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Assessing the Remaining Life Time of 220 kV and 400 kV OHTL and the Required Measures For the Coordination of Remaining Life Times of the Various Constructive Elements of Lines.

George A. Florea, *Senior Member, IEEE*, Laurentiu Lipan, Stelian Gal , Emil Kaytar, Vasile Metiu and Ioan Rodean

Abstract **-The paper makes an analysis of the eighteen 220 and 400 kV overhead electric lines belonging to C.N. Transelectrica - Sibiu Branch (TSO) on the basis of a unitary methodology for assessing their technical state and taking into consideration the different types of expertise conducted until now, including the multispectral analysis from the helicopter of seven lines.**

Performance criteria for insulators, risk analysis of special route area and maintenance strategies to extend the normal life time have been established.

Considering that different constructive elements of the line, located in a certain area, have different life times, concrete measures of lines alignment to obtain convergence of the partial remaining times have been established. Special attention was given to lines with major importance in the national electric system, proposing measures to increase their reliability based on detailed expertise methodology.

Index Terms **— foundations, NES (national electric power system), OHTL (overhead transmission lines), remaining life time, towers**

I. General considerations for the lifespan estimation

FIRST of all, the determination of the current technical status of elements of the over ground electrical lines has to be established and this includes four steps:

- preparation of technical documentation;
- expertise determination of the current technical status of OHTL;
- verification of the mechanical resistance of the components;
- sampling and specific testing.

For most designs of the current (RC) and capital (RK) repairing works only the first three steps were completed which highlights the following:

- length of service;
- incidents/damages during the operation time and the OHTL elements causing them;
- current (RC) and capital (RK) repairs performed, their proportions and the elements that have been repaired/strengthened;
- quality of maintenance work and in particular work related to the columns and foundations;
- mechanical resistance of the OHTL elements that is verified with outperformed computer programs, the calculations considering the imposed latest design standards.

The fourth step provides absolutely necessary data especially for the evaluation of the remanent lifespan as:

- current quality of the concretes included in the foundations, especially for areas were underground aggressive water exists;
- rezidual mechanical resistance to tension, compression and shearing of the steel angles and bolts as components of the towers, as well as degradation of the crystalline structure;
- current (real) section of the angles and bolts that can be affected (decreased) by corrosion;
- current mechanical resistance of the anchoring cables and corrosion grade of the component wires;
- current mechanical resistance, fatigue grade and current stage of zinc coating of the conductors' steel wires;
- degradation grade of the tension clamps and midspan joints;
- degradation grade of the glass or porcelain insulators.

Based on data obtained by covering the fourth phase, phase three can be reiterated, and the current capacity of OHTL elements can be established in a more accurate way when using as data input the actual and rated mechanical resistances. Therefore a correct evaluation of the remanent lifespan requires assays/testing in specialized laboratories or "in situ" that establishes the actual ageing level of the OHTL elements.

The following criteria are employed for estimating the remanent lifespan:

a. Length of operation;
b. The performed RC and RK workings, their quality and extent;
c. Number of incidents during exploitation and their seriousness;
d. Actual technical state of OHTL elements;
e. Mechanical resistance (capacity) of the elements computer verified following the latest design standards;
f. Current mechanical resistance (real) of OHTL elements determined on the basis of sampling and testing performed in specialized laboratories;
g. Intern and international working experience during the lifespan for the line's components (foundations, towers, conductors, insulators);
h. Weight of each component elements in the total OHTL value.

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II. OHTL FROM THE ST SIBIU PATRIMONY

The main important lines whose failure or lack of scheduled operation for long time periods can affect NES operation are:

- OHTL 220 kV Cluj Floreşti – Alba Iulia;
- OHTL 220 kV Mintia-Alba Iulia;
- OHTL 220 kV Ungheni – Fântânele;
- OHTL 220 kV Fântânele – Gheorgheni;
- OHTL 220 kV Stejaru – Gheorgheni;
- OHTL 400 kV Gutinaş – Braşov;
- OHTL 400 kV Ţânţăreni – Sibiu Sud;
- OHTL 400 kV Iernut-Sibiu Sud.

The lines whose importance for NES is of average importance, their failure not affecting the operation of NES, or whose lack of operation (scheduled) may lead to a reduction in static stability of NES, are the following:

- OHTL 220 kV Iernut – Ungheni, circuits 1 and 2;
- OHTL 220 kV Alba Iulia – Şugag;
- OHTL 220 kV Alba Iulia – Gâlceag;
- OHTL 220 kV double circuit Lotru – Sibiu Sud;
- OHTL 400 kV Bradu – Braşov;
- OHTL 400 kV Sibiu Sud – Braşov;
- OHTL 400 kV Sibiu Sud – Mintia.

Lines whose importance is materialized by optimizing the operation of NES (supplementing the paths between different areas, reducing losses in NES) - minor importance- are:

- OHTL 400 kV Brazi Vest – Dârste;
- OHTL 400 kV Braşov – Dârste.

ST Sibiu currently operates with 430 km of 220 kV OHTL and 554 km of 400 kV OHTL. The design and implementation of these lines began in 1960 when the first 220 kV artery in Romania was established, OHTL 220 kV-Bicaz Sîngiorgiu, which also contains the current OHTL 220 kV Stejaru Gheorgheni and Fântânele Gheorgheni.

In 1964 the first line of 400 kV, 400 kV OHTL Ludus-Slatina was employed, point from which, as a result of the occurrence of 400 kV s/s Sibiu Sud, the current OHTL 400 kV Iernut-Sibiu and OHTL 400 kV Ţânţăreni- Sibiu have resulted from.

The lines in operation by ST Sibiu have the operating times presented in Table 1 and Fig. 1:

Table 1

No.	OHTL name	PIF	Length (km)	Age years	OHTL running period (years)			
					25-30	31-35	36-40	41-45
1	OHTL 400 kV Iernut –Ungheni 2	1981	29.133	25	29.133			
2	OHTL 220 kV Cluj-Alba Iulia (section 193-316)	1963	39.425	43				39.425
3	OHTL 220 kV Alba Iulia-Şugag	1979	46.909	27	46.909			
4	OHTL 220 kV Alba Iulia-Gâlceag	1979	58.183	27	58.183			
5	OHTL 220 kV Mintia-Alba Iulia (section 157-261)	1963	33.54	43				33.54
6	OHTL 220 kV d.c. Lotru-Sibiu Sud	1972	85.133	34		85.133		
7	OHTL 220 kV Ungheni-Fântânele	1961	29.371	45				29.371
8	OHTL 220 kV Fântânele-Gheorgheni	1962	80.069	44				80.069
9	OHTL 220 kV Iernut-Ungheni 1	1961	30.155	45				30.155
10	OHTL 220 kV Stejaru-Gheorgheni (section 101-209)	1962	27.673	44				27.673
11	OHTL 400 kV Gutinaş-Braşov (section 125-385)	1974	86.835	32		86.835		
12	OHTL 400 kV Brazi Vest-Dârste (section 245-357)	1973	35.5	33		35.5		
13	OHTL 400 kV Bradu-Braşov (section 302-456)	1980	50.7	26	50.7			
14	OHTL 400 kV Ţânţăreni –Sibiu (section 616-754)	1966	47.302	40			47.302	
15	OHTL 400 kV Sibiu Sud-Braşov	1969	125.3	37			125.3	
16	OHTL 400 kV Dârste-Braşov	1977	13.2	29	13.2			
17	OHTL 400 kV Mintia –Sibiu Sud (section 131-407)	1971	87.327	35		87.327		
18	OHTL 400 kV Iernut-Sibiu Sud	1966	81.62	40			81.62	
TOTAL			987.375		198.125	294.795	254.222	240.233

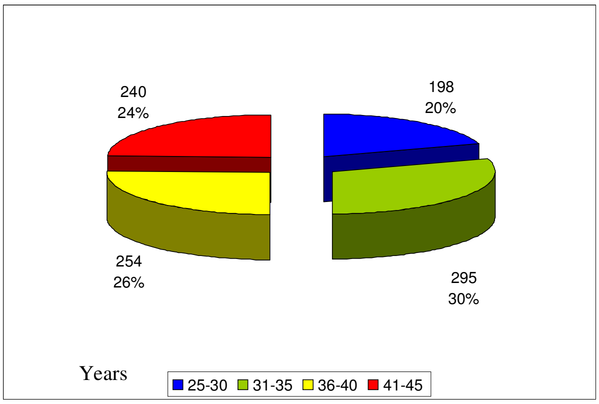

Fig. 1. The length of the lines from age point of view

Works of current and capital repairs have been executed, especially paintings, towers consolidation by mounting additional markings on sections and cornices, supplementing the missing markings and replacing the deformed ones, replacement of the anchors of the portal guyed towers, replacement of porcelain insulators with glass or composite insulators (in areas hard to reach), replacement of galvanized steel shieldwires.

In Fig. 2, the lengths of lines which had undergone repairs are specified (in km and %).

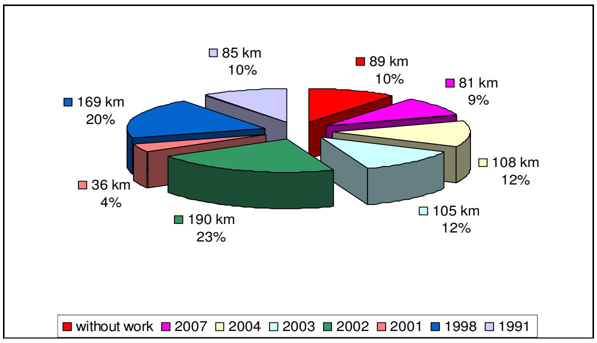

Fig. 2. The length of the lines from maintenance point of view

Lines designed and manufactured prior to 1980 were especially equipped with porcelain insulators. Given that after 25-30 years the porcelain insulations age, their electrical and mechanical properties no longer appropriate, these insulators were replaced.

In Fig.3 the duration of exploitation of the insulation is shown, with the note that the insulation is now changed with glass or composite material.

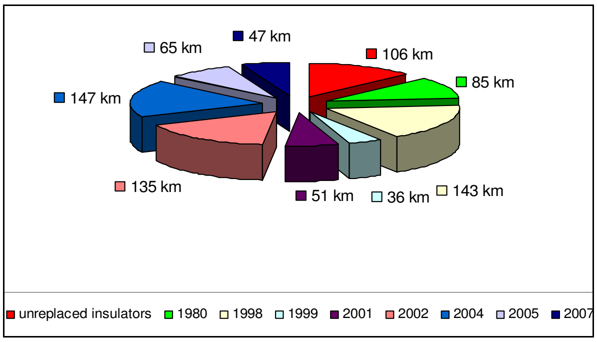

Fig. 3. The length of the lines from insulator point of view

If for the towers angles the maintenance works (changes and supplementation of missing or corroded elements, anticorrosive protection, etc.) can extend the lifespan, for the anchoring cables of the portal towers the lifespan is conditioned by initial layer thickness of zinc coverage that is estimated at 40-45 years.

Fig. 4 shows the operation times of the anchors of guyed tower (portal) with the note that there are about 72 km from the OHTL where the anchors are operating since the lines were first operated.

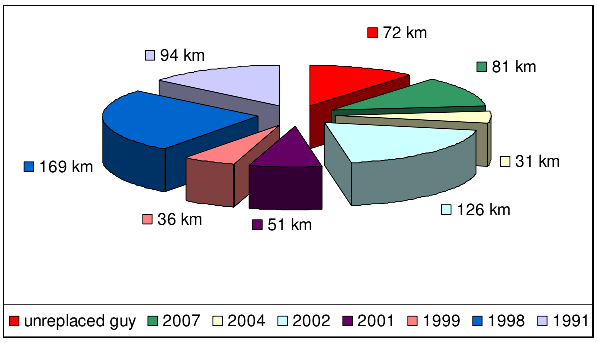

Fig. 4. The length of the lines from gay point of view

III. Lifespan of OHTL structural elements

The analyses performed for over 180.000 km of lines from 13 countries (as Germany, Canada, France, Sweden, USA, England, Iran, Brazil and Poland) have shown an average of 54 years lifespan with a 14 years deviation, while for the polluted areas the lifespan is 46 years with a 15 years deviation.

This broad distribution can be explained by:

- different construction and repairs policies of the network and therefore different levels of lines loading;
- different climate and environment conditions;
- corrosion level;
- quality of the materials employed;
- following the maintenance programme;
- different lifespan of the components.

There are still operating electrical lines build in 1930-1940 even if the NES has registered a peak in the transport lines construction in 1960s.

Lines' aging is due to damaging (physical usage, technical status) and technological usage (moral usage).

The damaging rate depends on:

- the age;
- operating mode (the load, the number of connections/disconnections);
- way of applying maintenance programmes.

Technological usage refers to:

- maintenance cost ;
- difficulty in obtaining replacement parts;
- lack of qualified personnel for the respective technologies;
- non-compliance with the newest technical prescriptions.

To estimate the lifespan of a line, the lifespan of the components have to be considered.

A. Foundations

The durability of the foundations that directly influences the behaviour of every other OHTL components is guaranteed by assuring the following demands:

- adequate design according to mechanical requirements, geological, hydrological and aggressively conditions of the locations;
- correct execution complying with the projects and standards and employing quality materials as specified;
- systematic follow-up in operation and on time remedy of deficiencies.

Main deficiencies are the use of non-corresponding concretes, lack of plaster adherence, cracks and tears in the foundation cap, luft at the metallic foot, aggressive underground waters.

A good execution of the foundations and in time repair of the deficiencies guarantees a long life span (80-100 years) that excels the lifespan of the other elements.

On the basis of criteria b, c, d and e, the following are resulting for the OHTL foundations:

- recent maintenance works were performed on 16 of the 18 OHTL (1998-2006) and that implied the integral repair of the deficiencies;
- no damages of the foundations (as uplifting and displacements) were to be found during operating time except

in the areas with earth flows;

- the technical state of the 18 OHTL foundations is adequate;
- the mechanical resistance (portent capacity) of the foundations frames into the one considered when OHTL was initially designed.

However, the following have to be emphasized:

- lack of sampling and laboratory testing does not allow a precise evaluation of the remanent lifespan;
- the foundations of the OHTL towers are dispersed on dozens of kilometres with very diverse geological, hydrological and aggressively conditions, therefore the evaluation can cover 80-90% of the foundations.

B. Towers

Together with the foundations, towers are the resistance structure of a OHTL; their durability directly influences the equipment (conductors, insulation).

The execution works of the towers are very difficult, requiring the presence of hard weight equipment at any site and handling of hundred or even thousand laminate tons.

For a correct execution that follows the projects and standard materials, the lifespan of the towers depends on the on time repair of the deficiencies (laminate replacement/doubling, complete the lacking bars or bolts etc) and especially on their anticorrosive protection.

At the internal level, the majority of the towers are protected against corrosion by paintings.

Following the painting cycles and their correct execution ensures a satisfying protection, however:

- At all joints between tower trunks, generally composed of three elements (external gusset, main member and inner fish-plate), an appropriate anticorrosive protection cannot be performed unless by dismantling them, that is impossible to be performed with mounted conductors as they are bars with too high efforts;
- Painting works of the towers are very difficult and performed at height, therefore their quality is affected. Moreover, they are very difficult to be verified especially in the cornice area.

On the basis of criteria b, c, d and e, the following are resulting for the OHTL towers in Sibiu branch:

- recent maintenance works for the 16 OHTL have included integral painting of the towers;
- no incidents/damages during the operation time (towers falling) have been detected;
- the current technical state of the towers from the 16 OHTL is satisfactory;
- the mechanical resistance of the towers, as calculated for the most representative towers from the number point of view, is good, it only requires minor consolidations for a small number of towers.

Therefore the estimated lifespan of the towers is 70-80 years.

The following have to be emphasized:

- the lack of mechanical tests and of metallographic samples does not allow a précised estimation of the remanent life time. In establishing this lifespan, the operation experience and the good behaviour of the towers in special areas (mountain) characterized by higher transversal and longitudinal efforts as a result of wind, white frost depositions and humidity over 80% has been considered.
- the towers of the same OHTL are placed in aggressive and different meteorological conditions.

Therefore, as for the foundations case, in the absence of laboratory samples the evaluation covers 80-90% of the towers of an OHTL.

C. Anchoring systems

The main issue of the component cables of the anchoring systems is the anticorrosive protection.

Because of the reduced section of the component wires, the zinc coverage is smaller than the one of the towers laminates, maximum 230 g/m^2 compared to 650 g/m^2.

Therefore the lifespan of the anchors is smaller than the one of the towers.

Laboratory samples have shown that after 30-35 years of operating, the zinc coverage has disappeared from all the component wires (including the central one).

The corrosion process is accelerated and cannot be controlled when the zinc coverage is absent.

Therefore the lifespan of the anchors is estimated to 40-45 years (lifespan that ensures normal operation).

D. Phase conductors

The results from testing hundreds of steel-aluminium conductors in Romania during 1984-2005 have emphasized the following:

- the values of the resistance to breaking of the steel-aluminium conductors sampled from OHTL with a operation time between 7 and 28 years, located in non-aggressive or weak aggressive areas , have varied between 85 and 95% of the calculated breaking burden;
- the values of the resistance to breaking of the conductors from the lines located in aggressive areas have varied between 70 and 80% of the calculated breaking burden.

The detailed exams performed in France on samples of old conductors (20-30 years of operation) have confirmed the results obtained in our country that have determined a very good behaviour of steel-aluminium conductors during operation. Thus:

- no serious damages of the conductors located in non-aggressive areas determined by corrosion with significant conductance losses not have been detected;
- internal corrosion is more pronounced in areas adjacent to the clamping points where wires unbinding are detected;
- internal corrosion is more pronounced when only the steel heart has been greased;
- no aluminium advanced corrosions have been detected in the absence of corrosions of the protecting coverage of the steel heart.

Trials of electrical resistance, mechanical traction and fatigue performed in Canada on conductors sampled from a not in use, 65 years old 132 kV OHTL has shown the following:

- in non-aggressive (or low aggressive) areas, the conductor’s damages were minor;
- in aggressive and very aggressive areas the conductors

have reached the final point of the lifespan, they couldn't have been used not even as a pilot wire for mounting new conductors.

Therefore, in normal operation conditions, in weak polluted areas, chemically non-aggressive and without excessive humidity, the lifespan of steel-aluminium conductors is estimated as 80-85 years, higher than the normal lines lifespan.

E. SHIELD WIRES

The shieldwires have a random lifespan conditioned by the thickness of the zinc layer on the component steel wires, by the quality of wire roping (a tight roping does not allow the entrance of corrosive agents in the inferior layers) and by the aggressivity class of the area where the electrical over ground line is passing through.

The tests performed on samples of steel conductors from the operating lines located in our country have shown that:

- the values of breaking resistance have varied between 70 and 90% of the calculated breaking load of the steel conductors sampled from OHTL with an operating time of 16-25 years and located in non-aggressive or weak aggressive areas;
- the values of breaking resistance have varied between 40 and 70% of the calculated breaking weight of the steel conductors sampled from OHTL with operating time of 4-16 years and located in aggressive areas ;
- the values of the breaking resistance for the wires within the external layer of the zinc steel conductors are 40 and 60% compared to the ones of the wires from within the internal layers because of the different corrosion grade which can be detected by the general aspect of the wires.

Because the OHTL resistance structure (foundations and towers) and the active conductors represent the major share of the investing cost of the lines - over 80% - (Fig. 5a., 5b, 5c and Table 2), and the performance of replacing works for these three components is difficult, employing high amounts of materials that require permanent presence during the work of high weight equipment and line disconnection, the estimation of OHTL lifespan will consider the lifespan of the three major components – foundations, towers and active conductors.

According to the mentioned data, the estimated lifespan for the components are:

- line's towers 70-80 years;
- line's foundations 80-100 years;
- aluminium-steel conductors 80-85 years;
- steel conductors 20-30 years;
- PAS towers' anchors 40-45 years;
- Glass insulation 35-45 years;
- Composite material insulation 25-30 years.

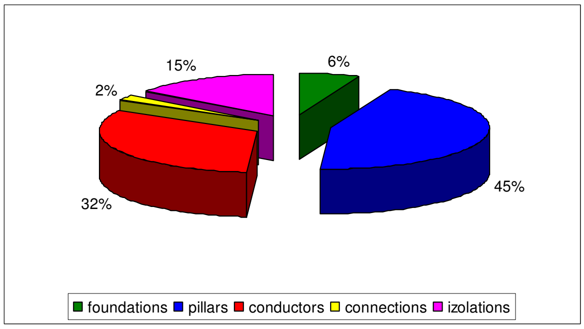

Fig. 5a. Share of component elements from the total cost of a 220 kV s.c. OHTL

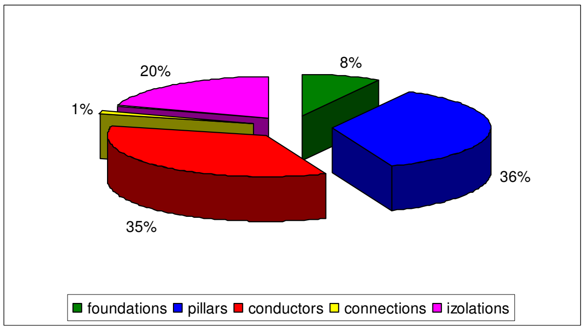

Fig. 5b. Share of component elements from the total cost of a 220 kV s.c. OHTL

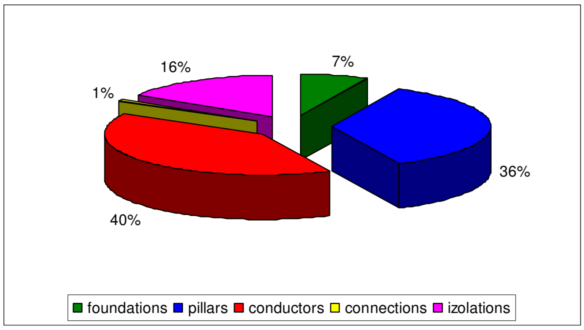

Fig. 5c. The share of component elements from the total cost corresponding to a 400 kV s.c. OHTL

Table 2

Components	OHTL 220 kV simple circuit	OHTL 220 kV double circuit	OHTL 400 kV simple circuit
Foundations	6%	8%	7%
Towers	45%	36%	36%
Connections	2%	1%	1%
Conductors	32%	35%	40%
Isolation	15%	20%	16%

From the three major components, the towers have the lowest estimated lifespan as a result of anticorrosive protection performed almost integrally by painting in Romania and not by hot-dip galvanizing.

Therefore it can be estimated that the lifespan of an OHTL is identical with the one of the towers, 70-80 years, 70-75 years for OHTL with anchored portal towers and 75-80 years for OHTL with autoportant towers.

Fig. 6 presents the diagram including the estimated lifespans for the 18 OHTL. These life spans were estimated considering that the periodical current and capital maintenance programmes are and will be respected and in the absence of tests on samples from different constructive elements of the line. The life spans can be redefined after sampling and testing. It is assumed that the resulting values will have some deviations (-15%; +5%) compared with the ones estimated in this study.

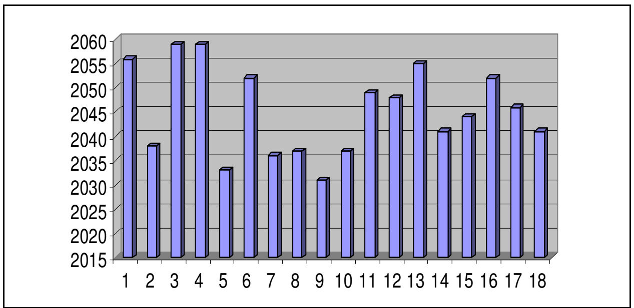

Fig. 6. The estimated life time for OHTL administrated by ST Sibiu

IV. Proposals for maintaining at required performances the transport lines from Sibiu branch

The necessary measures for preventive maintenance of the transport line in Sibiu branch are proposed in the following.

This program of measures will consider, as previously shown in this paper's chapters, the following criteria:

- technical state of the lines;
- the role in NES;
- for each line marks from 1 to 10 will be given for each criteria; the lines with higher marks will require more urgent maintenance works;
- The value of the marks will consider the existence of maintenance works, their scope, the period of being carried out, the predicted system investments and the consumed part of the lifespan.

Thus:

- Marks from 1 to 10 if the line's state is good to poor;
- From 1 to 10 if the line's importance is small to large;
- From 1 to 10 if the rate of failure is low to high.

The results are showed in Table 3.

Table 3

Line	Technical state	The role in system	Age	Total score
1. 220 kV OHTL Iernut – Ungheni - 2	6	8	4	18
2. 220 kV OHTL Cluj Floreşti – Alba Iulia	6	10	10	26
3. 220 kV OHTL Alba Iulia – Şugag	4	6	5	15
4. 220 kV OHTL Alba iulia – Gâlceag	4	6	5	15
5. 220 kV OHTL Mintia - Alba Iulia	3	9	10	22
6. 220 kV OHTL d.c. Lotru – Sibiu Sud	8	7	7	22
7. 220 kV OHTL Ungheni – Fântânele	9	9	10	28
8. 220 kV OHTL Fântânele – Gheorghieni	9	9	10	28
9. 220 kV OHTL Iernut – Ungheni – 1	9	7	10	26
10. 220 kV OHTL Stejaru – Gheorghieni	9	9	10	28
11. 400 kV OHTL Gutinaş – Braşov	6	8	7	21
12. 400 kV OHTL Brazi Vest – Dârste	6	4	7	17
13. 400 kV OHTL Bradu - Braşov	2	5	4	11
14. 400 kV OHTL Ţânţăreni – Sibiu Sud	2	10	9	21
15. 400 kV OHTL Sibiu Sud - Braşov	1	5	8	14
16. 400 kV OHTL Braşov – Dârste	1	4	6	11
17. 400 kV OHTL Sibiu – Mintia	8	7	8	23
18. 400 kV OHTL Sibiu Sud - Iernut	8	10	9	27

According to the data presented in this study, the necessity of performing maintenance works to ensure the estimated life span of OHTL and their priorities are underlined.

Stage I.

The sampling for testing has to be performed for each line group resulted from the application of operation time criteria. Samplings will be obtained from the oldest lines and from the ones in area with special climate (mountains area).

Promoting major maintenance works for:

- OHTL 220 kV Iernut-Ungheni 2;
- OHTL 220 kV Ungheni-Fântânele;
- OHTL 400 kV Iernut-Sibiu.

Redesign of maintenance works of the stopped works on OHTL 220 kV Fantanele- Gheorghieni and Gheorghieni-Stejaru adopting only live-line procedures.

Stage II.

Replacing all the anchors for all the portal towers anchored on OHTL 400 kV Dârste-Braşov.

Total replacement of existing AlOl 400/75 conductors with 450/75 ALOL section.

Stage III.

Consolidating auto-portants towers by installing diaphragms (rigid sections) preferably to all levels where horizontals members with effort exist (from calculation).

Stage IV.

Limiting very long panels by installing anti-cascade towers using the two variants:

- consolidating specific current towers;
- replacement with more resistant towers, according to the correlation coefficient of the portent capacity (1,0 sustaining tower, 1,1 anti-cascade tower, 1,2 top stretching or corner panel tower).
- gradual replacement portal towers anchored on 220 kV OHTL ;
- total replacement of two frequencies anti-vibration dampers with ones with four frequencies;
- total replacement of type U bolts;
- mounting armour rods and corresponding suspension clamps for all the suspension towers that have not undergone replacement of the old 60' supsension clamps.

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VI. Biographies

George Alexandru Florea (M’2001, SM’2002) was born in Bucharest, Romania, on October, 1, 1947 and received a Dipl. in Electric Power Engineering in 1970 and a Doctor’s degree in High Voltage Engineering in 1985, both from University Politehnica Bucharest, Romania. His employment experience includes the Institute of Power Studies and Design, Bucharest, Romelectro Foreign Trade Company, Bucharest, Tehnorob Ltd, Bucharest, Power & Lighting Thnorob S. A., Bucharest. His special fields of interest include the design of powerlines, surge propagation on transmission and distribution lines, electromagnetic field of electric network effect on biological systems and live-line maintenance methods.

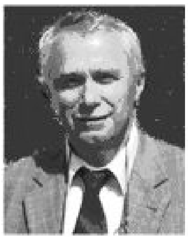
Stelian Iuliu Alexandru Gal was born in Jimbolia, Romania, on July, 2, 1947 and received a Dipl. in Electromecanical Engineering in 1970 and a Doctor’s degree in Digital Distance Protection for Power Systems in 1994, both from University Politehnica Timisoara, Romania. His employment experience include: Romania National Power Grid Company “Transelectrica”- S.A. – Sibiu Regional Branch and Headquarter, Romania. His special fields of interest include the live-line maintenance work technologies and different protection systems of electric network.

Laurentiu Constantin Lipan (M’2003) was born in Hunedoara, Romania, on June, 28, 1975 and received a Dipl. in Electric Power Engineering in 2001 with University poltehnica Bucharest. At this time is following the Ph.D stage, with University Politehnica Bucharest, Romania. He is currently working within the University Poltehnica Bucharest.

His special fields of interest include unconventional energy sources, the improvement of electric power quality and life-line maintenance technologies.

Emil Kaytar was born in Bucharest in Romania, on May 10, 1964. He gratuated from the Bucharest Polytechnic University. He works since 1988 in Institute for Studies and Power Engineering at Power T&D Division. Now he is OHTLs Head of Department. His special fields of interest include the design of powerlines and live-line maintenance methods.

Ioan Rodean was born in Sibiu, Romania, on April, 14, 1953 and received a Dipl. in Electric Power Engineering in 1978 from University Politehnica Bucharest, Romania and a Master’s degree in Electroheat in 1999 from University Lucian Blaga Sibiu. His employment experience includes the I.J.G.C.L. Sibiu – mechanical and electrical power services, Trust Electromontaj Bucharest - G.S.E.M. Bacau, Romania National Power Grid Company “Transelectrica”- S.A. – Sibiu Regional Branch – transmission system operation Sibiu. His special fields of interest include: transformer diagnosis methods, methods and models of system management, SCADA decision optimizing for substations.



Vasile Metiu was born in Aciliu, Romania, on August, 11, 1953 and received a Dipl. in Electric Power Engineering in 1979 from University Politehnica Bucharest, Romania. His employment experience includes the Romania National Power Grid Company “Transelectrica”- S.A. – Sibiu Regional Branch. His special fields of interest: operation and maintenance of the transmission lines.