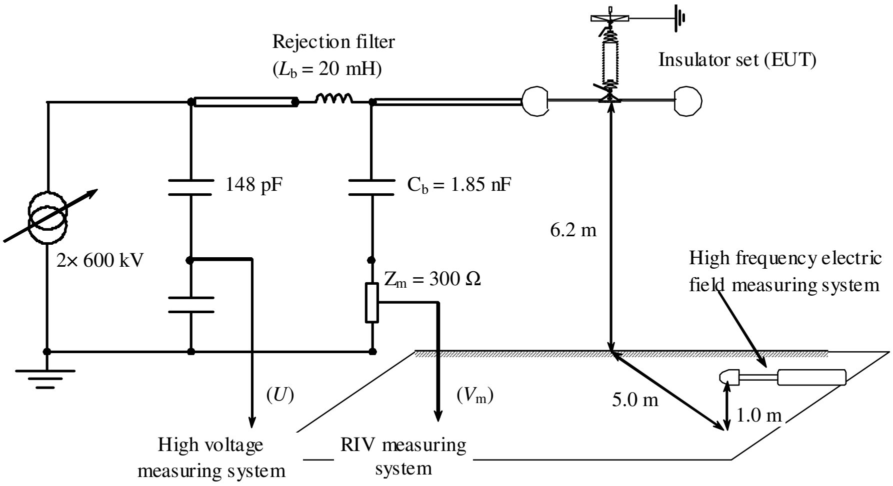

Fig. 3 – The main components of the experimental arrangement for combined measurements, RIV and radiated electric field.

The parallel measurements (RIV and radiated high frequency electric field) were performed for two frequencies, 500 kHz and 1 MHz and for the same steps of voltage recommended by [2].

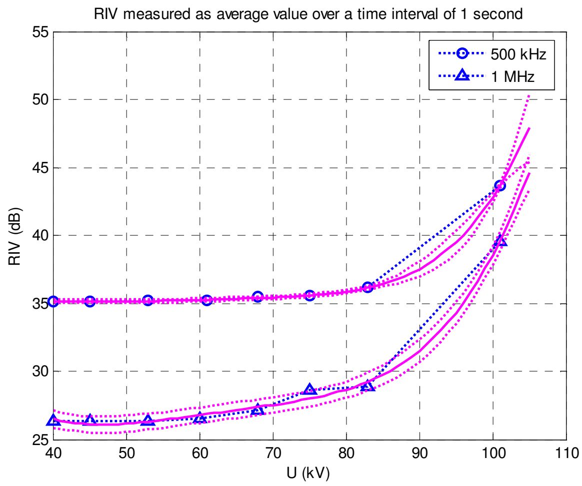

Fig. 4 – Results of RIV measurements using classical measuring system and polynomial fitting. The receiver is set to use average value detector.

Up to about 30 m from an electromagnetic field source an object is located inside “near electromagnetic field” zone (the wave length at the frequency of 1 MHz being 300 m). At this frequencies the electric and magnetic fields are independent each other. In this research we analyzed only the high frequency electric field radiated by equipment subjected to high voltage.

In the Figure 4, RIV level (evaluated using average value detector of receiver) versus applied voltage is presented. The high frequency electric field was measured for both series of RIV measurements (at 500 kHz and 1 MHz). The observed values exhibit the same type of voltage dependency and therefore the two series of measurements were combined, by averaging, in a single series. These results are presented in the Figure 5.

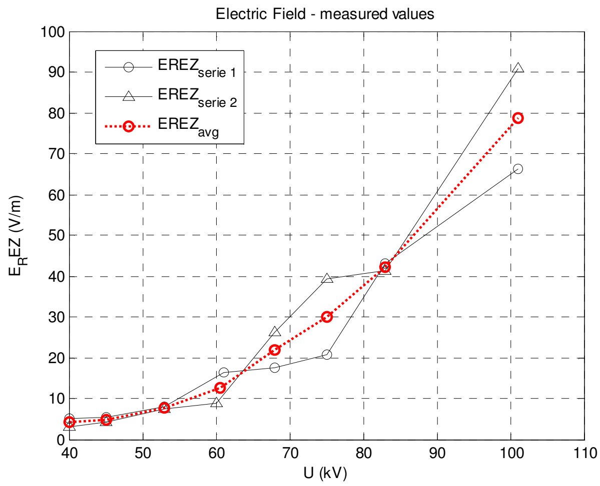

Fig. 5 – High frequency electric field (isotropic values) versus applied voltage, for 500 kHz and 1 MHz and their averages values.

Using these results a correlation between measured RIV and corresponding radiated electric field around tested equipment can be determined. The Fig. 6 presents the RIV values versus electric field values expressed in comparable manner (average values in the same time period).

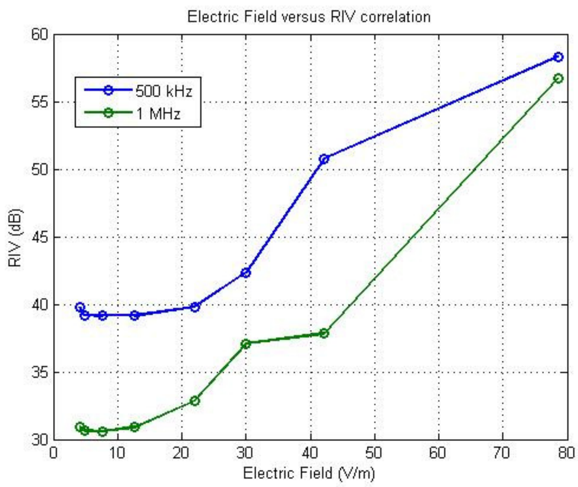

Fig. 6 – Correlation between measured RIV and radiated electric field for the two measurement frequencies.

The calculations reveal that the correlation coefficient for 500 kHz series is 0.96081 with 95% confidence interval (0.79314, 0.99310) and for 1 MHz series is 0.96862 with 95% confidence interval (0.83148, 0.99449).

The high correlation coefficients' values reject the hypothesis of a stochastic dependency between the electric field and the RIV. The only source of statistical variation is the measuring errors for both variables (the independent and the dependent one).

4. Conclusions

The measurement procedure which must be applied to asses the radio interference voltage due to high voltage equipment and described in the CISPR standards is with no doubt expensive and time-consuming. On the other hand the instability of displayed results for certain values of applied voltage make difficult the task to record them and to conclude about the behaviour of the object under test.

A simple, cheaper and saving time method could be the recording of radiated field components around tested object using high frequency field probes in a well defined electromagnetic environment such as a shielded high voltage laboratory. The first results are promising, the correlation between radio interference voltage and radiated electric field was proven, but more experiments are still necessary to refine this alternative method.

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R E F E R E N C E S

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