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Determining of the Real Condition of High-Voltage Overhead Power Lines

Aleksandar Simović
Faculty of Electrical Engineering, University of East Sarajevo, Vuka Karadžića 30, East Sarajevo 71123, Bosnia and Herzegovina

Abstract: Significant investments have been made regarding the construction of a great number of high-voltage overhead power lines of all voltage levels, and now the questions arise on where and how to direct the investments necessary for the maintenance of overhead power lines. To organise the process of maintenance of overhead power lines correctly, it is necessary to have the current information on the condition of particular components of a line. In this paper, special attention has been paid to the real condition of overhead power lines, with the aim of making the decision whether some of the following measures are necessary, and to what extent: the revitalisation for a certain number of years is perceived, the revitalisation up to five years and reconstruction of the overhead power line is performed, its restoration is performed or nothing is done. The approach to the perceiving of real condition of high-voltage overhead power lines is presented on a global block diagram. With the aim of setting out the list of priorities for revitalisation, the criteria have been defined with regards to the real condition of particular components of an overhead power line, as well as pursuant to the role and importance in an electric power system. The correctly defined criteria contribute to the solving of the problem of making a single list of priorities for the revitalisation of high-voltage overhead power lines. In that way, the recommendations are being given to the transmission companies, to achieve a higher reliability of an electric power system, with a minimum number of cancellations and a maximum extension of working life of all the components of overhead power lines. A correct maintenance of overhead power lines brings large financial savings to the owners of transmission companies, and that is the primary goal in a deregulated environment.

Key words: High-voltage overhead power line, real condition, reliability.

Abbreviations

HV	High-voltage
OPL	Overhead power line
EPS	Electrical power systems

1. Introduction

In the second half of the 20th century, a fast and intensive construction of HV (high voltage) OPLs (overhead power lines) occurred. The planned and designed working life of electrical equipment (conductor, shield wire, insulator and jointing equipment) is about 40 years, and for the construction equipment (pole and basis) it is about 80 years. With the aim of preventing the decrease of security in supplying the consumers with electricity, it is necessary to implement the actions of investment maintenance on HV OPLs [1-5]. These actions, almost as a rule, require radical technical and financial operations. In the work of electrical grids, there are insufficient experiences relating to the ageing and expected working time of the equipment. It is very important to evaluate the real condition of particular components of an OPL in an appropriate manner. An important decision of owners of transmission OPLs is the timely making of decisions, so that the working time of OPLs may be extended, as well as the increase of operational safety and security of OPLs and the increase of capacity of an OPL for 15-70% with the installation of new conductors. The important thing is to perceive the current condition of the HV OPLs, so that the need for some possible actions may be identified, with the exactly determined manner and extent, all that with the aim of preserving the reliability of an EPS (electric power system) and the security in supplying the consumers with electricity [6-12].

Corresponding author: Aleksandar Simović, Ph.D., Eng., research field: revitalization of high-voltage overhead power lines.

2. Designed Solution of HV OPLs

The first step in the decrease of maintenance costs is the correct design and construction of an overhead power line. At the analysis of the design solution of an HV OPL, it is necessary to pay special attention to the project task, climate conditions (wind pressure, additional load, isokeraunic level, air humidity and degree of pollution), route of the line, safety heights and distances in intersecting of the line with other objects.

3. Real Condition of HV OPLs

The decision on whether it is necessary to revitalise HV OPLs and to what extent is very important, so that it is necessary to set out and define the criteria for revitalisation, because the decision on the extent and manner of revitalisation of HV OPLs is made pursuant to the criteria. Block diagram of the real condition of HV OPLs is shown in Fig. 1.

To determine the real condition of HV OPLs, it is necessary to perform a set of activities, and some of the activities are the following ones: perform a detailed examination of OPLs, perform the analysis of the behaviour of OPLs in operation, perform the evaluation of particular components of OPLs and set out the necessary and sufficient conditions.

3.1 Detailed Examination of HV OPLs

To perceive the real condition of HV OPLs it is necessary to perform a detailed examination, with a compulsory participation of technical persons, as well as to perform certain measurements, and all that pursuant to a work programme was made before. A detailed examination of OPLs is discussed in "The report from a detailed examination of OPLs". The report contains all the observations considered as significant and made at the interventions and repairing, as well as the evaluation of the condition of equipment and the relation of OPLs with other objects. Pursuant to the instruction for a detailed examination of OPLs, the examination of the current status of the components of OPLs is performed, as follows:

- condition of concrete bases of poles,
- general observations at the pole and in the span,
- condition of steel lattice towers,
- condition of guy wires and anchor plates,
- condition of grounding of poles,
- condition of jointing equipment,
- condition of insulators,
- condition of supporting and tension clamps at the conductor and the shield wire,
- condition of conductors along the entire route of OPLs,
- condition of the shield wire along the entire route of OPLs and,
- intersecting of the line with other objects.

In the text that follows, particular current conditions of particular components of HV OPLs are discussed.

3.1.1 Overview of Status of Condition of Construction and Electrical Equipment on HV OPLs

At the overview of HV OPLs it is necessary to pay special attention to the following:

(1) Condition of the concrete bases of poles: cracks, damage, condition of bases at the places where the grounding resistance check is performed, covering of bases by soil, grown trees.

(2) Condition of concrete poles: damage of concrete and visibility of armature of its body, cracks and fissures of the body and top of the pole, status of consoles, whether there is visible damage to the concrete, in terms of cracks or fissures.

(3) Condition of grounding of poles: separate the grounding on a few poles and see the status of the clamp and the contact place of the grounding with main legs. It is also necessary to perform the examination of the grounding in the ground in a few pole places (at least three).

(4) Condition of steel lattice towers: damage of construction of towers and bolts, condition of painting works on the construction of towers and bolts, unscrew a few bolts on the extensions and console part of a few poles and it is necessary to describe their condition.

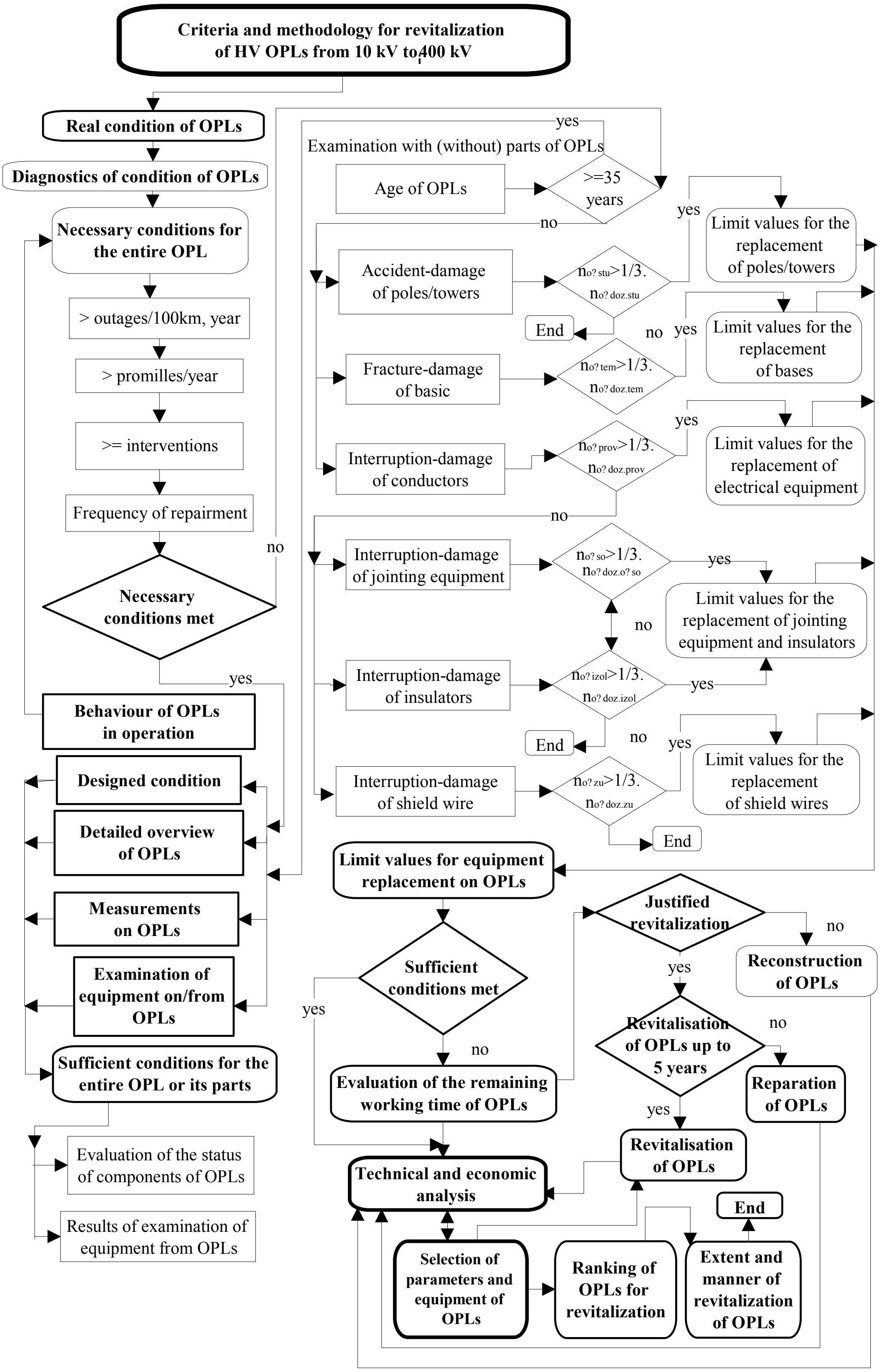

Fig. 1 Block diagram of the real condition of HV OPLs from 10 kV to 400 kV.

(5) Condition of jointing equipment: damage and corrosion of parts and bolts, condition of the jointing equipment, manufacturer of the jointing equipment, manner of fixing of the supporting and tensile chains to the console of the pole, register the overshoots, both on the parts of jointing equipment and on the surrounding metal parts of the pole.

(6) Condition of insulators: number and type of insulators in a chain and the number of chains per a phase on every pole, year of manufacture of insulators and the manufacturer, damage of insulators and dirtiness.

(7) Condition of supporting and tension clamps at the conductor and shield wire: type of tension clamps, corrosion and damage (by visual observation), remove the supporting clamp from the conductor and the shield wire on some poles and examine the condition of the conductor and the shield wire at the part where it passes through the clamp (at least at three places).

(8) Condition of conductors along the entire route of OPLs: determine the structure of conductors, record all the extensions of conductors with stating the type of extension coupling and the distance from the pole, determine the status of conductors on every pole at the entry into the supporting or tension clams and check if the conductor is wrapped with aluminium foil inside the clamp, dismantle the tension bridge in some tension poles, record the condition of electricity clamps and of conductors within the clamps.

(9) Condition of shield wire along the entire route of OPLs: register the structure of the shield wire in every tension field, general condition of the shield wire, record all the extensions of conductors with stating the type of extension coupling and the distance from the pole, examine the wire at its entry into the clamp on every pole and register possible sparking, register whether there is an additional connection, its type and condition.

(10) On the basis of insight into the technical and operational documentation, as well as the condition of OPLs, the places from which the samples will be taken for testing (of conductors, shield wire, insulators and insulating chain), and also the ranges for the sag control.

3.1.2 Intersecting of HV OPLs with Other Objects

It is necessary to register all the intersectings of a line with other objects, and for the objects which did not exist when the line was constructed, the relation with OPLs should be recorded or sketched. Register all the intersectings of OPLs with other objects:

(a) HV lines and LV networks,

(b) telephone and telegraph lines,

(c) roads (field, local, regional, highway, etc.),

(d) canals for irrigation, drainage, for sailing,

(e) railroads (local, industrial, etc.),

(f) gas lines, oil pipelines or pipelines of other purpose,

(g) orchards and plantation orchards,

(h) single trees or groups of trees in the OPL corridor,

(i) plantation vineyards and similar,

(j) wire fences around gardens, orchards, vineyards,

(k) register the type of trees, condition and width of the corridor, whether its expansion is necessary,

(l) register and record all the cases of intersecting and getting close to OPLs.

3.1.3 Measurement of the Sag of the Conductors and Shield Wire

The control of safety heights on 110 kV OPLs is performed in all tension fields and in one or more spans. The criteria for setting out a span, taking care that the height between the designed chainstitch which denotes the safety band and the ground point is minimal, are the following ones:

- significant intersecting of the line with other objects,
- span significantly higher than the ideal one,
- one span for a tension field of up to five spans,
- two spans for a tension field of more than five spans.

It is necessary to measure the angle of the conductor and the shield wire through the sighting method, and where the distance of conductor from the ground is suspicious. The measure should be performed by a theodolite, optical instrument for height measurement, by switching the wire.

The measurement results will serve in giving the bases for the design of revitalisation of OPLs to provide the conditions for coordinating OPLs with other objects.

3.1.4 Measurement of Ground Resistance of Poles

It is necessary to perform the measurement of ground resistance of poles with and without the influence of the shield wire. At the measurement, it is necessary to register the following information:

- date and hour of the measurement of ground resistance,
- air temperature (°C),
- time of last raining (how many days ago),
- humidity of ground (descriptive),
- type of ground (black soil, clay, sand or other),
- data on the instrument (type and label),
- measured ground resistance value with the shield wire connected,
- measured ground resistance value without the shield wire,
- naming of the person who performed the ground resistance measurement.

It is necessary to systematise the results of the ground resistance measurement obtained before putting the OPL in operation and during the operation, i.e. until the moment of perceiving the need for revitalisation. The real condition of grounding and the results of measurement of ground resistance of poles are the basis for obtaining the proposal for the range and manner of revitalisation.

3.1.5 Insulation Resistance Measurement

To obtain the conclusions on the condition of insulation, i.e. of insulators, it is necessary to perform the insulator resistance measurement. It is necessary to perform the measurement with an insulation tester of up to 5 kV, registering the following information:

- date and hour of the insulator resistance measurement,
- ambient temperature (°C),
- relative humidity of the air,
- data on the instrument (type and label),
- naming of the person who performed the ground resistance measurement.

It is necessary to perform the measurement at different relative humidity of the air, because of a more real evaluation of the insulation condition.

4. Behaviour of HV OPLs in Operation

It is necessary to input into the database the main information on all HV OPLs and their parts. To perceive a complete image of every single OPL, as well as of certain groups of OPLs, it is necessary to perform the analysis of behaviour of OPLs in operation for a time period which is as long as possible. The minimal observation period of OPLs in operation should be:

- five years for outages of OPLs,
- ten years for interventions on OPLs,
- ten years for replaced insulators on OPLs and
- five years for meteorological phenomena along the route of OPLs.

The most important information in the diagnostics of condition of OPLs is the number of line outages. The term outage implies the loss of electricity in a network component without any human intervention, by shutting down of a switch under the activity of protection devices. A database contains the following information: number of OPLs; year, month, day, hour and minute when the outage occurred, phase on which the outage occurred and type of outage (successful automatic restoration, unsuccessful automatic restoration, or without automatic restoration). Eq. (1) presents the number of outages of one or more OPLs for the time period of less than one year, for one year and for a few years:

$$\bar{n}_{isp.} = \frac{100}{\sum_{i=1}^{n_{NV}} L_{km\,i}} \cdot \frac{12}{\sum_{i=1}^{n_{NV}} n_{mjes\,i}} \cdot n_{NV} \cdot \sum_{i-1}^{n_{NV}} n_{isp\,i} \qquad (1)$$

where:

$\bar{n}_{isp.}$—number of line outages at 100 km per year,

n_{NV}—number of observed lines,

L_{kmi}—length of i^{th} line,

n_{mjesi}—number of months in operation of i^{th} line,

n_{ispi}—number of outages of i^{th} line.

The term intervention implies the going out to the OPL due to a permanent line outage. The causes for the performance of interventions are divided in two groups: accidents for poles, fractures for bases and interruptions-damage for electrical equipment. Eq. (2) presents the number of interventions of one or more OPLs for the time period of less than one year, for one year and for a few years:

$$\bar{n}_{interv.} = \frac{100}{\sum_{i=1}^{n_{NV}} L_{km\,i}} \cdot \frac{12}{\sum_{i=1}^{n_{NV}} n_{mjes_i}} \cdot n_{NV} \cdot \sum_{i-1}^{n_{NV}} n_{interv_i} \qquad (2)$$

where:

$\bar{n}_{interv.}$—number of line interventions at 100 km per year,

n_{NV}—number of observed lines,

L_{kmi}—length of i_{th} line,

n_{mjesi}—number of months in operation of i_{th} line,

$n_{intervi}$—number of interventions of i_{th} line.

The data on the replaced insulators are very important in making the decisions relating to the revitalisation of OPLs. Eq. (3) is shown for the replaced insulators of one or more lines for the time period of less than one year, for one year and for a few years:

$$\bar{n}_{iz.} = \frac{\sum_{j=1}^{n_{NV}} n_{ost.iz_j}}{\sum_{j=1}^{n_{NV}} n_{iz_j}} \cdot \frac{12}{\sum_{j=1}^{n_{NV}} n_{mjes_j}} \cdot n_{NV} \cdot 1000 \qquad (3)$$

where:

$\bar{n}_{iz.}$—number of replaces insulators in permille per year,

n_{NV}—number of observed lines,

$n_{ost.izj}$—number of damaged insulators of j_{th} line,

n_{izj}—number of insulators of j_{th} line,

n_{mjesj}—number of months in operation of of j_{th} line.

The data recorded on meteorological conditions in the time of outage near the place of the fault are relatively new and, due to that, for a great number of OPLs, especially with voltage level lower than 110 kV, there are mostly no data. However, these data, in the places where they exist, may significantly influence the decision making on the manner of revitalisation of a line, but it is necessary to emphasise that all the necessary data are collected, such as: time of outage, ambient temperature, relative humidity and type of meteorological phenomenon. Eq. (4) is shown for the meteorological phenomena along one OPL route for the time period of less than one year, for one year and for a few years:

$$\bar{n}_{met.poj.} = \frac{n_{poj.}}{n_{isp.}} \qquad (4)$$

where:

$\bar{n}_{met.poj.}$—participation of a meteorological phenomenon in percentage terms,

n_{poj}—number of phenomena,

n_{isp}—number of outages.

Very important data are related to the repairments on HV OPLs. Repairment is the work aiming at preserving an object in an operationally correct condition by major fixes and replacement of worn out parts, within the limits of operational needs. The relevant data on the repairments of OPLs, that is of its components, i.e. the frequency of repairment, are entered into the database. Eq. (5) presents the repairments of one or more OPLs for the time period of less than one year, for one year and for a few years:

$$\bar{n}_{rem.} = \frac{100}{\sum_{i=1}^{n_{NV}} L_{km_i}} \cdot \frac{12}{\sum_{i=1}^{n_{NV}} n_{mjes_i}} \cdot n_{NV} \cdot \sum_{i-1}^{n_{NV}} n_{rem_i} \qquad (5)$$

where:

$\bar{n}_{rem.}$—number of days of line reparation in 100 km per year,

n_{NV}—number of observed lines,

L_{kmi}—length of i_{th} line,

n_{mjesi}—number of months in operation of i_{th} line,

n_{remi}—number of days of reparation of i_{th} line.

5. Evaluation of Condition of Particular Components on HV OPLs

The evaluation of equipment condition of a single OPL depends on the condition of particular equipment, i.e. on whether the equipment may withstand the stipulated electromechanical loads without permanent deformations which will disturb the continuous operation of the line. The decision on the evaluation of condition of particular equipment of a line is very important and responsible.

5.1 Evaluation of Condition of Poles/Towers and Bases

The evaluation of condition of steel lattice towers mostly depends on the degree of corrosion. If the anti-corrosion protection is performed regularly, the working time of towers is 80 years. The towers are kept if after the examination of the tower elements or by means of static examinations are determined that the safety factor (k_{sig}) ≥ is 1.5 in particular cross-sections.

The evaluation of condition of concrete poles mostly depends on the quality of its initial construction. If the repairing is performed regularly, so that the armature does not get in touch with external environment, the working time of poles may be ≥ 60 years, so before the deciding on the replacement of electrical equipment it is necessary to pay special attention, and it is compulsorily necessary to perform a technical-economic analysis.

The evaluation of the condition of bases depends on mechanical damage and the quality of construction of foundation.

5.2 Evaluation of Condition of Conductors

The evaluation of condition of conductors mostly depends on the degree of corrosion and vibrations. A conductor is kept if after the examination its breaking strength is at least 2.5 times higher than the normal allowed strain, and it can be presented by a formula:

$$\sigma_{nd.pr} = 0.4 \cdot \sigma_{pr.cv} \left[daN/mm^2 \right] \tag{6}$$

$$K_{\min} = \frac{\sigma_{pr.cv}}{\sigma_{nd.pr}} \geq 2.5 \tag{7}$$

$$\sigma_{pr.cv} = 2.5 \cdot \sigma_{nd.pr} \left[daN/mm^2 \right] \tag{8}$$

$$\sigma_{pr.cv} = \frac{P_{kid}}{S_{pr}} = 0.9 \cdot \frac{P_{rac}}{S_{pr}} \left[daN/mm^2 \right] \tag{9}$$

The safety factor of a conductor is calculated pursuant to Eq. (10):

$$K_{sig.pr} = 0.9 \cdot \frac{P_{rac}}{S_{pr} \cdot \sigma_{mr.pr}} \tag{10}$$

In the relation of these two factors, the allowed decrease of calculated breaking force of a conductor is obtained:

$$\Delta P_{rac} \leq \frac{K_{sig.pr} - K_{\min}}{K_{sig.pr}} \cdot 100 [\%] \tag{11}$$

The following symbols have been used:

$\sigma_{\text{nd.pr}}$ (daN/mm^2)—normal allowed strain of a conductor,

$\sigma_{\text{pr.cv}}$ (daN/mm^2)—breaking strength of a conductor,

$\sigma_{\text{mr.pr}}$ (daN/mm^2)—maximum operational strain of a conductor,

P_{kid} (daN)—breaking force of a conductor,

P_{rac} (daN)—calculated breaking force of a conductor,

S_{pr} (mm^2)—calculated cross-section of a conductor,

K_{min}—minimal safety factor pursuant to the regulations,

$K_{\text{sig.pr}}$—safety factor per project,

ΔP_{rac} (%)—allowed decrease of calculated breaking force of a conductor.

5.3 Evaluation of Condition of Shield Wire

Evaluation of condition of a shield wire primarily depends on the degree of corrosion. The shield wire is kept if after the examination its breaking strength is at least 2.5 times higher than the normal allowed strain, and it can be presented by a formula:

$$\sigma_{nd.zu} = 0.4 \cdot \sigma_{nd.cv} \left[daN/mm^2\right] \quad (12)$$

$$K_{\min} = \frac{\sigma_{pr.cv}}{\sigma_{nd.zu}} \geq 2.5 \quad (13)$$

$$\sigma_{pr.cv} = 2.5 \cdot \sigma_{nd.zu} \left[daN/mm^2\right] \quad (14)$$

$$\sigma_{pr.cv} = \frac{P_{kid}}{S_{zu}} = 0.9 \cdot \frac{P_{rac}}{S_{zu}} \left[daN/mm^2\right] \quad (15)$$

The safety factor of a conductor is calculated pursuant to Eq. (16):

$$K_{sig.zu} = 0.9 \cdot \frac{P_{rac}}{S_{zu} \cdot \sigma_{mr.zu}} \quad (16)$$

In the relation of these two factors, the allowed decrease of calculated breaking force of a shield wire is obtained:

$$\Delta P_{rac} \leq \frac{K_{sig.zu} - K_{\min}}{K_{sig.zu}} \cdot 100[\%] \quad (17)$$

The following symbols have been used:

$\sigma_{nd.zu}$ (daN/mm^2)—normal allowed strain of a shield wire,

$\sigma_{pr.cv}$ (daN/mm^2)—breaking strength of a shield wire,

$\sigma_{mr.zu}$ (daN/mm^2)—maximum operational strain of a shield wire,

P_{kid} (daN)—breaking force of a shield wire,

P_{rac} (daN)—calculated breaking force of a shield wire,

S_{zu} (mm^2)—calculated cross-section of a shield wire,

K_{min}—minimal safety factor pursuant to the regulations,

$K_{sig.zu}$—safety factor per project,

ΔP_{rac} (%)—allowed decrease of calculated breaking force of a shield wire.

5.4 Evaluation of Condition of Inslulators

In evaluating the condition of insulators, it is necessary to pay attention to the following:

(a) That the electromechanical or mechanical loads of an insulator are at least three times higher than the tensile force of a conductor, and it can be presented by Eq. (18):

$$F_{cm} = 3 \cdot \sigma_{mr.pr} \cdot S_{pr} \left[daN\right] \quad (18)$$

The evaluation of whether to keep an insulator, with regards to its electromechanical load, may be performed pursuant to Eq. (19):

$$\Delta F \leq \frac{F_{pr.op} - F_{cm}}{F_{cm}} \cdot 100[\%] \quad (19)$$

The following symbols have been used:

F_{cm} (daN)—electromechanical breaking load of insulators on OPLs,

$\sigma_{mr.pr}$ (daN/mm^2) —maximum operational strain of conductors,

S_{pr} (mm^2) —calculated cross section of conductors,

$F_{pr.op}$ (daN)—breaking load of insulators,

ΔF (%)—allowed decrease of breaking load of insulators.

(b) That the testing with withstandable alternating voltage of industrial frequency in dry and rainy weather meets the prescribed values as though the insulators have been cleaned. If it is shown during the testing that the insulators meet the prescribed values, in the case when they are well-cleaned, then a technical-economic feasibility analysis should be made regarding whether to clean or replace an insulator.

5.5 Evaluation of Condition of Jointing Equipment

Regarding the previous experience, the evaluation of condition of jointing equipment presents the smallest problem, excluding the following:

(a) Hoffman jointing equipment where shield armature has not been well-solved.

(b) Corrosion of equipment within the insulation chain. In that case, the mechanical load of jointing equipment in the insulation chain should be at least 2.5 times higher than the tensile force of the conductor, and that can be presented by Eq. (20):

$$F_m = 2.5 \cdot \sigma_{mr.pr} \cdot S_{pr} \left[daN\right] \quad (20)$$

The evaluation of whether to keep the jointing equipment, with regards to the mechanical load, may be performed pursuant to Eq. (21):

$$\Delta F \leq \frac{F_{pr.op} - F_{cm}}{F_{pr.op}} \cdot 100\left[\%\right] \quad (21)$$

The following symbols have been used:

F_m (daN)—mechanical breaking load of insulators on OPLs,

$\sigma_{mr.pr}$ (daN/mm^2)—maximum operational strain of conductors,

S_{pr} (mm^2)—calculated cross section of conductors,

$F_{pr.op}$ (daN)—breaking load of jointing equipment,

ΔF (%)—allowed decrease of breaking load of jointing equipment.

6. Necessary Conditions for HV OPLs

To perform the evaluation of condition of OPLs, a period longer than last five years is necessary. In the case that there are no data for necessary conditions, it is possible to perform the setting out of limit values for replacing the equipment and the assessment of the remaining working time of the equipment. The non-existence of data for necessary conditions brings neither the validity of decision on limit values for replacing the equipment in question nor the assessment of the remaining working time of the equipment, but it decreases the perceiving of behaviour of the line in operation, i.e. of the need for increasing the operational safety.

(a) Outages of OPLs:

OPL110 kV: $\bar{n}_{isp.} > n_{isp.doz.}$ (outages/100 km, year); it is proposed: $n_{isp.doz.} = 20$;

OPL 220 kV: $\bar{n}_{isp.} > n_{isp.doz.}$ (outages/100 km, year); it is proposed: $n_{isp.doz.} = 15$;

OPL 400 kV: $\bar{n}_{isp.} > n_{isp.doz.}$ (outages/100 km, year); it is proposed: $n_{isp.doz.} = 10$.

(b) Replaced insulators:

OPL 110 kV: $\bar{n}_{z.izol.} > n_{z.izol.doz.}$ (‰/year); it is proposed: $n_{z.izol.doz.} = 4.5$;

OPL 220 kV: $\bar{n}_{z.izol.} > K_{z.izol.doz.}$ (‰/year); it is proposed: $K_{z.izol.doz.} = 3.0$;

OPL 400 kV: $\bar{n}_{z.izol.} > K_{z.izol.doz.}$ (‰/year); it is proposed: $K_{z.izol.doz.} = 1.5$.

(c) Interventions on the OPL equipment, except on the shield wire:

OPL 110 kV: $\bar{n}_{int.} \geq n_{int.doz.}$ (interv./100 km, year); it is proposed: $n_{int.doz.} = 3$;

OPL 220 kV: $\bar{n}_{int.} \geq n_{int.doz.}$ (interv./100 km, year); it is proposed: $n_{int.doz.} = 2$;

OPL 400 kV: $\bar{n}_{int.} \geq n_{int.doz.}$ (interv./100 km, year); it is proposed: $n_{int.doz.} = 1$.

(d) Frequency of repairment:

OPL 110 kV: $\bar{n}_{rem.} \geq n_{rem.doz.}$ (days/100 km, year); it is proposed: $n_{rem.doz.} = 10$;

OPL 220 kV: $\bar{n}_{rem.} \geq n_{rem.doz.}$ (days/100 km, year); it is proposed: $n_{rem.doz.} = 11$;

OPL 400 kV: $\bar{n}_{rem.} \geq n_{rem.doz.}$ (days/100 km, year); it is proposed: $n_{rem.doz.} = 12$.

Table 1 consists of an overview of necessary conditions for 110 kV, 220 kV and 400 kV OPLs.

When the necessary conditions are not met: outages, replaced insulators, interventions and frequency of repairment, or when all four conditions are not met, the following examinations are performed.

(1) Age of OPLs

If $n_{st.nv.} \geq 35$ years, then the sufficient conditions for the line are discussed.

The following symbol has been used:

$n_{st.nv}$—number of years of age of OPL.

Table 1 Proposals of necessary conditions for 110 kV, 220 kV and 400 kV OPLs.

Un	Outages	Replaced insulators	Interventions	Frequency of repairment
110	20	4.5	3	10
220	15	3.0	2	11
400	10	1.5	1	12

(2) Failure/damage of poles/towers

If,

$$n_{oš.stub.}\ (‰/year) > K_{oš.stub.} \cdot n_{oš.doz.stub.}\ (‰/year)$$

It is proposed:

$$K_{oš.stub.}=1/3 \quad (22)$$

For $n_{oš.doz.stub.}$ (‰/year), it is proposed 1.5. (23)

Then the sufficient conditions for the poles are discussed.

The following symbols have been used:

$n_{oš.stub.}$ (‰/year)—number of damages of poles/towers,

$K_{oš.stub.}$—calculated factor of damages of poles/towers,

$n_{oš.doz.stub.}$ (‰/year)—number of allowed damages of poles/towers.

(3) Fractures-damage of basis

If,

$$n_{oš.tem.}\ (‰/year) > K_{oš.tem.} \cdot n_{oš.doz.tem.}\ (‰/year)$$

It is proposed:

$$K_{oš.tem.}=1/3 \quad (24)$$

For $n_{oš.doz.tem.}$ (‰/year), it is proposed 15. (25)

Then the sufficient conditions for the bases are discussed.

The following symbols have been used:

$n_{oš.tem.}$ (‰/year)—number of damages of basis,

$K_{oš.tem.}$—calculated factor of damages of basis,

$n_{oš.doz.tem.}$ (‰/year)—number of allowed damages of basis.

(4) Interruption-damage of conductors

If,

$$n_{oš.prov.}\ (‰/year) > K_{oš.prov.} \cdot n_{oš.doz.prov.}\ (‰/year)$$

It is proposed:

$$K_{oš.prov.}=1/3 \quad (26)$$

For $n_{oš.doz.prov.}$ (‰/year), it is proposed 3.0. (27)

Then the sufficient conditions for the all electrical equipment are discussed. In Fig. 2, the least expected working time of greased aluminium/steel conductors has been shown. One of the basic features in conductors is tensile strength. By means of examinations, the average loss of strength has been determined, which is 0.75% per year. The replacement of a conductor is necessary in the case when tensile strength is decreased by 15%, and that corresponds to an average annual loss of aluminium of 1.5%.

The following symbols have been used:

$n_{oš.prov.}$ (‰/year)—number of damages of conductors,

$K_{oš.prov.}$—calculated factor of damages of conductors,

$n_{oš.doz.prov.}$ (‰/year)—number of allowed damages of conductors.

(5) Interruption-damage of jointing equipment

If,

$$n_{oš.so.}\ (‰/year) > K_{oš.so.} \cdot n_{oš.doz.so.}\ (‰/year)$$

It is proposed:

$$K_{oš.so.}=1/3 \quad (28)$$

For $n_{oš.doz.so.}$ (‰/year), it is proposed 0.45. (29)

Then the sufficient conditions for the jointing equipment and insulators are discussed.

The following symbols have been used:

$n_{oš.so.}$ (‰/year)—number of damages of jointing equipment,

$K_{oš.so.}$—calculated factor of damages of jointing equipment,

$n_{oš.doz.so.}$ (‰/year)—number of allowed damages of jointing equipment.

(6) Interruption-damage of insulators

If,

$$n_{oš.izol.}\ (‰/year) > K_{oš.izol.} \cdot n_{oš.doz.izol.}\ (‰/year)$$

It is proposed:

$$K_{oš.izol.}=1/3 \quad (30)$$

For $n_{oš.doz.izol.}$ (‰/year), it is proposed 4.5. (31)

Then the sufficient conditions for the insulators and jointing equipment are discussed.

The following symbols have been used:

$n_{oš.izol.}$ (‰/year)—number of damages of insulators,

$K_{oš.izol.}$—calculated factor of damages of insulators,

$n_{oš.doz.izol.}$ (‰/year)—number of allowed damages of insulators.

(7) Interruption-damage of shield wire

If,

$$n_{oš.zu.}\ (‰/year) > K_{oš.zu.} \cdot n_{oš.doz.zu.}\ (‰/year)$$

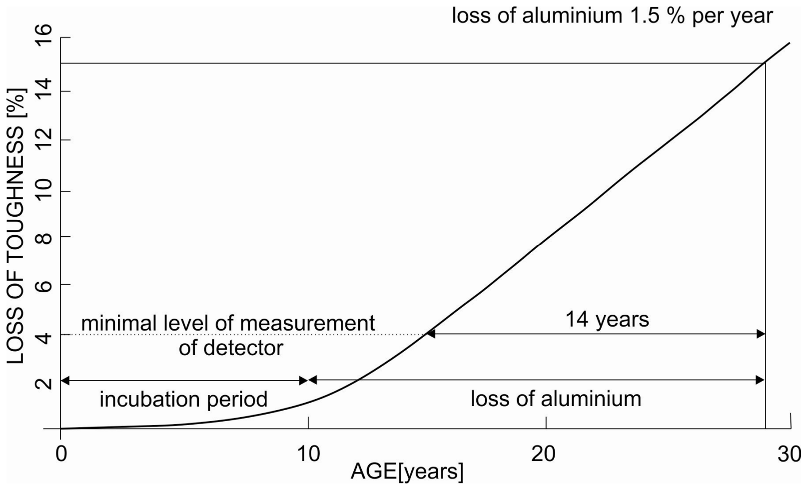

Fig. 2 The least expected working time of greased aluminium/steel conductors.

It is proposed:

$$K_{\text{oš.zu.}}=1/3 \quad (32)$$

For $n_{\text{oš.doz.zu.}}$ (‰/year), it is proposed 3. (33)

Then the sufficient conditions for the shield wire are discussed.

The following symbols have been used:

$n_{\text{oš.zu.}}$ (‰/year)—number of damages of shield wire,

$K_{\text{oš.zu.}}$—calculated factor of damages of shield wire,

$n_{\text{oš.doz.zu.}}$ (‰/year)—number of allowed damages of shield wire.

7. Sufficient Conditions for HV OPLs

The evaluation of the condition of components is made pursuant to the "Report from a detailed examination of OPLs", and the detailed examination of OPLs is performed pursuant to the "Instruction for a detailed examination of OPLs". A detailed examination of a line is performed with several independent groups. Pursuant to the "Instruction for a detailed examination of OPLs", the examinations of the existing condition of the line equipment and the relation with other objects are performed. The evaluation of the condition of components is performed for poles/towers, bases, conductor, jointing equipment, insulators and protective rope. The grades are: unsatisfactory, satisfactory, good, very good and excellent. On the basis of discussing the condition of OPLs, the perceiving of a real status of line occurs, as well as the evaluation of both particular equipment and the line as a whole.

8. Conclusions

The components of HV OPLs in exploitation have their working time within which they are expected to work without a great number of interruptions and faults. After a certain time period of exploitation, the violation of reliability occurs, i.e. the operating costs of an OPL as a whole increase. The planned designed working time of electrical equipment is 40 years, and for construction equipment it is 80 years. After a time period of large investments into the development of network and the construction of new OPLs, a period of investing in the existing networks occurs, based mostly on the investing in the OPLs which are not new anymore. To perceive the real condition of OPLs it is necesary to perform a set of activities which have been shown on a global block diagram, and pursuant to that a final conclusion may be made, whether it is necessary to perform revitalisation, restoration, reconstruction or nothing should be done on some OPLs. Pursuant to the analysis of behaviour of OPLs in operation, necessary conditions are being set out, while pursuant to a detailed examination of OPLs the evaluation of equipment is performed and, pursuant to the testing of equipment, sufficient conditions are being set out. The steps for the extension of working time of OPLs have been defined, contributing to the solving of problem of making a single list of priorities in replacement or installation of new components of particular discussed OPLs, strictily paying attention to whether discussed "steps" are technically and economically justified or not. The perceiving of real condition of HV OPLs enables the increase of income in transmission companies and in that way the answer to the key question is obtained: how to use the available financial resources appropriately.

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