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LABORATORY TESTS AND CRITERIA FOR EVALUATING THE CONDITION OF OVERHEAD LINE CONDUCTOR

LABORATORIJSKA ISPITIVANJA I KRITERIJUMI ZA OCJENU STANJA VODIČA NADZEMNIH VODOVA

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Abstract: Guidelines for sampling and testing the overhead lines components, dismantled from overhead lines (OHLs) in operation do not contain acceptance criteria for samples of materials neither the guidelines how to estimate life expectancy of material. This paper shows results of sample tests of conductors taken from OHLs: 110 kV Banja Luka 1 – Banja Luka 6/I, 2×110 kV HPP Jajce 1 – HPP Bočac, 2×110 kV HPP Bočac – Banja Luka 1 and OHL 2×110 kV Banja Luka 1 – Banja Luka 6/II, analysis of results according to criteria found in literature and specific author's dilemmas as well as the conclusions regarding tests results and acceptance criteria.

Keywords: overhead line, overhead line conductors, overhead line conductors sample tests

Sažetak: Pravilnik za ispitivanje uzoraka materijala i opreme demontirane sa dalekovoda u eksploataciji nije dao odgovor na pitanje kada su rezultati ispitivanja nekog uzorka zadovoljavajući a kada ne i kako procijeniti preostali životni vijek materijala ili opreme. Rad prezentuje rezultate ispitivanja uzoraka provodnika uzetih sa DV 110 kV Banja Luka 1 – Banja Luka 6/I, DV 2×110 kV HE Jajce 1 – HE Bočac, DV 2×110 kV HE Bočac – Banja Luka 1 i DV 2×110 kV Banja Luka 1 – Banja Luka 6/II, izvršena je analiza prema kriterijumima dostupnim u literaturi i navedene određene dileme autora i zaključci u pogledu ocjene dobijenih rezultata.

Ključne riječi: nadzemni vod, vodiči nadzemnih vodova, ispitivanje uzoraka vodiča

ABBREVIATIONS

OHL – overhead power line
SS – power substation
HPP – hydro power plant
ACSR – aluminium conductor steel-reinforced
UTS – ultimate tensile strength
RTS – rated tensile strength
FAT – factory acceptance test

INTRODUCTION

The goal of this paper is to present results of tests performed on samples of 57 years old conductor and to discuss acceptance criteria for evaluation of tests performed on conductor samples taken from OHLs in operation.

The manner of sampling and testing was processed by the Rulebook for testing samples of materials and equipment disassembled from the transmission lines in exploitation and the corresponding standards for a specific type of equipment.

When the results of sample testing are satisfactory or not, and how to estimate life expectancy of materials or equipment were not found in The Rulebook [1].

The OHL 2×110 HPP Bočac – Banja Luka 1 and the OHL 2×110 kV Banja Luka 1 – Banja Luka 6/II was built in 1957 and reconstructed in 1989 and 1990. The reconstruction included restoration and reinforcement of steel structures reconstruction in accordance with applicable regulations. Testing of the then 32 years old conductors based on the above-mentioned Rulebook [1] in the preparation phase of the above-mentioned reconstruction resulted in the decision to retain the conductors, hardware and fittings in further exploitation. The conductors, insulators, hardware and fittings were subsequently replaced during 1999 and 2000 at the entry-exit section of the SS Banja Luka 1 which was passing through the densely populated area.

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Due to malfunction, the insulators were sporadically replaced through regular exploitation while systematic replacement of insulators with polymeric rod insulators and glass cap and pin insulators took place at the section from HPP Bočac to tower No. 115.
The revitalization of the transmission line was carried out during 2015 and 2016 while the previously conductors testing resulted in keeping the conductors installed in 1957 in further operation.

1. EXPERIENCE WITH THE EXECUTED EXAMINATION

Conductor sample testing was carried out for the needs of Elektroprenos BiH, Operational Area Banja Luka (ACSR240/40, installed in 1957) taken from the OHL 2×110 kV HPP Jajce – HPP Bočac (samples from towers: 26, 34, 38 and 53), OHL 2×110 kV HPP Bočac – Banja Luka 1 (samples from towers 126 and 138), OHL 2×110 kV Banja Luka 1 – Banja Luka 6/II (tower 157) and OHL 110 kV Banja Luka 1 – Banja Luka 6/I (conductor ACSR 150/25 installed in 1964). The testing was carried out in December 2014 in accordance to the JUS N.C1. 385, JUS N.C1. 302 and JUS N.C1.702 standards [3].

A visual inspection determined that the ACSR 240/40 conductors were held in "satisfactory" condition (Figures 1-4). No corrosion was noticed on the wires of the conductor's steel core. The traces of frozen grease were kept on samples taken from the less loaded and less air-polluted sections (OHL 2×110 kV HPP Jajce - HPP Bočac, OHL 2×110 kV HPP Bočac Banja Luka 1), while the core of the conductor remained practically free of neutral grease on samples taken from high loaded section (OHL 2×110 kV Banja Luka 1 Banja Luka 6/II). No blemish was noticed on the aluminium wire sheets (scratches and similar). On the other hand, the wires of the conductor ACSR 150/25 from the OHL 110 kV Banja Luka 1 – Banja Luka 6/I were affected by the corrosion inside the core.



Figure 1: Conductor sample before testing



Figure 2: The state of the cross-section of the conductor before testing



Figure 3: The conductor core before testing



Figure 4: The detail of conductor core before testing

Laboratory tests (Figures 5-8) and measurements showed the following:

- The calculated RTS is lower up to 10% compared to the minimal RTS of the new conductor.
- Reduction of the tensile strength (tension at the elongation of 1%) is more noticeable for steel than for aluminium wires.
- The number of twists of steel wires and the mass of zinc coating were reduced by 50%.
- On the sample taken from tower 38, the number of immersion counts 1.5. On other samples, the uniformity of zinc coating is satisfactory.

- Testing with twisting of aluminium wires is satisfactory.
- The electrical resistance of samples from the OHL 2×110 kV HPP Jajce HPP Bočac is satisfactory, while on the OHL 2×110 kV HPP Bočac Banja Luka 1 and the OHL 2×110 kV Banja Luka 1 Banja Luka 6/II is about 1% higher than the maximum allowed for the new conductor.

Taking into consideration the laboratory tests, it can be concluded that the test results for ACSR 240/40 conductor do not satisfy the criteria that apply to the new conductor.

However, in terms of safety factors prescribed by the Rulebook on technical norms for the construction of overhead power lines of rated voltage from 1 kV to 400 kV [2], these conductors still have satisfactory values, greater than the ultimate strains i.e. for the samples taken, the following conditions are met: tension under normal ice load is less than 40% of the UTS and the tension under heavy ice load (double normal ice load) is less than 75% of the UTS.

In accordance with the above-mentioned conclusion it was decided that the existing ACSR 240/40 conductors would be kept on the OHL 2×110 kV HPP Jajce – HPP Bočac, OHL Bočac – Banja Luka 1 and OHL 2×110 kV Banja Luka 1 - Banja Luka 6/II with repeated testing in the following period, not longer than 10 years.



Figure 5: Conductor core wires before testing



Figure 6: Test result of immersion test



Figure 7: The detail of immersion test in CuSO4 solution



Figure 8: The detail of test with twisting of aluminium wires

The results of laboratory tests are shown in Table I in the Annex.

2. DISCUSSION

The Rulebook for testing samples of materials and equipment disassembled from the transmission lines in exploitation [1] and the corresponding standards for a particular type of equipment did not provide clear instructions regarding the interpretation of the conductor laboratory test results. If the limit values applicable to the new conductors are applied, it is likely that the most conductors between 30 and 40 years old would have been designed to be replaced.

Taking into consideration the conditions prescribed in [2], despite the 57-year exploitation period, the safety factor of the conductors are still higher than prescribed standards (2.50 in the case of regular ice load or 1.33 in the case of heavy ice load).

Taking into account only this criterion and assuming linear degradation of the conductor RTS over time, according to formula (1), the remaining life expectancy of conductors of the 30 years order is obtained (Table II in the Appendix).

$$\Delta T = \frac{F_{uz} - F_{gr}}{F_n - F_{uz}} \cdot T \qquad (1)$$

The following symbols represent:
ΔT (years) – remaining life expectancy of conductors;
T (years) – sample age;
F_{uz} (daN/mm^2) – measured RTS of the sample;
F_{gr} (daN/mm^2) – minimal RTS to meet prescribed safety factors;
F_n (daN/mm^2) – measured RTS of the new conductor (if no measurement data from FAT is available, it can be assumed that it is 20% higher than the minimum RTS).

On the other hand, even the conductor sample ACSR 150/25 from the OHL 110 kV Banja Luka 1 Banja Luka 6/I with completely corroded steel core meets the above-mentioned criterion. The conductors ACSR 150/25 of the transmission line Banja Luka 1 Banja Luka 6/I were replaced in 2012, while in a period from 2004 to 2012 several operational events were recorded which caused interruptions of conductors due to the increased current load and damaged conductors. Therefore, it is clear that the criterion for satisfying the safety factor of the conductors according to [2] is too insignificant.

The criteria for assessing the RTS of the conductors, the allowed reduction of the RTS of the conductors was defined in the literature [4–7] but the level of allowed reduction of interrupted force was not indicated nor was the corresponding literature on the allowed reduction of RTS determined. The information that the reduction of interrupting force of the conductor is allowed up to 10% with regard to the minimal RTS of the new conductor provided by the corresponding standards for conductors was presented in an agreement with the leading author. If this criterion is applied to the samples of conductors from the OHL 2×110 kV HPP Jajce HPP Bočac, HPP Bočac Banja Luka 1 and Banja Luka 1 Banja Luka 6/II according to (1) that would result with the remaining life expectancy of 1 year (Table III in the Appendix), therefore the conductors should be replaced.

The criterion for reducing the number of steel wires twisting (allowed reduction of 50%) in relation to the value defined by the standard for the new, and the criterion of the number of conductor failures (the permitted number of failures in the suspension clamps due to vibrations less than 10%) were also defined in the literature [4–7]. Taking into account these criteria, the conductors on the section from tower 26 to HPP Bočac are completely in a satisfactory state (except for the sample on tower 34 with a number of twists (Nuv) 7.86 slightly less than 50% of the value for the new conductor (16 · 0.50 = 8 twists). On the other hand, according to the criterion of the number of twisted steel wires, the conductor samples on the section tower no. 118 SS Banja Luka 6 give results that are slightly below the defined limit value. Thanks to the fact that the high-quality suspension equipment with armour rods which despite its age and long spans (frequently 450-600 m) ensures good protection of the conductors at the point of suspension, no damage to the conductors in suspension was recorded in the whole section from tower 26 to the substation Banja Luka 6.

As previously mentioned, the conductors from the 2×110 kV HPP Jajce – HPP Bočac, HPP Bočac – Banja Luka 1 and Banja Luka 1 – Banja Luka 6/II transmission line have not been replaced. The revitalization of transmission line carried out in 2015 and 2016 included the replacement of insulation and part of the suspension equipment, replacement of the grounders, anticorrosion protection and repair of the tower construction. As built project documentation, as well as the calculation of true strain were provided during the process of revitalization. The calculation shows that the strains are less than projected 8 daN/mm^2 in almost all tensile sections; this could be related to the plastic deformation of conductors due to long-term exploitation.

In order to achieve prescribed safety heights, after recording suspensions and longitudinal profiles, the safety height control was performed which resulted in conductor tightening up in specific tensile sections and extension links removal from specific suspension towers. High quality suspension equipment with armour rods which additionally protects the conductor in suspension points that normally have the greatest strains was the additional reason for not having the conductors replaced during the revitalization process, as well as the absence of operational events related to damage or interruption of conductors in the previous period (2004-2014) which is in accordance with revitalization methodologies relying on behaviour of transmission line in operation, described in literature [8], [9].

According to conducted tests, it is evident that better results are obtained with samples from sections under lower load and in areas with lower air pollution. It is shown that the test results on steel wires (quantity of grease, zinc quality, number of twisting) are in correlation with these conditions. Regarding the state of aluminium wires, their performances were less degrading over time in comparison to the standards of prescribed value, therefore, it can be concluded that the state of ACSR conductors is primarily related to the state of the steel core.

A reliable and objective criterion for determining the life expectancy of conductors was not found in the literature [4–7].

Condition monitoring and operational events related to conductors used in the transmission lines 2×110 kV HPP Jajce – HPP Bočac, HPP Bočac – Banja Luka 1 and Banja Luka 1 – Banja Luka 6/II require special attention in the forthcoming period. It is necessary to identify the causes, i.e. to examine the circumstances which caused defect (whether it was previously damaged and damage degree, whether the additional load existed and its level, the level of current

load at the time of failure) for any potential failure of the conductor. Sample testing should be repeated after 5 to 10 years, depending on repair schedule and future behaviour of OHLs in operation. According to conducted testing, the section from tower 118 to TS Banja Luka 6 represents the priority section due to higher current loads, higher levels of air pollution and the fact that certain sections pass through densely populated areas where any interruption of conductors could cause serious consequences.

Since there are certain reserves when it comes to the application of conductors (maximum working tension of conductors is usually 8-9 daN/mm^2, and the stress limit for conductors of ACSR ratio 1:6 is 11-13 daN/mm2), standards which apply to new conductors would be too strict for conductors in operation. The criterion for meeting the requirements described in [2] is too insignificant, while each criterion between these two is arbitrary, i.e. based on the author's personal attitude and insufficiently explained.

3. CONCLUSION

The conclusions are as follows:

1. Conductors that meet requirements for conductor standards apply to new conductors can safely remain in operation for the next 10-15 years. Testing of conductors under 30 years old is not necessary.
2. The conductors of heavy loaded transmission lines, transmission lines in areas with increased air pollution and transmission lines in densely populated areas should undergo testing more often.
3. Conductors with corrosion in the core need to be replaced in the shortest possible period of time. In case of such conductors, the inevitable failures occur at increased loads and ice loads, such as 110 kV OHL Banja Luka 1 – Banja Luka 6/I (operational events in 2006 – two cases of interruption of conductors due to damage and increased current load), as well as interruptions of conductors on the OHL 110 kV Doboj 2 – Doboj 3 in winter 2006 due to ice load).
4. The operating condition of other transmission lines requires careful monitoring and development of databases in order to determine the correlation between the condition of the conductor determined by testing and the number of conductor interruptions.

ANNEX

Table I: Laboratory test results

Limit values for new conductor					Values measured on sample						
					tower 26	tower 34	tower 38	tower 26	tower 53	tower 126	tower 157
m'	987	±	19.74	kg/km	979.00	990.45	986.7	977.9	980.8	975.75	996.5
d	21.9	±	0.219	mm	21.75	21.85	21.9	21.6	21.8	21.9	21.95
grease	7.8	±	1.56	kg/km	2.45	none	13.5	6.55	none	none	none
dj	6.3			mm	8.2	8	8	8.15	7.9	8.1	8.2
FKj	13	÷	28		12.2	12.5	12.5	12.26	12.66	12.34	12.2
dAl1	14.94				14.8	14.7	14.9	14.9	14.85	15.1	15
FK1	10	÷	17		11.8	11.9	13.1	11.4	11.45	11.92	11.3
FKU	10	÷	14		10.8	10.76	10.5	10.6	10.55	10.96	10.48
D_{Al}	3.45	±	0.035	mm	3.39	3.38	3.38	3.37	3.38	3.38	3.39
$D_{č}$	2.68	±	0.04	mm	2.69	2.71	2.70	2.70	2.70	2.71	2.71
Z_{Al}			16.4	daN/mm^2	16.12	15.87	16.33	17.01	16.00	16.24	16.29
$Z_{č\%}$			117.7	daN/mm^2	97.20	100.66	89.32	97.28	99.03	97.73	96.55
$Z_{č}$			124.5	daN/mm^2	127.90	132.63	135.29	133.15	126.71	136.73	135.12
N_{UV}			16		23.43	7.86	15.43	14.29	6.43	7.43	9.86
M_{Zn}			230	g/mm^2	220.39	160.96	261.64	215.71	145.81	135.33	141.27
N_{ur}			3		3	3	1.5	1.5	3	2.5	3
$F_{rač}$			8500	daN	7640.2	7763.4	7389.2	7861.0	7706.0	7736.6	7708.4
ρ_{max}			0.1188	Ω/km	0.117409	0.114157	0.118029	0.118906	0.120223	0.120327	0.119492
σ_{nd}			11	daN/mm^2	9.73	9.89	9.41	10.02	9.82	9.86	9.82
σ_{id}			21	daN/mm^2	18.25	18.55	17.65	18.78	18.41	18.48	18.42
σ_{ndpr}	projected			daN/mm^2	8	8	8	8	8	8	8
σ_{ndpr}	measured/recalculated			daN/mm^2	7.38	7.96	7.35	7.62	8.71	7.71	7.96
σ_{idpr}				daN/mm^2	14.5	13.4	14.48	14.23	15.5	15.5	15.5
Safety factor for normal ice load (NIL) - min. 2.50					3.66	3.45	3.56	3.65	3.13	3.55	3.43
Safety factor for ultimate ice load (2xNIL) - min. 1.33					1.86	2.05	1.81	1.96	1.76	1.77	1.77

Table II: Estimation of residual lifetime of conductors according to criteria from [2]

Calculation of life expectancy of conductor	tower 26	tower 34	tower 38	tower 26	tower 53	tower 126	tower 157	BL1-BL6/I
Age of sample (years):	57	57	57	57	57	57	57	48
RTS of the new conductor:	10200	10200	10200	10200	10200	10200	10200	6672
Calculated RTS of the sample:	7640	7763	7389	7861	7706	7737	7708	5221
RTS limit-criterion 1:	6279	6279	6279	6279	6279	6279	6279	4328
RTS limit-criterion 2:	6069	5609	6061	5956	6488	6488	6488	-
Life expectance-criterion 1:	30.3	34.7	22.5	38.6	32.6	33.7	32.7	29.5
Life expectance-criterion 2:	35.0	50.4	26.9	46.4	27.8	28.9	27.9	-

Table III: Estimation of residual lifetime of conductors according to criteria from [4–7]

Calculation of life expectancy of conductor	tower 26	tower 34	tower 38	tower 26	tower 53	tower 126	tower 157	BL1-BL6/I
Age of sample (years):	57	57	57	57	57	57	57	48
RTS of the new conductor:	10200	10200	10200	10200	10200	10200	10200	6672
Calculated RTS of the sample:	7640	7763	7389	7861	7706	7737	7708	5221
RTS limit:	7650	7650	7650	7650	7650	7650	7650	5004
Life expectance:	-0.2	2.7	-5.3	5.1	1.3	2.0	1.3	7.2

Note: life expectance less than 0 means that according to residual lifetime calculation for samples taken from towers 26 and 38 conductors should have already been replaced.

REFERENCES

[1] Rule book for testing samples of materials and equipment disassembled from the transmission lines in exploitation, JUKO CIGRÉ, Work gorup 22-04 ageing of materials, 1987

[2] Rule book on technical norms for construction of overhead power lines of rated voltage 1 kV to 400 kV, Official Gazette SFRJ 65/88 and Official Gazette Republic of Srpska 7/12

[3] Standards: JUS.N.C1.301/1985 (Hard drawn aluminium wire for electrical purpose. Technical requirements), JUS.N.C1.701/1985 (Zinc coated steel wires for stranded conductors. Technical requirements for for production and delivery), JUS.N.C1.351/1985 (Aluminium conductors, steel reinforced for overhead lines. Technical requirements)

[4] M. M. Dutina, Z. J. Hrubenja, G. Radovanović, Z. Slijepčević: Revitalization of high voltage overhead lines, III Conference SLOKO CIGRÉ, Nova Gorica, 1997

[5] M. M. Dutina, Z. J. Hrubenja: Estimation of life expectance of overhead lines equipment, XXV Conference JUKO CIGRE, Herceg Novi, September 2001

[6] M. M. Dutina, M. N. Nimrihter, S. B. Novaković, S. Dukić: Methodology for revitalization of overhead lines, Infoteh, Jahorina, March 2002

[7] M. M. Dutina, M. N. Nimrihter, S. B. Novaković: Methodology for revitalization of high voltage overhead lines, Colloquium SC 22 JUKO CIGRE, Belgrade, May 2003

[8] D. Bajs: Method and Criteria for Revitalization of Transmission Network, Ph.D. Thesis, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia, July 2007

[9] S. Gušavac, S. Đukić, Lj. Gerić, M. Nimrihter, D. Lovrić: Ranking of condition of overhead lines based on exploitation data, XXIX Savetovanje CIGRÉ Srbija, Zlatibor, May 2009

BIOGRAPHY

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