RECOGNITION OF CORONA DISCHARGES OCCURRING ON THE WET SURFACE OF HIGH-VOLTAGE OHL PHASE CONDUCTORS

M. Babuder[1*] and I. Kobal[2]
[1]Elektroinstitut Milan Vidmar, Hajdrihova 2, 1000 Ljubljana, Slovenia
[2]Elektroinstitut Milan Vidmar, Hajdrihova 2, 1000 Ljubljana, Slovenia
*Email: <maks.babuder@eimv.si>

Abstract: The paper reports on case-study results based on testing OHL conductor samples. It comments on the respective results and gives an insight into the origin of discharge phenomena producing high-frequency electromagnetic field emissions and audible noise emissions. The tested conductor samples were the commonly used standard conductors (hydrophobic conductors) and special surface treated conductors (hydrophilic conductors). Reduction in noise emissions caused by surface treatment was identified and evaluated.

1. INTRODUCTION

In recent years, spatial sitting of overhead power-transmission lines (OHL) has been subject to rigorous restrictions imposed on environmental stressing. One of the critical stresses seriously burdening our environment is also the corona effect (partial discharges) taking place on the surface of OHL phase conductors. Its consequences are radiated high-frequency electromagnetic disturbance fields and thus resulting noise effects. The corona effect is further accelerated also by water drops deposited on the conductor surface and affecting the corona-effect dynamics. The intensity of the corona effect depends on the electric-field strength as well as on the geometry of the entire structure of the used phase conductor. In Slovenia, there is only one conductor used for the 220 kV OHLs and a bundle of two or three conductors for the 400kV OHLs. Elsewhere in Europe, the situation is different. In their transmission networks of higher voltage levels, there are mostly bundles of three, four or even more conductors used. Owing to the fact that some of the Slovenian OHL rights-of-the-way are running quite close to populated areas, an initiative has been raised to envisage an investigation enabling us to find optimal solutions for wires to be used in particular cases.

In our investigation in corona discharges, which was based on our experiences described in [1], we compared measurement results of various disturbance phenomena occurring on samples of the currently used conductors (hydrophobic conductors) and those whose surface roughness has been obtained by glass beds abrasion (hydrophilic conductors). Our laboratory tests and measurements were made on samples of the actually used phase conductors, precisely on a conductor bundle composed of two wires and on a conductor with a single wire. Different surface-watering methods were applied. All the investigated phenomena were investigated in precisely the same way and on each of the compared samples. We were not interested neither in making a comparison between the obtained values and the specified reference values nor in using the standard methods. Our special focus was on investigating the phenomena taking place on the voltage interval at which the partial discharge phenomenon at practically any surface state is strongly intensified. The dynamics of watering the conductor surface, effected either by applying artificial rain or being the result of the electric-field activity, made us investigate the discharge phenomena occurring inside water drops at an extremely strong electric field. To find out what these phenomena were, we in certain cases varied the inner resistance of the applied liquid. Fortunately, we found it possible to capture the dynamics of the perceivable phenomena occurring on the conductor surface by taking pictures with a movie camera. The aim of the first part of our investigation was to provide answers to the following questions:

(a) Does a specially treated surface of a realistically modelled conductor at a field stress similar to the one in real circumstances at which OHLs operate importantly contribute to minimisation of disturbance phenomena? and

(b) Speaking from the point of view of the applicable Slovenian legislation, can values of the disturbance phenomena be expected to be relatively low if only one wire is used for the 220 kV OHLs and only two of them for the 400 kV OHLS and if the conductor surface is specially treated?

In this part of our investigation we did not measure the intensity parameters of the simulated surface-watering of phase conductors. We studied the electrical phenomena of (A) partial discharges occurring on the conductor surface, (B) spectrum of the radiated high-frequency disturbance field in the vicinity of the tested sample and (C) equivalent sound-pressure level (SPL) L_{eq}. To perform these tasks correctly, we made it sure that our comparative measurements were taken under optimally equal conditions.

In the second part of our investigation we wished to answer the following two questions:

(c) To what extent do the different methods applied in watering the surface of the comparable conductor samples contribute to variations in the disturbance-phenomena intensity? and

(d) Which discharge-originating electrical phenomena can be identified by means of available usual standard testing and measuring equipment?

2. PRESENTATION OF THE TESTED SAMPLES

In the first part of our investigation, the following type of phase conductors designated with GACSR/ACS 490/65 were used. The tested samples are shown in Fig.1 (standard manufacturing procedure, without any surface treatment, designated as "hydrophobic")

Figure 1

and in Fig.2 (special manufacturing procedure, glass bead blasted, designated as "hydrophilic")

Figure 2

In the second part of our investigation, the object under test was simply a tube of the same diameter as the wire used in the first part of our investigation.

3. USED MEASUREMENT METHODS AND EQUIPMENT

3.1 Measurement of Partial Discharges (PD)

The PD measurement was done according to the standard procedure (IEC 60270). The measuring set-up is shown in Fig. 3.

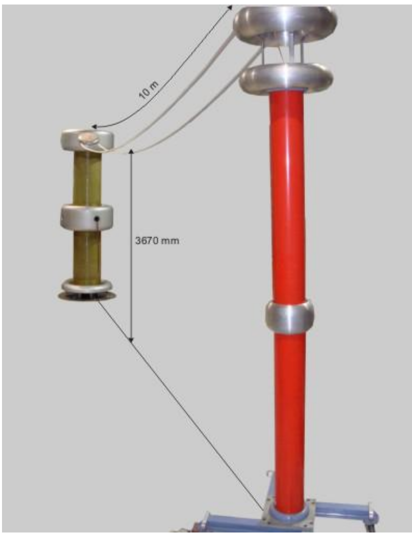

Figure 3

The measurement of the apparent charge was made simultaneously with the measurement of the equivalent sound-pressure level and the radio-frequency interferences. The measuring set-up consisted of the Tettex instrument, Type 9120 with a broad-band amplifier and a coupling capacitor of 2 nF capacitance.

3.2 Measurement of the equivalent sound-pressure level

Noise measurements were made compliably with the requirements of the OPA.6.HR-MOK organisational regulation, edition 03/2, dated March 10, 2009, and the SIST ISO 1996 standard – 2: 2007; Acoustics - Description, measurement and assessment of environmental noise (Noise description, measurement and assessment in the environment – Part 2: Determination of the noise level in the environment). The measuring device used was of the Brüel&Kjaer manufacture, Type Observer 2260.

3.3 Measurement of radio-frequency interferences

The used measuring method met specifications of IEC 60018-2 (1986) (CISPR/C 18-2). The measuring device was the ROHDE&SCHWARZ,

Type ESH 3/EZM instrument with the frequency range from 400 kHz up to 30 MHz. The measuring set-up is shown in Fig.4.

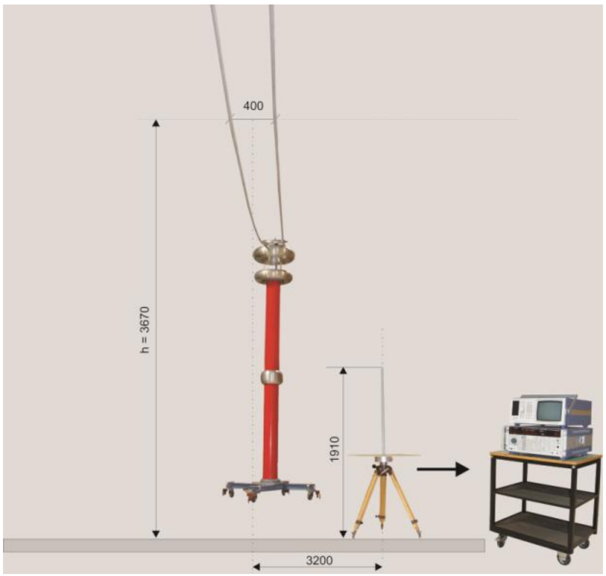

Figure 4

3.4 Investigation of the dynamic behaviour of water drops and their impact on PD

3.4.1 Physical model To clarify the dynamical behaviour of the drops in the intensive field, an approximate physical model shown in Fig. 5 was used.

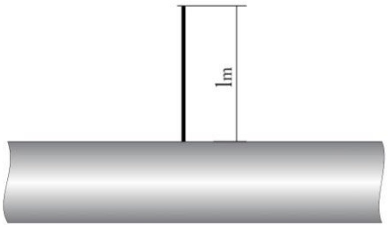

Figure 5

It consisted of a thin wire of length l_m applied on a tube of 5 centimetres in diameter. The point of the wire was of a cylindrical shape. The voltage was raised up to the streamer inception threshold value verified by measurements and timely positioning of partial discharges in correlation with the applied voltage. In that case the discharges appeared at the positive half-cycle of the applied voltage and involved considerably higher charges (above 15000 pC).

3.4.2 Recordings The obtained results shown in Table 1 led us to the conclusion that higher distance from the conductor l_m reduces the threshold voltage.

Table 1

l_m [mm]	U_{crit} [kV]	Q [pC]
2,0	246	60000
5,0	200	60000
10,0	181	22000
15,0	170	18000
20,0	168	18000
25,0	164	19000
30,0	162	18000

As well known [2] and also demonstrated during our investigation, the electric field impacts the shape of drops. They take a conical shape but their maximum length does not timely coincide with the peak value of the applied voltage.

The visual phenomena taken by a movie camera are shown in Figs. 6 and 7.

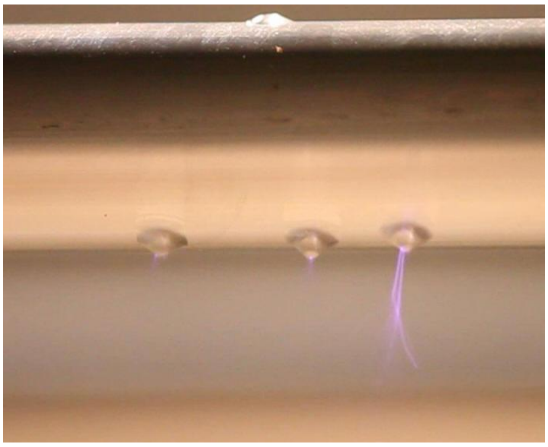

Figure 6

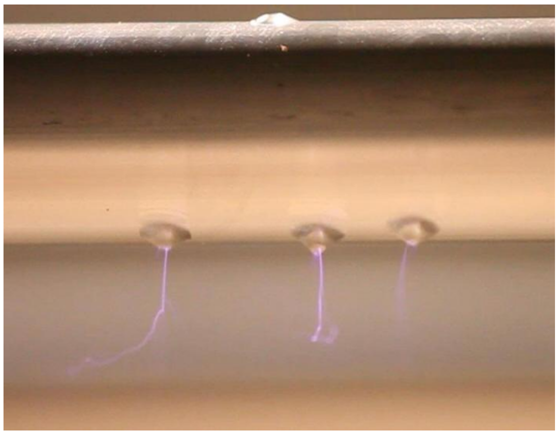

Figure 7

Currently still to be done is to timely correlate the above shown discharges recorded with the used PD measuring system. The droplets elongation velocity was found moderate enough to clearly see their deformation on the photos taken during testing. The dynamic behaviour and the deformation sequence, particularly creation of sharp peaks leading to an increase in the field intensity, can be well observed. The only problem still left to be solved is to correlate the visual recordings with electrically recorded discharges.

4. MEASURING RESULTS AND COMMENTS

4.1 Partial discharges

Results of PD measurements for the two observed wire types in dry conditions are given in Table 2 and in wet conditions in Table 3.

Table 2

U(kV)	Hydrophobic dry (pC)	Hydrophilic dry (pC)
50	5	4
100	10	15
150	60	400
160	150	500
170	200	550
180	300	650
190	350	750
200	450	900
210	600	1500
220	700	2500
230	5000	2600
240	>100000	3500
250	>100000	5500

Table 3

U(kV)	Hydrophobic wet (pC)	Hydrophilic wet (pC)
50	4	4
100	700	150
150	32000	8000
160	45000	10000
170	60000	15000
180	65000	18000
190	75000	23000
200	80000	30000
210	100000	55000
220	>100000	70000
230	>100000	100000
240	>100000	>100000
250	>100000	>100000

A graphic comparison of the two dry conductors is given in Diagram 1 and of the wet conductors in Diagram 2

As the instrument calibrated measuring range is up to 100.000 pC, results exceeding this value are not figuring in the diagrams.
The advantageous behaviour of the hydrophilic wire in dry conditions at voltages above 220 kV is surprising. A detailed analysis of the records of the PD phenomena did not reveal any streamer appearance at these voltages. Obviously, the PD level in wet conditions is much more intensive in both samples. As the hydrophilic sample did not produce any acoustically noisy streamers, the obtained sound-pressure level was fairly lower.

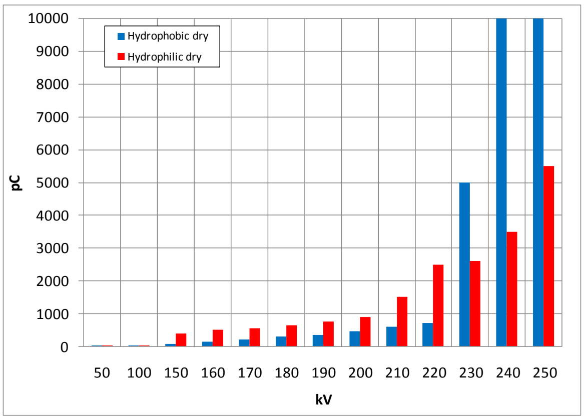

Diagram 1

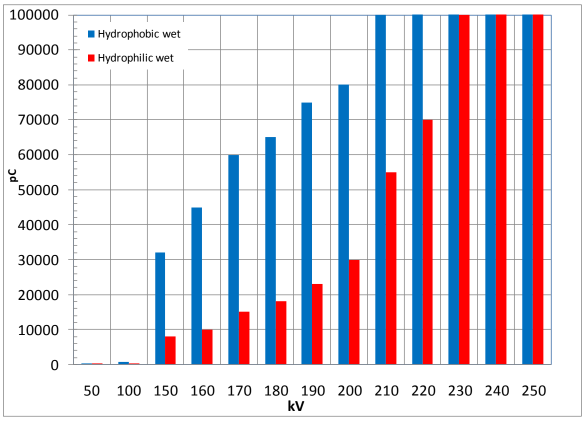

Diagram 2

4.2 Equivalent sound-pressure level

The measuring conditions did not satisfy the usual procedural requirements and the pertaining results are to serve only for comparison in order to estimate effectiveness in suppressing the acoustic noise by applying surface treatment. During our laboratory measurements there was also a certain level of noise produced by the used testing equipment (transformer buzz). This is why we considered only the measured values obtained at voltages above 190 kV. The results are shown in the below diagrams.

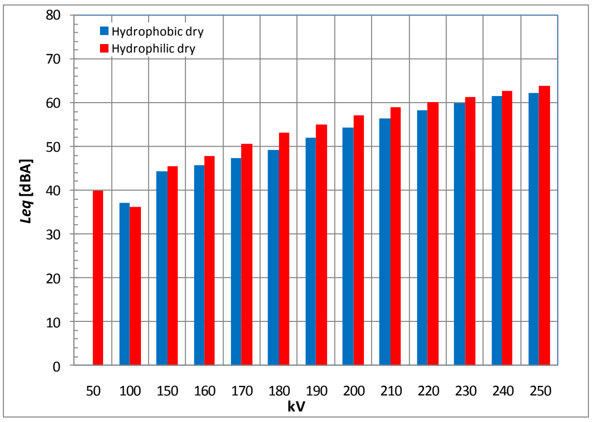

Diagram 3

A very general remark that can be given at the first sight at the two diagrams is that the values obtained for the hydrophilic sample in dry conditions are on average 2 - 3 dB lower and show only slight changes in wet conditions. The hydrophobic sample, on the contrary, shows a higher sound-pressure level increment caused by moisture on its surface.

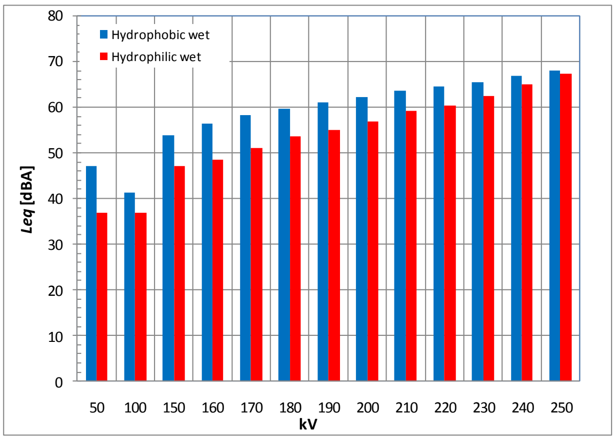

Diagram 4

4.3 Radio-frequency interferences (RFI)

Our measurement results are for one of the tested cases given as photos of the RF spectrum. The diagrams show the readings expressed in dB (1µV/m). The diagram below shows RFI at a 250 kV applied voltage for the hydrophobic sample in wet conditions. We apologize for the poor quality of Fig. 8.

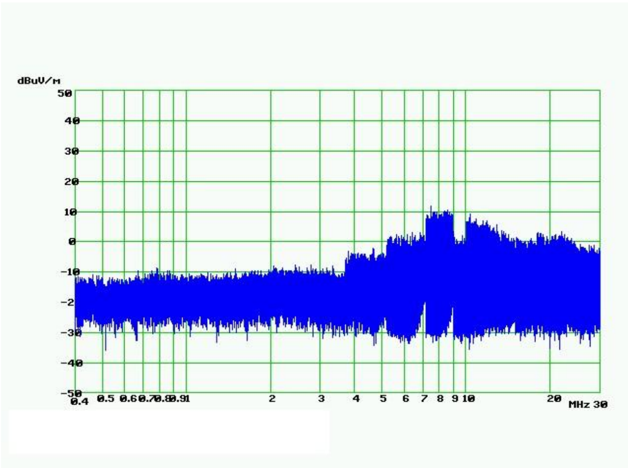

Figure 8

The level of the emitted high-frequency fields generated by PDs on the surface of the tested wires showed minor impacts produced by surface treatment and/or watering the surface. The achieved reductions are roughly estimated to be of the order of 10dB for the hydrophilic sample over the whole measured frequency range. Some deviations from this finding are in the frequency interval from 7-9 MHz where values do not change at all for whichever cause there may be. To draw more reliable conclusions, much more scrutinizing work should be done.

5. CONCLUSIONS

Our introductory electric-field calculations made to estimate the necessary testing voltage proved that the voltage applied in our tests can be regarded as a representative testing voltage to be used in reproducing stresses encountered during normal operation of 400 kV OHLs.

Our PD measurements gave us useful data about the basic events giving rise to deteriorating environmental stresses.

While applying a voltage ranging from 50% to 100% of the rated operating voltage, the hydrophilic wet conductor experienced considerably lower discharges compared to the hydrophobic one.

The average noise level emitted from the hydrophilic conductor is about 10dB lower compared to that emitted from the hydrophobic conductor.

As noted at the different applied voltages and frequencies of up to 30MHz, the spectrum of the high-frequency electromagnetic field emitted from conductors tested in dry conditions is slightly different in both types of conductors. In the part of the spectrum ranging from 0.4 to 4.5MHz at voltages applied to produce the rated operation field stress, an important reduction of 10dB was noted in hydrophilic conductors when tested under wet conditions. The part of the spectrum from 5 to 30MHz shows no difference in its development regardless of the type of the sample, applied voltage or sample state (wet or dry).

Our current recording of the visual phenomena appears to be useful. We show that there is a good possibility of having the relatively slow droplet deformation process captured, thus providing promising basis for our future work.

REFERENCES

[1] M. Babuder, I. Kobal, B. Cestnik, I. Rozman, V. Vuga: “Comparative research in electromagnetic and acoustic phenomena as a result of the electric field on the surface of phase conductors of a 400 kV overhead transmission line”, Investigation report no. 2044 Elektroinstitut Milan Vidmar, June 2010

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