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HOW OH LINES ARE RE-DESIGNED FOR UPRATING / UPGRADING

ANALYSIS OF THE ANSWERS TO THE QUESTIONNAIRE

Working Group B2.06

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How Overhead Lines are Re-designed for Uprating/Upgrading
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Abstract

How Overhead Lines are Re-designed for Uprating/Upgrading Analysis of the Replies to the Questionnaire

The scope of the Questionnaire was to collect and compare worldwide best practices on Uprating and/or Upgrading works of overhead transmission lines in order to assess the reasons, the design requirements and the results achieved. This Technical Brochure describes the correlation noticed between actions such as increasing transmission capacity and structural reliability, improving line performance and extending remaining life. The methods and tools for Uprating/Upgading are summarized. Finally, some didactic cases are provided as well as the remarkable results from the statistical analysis of all answers.

Résumé

Comment les Lignes Aériennes sont re-conçues pour l'Uprating/ Upgrading - Analyse des Réponses au Questionnaire

L'objectif du Questionnaire était de rassembler et de comparer les meilleures pratiques dans le monde entier au sujet des travaux d'Uprating et/ou d'Upgrading sur les lignes aériennes afin d'évaluer les motifs, les prescriptions de conception et les résultats obtenus. Cette Brochure Thématique décrit la corrélation constatée entre les actions comme l'augmentation de la capacité de transport et de la fiabilité structurelle, l'amélioration de la performance de la ligne et le prolongement de la durée de vie restante. Les méthodes et les moyens d'Uprating et/ou d'Upgrading sont résumés. Enfin, quelques exemples didactiques sont donnés, ainsi que les résultats remarquables de l'analyse statistique des réponses.

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Introduction and scope

Task Force 03 “Reduction of Overall Line Costs – An Assessment of Operation Costs and Reliability of Overhead Lines after Uprating or Upgrading” of CIGRE WG B2.06 “Principles of Overhead Line Design” was created aimed at evaluating results obtained from works of Uprating and/or Upgrading existing overhead lines. A Questionnaire was issued to collect information on utilities’ policies and best practices in regard to the Uprating and Upgrading works carried out on overhead transmission lines around the world.

After analyzing all 43 replies provided by 20 countries from all continents, it was easy to conclude that the sets of reports received there from was big enough to compose a scientifically extensive and valid statistical sample. The multifarious cases reported included very interesting didactic solutions that can be used for other utilities or line owners to help them in treating technically and economically similar domestic cases.

All statistical data are collected and conveniently arranged in appropriate tables, so that relevant conclusions could be drawn.

Design criteria for Uprating/Upgrading

The International Standard IEC 60826 “Design Criteria for Overhead Transmission Lines” [1], Edition 3, October 2003, based on CIGRE Technical Brochure No. 178 “Probabilistic Design of Overhead Transmission Lines” [2], provides the Reliability Based Design criteria for overhead lines.

Although the design criteria in this Standard apply to new lines, many concepts can be used to address the reliability requirements for Upgrading [3], life extension and Uprating of existing lines. Transmission lines age and lose strength with time. The amount of strength reduction of the components and elements varies from one component or element to another, and also depends on the age, the type of material, the manufacturing processes and the environmental influences (corrosion, wear, fatigue, annealing, etc.).

Review of definitions for Uprating and Upgrading

In most publications [4], Uprating has been defined as improving the electric characteristics of an overhead line while Upgrading has been defined as strengthening line components.

For the purpose of this Technical Brochure the definitions of Uprating and Upgrading have been reviewed:

- Uprating of a line is the increase in its transmission capacity;
- Upgrading of a line means improvement of its structural reliability.

Structural reliability can be improved not only by increasing strength but also by decreasing weather related loads [3].

The yearly reliability is the probability of survival of the line in one year. For typical transmission lines where the principles of strength coordination are applied appropriately, the reliability of the line can be approximated by the reliability of its least reliable component [1,2].

For the purpose of this Technical Brochure the extension of the body of the tower to increase the height of conductors for operation at higher temperatures, has not been considered as an Upgrading action, but as an integral part of the Uprating process.

Definitions for line performance and life extension

Most definitions of Upgrading consider that life extension and refurbishment are special cases of Upgrading. For the purpose of the Technical Brochure both definitions are clearly distinguished. There are two main practical reasons:

- According to the answers to the Questionnaire, the decision to increase the expected remaining life seems to be an action irrespective of whether the action is Uprating or Upgrading;
- The expected remaining life is significantly lower than the return period for the climatic limit load. The ratio varies between 20% and 120%. The mean value is 65%.

The life of the transmission line can be extended by the repair or replacement of defective elements and/or elements where the rate of deterioration with time is too high (due to corrosion, wear, fatigue, annealing, etc.). The expected remaining life is a good indicator to characterize the deterioration rate of the various line elements. Similarly the availability with regard to outages and failures is a good indicator for line performance.

- Unreliability is the probability of a failure/outage during a specified time;
- Unavailability is the product of unreliability and the mean duration time of the outage.

The indicators to measure Uprating/Upgrading, line performance and remaining life are summarized in Table 1.

Table 1 – Indicators for Uprating/Upgrading, performance and remaining life		
Action	Increasing	Indicator
Uprating	Transmission capacity	Ratio new to old power (%)
Upgrading	Strength/Load	Return period of climatic load event (years)
Line performance	Availability	Unavailability = Number of outages x mean unavailable duration per outage (h/year)
Life extension	Decreasing deterioration rate	Expected remaining life (years)

Table 2 shows the relations between Uprating/Upgrading, line performance and remaining life.

Table 2 – Relations between Uprating/Upgrading, line performance, remaining life		
	Re-design	Life experience/statistics
Electrical	Uprating	Performance improvement
Mechanical	Upgrading	Life extension

Basis for improving line performance and extending remaining life

For any kind of Uprating/Upgrading aimed for a line, it is important to have the records of its operation and performance along the years. Three kinds of recordings are considered as shown in Table 3 [4].

Table 3 - Performance recordings			
Level	Line/circuit (1)	Components (2)	Elements (3)
Statistics	Availability	Reliability	Deterioration rate
Administrative decisions	Improvement in line design	Action on components	Maintenance (repair or change)

Line performance can be characterized by its availability (1st level), the condition of its components by their reliability (2nd level), while the remaining life expectancy of a line can be characterized by the deterioration rate of the elements (3rd level).

Statistics on line availability and deterioration rate permit to identify the behaviour degree of the line and to determine in what an extent the design can be improved, starting from the 3rd level (element) which has the lowest cost of improvement. It is fundamental in all cases of Uprating and Upgrading to carry out complete diagnostics of the line, so detecting all components and elements which need any kind of action for repair, replacement or reinforcement.

Questions

There were 12 questions in the Questionnaire sent abroad. Questions Q2 to Q9 are specific questions for lines that have been Uprated/Upgraded. Questions Q1 and Q10 to Q12 are general questions, even for responders without any experience on Uprating/Upgrading.

Q1 – Name of the overhead lines(s) considered;
Q2 – Line data before/after Uprating/Upgrading;
Q3 – Works carried out on components;
Q4 – Line parameters;
Q5 – Uprating/Upgrading costs;
Q6 – Electrical/mechanical reliability before/after Uprating/Upgrading;
Q7 – Operation and maintenance costs;
Q8 – Main decision factors;
Q9 – Expected remaining life;
Q10 – Decision factors for Uprating/Upgrading rather than a new line;
Q11 – Quantification methods for decisions;
Q12 – Influence of operation and maintenance costs on decision.

Responses to the Questionnaire

The following countries responded to the Questionnaire (the values between brackets indicate the number of Questionnaires filled up per country):

- Africa: South-Africa (3);
- Asia: Japan (1);
- Europe: Austria (1), Belgium (3), Denmark (1), Finland (1), France (1), Germany (2), Great Britain (3), Italy (5), Norway (1), Poland (3), Serbia and Montenegro (4), Spain (1), Sweden (1);
- North America: Canada (2), USA (2);
- Oceania: Australia and New Zealand (1);
- South America: Brazil (11).

Replies regarding voltage levels

Regarding voltage classes and types of works carried out, a summary is presented in Table 4. The values outside brackets give the number of answers for different voltage classes. The values between brackets correspond to the number of lines considered.

Table 4 - Replies regarding voltage classes				
Voltage kV	Uprating		Upgrading	
	only	with Upgrading	only	with Uprating
33-69-88	7 (88)	3 (3)	-	1 (1)
110-132-145	8 (8)	2 (4)	1 (2)	-
220-245	7 (17)	1 (1)	1 (2)	1 (3)
275-285	2 (4)	-	-	-
380-400	4 (42)	1 (1)	2 (2)	2 (2)
500-550	-	-	1 (>1)	-
765	-	-	1 (2)	-
Subtotal	28 (159)	7 (9)	6 (>9)	4 (6)
Total	45 (>183)			

Uprating process

Uprating of an overhead line means in general to increase its transmission capacity, and this can be made by increasing current rate, voltage level or both.

The increase of current rate means the need either to raise the conductor temperature or to reconductor the line, while the increase of voltage level requires the reinsulation of the line to the new voltage level, including increasing phase to phase distances and ground clearances. The main methods and tools to uprate overhead lines are summarized in Table 5.

Table 5 – Main methods for Uprating			
	Increasing	Method	Tool
Uprating	Current rate	Increasing temperature or	Increasing height attachment point
			Re-tensioning
		Reconductoring or	Compact/smooth conductor
			High temperature conductor
		Special engineering methods	Statistical approach
			Real time approach
	Voltage level	Reinsulation and	Adding/substituting insulators
			Cross-arm modified
		Ground clearance and	Increasing height attachment point
			Re-tensioning
		Phase-phase distance	Conversion of 2 to 1 circuit
			New tower top

Rating monitoring with weather stations or on real time is seldom used to uprate lines permanently, but are more frequently applied to allow use of higher emergency ratings or postponement of more expensive physical upratings. However, physical uprating of a major line can cause new constraints on other lines in contingency conditions. In this case real time monitoring can be a more economical solution.

Upgrading process

Upgrading an overhead line means an improvement in its structural reliability level. Reliability is a result of the combination between load and strength of the overhead line. It is obvious that reliability can be increased either by decreasing climatic loads or increasing strength of line components [3]. The main methods and tools to upgrade overhead lines are summarized in Table 6.

Table 6 - Main methods for Upgrading

	Method	Tool
Upgrading	Reducing impact of climatic loads	Compact/smooth conductor
		Decreasing ice accretion
		Decreasing number of sub-conductors
		Decreasing number of circuits
	Increasing characteristic strength	Support: leg members
		Support: bracings
		Foundation: uplift
		Foundation: compression

Relevant aspects of Uprating/Upgrading works per country

Several important aspects have been reported in the different responses received, and it could be stressed the following ones.

Australian and New Zealand reply comprised a significant list of methods to achieve greater line ratings and covered practically all types of uprating. aMost of the solutions are driven around least cost and cost effectiveness. Achieving uprating can also be motivated by replacement of conductors due to their condition and their age. However it is still unlikely that conductors will run at their actual design rating.

A huge work of line upgrading in Brazil constituted big reinforcements carried out, covering about 600 km of 765 kV lines, having both guyed and self-supporting towers, the works being carried out practically without interruption of power supply.

Uprating of double-circuit lines in Brazil, by doubling the voltage in a single-circuit, e.g. from 69 into 138 kV, regrouping the same existing conductors in bundle configurations, has permitted to quadruple the line capacity at a relatively low cost.

Recent upgrading work of a major transmission line system (1997-2002) in Canada was based on a reliability study which was primarily driven by a large number of failures due to severe icing. The system was designed in late 60's and a number of failures occurred during the past 35 years operation life and this high failure rate was unacceptable. The new revised design load was estimated based on running an ice accretion model supported by data obtained from the nearby airport weather station and then updating this information based on the actual line failure information due to ice that was available historically. A revised Gumbel plot was used to estimate the new ice design load. Sharp reduction of unavailability of the lines has been determined after line upgrading.

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An interesting observation was made regarding lines in Finland, namely that the existing structures are such that application of higher voltage level or bigger conductors is usually not feasible without change of the guyed supports. As a result usually old 110 kV lines are replaced with new ones.

A project of a 400 kV line (30 km, 60 supports) in France was included in the strengthening program and policy following the severe wind storm events of December 1999.

Upgrading was carried out in Germany: the wind pressure increased by 35%; ice loads doubled. The towers were modified to accommodate the increased wind and ice loads. To increase load capacity under compression, additional angle sections were added to the leg members and bracings were replaced. Foundations were upgraded by installing additional piles. Return period for wind velocities increased from 35 years to 300 years, for ice load from 40 to 400 years. Estimated remaining line life increased from 30 to 50 years.

A transmission line on the South coast of Great Britain was nearing the end of its design life, and poor condition of the line and its components was resulting in an unacceptable level of reliability. The original conductor bundle was 4 x 400 ACSR rated at 50ºC, replaced with 3 x 700 AAAC conductor rated at 50ºC. The triple bundle was chosen for the refurbishment as it was considered less prone to wind-induced motion, and hence the conductors would be less prone to fatigue damage. Savings in operation costs came from the reduction in thermal loses.

Typically, lines thermally uprated in Great Britain were originally constructed in the early 1960's, and uprated with higher capacity conductors in the mid to late 1980's, with many then being uprated in the 1990's. Mention was made to 30 lines thermally uprated. Thermal uprating is carried out where relatively small enhancements are needed. As important cost parameter, it was informed that the transmission constraint costs were either totally eliminated or reduced in the range 0-50%.

In Norway, significant Uprating was carried out in a 132 kV double-circuit line conveniently converted into a single-circuit 300 kV. Power increased four times by using the same conductors in a twin bundle configuration.

Uprating of a 220 kV overhead line in Poland was associated with extensive renovation and exchanging of elements which had reached their life time.

For the Uprating of a 400 kV line in South Africa, the templating temperature of 50°C was increased to 76ºC, and statistical rating applied. Real Time Monitoring was also added to monitor particularly a critical 400 kV crossing.

Statistical tables per question

The Statistical Tables in the Technical Brochure are followed by some conclusions and a summary table.

For a total of 42 cases we counted 24 cases of Uprating only without Upgrading, 9 cases of Uprating where Upgrading was necessary to keep at least the same reliability level, 5 cases of Upgrading only without Uprating and 4 cases of Upgrading where Uprating was an opportunity (Table 7). Uprating and Upgrading are often combined (31%).

Table 7 – Combination of Uprating and Upgrading

Main action	Uprating	Upgrading	Total
No combination	Uprating only 57% (24 cases)	Upgrading only 12% (5 cases)	69% (29 cases)
Combination	Uprating with Upgrading 21% (9 cases)	Upgrading with Uprating 10% (4 cases)	31% (13 cases)
Total	78% (33 cases)	22% (9 cases)	100%(42 cases)

Uprating/Upgrading statistics

For Uprating actions, increasing current rate is significantly more popular than increasing voltage level:

- 71% or 30 cases for increasing current rate;
- 24% or 10 cases for increasing voltage level.

For increasing current rate, increasing conductor temperature is nearly as popular as reconductoring:

- 43% or 18 cases for increasing conductor temperature;
- 50% or 21 cases for reconductoring.

Moreover increasing conductor temperature and reconductoring are combined in 9 cases (21%). For the 21 reconductoring cases, Upgrading could be avoided in 10 cases (48%).

For increasing conductor temperature, both raising conductor attachment point and re-tensioning are also as popular:

- 17% or 7 cases for raising conductor attachment point.
- 17% or 7 cases for re-tensioning.

The return period for limit wind loads varies between 25 and 300 years (after Upgrading). For ice loads, the return period is sometimes higher (up to 500 years). Only in 5 cases (13%), the return period for wind loads increases. The number of Upgrading actions due to higher climatic loads (7 cases) and higher total conductor diameter (8 cases) are comparable.

Life extension and line performance statistics

The values of the expected remaining life are mentioned for 32 cases (82%). The value varies between 10 years and 80 years. The mean value is 36 years and the median 35 years. In 23 cases (59%), the expected remaining life increases after Uprating/Upgrading. This increase varies between 5 years and 40 years. The mean value of the increase is 22 years, the median is 20 years.

It is surprising that Life Extension is mostly combined with an Uprating/Upgrading action (62% or 26 cases) (Table 8). Even for the 24 Uprating cases, the percentage is higher.

Table 8 – Probability that Life Extension is combined with Uprating/Upgrading

Main action	Uprating	Upgrading	Total
No combination	Uprating only 67% (16/24 cases)	Upgrading only 60% (3/5 cases)	66% (19/29 cases)
Combination	Uprating with Upgrading 56% (5/9 cases)	Upgrading with Uprating 50% (2/4 cases)	54% (7/13 cases)
Total	64% (21/33 cases)	56% (5/9 cases)	62% (26/42 cases)

We may conclude that Life Extension is irrespective of whether the action is Uprating or Upgrading. It justifies the assumption made not to link Upgrading and Life extension.

The expected remaining life is significantly lower than the return period for the climatic limit load. The ratio of the remaining life to the return period (after Uprating/Upgrading) varies between 20% and 120%. The mean value of the ratio is 65% and the median is 70%.

Indicators for the results of actions

Table 9 summarizes for various indicators the total number of answers received, the range of values (min. to max.) and the mean and median values.

Table 9 – Indicators for the results of Uprating/Upgrading and Life Extension

Indicator	Number	Min	Max	Mean	Median
Increase of transmission capacity (-)	26	1.1	4.0	1.8	1.5
Increase of operation temperature (°C)	15	5°C	95°C	29°C	26°C
Reference wind speed (m/s)	20	21 m/s	40 m/s	29 m/s	30 m/s
Return period of limit wind load (years)	25	25 a	300 a	71 a	50 a
Expected remaining life (years)	32	10 a	80 a	36 a	35 a
Increase of remaining life (years)	23	5 a	40 a	22 a	20 a
Ratio: remaining life/return period (%)	23	20%	120%	65%	70%

Unfortunately we received very few information about the improvement of the performance of the line. Only for 7 cases the values given show improvement of the number of outages (1/100 km.year) or the unavailability (h/year) after Uprating/Upgrading.

Decision factors

The decision factors on Uprating/Upgrading works are ranked hereunder according to the preference (total votes: 40):

1. 68% (27 votes): Lower investment of the works;
2. 58% (23 votes): Lower Life Cycle Assessment costs (investments, losses, O&M);
3. 35% (14 votes): Unacceptable mechanical or electrical reliability;
4. 18% (7 votes): Real return periods lower than design;
5. 13% (5 votes): Political costs of unavailability.

There are also various additional comments for many cases (68%).

In about 59% of the cases the Operation and Maintenance (O&M) costs are registered, but only in 32% of the cases they are taken into account for the decisions on Uprating/Upgrading. Probably, they are not registered per line, but globally. Anyhow, there is a general agreement that O&M costs decrease sharply after Uprating/Upgrading. In this context reduction of transmission constraint costs, damage and failure costs can lead to considerable savings in O&M. The Uprating/Upgrading costs are mostly compared with the construction of a new equivalent line. The range is quite large: from 0.25% to 100% with a mean value of 33% and a median of 20%.

Conclusion

With the answers to the Questionnaire sent abroad, CIGRE WG B2.06 TF03 was able to collect and compare worldwide best practices on Uprating/Upgrading works of overhead lines to assess the reasons, the design requirements and the results achieved.

References

[1] IEC 60826, "Design Criteria of Overhead Transmission Lines", Edition 3, October 2003

[2] WG 22.06, "Probabilistic Design of Overhead Transmission Lines", CIGRE Technical Brochure No.178, February 2001

[3] Ghannoum Elias, "Increasing Structural Reliability and Security using IEC 60826 Principles", Report R9-03, Colloquium on Overhead Lines Revitalization, Belgrade, May 6-10, 2003

[4] WG 22.13, "Management of Existing Overhead Transmission Lines", CIGRE Technical Brochure No.175, December 2000

2. Introduction and scope

The Task Force 03 “Reduction of Overall Line Costs – An Assessment of Operation Costs and Reliability of Overhead Lines after Uprating or Upgrading” of CIGRE WG B2.06 “Principles of Overhead Line Design” was created aimed at evaluating results obtained from works of uprating and/or upgrading existing overhead lines. A Questionnaire was issued to collect information on Utilities’ policies and practices in regard to the uprating and upgrading works carried out on overhead transmission lines around the world. For investigating such results, precise definitions were necessary about the main types of works carried out in overhead transmission lines, which are:

- Uprating is the increase in transmission capacity of a line;

- Upgrading of a line means improvement of its structural reliability.

After analyzing all 43 replies provided by 20 countries, from all continents, it was easy to conclude that the sets of reports received there from was big enough to compose a scientifically extensive and valid statistical sample. From such many uprating/upgrading reports it was possible to assemble an array of practically all alternatives of such renovating services carried out in overhead transmission lines. Moreover, the multifarious cases reported included very interesting didactic solutions that can be used for other utilities or line owners to help them in treating technically and economically similar domestic cases.

The aim of this Technical Brochure is to compare worldwide information about practices and experiences in order to undertake actions such as Uprating, Upgrading, and how they are combined with actions to improve line performance and to extend remaining life.

It is important to note that the aim of this Technical Brochure is not to provide criteria for re-designing overhead lines for Uprating/Upgrading. It only provides worldwide collection on experience on:

- how existing overhead lines are re-designed for Uprating/Upgrading;
- which methods and tools are used;
- why they are decided;
- how the various actions are combined;
- and finally how the results can be measured and compared through indicators.

Clause 3 provides the list of questions and the countries responding to the Questionnaire. It also includes the justification for the review of the definitions on Uprating and Upgrading in order to comply with the works carried out. The definitions of line performance and life extension are also included.

Clauses 4 to 5 summarize the theory related to all cases of respectively uprating and upgrading which were reported by the respondents in the replied questionnaires.

Clause 6 deals with actions on components and elements.

Clause 7 summarizes per country the most remarkable aspects of re-designing lines for Uprating and/or Upgrading.

In the Statistical Tables of Clause 8, all data are collected and classified ready for comparison, assessment of the results and conclusion per question.

Clause 9 summarizes the statistical results of the combined actions to Uprate and Upgrade overhead lines, to improve line performance and to extend remaining life. The indicators to measure the achievement of those actions are provided and discussed. Finally the decision factors for Uprating and/or Upgrading are classified according to the preference of the responders to the Questionnaire.

The Questionnaire sent abroad is given in the Appendix.

3. Questionnaire

3.1 Design criteria for Uprating/Upgrading

The International Standard IEC 60826 “Design Criteria for Overhead Transmission Lines” [1], based on CIGRE Technical Brochure No. 178 “Probabilistic Design of Overhead Transmission Lines” [2], provides the Reliability Based Design criteria for overhead lines. Although the design criteria in this Standard apply to new lines, many concepts can be used to address the reliability requirements for upgrading [3], life extension and uprating of existing overhead lines.

It is a fact of life that transmission lines age and lose strength with time. In principle, the reliability level or the return period of the climatic limit load is not affected directly by this process, because reliability depends mostly of the least reliable component or the component with the lowest strength, while this component has been chosen for his low coefficient of variation and his low variability with time. The amount of strength reduction of the other components and elements is difficult to generalize, as it varies from one component or element to another, and also depends on the age, the type of material, the manufacturing processes and the environmental influences (for corrosion, wear, fatigue, annealing, etc.).

3.2 Review of definitions

According to CIGRE Technical Brochure No. 175 “Management of Existing Transmission Overhead Lines” [4], the definitions of Uprating, Upgrading and Life extension are:

- Uprating: Increasing the electrical characteristics of a line due to, for example, a requirement for higher electrical capacity or larger clearances. Uprating will increase the electrical capacity of the line thereby potentially increasing the consequences of a failure.
- Upgrading: Increasing the original mechanical strength of an item due to, for example, a requirement for higher meteorological actions. Upgrading will decrease the probability of failure.
- Life extension: Extensive renovation or repair of an item without restoring its original design working life.

If the original design working life is restored, life extension becomes refurbishment.

For the purpose of this Technical Brochure those definitions have been slightly reviewed in order to comply with the works described in the Questionnaires and to establish comparable statistical data.

In the answers to the Questionnaire, Uprating has been mentioned only for increasing transmission capacity. Sometimes the earthwire has been changed with an OPGW, but this is not relevant for this study.

According to the answers, Upgrading is used not only for strengthening, but also for reducing climatic loads irrespective of the wind speed considered. Both aspects are included in the reliability concept. As developed in Clause 5.1, reliability is a result of the combination between load and strength of the overhead line. Reliability can be increased by either decreasing climatic loads or increasing strength.

For the purpose of this Technical Brochure the definitions of Uprating and Upgrading have been reviewed:

- Uprating is the increase in transmission capacity of a line;

- Upgrading of a line means improvement of its structural reliability.

The change of the transmission capacity in MVA is a good indicator for Uprating. This indicator has been requested in Question 6 and Table 2 of the Questionnaire.

The change of the structural reliability level (1, 2 or 3) or the Return Period of the climatic limit load in years is a good indicator for the Upgrading. This indicator has been requested in Question 6 and Table 3 of the Questionnaire. The yearly reliability is the probability of survival of the line in one year. For typical transmission lines where the principles of strength coordination are applied appropriately, the reliability of the line can be approximated by the reliability of its least reliable component [1, 2].

For the purpose of this Technical Brochure the extension of the body of the tower to increase the height of conductors operating at higher temperatures, has not been considered as an upgrading action, but as an integral part of Uprating. On the other hand strengthening towers before replacement of conductors with new ones with a larger diameter has been considered as upgrading, even if the reliability level was unchanged or restored after this particular uprating action.

Most definitions consider that life extension and refurbishment are special cases of Upgrading. Again, for the purpose of the Technical Brochure both definitions have been distinguished clearly. There are two main reasons explained in Clauses 8.5 and 8.9:

- According to the answers to the Questionnaire, the decision to increase the expected remaining life is an action irrespective of the acion is whether Uprating or Upgrading. Moreover it is combined with 60% of all Uprating/Upgrading works;
- The expected remaining life is significantly lower than the return period for the climatic limit load. The ratio of the remaining life to the return period varies between 20% and 120%. The mean value is 65%.

The life of the transmission line can be extended by the repair or replacement of deteriorated elements and/or elements where the rate of deterioration with time is too high (due to corrosion, wear, fatigue, annealing, etc.). Deteriorated elements may affect the reliability level as soon as they become weaker than the weakest component. The expected remaining life is a good indicator for the deterioration rate of line elements. It has been requested in Question 9 of the Questionnaire. The availability with regard to outages and failures is a good indicator for line performance.

- Unreliability is the probability of a failure/outage during a specified time;
- Unavailability is the product of unreliability and the mean duration time of the outage.

The indicators to measure Uprating/Upgrading, line performance and remaining life are summarized in Table 3.1a.

Table 3.1a – Indicators for Uprating/Upgrading, performance and remaining life

Action	Increasing	Indicator
Uprating	Transmission capacity	Ratio new to old Power (-)
Upgrading	Strength/Load	Return period of climatic load event (years)
Line performance	Availability	Unavailability = Number of outages x mean unavailable duration per outage (h/year)
Life extension	Decreasing deterioration rate	Expected remaining life (years)

Table 3.1b shows the relations between Uprating/Upgrading, performance and remaining life.

Table 3.1 b – Relation between Uprating/Upgrading, performance and remaining life

	Re-design	Life experience/statistics
Electrical	Uprating	Performance improvement
Mechanical	Upgrading	Life extension

Thermal uprating is carried out where relatively small enhancements are needed. In such cases, there is insufficient cost justification for a full refurbishment or for a new line. The responder from the UK refers to the latter works as “refurbishment”, rather than “upgrading”, as the line is usually returned to an “as new” condition, with the same design reliability, rather than, say, re-design for a new return period.

3.3 Questions

There were 12 questions and 7 tables in the Questionnaire sent abroad. This Questionnaire is given in the Appendix. The answers to the Questionnaire are given in bold characters. The relevant points at the end of each Questionnaire filled in are in italics.

Questions Q2 to Q9 are specific questions for lines that have been Uprated/Upgraded. Questions Q1 and Q10 to Q12 are general questions, even for responders without any experience on Uprating/Upgrading.

Q1 – Name of the overhead lines(s) considered;
Q2 – Line data before/after Uprating/Upgrading;
Q3 – Works carried out on components;
Q4 – Line parameters (incl. Table 1);
Q5 – Uprating/Upgrading costs;
Q6 – Electrical/mechanical reliability before/after Uprating/Upgrading (incl. Table 2 & 3);
Q7 – Operation and maintenance costs (incl. Table 4);
Q8 – Main decision factors (incl. Table 5);
Q9 – Expected remaining life;
Q10 – Decision factors for Uprating/Upgrading rather than a new line (incl. Table 6);
Q11 – Quantification methods for decision (incl. Table 7);
Q12 – Influence of operation and maintenance costs on decision.

In the Questionnaire four kinds of answers were possible:

- A numerical value (e.g. number of lines, mean geographical length, voltage level, power capacity, reliability level, return period, expected remaining life, number of outages per year, availability, etc.);
- Costs for Uprating/Upgrading works (absolute value or percentage with regard to the construction of a new line) and costs for operation and maintenance;
- Yes or no if reasons for decisions are applicable;
- Additional comments.

All these answers have been ranked per Question and per country in the Statistical Tables of Clause 8. Further, they have been classified per Uprating/Upgrading action. In this way it was possible to identify the most remarkable correlations between actions.

3.4 Responses to the Questionnaire

The following countries responded to the Questionnaire (the values between brackets indicate the number of Questionnaires filled up per country):

- Africa: South-Africa (3);
- Asia: Japan (1);
- Europe: Austria (1), Belgium (3), Denmark (1), Finland (1), France (1), Germany (2), Great Britain (3), Italy (5), Norway (1), Poland (5), Serbia and Montenegro (4), Spain (1), Sweden (1);
- North America: Canada (2), USA (2);
- Oceania: Australia and New Zealand (1);
- South America: Brazil (11).

Each respondent has been considered as an expert and consequently as a unique entity, irrespective of the number of responses from the corresponding country and of the scale of this country.

This Technical Brochure does not intend to evaluate the accuracy of each answer.

3.5 Summary of answers received

The countries which answered the questionnaire are described below with the number of lines indicated for each reply:

Australia and New Zealand
- Reply AN1: covering general criteria for Uprating/Upgrading of many lines.

Austria
- Reply AU1: covering only general criteria.

Belgium
- Reply BE1: covering Upgrading for ice load (with Uprating) of a double-circuit 70 kV line;
- Reply BE2: covering Uprating of a double circuit 220 kV line;
- Reply BE3: covering Uprating of 62 lines rated 70 kV.

Brazil
- Reply BR1: covering Uprating of 3 lines and Upgrading of 4 lines;
- Reply BR2: covering Uprating of 1 line;
- Reply BR3: covering Uprating of 28 lines;
- Reply BR4: covering Upgrading of a huge 765 kV line system;
- Reply BR5: covering Uprating with Upgrading of a 88 kV line into 138 kV;
- Reply BR6: covering Uprating of a 138 kV line with concrete supports;
- Reply BR7: covering Upgrading of 750 km of 500 kV lines;
- Reply BR8: covering only general criteria;
- Reply BR9: covering Uprating with Upgrading of a 69 kV wood-pole line into 138 kV;
- Reply BR10: covering Uprating of a double-circuit 69 kV single conductor steel tower line into single circuit 138 kV with twin conductors;
- Reply BR11: covering Uprating of a 138 kV line.

Canada
- Reply CA1: covering Upgrading with Uprating of three 230 kV lines for ice load;
- Reply CA2: covering Uprating with Upgrading of a 230 kV line.

Denmark
- Reply DK1: covering only general criteria.

Finland
- Reply FI1: covering only general criteria.

France
- Reply FR1: covering Upgrading of a 400 kV line.

Germany
- Reply GE1: covering Upgrading of a 380/220 kV line for ice load;
- Reply GE2: covering Upgrading with Uprating of a 380 kV line.

Great Britain (UK)
- Reply GB1: covering Upgrading with Uprating of a double-circuit 400 kV line;
- Reply GB2: covering Uprating of 30 double-circuit 400 kV lines;
- Reply GB3: covering Uprating with Upgrading of a double-circuit 400 kV line.

Italy
- Reply IT1-3: covering Uprating with Upgrading of three 132 kV lines;
- Reply IT4-5: covering Uprating with Upgrading of two 70 kV lines into a 132 kV single circuit line.

Japan
- Reply JA1: covering Uprating of a 66 kV circuit with compact high-temperature conductors.

New Zealand: See Australia

Norway
- Reply NO1: covering Uprating with Upgrading of two single-circuit 132 kV lines using single conductors into a single-circuit 300 kV line using bundle conductors (the same).

Poland
- Reply PO1: covering Uprating of a 220 kV line;
- Reply PO2: covering Uprating of a 220 kV line;
- Reply PO3: covering Uprating of a 220 kV line.

Serbia and Montenegro
- Reply SM1: covering Uprating of a triple circuit 110 kV line;
- Reply SM2: covering Uprating of a single circuit 110 kV line;
- Reply SM3: covering Uprating of a single circuit 110 kV line;
- Reply SM4: covering Uprating of a double circuit 110 kV line.

South Africa
- Reply SA1: covering Uprating of a double circuit 400 kV line;
- Reply SA2: covering Uprating of two parallel 275 kV lines to 400 kV lines;
- Reply SA3: covering Uprating of a single circuit 66 kV line to 32 kV lines.

Spain

- Reply SP1: covering Uprating of 12 lines, four of them 220 kV and eight 400 kV.

Sweden

- Reply SW1: covering Uprating of five lines, one of them 220 kV, one 285 kV and three 400 kV.

United States

- Reply US1: covering Uprating with Upgrading of a 34,5 kV line into 115 kV;
- Reply US2: covering Uprating of a 115 kV line into 230 kV.

3.6 Replies regarding voltage levels

There are a series of interesting and valuable statistical evaluations which can be made from the rich universe of replies received regarding uprating and upgrading of overhead lines.

Regarding voltage classes and types of works carried out, a summary is presented in Table 3.6. The values outside brackets give the number of answers for different voltage classes. The values between brackets correspond to the number of lines considered.

Table 3.6 has been drawn up taking into account the data collected in the Statistical Table 8.2. For the other Statistical Tables, we refer to Clause 8.

Table 3.6 - Replies regarding voltage classes

Voltage kV	Uprating		Upgrading	
	only	with Upgrading	only	with Uprating
33-69-88	7 (88)	3 (3)	-	1 (1)
110-132-145	8 (8)	2 (4)	1 (2)	-
220-245	7 (17)	1 (1)	1 (2)	1 (3)
275-285	2 (4)	-	-	-
380-400	4 (42)	1 (1)	2 (2)	2 (2)
500-550	-	-	1 (>1)	-
765	-	-	1(2)	-
Subtotal	28 (159)	7 (9)	6 (>9)	4 (6)
Total	45 (>183)			

4. Uprating Process

4.1 Generalities

Uprating of an AC overhead line means in general to increase its transmission capacity, and this can be made either by increase of current rate or voltage level or both, considering the simple power equation formula which relates the power to the current rate and the voltage level, that is:

$$P = \sqrt{3}.V.I$$

The increase of current means the need either to raise the conductor temperature or to reconductor the line, while the increase of voltage requires the reinsulation of the line to the new voltage level and the respective overvoltages classes, including increasing phase to phase distances and ground clearances.

In all cases, the main purposes of uprating is the use of existing rights of way and the reduction of costs as compared to the construction of a new line. The simultaneous increase of the current rate and the voltage level is naturally possible and is frequently carried out.

The main methods and tools to uprate overhead lines are summarized in Table 4.1 below.

<table>
<tr><th colspan="4">Table 4.1 – Main methods for Uprating</th></tr>
<tr><td></td><td>Increasing</td><td>Method</td><td>Tool</td></tr>
<tr><td rowspan="12">Uprating</td><td rowspan="6">Current rate</td><td rowspan="2">Increasing temperature
or</td><td>Increasing height attachment point</td></tr>
<tr><td>Re-tensioning</td></tr>
<tr><td rowspan="2">Reconductoring
or</td><td>Compact/smooth conductor</td></tr>
<tr><td>High temperature conductor</td></tr>
<tr><td rowspan="2">Special engineering
methods</td><td>Statistical approach</td></tr>
<tr><td>Real time approach</td></tr>
<tr><td rowspan="6">Voltage level</td><td rowspan="2">Reinsulation
and</td><td>Insulators added/substituted</td></tr>
<tr><td>Cross-arm modified</td></tr>
<tr><td rowspan="2">Ground clearance
and</td><td>Increasing height attachment point</td></tr>
<tr><td>Re-tensioning</td></tr>
<tr><td rowspan="2">Phase-phase distance</td><td>Conversion of 2 to 1 circuit</td></tr>
<tr><td>New tower top</td></tr>
</table>

4.2 Tools for increasing current rate

4.2.1 Increasing conductor temperature

Increase in conductor temperature has as main requirement to raise conductor for increasing clearances to ground. In this case, a terrain profile is used, where tower spotting was carried out in the past. New tools for reevaluating the terrain profile can be used, such as “Laser Scanning Technology”.

In order to compensate higher conductor sags when operating conductor at higher temperature, conductors are raised either:

- at the attachment point;
- or in the mid-span.

The main tools used for raising conductor *attachment* heights and simultaneously keeping the same safety levels are:

- Change of conductor cross-arms by insulated cross-arms (line post or composite insulators) or replacement of vertical suspension strings by suspended strain strings.

- Structure body extension. Also increase in tower heights by adding intermediate extensions has been carried out in Germany, at live-line conditions;

- Replacement of existing towers by higher ones.

For increasing conductor heights *at mid-spans* to compensate higher conductor sags due to higher operation temperature, the following design tools can be used in the line re-design:

- Insertion of new towers in existing spans which have conductors too low regarding the soil; an increase around to 2% to 3% in the EDS (Every Day Stress) tension of the conductor is generally possible in such cases;

- Conductor re-tensioning to higher tensions or only compensating creep occurred along the past life of the line (reduction of conductor length; replacement of hardware in dead-end insulator strings, negative sag devices);

- Ground re-profiling or excavation.

4.2.2. Reconductoring

Reconductoring is one of the more usual techniques for increasing current rate. Various options are possible, always consisting in installing a conductor or a bundle of conductors with a higher current capacity and if possible a higher H/w ratio (by either a higher horizontal tension, H, or a lower conductor unit weight, w). This permits lower sags and therefore makes it possible to raise the conductor height, with lower money expenditures.

Two tools are in this case employed regarding reconductoring of existing lines, which are:

- Replacing existing conductors by conventional ones with a higher conductibility and/or a higher transversal cross-sectional area by operating at same moderated temperatures. Some smooth and compact conductors feature a higher transversal cross-sectional area without increasing the conductor diameter seen by the wind;

- Replacing existing conductors by special conductors apt to operate at high temperatures with low thermal expansion. It is a special case, so classified when conductors are apt to operate at temperatures higher than 100ºC [5].

4.2.3 Use of special engineering methods

a. The use of statistical methods instead of former deterministic approaches often makes it possible to reevaluate design criteria regarding the maximum permissible current on the line. Usually the so called *statistical ampacity approach* permits to set higher currents for the normal operation of a line, without risks for humans and animals circulating below the line;

b. Use of r*eal time ampacity approach,* consisting in measuring the current tensile tension or the instantaneous current flowing in the line and controlling real temperatures which do not provoke risky clearances conductor to ground. Rating monitoring with weather stations or on real time is seldom used to uprate lines permanently, but are more frequently applied to allow use of higher emergency ratings or postponement of more expensive physical upratings. However, physical uprating of a major line can cause new constraints on other lines in contingency conditions. In this case real time monitoring can be a more economical solution.

4.3 Tools for increasing voltage level

The increase of voltage level requires the reinsulation of the line to the new voltage level and the respective overvoltages classes, including increasing phase to phase distances and ground clearances.

Reinsulation can be carried out either by adding insulators or by replacing old insulators by new ones.

Increasing ground clearance for a higher voltage level can be achieved by the tools already mentioned in Clause 4.2.1.

A typical example for reducing the reinforcement of the main body of the supports is to regroup the single conductors of a double circuit line into a twin bundle of a single circuit line. An example is provided for a power enhancement with a factor 4.

5. Upgrading process

5.1 General criteria

Upgrading of an overhead line means an improvement in its structural reliability level.

The basic criteria for upgrading a line consists in using the return period of the limit wind load (or of the limit ice load when applicable), by designing the line for a higher return period (say increasing it from 50 to 150 years).

Reliability is a result of the combination between load and strength of the overhead line. It is obvious that reliability can be increased by either decreasing impact of climatic loads or increasing characteristic strength [3].

The main methods and tools to upgrade overhead lines are summarized in Table 5.1 below.

Table 5.1 - Main methods for Upgrading

	Method	Tool
Upgrading	Reducing impact of climatic loads	Compact/smooth conductor
		Decreasing ice accretion
		Decreasing number of sub-conductors
		Decreasing number of circuits
	Increasing characteristic strength	Support: leg members
		Support: bracings
		Foundation: uplift
		Foundation: compression

The magnitude and occurrence of climatic loads and the strength of line components can be generally described by statistical distributions.

Representative statistical data on wind and/or ice are acquired over a significant period of years. A too low number of years with observations may affect the distribution, in particular regarding the prediction of the structural reliability.

In the same way, if the characteristic strength is based on tests performed with a finite number of samples without using appropriate statistical techniques to account for the statistical uncertainty, it may also affect the prediction of the structural reliability.

5.2 Reducing impact of climatic loads

Once the line is built for given design criteria, it is very difficult to act on reducing weather related loads. However the effect of wind and ice loads applied to supports can sometimes be reduced [3]:

- Reducing wind load by replacing conductors with compact and smooth conductors that have a much lower drag coefficient for high wind speeds;
- Ice accretion on conductors can be decreased in various ways (ice-phobic coatings, increasing torsional rigidity by adding special devices, ice melting procedures such as increasing momentarily power transfer or creating short-circuits);
- Decreasing number of sub-conductors. The substitution of a twin bundle by an equivalent single conductor will provide a significant decrease in wind and ice loads;
- Decreasing number of circuits, especially as they can be modified for a higher voltage level.

5.3 Increasing strength of line components

Increasing strength of line components is more common. Supports and foundations constructed a long time ago have generally built-in reserve in strength due to several reasons such as the original analysis method, the original loading cases and design wind and weight spans that are much larger than the as-built values in the line (effect of use factor). When a new structural analysis of the supports is carried out, many savings in reinforcement can be achieved. The designer can identify the least reliable members for the new loading assumptions and cases. Reinforcing only these members may lead to a significant increase in overall reliability.

Testing of strength of foundation and soil investigation are recommended before undertaking expensive reinforcement measures. Generally speaking it is easier and more economical to increase uplift capacity of foundations than to increase compressive capacity. Uplift capacity can be increased by adding concrete to the foundation, adding screw anchors, soil compacting, substituting backfill material with more appropriate one, drainage of water if the water table is close to the surface [3], etc. Compressive capacity can be increased by drilling piles and combining them with concrete beams.

Conductors and insulators are relatively easy to change. They are mostly replaced due to ageing and repeated electrical and mechanical stresses.

6. Diagnostics on line components and elements - Line redesign

6.1 Basis for improving line performance and extending remaining life

For any kind of Uprating/Upgrading aimed for a line, it is important to have the records of its operation and performance along the years. Three kinds of recordings are considered as shown in Table 6.1 [4].

Table 6.1 - Performance recordings			
Level	Line/circuit (1)	Components (2)	Elements (3)
Statistics	Availability	Reliability	Deterioration rate
Administrative decisions	Improvement in line design	Action on components	Maintenance (repair or change)

Definitions of components and elements are reminded hereunder:

- Components: different parts of a transmission lines. Typical components are supports, foundations, conductors and insulator strings;
- Elements: different parts of a component. Typical elements of a steel lattice tower are steel angles, plates and bolts.

Line performance can be characterized by its availability (1st level), the condition of its components (2nd level) by their reliability.

Availability of lines with regard to failures and (planned and) unplanned outages is a good indicator for line performance. This indicator was requested in Question 6 or Table 2 of the Questionnaire (See Clause 8.8).

The remaining life expectancy of a line can be characterized by the type and number of defects on the elements (3rd level) and by their deterioration rate.

The expected remaining life is a good indicator for the deterioration rate of the line elements. This indicator was requested in Question 9 of the Questionnaire (See Clause 8.9).

The statistics of line performance and the statistics of deterioration permit to identify the behaviour degree of the line and to determine in what an extent the design can be improved, starting from level 3 (element) which has the lowest cost of improvement.

6.2 Phase of planning, design and construction

It is fundamental in all cases of uprating and upgrading to carry out complete diagnostics of the line, so detecting all components and elements which need any kind of action for repair or reinforcement or replacement.

The following steps are included in the design of actions into an existing line:

a) Updating of the original project based on present criteria. This comprises the check of support design by using new design methods available complementary to the regulations for overhead lines. Also the electric determination of ampacity and clearances can be checked and updated. Field surveys, especially by using modern equipment such as “laser scanning technology” are important;

b) Setting of improvement types to be implemented, such as the new reliability and availability targets, new return period for the limit wind load and consequent loads;

c) Optimization of conductors to be used when reconductoring the line;

d) Respotting the line for the new conditions, being important to look for the reduction of costs and of line interruptions;

e) Careful planning of construction works, what can be made at dead-line or shall be live-line, in order to minimize the interruptions. When outages are necessary, they should be planned with enough antecedence.

6.3 Actions on line components

Fitting the original project to a new meteorological model is a decisive step for carrying out the upgrading of a line. New design wind or ice loads may turn out necessary, so as to avoid repeated line failures and consumer’s interruptions. This can often require the upgrading of a line.

The components, elements or functions in which actions can be required are:

a) Re-design of the insulation: in several cases, the improvement of line quality requires increasing the line insulation levels and the respective clearance distances. Measures carried out in such cases include adding insulators to the strings, transformation of suspension strings into suspended strain strings, replacement of conventional insulators by polymeric or composite insulators, use of insulating crossarms instead of existing metallic ones etc;

b) Support reinforcements: supports, especially steel towers, are designed for higher loads, requiring reinforcements, so being able to operate at higher reliability levels.

For instance, adopting statistical approaches for old deterministic methods may increase the return period from 25 into 50 or 150 years, frequently with relatively low amount of reinforcements, as most tower members are designed with big safety margins, and therefore few ones require reinforcements;

c) Reinforcements of foundations: most foundations have been designed with higher safety margins due to the soil uncertainties, thus originating low need of reinforcements. If grillage footings were used, the practice is generally to install new ones if detected their deterioration or failure; in case of concrete footings, installation of micropiles may be an option;

d) Other reinforcements or additions. It is common nowadays to replace existing conventional shield-wires by optical cables (such as OPGW), what requires support and foundation design checks, for eventually installing reinforcements. Substitution or insertion of other line accessories, such as dampers, spacer-dampers, earthing systems, splices are among others, some of the improvements employed.

7. Relevant aspects of Uprating/Upgrading Works per country

Several important aspects have been reported in the different responses received, and it could be stressed the following ones.

7.1 Australia and New Zealand

- **Australian and New Zealand** reply comprised a significant list of methods to achieve greater line ratings and covered practically all types of uprating. Several points can be emphasized as below (The values between brackets indicate the number of Utilities using the method concerned):

Weather monitoring stations (4/7):
- Conventional weather station (3/7);
- Field weather stations (1/7);
- Weather station placed at substations (1/7).

Tension monitoring (4/7):
- On fairly regular basis (2/7);
- To answer specific tension questions (1/7);
- Real time monitoring (1/7).

Changes to supports to raise attachment points:
- Insertion of body/waist extension or the insertion /replacement of the lower structure with taller legs /foundations (5/7);
- Replacing existing structures with new taller structures (1/7);
- Use of intermediate supports to raise conductors at mid-span (7/7).

Changes to cross-arms to raise attachment points:
- Cross-arm modification using horizontal line post (HLP) insulators or long rods (5/7);
- Raising cross-arm attachment points (1/7);
- Inversion of cross-arm (0/7);
- Raising the attachment points to the top of the cross-arm (3/7);
- Installation of post insulators on cross-arm top (3/7).

Changes to insulator strings to raise attachment points:
- Suspension-to-strain conversion (3/7);
- Suspension to semi-strain/floating strain conversion (4/7);
- Suspension replaced with short link-tension insulators either side (1/7);
- Removal of insulator discs (3/7);
- Conversion to V-strings (1/7);
- Removal of insulator hanger brackets (3/7).

Increasing conductor tension:
- Conventional re-tensioning (6/7);
- Cut-and-shut technique (1/7);
- Removal or replacement of hardware (0/7);

Conductor replacement to achieve greater line ratings:
- Conductor replacement of older copper or ACSR conductors with newer AAC and AAAC conductors (4/7);
- Watching developments with high temperature conductors (4/7);
- Installation of high temperature conductors (1/7).

Ground re-profiling and excavation (5/7).

There is a wide diversity in the level of structural upgrade that has been applied. Most utilities attempt to achieve criteria of today. Some selected bracing and corner members are reinforced.

One utility uses only the excess capacity of the supports based on its design using the standards of its initial design. Another utility has avoided this question by preferring to replace existing structures with new taller structures altogether.

It is interesting to note that no utility describes a consideration of reducing the structural reliability of an overhead line.

Regarding supports:

- Insertion of body/waist extension or the insertion/replacement of the lower structure with taller legs/foundations to raise attachment points;
- Replacing existing structures with new taller structures (under live-line conditions);
- Use of intermediate supports (of wood, steel, concrete) to raise conductors at mid-span.

Regarding cross-arms:

- Cross-arm modification using horizontal line post (HLP) insulators or long rods;
- Raising cross-arm attachment points;
- Inversion of cross-arm;
- Raising the attachment points to the top of the cross-arm;
- Installation of post insulators on cross-arm top (less common).

Regarding weather and tension monitoring:

- Weather monitoring stations – Weather monitoring offers considerable benefits to the real ratings that apply on a given day. There are a few weather stations at sites along OH lines that are representative of the weather experienced by the whole line. The tendency is to use conventional weather stations or weather gathering instruments placed at substations. They are to date cheaper and more reliable than field weather stations.
- Tension monitoring – They are in use to varying degrees. This technology is still attracting interest. One Utility will allow circuits to run close to their design limits. The method of calibrating tension monitors to temperature is an area where some form of common development may arise.

Regarding increasing conductor tension through:

- Conventional re-tensioning – Tensions are limited by vibration considerations and additional damping has often been installed;
- Cut-and-shut technique – Two helical dead ends are fitted back-to-back and pulled together with a direct link to create a loop in the span and shorten the apparent conductor length. There is no evidence that it has been really installed;

- Removal or replacement of hardware to change conductor length (only for small tension changes).

Regarding conductor replacement to achieve greater line ratings:

- Conductor replacement of older copper or ACSR conductors with newer AAC and AAAC conductors is regularly carried out;
- Watching developments with high temperature conductors;
- Installation of high temperature conductors is considered by one Utility.

There is little or no concern over reduced conductor life yet as a result of operating conductors at higher temperatures. All Utilities, however plan to continue, or in some cases, will increase the thermal inspection of conductor joints and terminations in conjunction with significant upgrades.

Regarding insulation:

- Suspension-to-strain conversion (it compromises cross-arm strength);
- Suspension to semi-strain/floating strain conversion;
- Suspension replaced with short link-tension insulators either side;
- Removal of insulator discs;
- Conversion to V-strings;
- Removal of insulator hanger brackets is common where these exist.

It is very seldom to remove discs from an insulator string to achieve greater ground clearance while reducing insulation levels. It is only done in low pollution areas.

Regarding how to recompose ground clearances:

Ground re-profiling has been an accepted uprating method where this has been found to be the cheapest solution. In some cases it is not a preferred method where impact on landowners has significance.

Regarding costs:

The cost of all solutions vary and the range is indicated from 10 000 to 50 000 AUS $ per line km. The historical cost of a weather/tension station is approximately 60 000 to 100 000 AUS $, but latest quotations are significantly higher.

Indications are that most of the solutions are driven around least cost and cost effectiveness and those methods indicated as preferred above are also the more cost effective and less intrusive to landowners and, in most cases, the overall system.

Conductor replacement is sometimes linked to the age and condition of the conductor and used as a factor in motivating its replacement and the capacity benefits that arise.

Work is analyzed from a cost benefit perspective after refurbishment assessments are carried out. In some cases lines are replaced and others refurbished.

Achieving uprating can also be motivated by replacement of conductors due to their condition and their age. However it is still unlikely that conductors will run at their actual design rating.

Indications are also that no one contemplates running their overhead lines above their design temperature.

Apart from the expected response of the most cost effective solution, the most preferred solutions are listed below.

- Support raising: the line can be returned to service quickly rather than conductor replacement;
- Removal of insulator hanger brackets: cheap and quick; low impact on landowners;
- Semi-strain conversions: relatively easy; low impact on landowners;
- New taller supports: this method reduces the extent of compromise on safety margins in old design.

The least preferred methods are:

- Re-tensioning: cost; length of outage required; risk of over tensioning;
- Conversion to strain or semi-strain: this method compromises cross-arm strength in suspension towers.

There is a general consensus that the most cost effective combination of all of the above methods is applied to achieve the maximum uprating possible. Choice is influenced by least cost, line condition, impact on landowners and outage limitations.

7.2 Austria

- From **Austria** it came an answer from a Uitility, showing that so far neither uprating nor upgrading of overhead lines had been carried out in the area of such Utility. Uprating from 220 kV to 380 kV was not possible due to other prescriptions from standards to be applied (higher loads). Change of conductors was not sufficient for the envisaged increase in transmission capacity. A much longer line route would have been necessary for the “uprating version” compared with the “shortcut” for a new line.

7.3 Belgium

- An almost 50 year old line in **Belgium** provided with copper conductors 2 x 3 x 54 Cu has been replaced with 2 x 3 x 177 AAAC-1Z (same weight per unit length but the ultimate tensile strength was increased by a factor 2.7) to withstand higher ice accretion.

As the critical load was due to ice accretion, the return period of ice limit load during last fifteen years has been increased from something around 10 years (based on recent historical statistics) to more than 100 years. Cost of maintenance decreased sharply, probably to around 20% of the former value.

- Another Belgian reply covered uprating already carried out or in planning stages of 62 lines rated at 70 kV. One of them is the oldest line of the Belgian system as described in the text; it was built in 1920 for operation at 40°C. The uprating has been scheduled between 1999 and 2005. Some uprating actions are delayed until the line will run close to its design thermal limit.

  According to the National Belgian Regulations for OH lines the maximum operation temperature of Overhead Lines built before 1983 was only 40°C except in the case of derogations. Since 1983 all new lines may be operated up to 75°C.

  In order to check ground clearance of existing lines built before 1983 for operation at 75°C instead of 40°C, the profile drawings were checked. Sometimes verification directly on site or indirectly by laser scanning was necessary. Generally, the ground clearance for operation at 75°C was sufficient. In some sections restringing of the conductors was useful to balance conductor tension between line sections. In order to guarantee conductor clearance at 75°C, it was necessary to raise some attachment points of the conductors. Some suspension-to-strain conversions were sufficient. Only in very rare cases, the insertion of a body extension just above the foundations stubs was necessary.

  The lines were classified in 2003 according to the following list:

  - 10 lines have already been uprated to 75°C in the period 1999-2002;
  - 12 lines are running close to their design operation temperature of 40°C. They have to be studied very quickly to examine the possibility of uprating to 75°C;
  - 2 lines are less urgent, but must be examined;
  - 6 lines are less urgent and their examination may be delayed;
  - 23 lines are still running very far away from their design operation temperature or have not to be examined presently;
  - 6 lines have to be examined because their maximum operation temperature is not certain due to historical reasons;
  - 3 lines may be dismantled.

  The description of the general sequence of activities carried out in Belgium before uprating and/or upgrading is very interesting.

  The components of the OH lines are inspected. The condition of the OH line depends on the initial type of design (including materials used and fabrication/construction process), the age and the environment (wind, humidity, etc.). The line concerned is compared with similar lines (similar design, age and environment) to evaluate and compare types of defects, rate of degradation and possibilities for uprating, upgrading, life extension or refurbishment. The cost of the risk to maintain the line in the present condition is compared with the total cost of the new investment and the reduced risk. If several actions are considered, their total costs (investment and corresponding residual risk) are compared. So, the final proposal is based on Risk Management (See CIGRE TB No. 175 [4]).

- According to another reply an action plan was proposed to extend life of a 220 kV line in Belgium to either 10, 20 or 50 years before uprating from 40°C to 75°C. Finally the decision was taken to keep the line for another 10 years, and to delay the investment for extending life to 20 or 50 years. Only some actions, where the cost of risk was higher than the investment, were approved, e.g. the replacement of U-bolts (for the attachment of suspension sets) where the rate of wear was too advanced. The cost of uprating was 7% of a new line.

It should be borne in mind that although the 220 kV line was designed initially for operation at 40°C, it is feasible at little cost to operate at 75°C as authorized by the present Belgian regulations. This is possible at very low cost because the spans are generally very short (< 200 m). The transition from 40°C to 75°C allows increasing the transmission capacity by a factor 2.6. This value is more theoretical because the ambient temperature considered in the design calculation is different.

7.4 Brazil

- According to a reply from **Brazil**, an increase of 33% in the transmission capacity of three 230 kV lines was obtained by replacing ACSR 636 MCM (Grosbeak) conventional conductors by TACSR 636 MCM (high-temperature conductor), what produced an increase in the power transmitted from 270 MVA to 350 MVA.

- Increase in conductor tension (reference EDS) from 18.5 to 20% was used in several cases for providing the elevation of the conductors, permitting transmission of the power from a new generator connected to the electric network.

- A Utility reported the uprating of 28 lines (17 lines with voltage increase and 11 lines with current increase). This significant number of lines which have been uprated underwent several types of works, such as:

  . Use of suspended strain insulator strings in order to raise the conductor height for operation at 75°C instead of 55°C;

  . Use of several uprating tools, such as use of polymeric cross-arms replacing steel cross-arms, use of suspended strain strings, use of high temperature conductors;

  . As grounding electrodes the practice has been the use of counterpoise wires or cables. Originally, galvanized steel cables were used, afterwards, copperclad steel wires were substituted for the steel cables. Recently galvanized steel cables came in use again, as it was verified that copperclad wires provoked corrosion to the metallic foundations. In the uprating of such old lines, the practice has been the replacement of grillage or concrete stub foundations. In some cases, also anti-corrosive treatment has been used;

  . Some 69 kV overhead lines were originally constructed with 6 suspension insulators (some contained arcing horns) and have been uprated to 138 kV with 8 insulators, without arcing horns. Some 230 kV urban or suburban lines were uprated from a 16-insulator string with arcing horns into a 14-insulator string without arcing horns. In some urban areas, composite insulators were used instead;

. The lightning performance increased with the voltage level from 15 outages/100 km/year, when operating in 69 kV, into 4 outages per 100 km and per year, when operating in 138 kV, and 2 outages per 100 km and per year, when operating in 230 kV.

- A huge work of line upgrading constituted big reinforcements carried out, covering about 600 km of 765 kV lines, having both guyed and self-supporting towers, the works being carried out practically without interruption of power supply. Using IEC 60826 methodology, new reference wind velocity was determined and therefore a new return period of about 150 years. As a consequence, wind loads on different towers were increased in a ratio between 1,42 and 2,15 as compared to the original loads. The basic change to withstand higher wind loads consisted in reinforcing the external leg member of the masts and the first diagonals on the longitudinal face of the mast top part (Fig BR4-1, 2 and 3).

  It should be mentioned that recently new tower failures occurred involving towers which had already undergone reinforcements for upgrading.

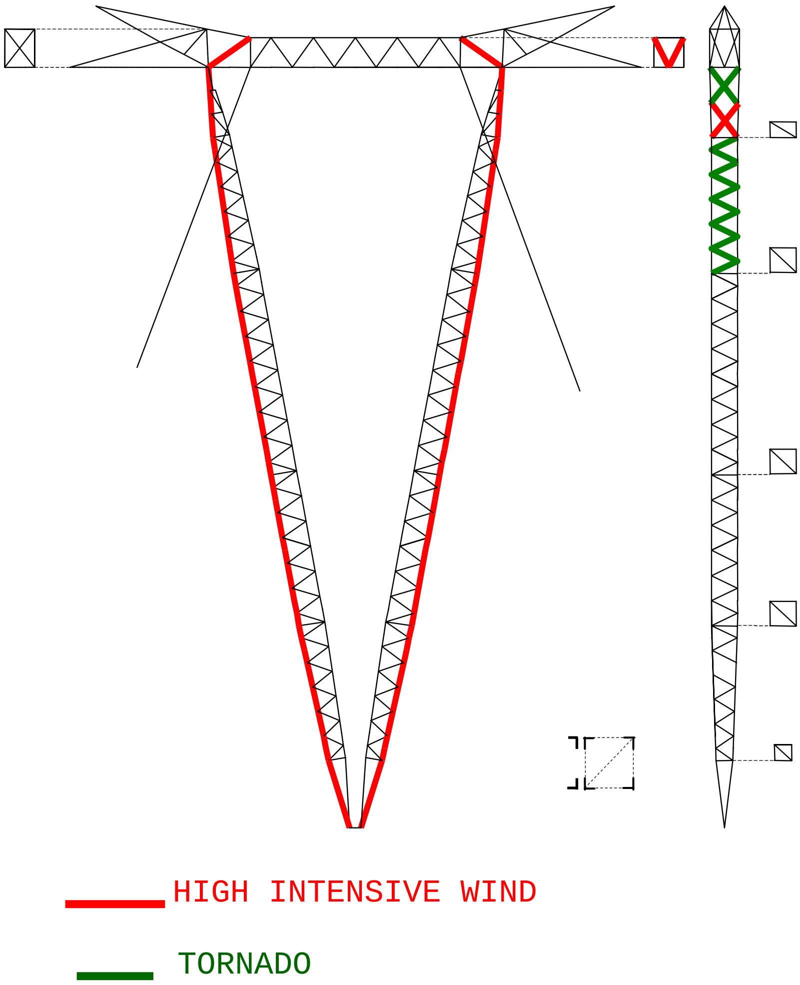

Figure BR4-1: Upgrading of 500 kV towers

Figure BR4-2: Aesthetic view of reinforced guyed tower

Figure BR4-3: Reinforcements in typical self-supporting towers

- There was an increase of voltage from 88 to 138 kV and a change of conductors, with a 100% increase in the power transmitted, at the price of 60% of a new line for the same power. The decision to uprate lines is based only on the need to carry more power on the line. Furthermore, the life expectancy was increased from 10 to 30 years.

- Old concrete poles have been changed by new concrete poles or metallic supports, and there was a conductor restringing from EDS 18 into 20%.

- There was an interesting line upgrade, where tower reinforcements were prioritized inside a long period, being made at live-line conditions, with a big increase in reliability level (wind return period increased from 15 to 150 years) and correspondingly low money expenditures. The original design of the line was based on a semi-statistical method. However, the return period turned out wrong in view of the lack of enough wind data measurement. For the upgrading of the line, a statistical method was used, using at this time a bigger and more representative sample of wind data. Also the availability of the lines increased significantly, thus reducing loss of income. There was a theoretical increase in both electrical and mechanical reliability of the lines, what has been confirmed in the practice.

- There was also a very precise work of uprating a line at live-line conditions: practically all wood-pole structures were replaced by new and taller ones. Also the wood cross-arms as well as the insulator strings were substituted or increased at live-line work. It was possible to multiply the power transmitted by a factor 4, with a relatively low money expenditure (around 20% of the cost of a new line for the same power increase).

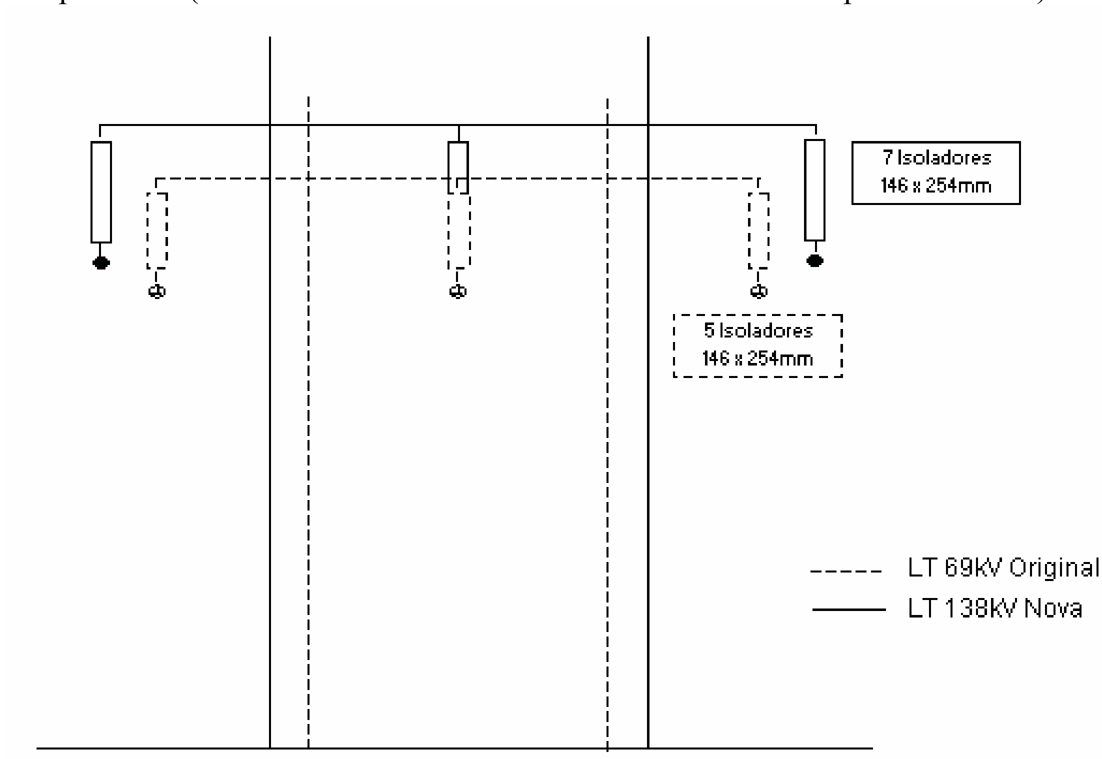

Figure BR9-1: Original and new structure

- Uprating of double-circuit lines, by doubling the voltage in a single-circuit, e.g. from 69 into 138 kV, regrouping the same existing conductors in bundle configurations, has permitted to quadruple the line capacity at a relatively low cost. For example a 69 kV rated 2 x 18 MW was converted into a single circuit 138 kV with twin bundles rated 144 MW, at a cost of approximately 25% of a new line for the same capacity. The old towers were considered apt for the new operation without reinforcements other than the change of the tower top.

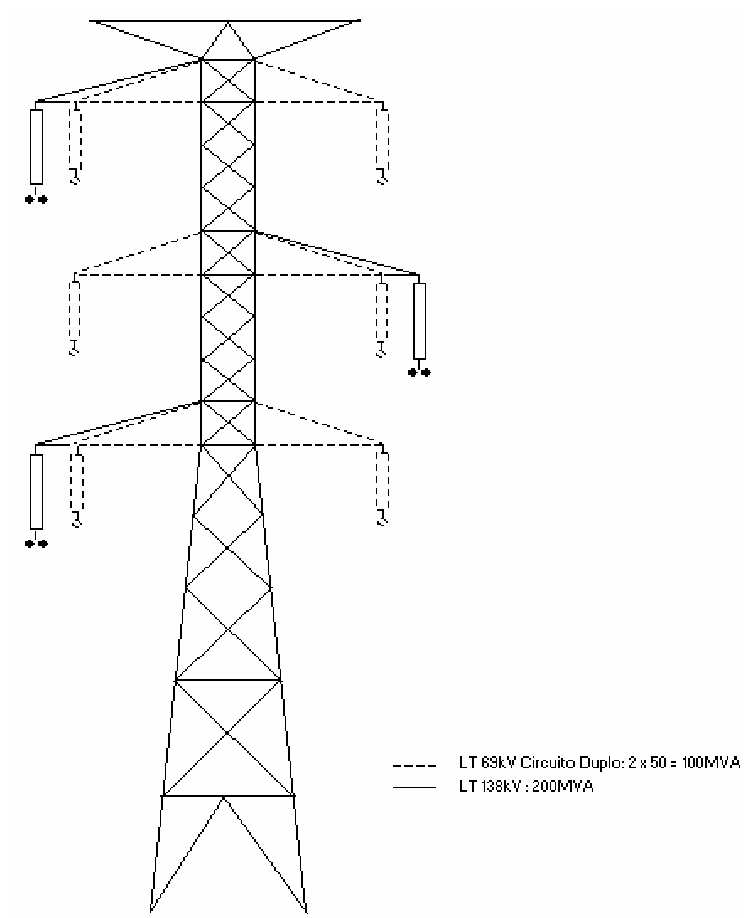

Figure BR10-1: Uprating of a double circuit 69 kV into a single circuit 138 kV line by regrouping the same conductors in a twin bundle

- A double circuit 138 kV TL, in urban areas, 3.2 km long and with 30 metallic towers type, was reconductored from 2 x 2 x 636 MCM ACSR to 2 x 2 x 636 MCM TACR/TACIR (high temperature conductor) achieving an increase of 30% in the transmission capacity of the line, from 234 MVA to 300 MVA. All the works were completed in 3.5 months.

7.5 Canada

- Recent upgrading work of a major transmission line system (1997-2002) in **Canada** was based on a reliability study which was primarily driven by a large number of failures due to severe icing. The system was designed in late 60’s and a number of failures occurred during the past 35 years operation life and this high failure rate was unacceptable.

  The reliability study did consider the damage cost based on historical information which was available and tried to determine the BEI (Break Even Index) where the cost of upgrading is balanced against the future damage cost. It did not consider the cost of maintenance.

  In this utility new lines are constructed based on the initial cost, not considering the life cycle cost in which the cost of maintenance is normally included (steel vs. wood).

  Upgrading study did consider the cost of upgrading to a new revised design load and the expected cost of damage. The new revised design load was estimated based on running an ice accretion model supported by data obtained from the nearby airport weather station and then updating this information based on the actual line failure information due to ice that was available historically. A revised Gumbel plot was used to estimate the new ice design load.

  Regarding ice loads, although the original design in late 60’s used 25 mm radial glaze ice, it was observed and determined based on historical failure data that this load was close to 7- 10 year return period. Therefore based on historical airport data since 50’s, the icing model and the actual observed icing, the design load was increased to 66 mm radial glaze ice for 25 year return period and 75 mm glaze radial for 50 year return period using updated Gumbel Plot. For the old upgraded section a 25 year service life was used while for the new section, a 50 year service life was assumed. This will still maintain the same expected rate of exceeding the load (64% probability).

  Sharp reduction of unavailability of the lines has been determined after line upgrading. Cost of maintenance: before upgrading, US$ 2428/km; after upgrading: not known yet.

- For a 230 kV line the original 795 ACSR conductors were replaced with 1113 ACSS conductors. Suspension lattice towers were modified by replacing bracing members. Their foundations were changed. Dead-end towers and foundations were installed new.

7.6 Denmark

- **Denmark** mentioned only painting/regalvanizing of towers in order to extend life.

7.7 Finland

- An interesting observation was made regarding lines in **Finland**, namely that the existing structures are such that application of higher voltage level or bigger conductors is usually not feasible without change of the guyed supports. As a result usually old 110 kV lines are replaced with new ones.

7.8 France

- A project of a 400 kV line (30 km, 60 supports) in **France** was included in the strengthening program and policy following the severe wind storm events of December 1999.

  Main technical measures taken on the line were:

  - Implementing anti-cascade towers (about every 10 towers) using a new specific mechanical assumption (specific conductor configuration),
  - Mechanical reinforcement (towers and foundations) using new mechanical assumptions (570 Pa wind on conductors instead of 480 Pa).

  The original support types didn't change. 7 anti-cascade towers have been created: 3 supports have been reinforced, 2 have been replaced and 2 were strong enough. 14 other towers have been reinforced in regards with new assumptions (bolts and bracing replaced, buckling length reduced). 20 foundations had to be reinforced, each of them by 2 micro piles (about 10 m long and 0.2 m diameter).

7.9 Germany

- Upgrading was carried out in **Germany** on a 380/220 kV four circuit line across the river Weser. The suspension towers are 130 m tall. Upgrading was based on DIN VDE 0210/12.85. The basic wind speed was increased from 31 m/s as stipulated for the original design to 36 m/s, the ice load from 25 N/m into 40 N/m. Compared with the standard, the wind pressure was increased by 35% and ice loads doubled. Thus the yearly failure probability was reduced from $10^{-1.5}$ to $10^{-2.7}$. Return periods for design wind increased from 35 years to 300 years, for design ice from 40 to 400 years. Estimated remaining line life increased from 30 to 50 years.

  The suspension and strain towers were reinforced to accommodate the increased loads. The cross-arms were modified to accommodate the increased ice loads. To increase load capacity under compression, additional angle sections were added to the leg members and bracings were replaced. Foundations were upgraded by installing additional piles and combining them with concrete beams.

- On a 380 kV line in Germany, twin conductors ACSR 560/50 were replaced by quadruple bundles ACSR 265/35 to reduce corona effects and increase thermal capacity. The thermal capacity increased from 2700 MVA to 3600 MVA. Shield wire ACSR 120/70 was replaced by OPGW. At this occasion, wind pressures were increased by 27%; ice loads doubled. The new conductors necessitated replacing of I-type insulator sets with three long rods by asymmetric V-sets with a rigid leg and vertical GRP rods to limit the right-of-way. As a consequence of uprating and upgrading significant modifications on towers were needed: modification of cross-arms to accommodate the redesigned insulator sets; adding additional angle sections to leg members to form cruciform sections with higher strength capacity; replacement of bracings.

  Design wind return period increased from 50 years into 150 years by increasing the basic wind speed from 24 m/s to 27,4 m/s. The resulting reliability went from $(1 - 10^{-1.7})$ into $(1 - 10^{-2.2})$. The remaining estimated line life increased from 40 years (before upgrading) to 80 years (after upgrading).

7.10 Great Britain

- A transmission line on the South coast of **Great Britain** was nearing the end of its design life. Poor condition of the line and its components was resulting in an unacceptable level of reliability. Due to high outage costs associated with this unreliability, the decision was taken to refurbish the route a few years earlier. Some steelwork and full tower replacement were carried out owing to the condition of the line (corrosion).

  The original conductor 4 x 400 54/7 ACSR "Zebra" rated at 50ºC, was replaced with 3 x 700 AAAC "Araucaria" conductor rated at 50ºC. The triple bundle was chosen for the refurbishment as it was considered less prone to wind-induced motion (sub-conductor oscillation), and hence the conductors would be less prone to fatigue damage. Savings in operation costs came from the reduction in thermal loses (lower bundle resistance). Although the works carried out are reported as upgrading, there was an increase in the power transmitted from 2780 MW per circuit to 3070 MW per circuit.

- Typically, lines thermally uprated in Great Britain were originally constructed in the early 1960s, and uprated with higher capacity conductors in the mid to late 1980's, with many then being uprated in the 1990's. Mention was made to 30 lines thermally uprated.

  Also, in England and most other countries which informed about current uprating by increased in conductor temperature, it was stated clearly that occasionally, it was necessary to carry out minor engineering works in order to gain necessary electrical clearances to ground. This might include a small over-tension on the conductors, and/or the movement of suspension clamps to force a longitudinal swing of the insulator set.

Thermal uprating is carried out where relatively small enhancements are needed. In such cases, there is insufficient cost justification for a full refurbishment or for a new line. The author refers to these works as “refurbishment”, rather than “upgrading”, as the line is usually returned to an “as new” condition, with the same design reliability, rather than, say, re-design for a new return period.

Also for this group of lines in UK, construction costs of uprating lines for a power 20% higher were, on average, around 0.25% of the cost of constructing a new, double circuit overhead line.

As important cost parameter, it was informed that the transmission constraint costs were either totally eliminated (100% lower) or reduced in the range 0-50%.

- A transmission line in the North West of England was causing a thermal constraint on the network, and required a rating enhancement. The line was reconductored with the “gap-type” high temperature low sag conductor system in order to give the necessary increase in capacity. The alternative would have had to have been a new overhead line. Consider additionally that there was a significant increase in the power transmission from an original value of 1710 MW per circuit to 3100 MW per circuit.

  Life extension reached until 40 years for the remaining life. Also, the reduction of maintenance costs was total, the line supposedly not requiring more maintenance.

  Approximately the same cost as building a new line with standard conductors was the result. Note that this involves construction costs only. In reality, a new line will require very high costs associated with obtaining planning permission, and take a long time. Therefore there were significant savings in reconductoring the existing route.

7.11 Italy

- Some 70 and 132 kV lines in **Italy** were uprated by reconductoring with new conductors with higher cross-sectional areas. Both the foundations and earthing system were totally replaced by new designs. All the towers have been substituted at the original places. The line transmission capacity was increased between two and three times.

7.12 Japan

- For some 66 kV lines in **Japan**, several interesting works of uprating were carried out in a line, with outstanding results as follows:

  a) The transmitted power was more than doubled by stringing the second circuit;

b) In a smooth body ACSR conductor (SBACSR), aluminum strands are processed as a sector form to have a large cross-sectional area of an aluminum conductor with the same diameter (compacted conductor). SBACSR conductors have compacted smooth surfaces in the strands. Accordingly it has the advantage of bearing the wind pressure with its small outer diameter. A compacted conductor can change the configuration of steel core and aluminum conductors, and enhance sag characteristics.

The use of compact conductor for uprating the lines without increasing the tower loads but doubling the transmission capacity was a paramount point of this uprating work. The original conductors of the first circuit were ACSR 160 mm^2 and ACSR 240 mm^2. To uprate the line, the second circuit was added. The new conductors were SBACSR 210 mm^2 and SBACSR 320 mm^2. SBACSR 210 mm^2 was added to the section of ACSR 160 mm^2 of the first circuit, and SBACSR 320 mm^2 to ACSR 240 mm^2.

c) Table Jpn-4a in Appendix A2 shows interesting information of maintenance costs for each circuit of double-circuit lines. For instance the maintenance cost of the second circuit installed is 19% against 38% of the first one, only because of the "trimming costs";

d) The line was provided with an insulated neutral point to earth method before but changed to a Peterson Coil (PC) with a neutral point resistively grounding method, when changing to a double circuit line;

e) There was a sharp reduction in the line fast-front (lightning) performance, and the failure index dropped from 6.1 to 0.4/100 km.year. Also the power-frequency performance dropped from 9 failures in 10 years to 1 failure in 16 years.

7.13 Norway

- In **Norway**, significant Uprating was carried out in a 132 kV double-circuit line conveniently converted into a single-circuit 300 kV. The lines used internally guyed components, by using bundle conductors. The suspension supports got new attachments for the V-chains. The tension supports got new attachments for the outer phases. Some of the lattice members were reinforced. Power increased four times by using the same conductors in a twin bundle configuration.

7.14 Poland

- Some different additional reasons were indicated to support the decision about the uprating and renovation of lines in **Poland**, such as:

. The great importance of the line in the system;
. The need of increasing the transmission capacity of the line;
. The possible high costs of unavailability of this line;
. The considerable age of line;
. New 220 kV lines are no longer constructed and 400 kV system was not planned in the nearest future in that region;
. Results of the condition assessment of line indicated a possibility of life extension of supports and foundations.

Uprating of a 220 kV overhead line in Poland was associated with extensive renovation and exchanging of elements which had reached their life time (steel ground wire and insulators). All these tasks were carried out as a turn-key project, that's why the costs of uprating itself cannot be clearly determined. It can be said that a true upgrading has also been simultaneously performed, as the remaining line life after the renovation was estimated 35 years against the 10 years considered beforehand.

- For the uprating of a double-circuit line in Poland, more than 100% increase was obtained, from a previous value of (180 + 196) MW to 2 x 400 MW. The uprating was carried out by reconductoring from a previous temperature of 55ºC, circuit “1” with conductor ACSR, stranding 30/3.85 mm 19/2.3 mm, diameter 26.9 mm, circuit “2” - ACSR “Condor”, to conductor AAL 400 for both circuits at a continuous temperature of 106ºC.

Other reasons were indicated for uprating lines. There is no quantifying method like this one which was described in paper B2-102 (CIGRE 2004). The Utility has its own procedure of decision taking which takes into account most important aspects like:

. initial investment costs of uprating/upgrading;
. life expectancy before and after works carried out;
. importance of the line;
. planned development of the 400 kV network;
. need of increasing power transmission;
. results of condition assessment;
. rates and the cost of failures and other consequences of unavailability.

7.15 Serbia and Montenegro

- Four 110 kV lines have been uprated in **Serbia and Montenegro** by reconductoring with conductors with a larger cross-sectional area. Two line sections cross the Danube river. A structural analysis of the towers has been carried out. Thanks to the use factor and the strength excess of the towers in the longitudinal direction, the reinforcement of the towers could be avoided. Only the damaged steel angles have been replaced in the towers. The insulators were replaced with the conductors. The objective of the Uprating was the increase in transmission capacity and the increase of the clearances above the ground and the river Danube with the lowest investment costs.

7.16 South Africa

- For the Uprating of a 400 kV line in **South Africa**, the templating temperature of 50°C was increased to 76ºC, and statistical rating applied. Real Time Monitoring was also added to monitor particularly a critical 400 kV crossing where the phase conductors of this line cross over the ground wires of another 400 kV line (minimum of 3.2 m clearance to be maintained there).

  The original conductors were re-tensioned and integrity of joints verified with Infrared Thermal Scanning under excessive current loading conditions.

  Thermal capacity was increased by increasing tension after airborne laser survey and PLS-CADD modeling of phase conductors and checking of joints (resistance measurement) as well.

  Tower footing resistance is limited to the value of 40 Ω. Different solutions, combinations of foundation earthing, vertical rods and counterpoise were used. The earthing standard specifies that the earth wires of the gantry are connected to the terminal towers (not insulated). Only if the tower footing resistance of the first five towers are less than 10 ohms each, it will be required that the ground wires are insulated from the towers but still jumped through to substation gantries. When a line is within 800 m of a pipeline, the ground wire is also insulated from the towers.

  Cost of maintenance: 35 E/MW Year before the uprating and 20 E/MW Year after the uprating.

- After some recent simultaneous failures and unavailability of power stations, it was decided to uprate two parallel single-circuit 275 kV lines into 400 kV lines. In essence the line uprate consisted of the re-insulation of the line to increase the insulation capacity, and re-tensioning of phase conductors to accommodate the change in height. Before re-tensioning, the joints were verified with Infrared Thermal Scanning under excessive current loading conditions.

  Standard glass cup-and-pin insulators were originally used. For re-insulation, glass insulators with the extended creepage length (545 mm for 146 mm insulator unit) were used.

  To obtain the required connecting length of the insulator strings, insulation assembly on middle phase changed from I-string to inverted V-string. On outer phases, length of insulator string was extended. The insulator which was used has given a required total creepage of 20 mm/kV on 400 kV level.

- Another example deals with the uprating of the Marathon - Kiepersol 66 kV line to an operating voltage of 132 kV. Required modifications were defined, based on assessment of the corona performance, insulation co-ordination and high voltage impulse tests performed on the 66 kV structure, as well as physical measurements of the line.

  Uprating is possible with modifications to the attachment and insulation of the existing towers. Line route will need to be re-surveyed. Most of the work can be performed by live line technique.

  Parts of the fittings (e.g. shackle U-bolts and straight shackles) were found to be in good condition. However there were structures in the line where the glass disc insulators were replaced with the composite long rods. There is a variation in length between installed long rod insulators.

  It is commonly accepted that, for altitudes prevailing in South Africa, the smallest single conductor to be used for 132 kV lines is a Wolf conductor with diameter of 18.13 mm. Since Hare conductor has a lower diameter (14.16 mm), the evaluation of Corona performance was required for the specific altitude.

  This study revealed the following:

  - Conductor will be in corona at this altitude if the maximum line voltage will reach the level of 145 kV, assuming the conductor roughness factor not to be better than 0.75.
  - Audible noise levels will be lower than that of a 400 kV twin Dinosaur line, despite the fact that the conductor will be in corona.
  - The expected radio interference levels will be below that of the 400 kV line. Radio interference levels will be negligible for frequency spectrum above 10 MHz and for lateral distances from the centre line of more than 32 m in dry air conditions and more than 95 m in wet air conditions.
  - Corona losses cannot be accurately predicted. However, it is expected that the losses would not be more than 2 - 6 kW/km.phase for dry and very wet weather conditions respectively.

  The expected weaker Corona performance is seen to be within a tolerable level. It is also predicted that the maximum operating voltage of this line should not exceed 135 kV. The strings of five or six glass disc insulators are used on the existing line. The required insulation strength can be achieved either by adding the glass disc insulators or by replacing the string with a composite long rod insulator.

The existing suspension insulator assembly consists of:

- Shackle U – bolt;
- Ball - oval eye;
- X glass disc insulators, 16 mm ball & socket, 146 X 250 mm;
- Socket – tongue;
- Suspension cradle pivoted clamp with armour rods.

Overall length of the assembly, measured from the bottom of the cross-arm to the bottom of the clamp, is 1020 mm.

The addition of glass discs is considered since:

- this is a simple operation where not much can go wrong;
- the string of 8 glass disc insulators provides an adequate insulation strength;
- the probability of air gap clearance failure is acceptable;
- it constitutes no problem with ground clearance;
- it allows live line work;
- material and labour costs are minimal;
- the insulator string can be replaced with the composite long road insulator at a latter stage.

To achieve the required insulation strength of the existing insulator string, only two additional glass discs are required. The amount of sag increase, due to the increased overall coupling length of the insulator string, will be prohibitive. The conductor therefore will have to be marked, cut and made off again with a new compression dead-end. This is a specialised, labour intensive operation and cannot be performed live.

Since it has to be performed anyway, the use of new composite insulators can be considered. Longer creepage distance and electrical characteristics better than those of 8 glass discs will be achieved. Removed glass disc insulators may be used on suspension string assemblies.

7.17 Spain

- 12 lines of 400 kV have been uprated in **Spain**, predominantly due to the changes in the regulatory market, as there was an important change of power flow across the transmission grid (new locations of generation plants, increase of demand, bottlenecks in some lines…). This, together with the difficulties of constructing new lines, makes it necessary to increase power transmission of new lines.

  Four 220 kV and eight 400 kV lines were uprated by increasing conductor temperatures from 50ºC into 85ºC (one line was uprated into 75ºC), with a power increase from 30% to about 50%.

7.18 Sweden

- In **Sweden** some lines of 220 to 400 kV have been uprated. It was stressed that the relative costs for uprating the lines was indicated as having been between 5 to 10 % of the cost of new equivalent lines, while the increase in capacity carried out through conductor temperature increase varied in the range from 10% to 60%.

7.19 United States

- A significant increase in the remaining life of the line was reported in **USA**, from 15 to 50 years, for a line uprated from 33 kV to 115 kV.

- Most often the issue of limited right of way is the determining factor in USA, as reported for the uprating of a 115 kV line into 230 kV, for both uprating and upgrading before taking a decision on what to do and how to do.

8. Statistical tables per question

The following Statistical Tables 8.1 to 8.14 summarize per question and per reply (or per country) the various answers to the Questionnaire. The information between brackets after the title of the Table refers to the number of Question (Q1 to Q12) or Table (T1 to T7) from the Questionnaire.

Q = Number of Question from Questionnaire
T = Number of Table from Questionnaire

Table 8.1 – Overview of the number of answers provided to the Questionnaire (Q1 to Q12; T1 to T7)
Table 8.2 - Line data before and after Uprating and/or Upgrading (Q2)
Table 8.3 - Overview of the main Uprating/Upgrading works carried out (Q3 to Q5 & T1)
Table 8.4 - Typical Uprating/Upgrading works carried out (Q3)
Table 8.5 - Classification of Uprating/Upgrading works carried out (Q3)
Table 8.6 - Uprating works carried out on conductors and insulator strings (Q3)
Table 8.7 - Upgrading works carried out on supports and foundations (Q3)
Table 8.8 - Results of Uprating works (Q6.1 & T 2)
Table 8.9 - Results of Upgrading works (Q6.2 & 9 & T3)
Table 8.10 - Operation and maintenance costs (Q7 & T4)
Table 8.11 - Decision factors on Uprating and/or Upgrading works (Q8 & T5)
Table 8.12 - Decision factors on Uprating/Upgrading rather than a new line (Q10 & T6)
Table 8.13 - Quantification methods for decision on Uprating/Upgrading (Q11 & T7)
Table 8.14 - Influence of operation and maintenance costs on decision (Q12)

Most of the Statistical Tables are followed by some conclusions and a summary table per item and per specific Uprating/Upgrading activity.

8.1 Overview of the number of answers provided to the Questionnaire

Table 8.1 - Overview of the number of answers provided to the Questionnaire																	
Question Q – Table T	No Uprating/Upgrading done	Name of the overhead line	Line data before/after Upr/Upgr	Works carried out on components	Line parameters	Uprating/Upgrading costs	Electrical reliability	Mechanical reliability	Operation & maintenance costs	Main decision factors	- Additional information	Expected remaining life	Decision factors for no new line	- Additional information	Quantification methods	- Additional information	Influence O&M costs on decision
Table					1		2	3	4	5			6		7		
Quest	0	1	2	3	4	5	6	6	7	8	8	9	10	10	11	11	12
AN1	-	-	-	x	-	x	-	-	-	x	x	-	x	x	x	x	x
AU1	x	-	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-
BE1	-	x	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x
BE2	-	x	x	x	x	x	-	x	x	x	x	x	s	s	s	s	s
BE3	-	-	x	x	x	x	-	x	x	x	x	x	s	s	s	s	s
BR1	-	x	x	x	x	x	-	-	-	-	x	-	x	-	x	-	x
BR2	-	x	x	x	x	-	x	-	-	x	x	x	x	x	x	x	x
BR3	-	-	x	x	-	-	x	x	-	x	-	-	x	-	x	-	-
BR4	-	x	x	x	x	-	-	x	-	x	-	x	x	-	-	-	-
BR5	-	-	x	x	x	x	-	x	-	x	-	x	x	-	x	-	x
BR6	-	x	x	x	x	-	-	-	-	x	-	x	s	s	s	s	s
BR7	-	-	x	x	x	-	x	x	x	x	x	x	x	x	x	x	x
BR8	x	-	-	-	-	-	-	-	-	-	-	-	x	-	x	-	x
BR9	-	-	x	x	x	x	-	x	-	x	-	x	x	-	x	-	x
BR10	-	-	x	x	x	x	-	x	-	x	-	x	x	-	x	-	x
BR11	-	x	x	x	x	-	-	x	-	x	-	-	x	-	x	-	-
CA1	-	-	x	x	x	-	x	x	x	x	x	x	-	x	-	x	x
CA2	-	x	x	x	x	-	-	x	-	x	-	x	x	-	x	-	x
DK1	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	x	x
FI1	x	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-
FR1	-	x	x	x	x	-	-	-	-	x	x	-	x	x	x	x	-
GE1	-	x	x	x	x	-	x	x	-	x	x	x	x	x	x	x	x
GE2	-	x	x	x	x	-	x	x	-	x	x	x	s	s	s	s	s
GB1	-	-	x	x	x	x	x	x	-	x	-	x	-	x	-	-	x
GB2	-	-	x	x	x	x	-	-	x	x	x	x	x	x	x	x	x
GB3	-	-	-	x	x	x	-	x	-	x	x	x	-	x	-	-	x

IT1-5	-	x	x	x	x	-	-	-	-	-	x	x	x	-	-	-	x
JA1	-	x	x	x	x	x	x	x	-	x	-	x	-	-	-	-	x
NO1	-	x	x	x	x	x	-	x	-	x	-	x	x	-	x	-	x
PO1	-	x	x	x	x	x	x	x	-	x	x	x	s	s	s	s	s
PO2	-	x	x	x	x	x	-	x	-	x	-	x	x	x	x	x	x
PO3	-	x	x	x	x	x	x	x	-	x	x	x	s	s	s	s	s
SA1	-	x	x	x	x	x	x	x	x	x	x	x	s	s	s	s	s
SA2	-	x	x	x	x	x	x	x	x	x	x	x	s	s	s	s	s
SA3	-	x	x	x	x	-	x	x	-	x	x	x	x	x	x	-	x
SM1	-	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x
SM2	-	x	x	x	x	x	-	-	-	x	x	x	s	s	s	s	s
SM3	-	x	x	x	x	x	-	-	-	x	x	x	s	s	s	s	s
SM4	-	x	x	x	x	x	-	-	-	x	x	x	s	s	s	s	s
SP1	-	x	x	x	-	x	-	-	-	x	x	-	x	x	x	x	x
SW1	-	x	x	x	x	x	-	x	-	x	x	x	x	x	x	x	x
US1	-	-	x	x	x	-	-	x	-	x	-	x	x	-	x	-	x
US2	-	x	x	x	x	-	x	-	-	-	x	-	x	x	-	-	x
Table					1		2	3	4	5			6		7		
Quest	0	1	2	3	4	5	6	6	7	8	8	9	10	10	11	11	12

We received in total 43 Questionnaires with answers filled up. Statistical Table 8.1 above indicates per country which answers to Questions Q1 to Q12 have been provided and which Tables T1 to T7 in the Questionnaire have been filled up, even partially. Four answers (AU1, BR8, DK1 and FI1) mentioned that neither Uprating nor Upgrading works have been carried out. As they provided only some answers to the general Questions Q10 to Q12 and Tables T6 to T7, they are not mentioned in the next Statistical Tables 8.2 to 8.11. Their answers to the general Questions are incorporated in the Statistical Tables 8.12 to 8.14. The Summary Table 8.1/S below gives for the other 39 Questionnaires in both absolute value and in % the response to the different Questions (Q), Tables (T) and requests for additional information.

Table 8.1/S - Overview of the number of answers provided to the Questionnaire

		Answers provided to the Questionnaire (Questions Q1- Q12; Tables T1- T7)	R or G				No R/noG	
			No reply		Reply		Reply	
Q	T		Abs	%	Abs	%	Abs	%
		Number of replies with neither R nor G	-	-	-	-	4	100
		Total number of replies R or G	0	0	39	100	-	-
1		Name of the overhead line	12	31	27	69	-	-
2		Line data before/after Uprating	2	5	37	95	-	-
3		Works carried out on components	0	0	39	100	-	-
4	1	Line parameters	3	8	36	92	-	-
5		Uprating/Upgrading costs	15	38	24	62	-	-
6	2	Electrical reliability	25	64	14	36	-	-
6	3	Mechanical reliability	13	33	26	67	-	-
7	4	Operation & maintenance costs	31	79	8	21	-	-

8	5	Main decision factors	3	8	36	92	-	-
8		- Additional information	13	33	26	67	-	-
9		Expected remaining life	7	18	32	82	-	-
10	6	Decision factors for no new line	4	10	35	90	3	75
10		- Additional information	12	31	27	69	2	50
11	7	Quantification methods	7	18	32	82	1	25
11		- Additional information	16	41	23	59	1	25
12		Influence of O&M costs on decision	4	10	35	90	2	50

All those 39 responders replied to Question Q3 (100%) on the works carried out. They are summarized in Statistical Table 8.3 in only one line, with inclusion of the relative costs of the works.

We were also very successful with the questions on the decision factors (Q8: 92%; Q10: 90%; Q12: 90%) and line data before and after Uprating/Upgrading works (Q2: 95%; Q4: 92%). However, we received relatively very few answers on the electrical reliability (Q6: only 36%) compared with the mechanical reliability (Q6: 67%) and the expected remaining life (Q9: 82%) of the line concerned. Finally only 21% of the 39 responders replied to Question Q7 on Operation and Maintenance (O&M) costs. It already indicates how complex it is to follow up and assess line performance and O&M costs.

The different questions are classified below according to the success of the response in order to assess the significance of their statistical value.

100%: Works carried out on components;
95%: Line data before/after Uprating;
92%: Line parameters;
92%: Main decision factors;
90%: Decision factors for no new line;
90%: Influence of O&M costs on decision;
82%: Expected remaining life;
82%: Quantification methods;
69%: Name of the overhead line;
67%: Mechanical reliability;
62%: Uprating/Upgrading costs;
36%: Electrical reliability;
21%: Operation & maintenance costs.

Some general answers to Q10-12 are common to one specific Reply (B2, B3 for B1; BR6 for BR2, GE2 for GE1; PO1, PO3 for PO2; SA1, SA2 for SA3; SM2, SM3 and SM4 for SM1) (see “s” instead of “x” in Table 8.1).

8.2 Line data before and after Uprating and/or Upgrading

Table 8.2 - Line data before and after Uprating and/or Upgrading

Item	Number of lines considered	Mean geographical line length (km)	Type of support	kV level (before Uprating/Upgrading)	- Number of circuits	- Number of sub-conductors	kV level (after Upr/Upgr) (if modified)	- Number of circuits (if modified)	- Number of sub-conductors (if modif.)	Construction year	Year of Uprating/Upgrading
Item	1	2	3	4	5	6	7	8	9	10	11
AN1	-	-	-	-	-	-				-	-
BE1	1	1	T	70	2	1				55	03
BE2	1	47	T	220	2	1				34	03
BE3	62	20	T+C	70	1(2)	1				>20	99-05
BR1	3	164	T	230	1	1				-	04
	2	78	T	230	1	1				-	03
	2	164	T	138	2	1				-	03
BR2	1	18	T	138	1	1				94	04
BR3	17	23	T(C)	69	1(2)	1	138			-	82-95
	5	13	T	69	2(1)	1				-	91-04
	6	39	T	230	1(2)	1				-	99-04
BR4	2	299	V	765	1	4				80	00
BR5	1	10	T	88	2	1	138			59	02
BR6	1	93	C	138	1	1				67	01
BR7	?	750	V	500	1	3				76	90
BR9	1	70	W	69	1	1	138			65	-
BR10	1	70	T	69	2	1	138	1	2	60	-
BR11	1	3	V	138	2	2				-	04
CA1	3	53	V+W	230	1	1				68-70	98-00
CA2	1	18	T	230	1	1				-	00
FR1	1	30	T	400	2	2				78	03
GE1	1	2	T	220/400	4	3				68	92
GE2	1	45	T	380	2	2		2	4	78	97
GB1	1	45	T	400	2	4		2	3	64	01
GB2	30	30	T	400	2	2				60's	90's
GB3	1	60	T	400	2	2				77	04

IT1-3	3	30	T	132	2-1	1				20-22	88-94
IT4-5	2	8	T	70	2-1	1	132	1		28-31	01
JA1	1	15	T	66	1	1		2	1	78	88
NO1	1	15	I	132	2	1	300	1	2	79	95
PO1	1	50	T	220	1	1				47	02
PO2	1	15	T	220	2	1				61	01
PO3	1	19	T	220	1	1				65	04
SA1	1	100	T	400	2	2-4				76	99
SA2	2	20	T	275	2	4	400			86	05
SA3	1	25	T	66	1	1	132			60’s	02
SM1	1	1	T	110	3	1				58	00
SM2	1	2	T	110	1	1				55	00
SM3	1	20	T	110	1	1				58	04
SM4	1	77	T	111	2	1				48	02
SP1	8	53	T	400	-	-				67-86	02-04
	4	71	T	220	-	-				66-77	03-04
SW1	3	112	I	400	-	-				60-78	00-03
	2	14	I	220-285	-	-				45-65	03-04
US1	1	25	W	34	1	1	115			80	90
US2	1	11	T	115	2	1	230			72	-
Item	1	2	3	4	5	6	7	8	9	10	11
T = Self-supporting lattice Tower; I = Internally guyed tower; V = V-guyed support; C = Concrete pole; W = Wood pole											

The Statistical Table 8.2 above summarizes the replies to Question Q2 of the Questionnaire:

- Column 1 - The number of lines considered for one specific voltage level;
- Column 2 – The mean geographical length (km);
- Column 3 – The main type of support (See the legend immediately under Statistical Table 8.2);
- Columns 4 to 6 – The voltage level, the number of circuits and the number of sub-conductors before the Uprating/Upgrading works;
- Columns 7 to 9 – The voltage level, the number of circuits and the number of sub-conductors after the Uprating/Upgrading works, only when they changed;
- Column 11 – Year of original construction;
- Column 12 – Year of commissioning for the Uprating/Upgrading works.

Some answers have been split in two or three cases if for one case:

- The lines considered have different voltage levels (BR1, BR3, SP1, SW1);
- One or more lines changed their voltage level and the other lines did not (BR1, BR3).

There is no precise information about the lines considered in Australia and New Zealand. Probably they deal with a large number of 50 to 100 lines with a mean length of 100 km.

8.3 Overview of the main Uprating/Upgrading works carried out

Table 8.3 - Overview of the main Uprating/Upgrading works carried out		
1. Main Uprating and/or Upgrading Works carried out 2. Uprating/Upgrading Costs (% of a new line)		
Item	1	2
AN1	Several lines: range of uprating methods (incl. Real Time Monitoring)	-
BE1	Higher ice load→conductor RTS increased with a factor 2.7	100
BE2	Operation temperature: 40→75°C. Clearance checked	7
BE3	Operation temperature: 40→75°C. Clearance checked	2.5
BR1	Uprating: ACSR 636→TACSR 636	30
	Upgrading: too high probability of failure	3
BR2	Restringing due to low clearance. EDS: 18.5→22%.	-
BR3	69→138 kV. Same conductors	-
	55→75°C; 1 line: ACSR→TACSR	-
BR4	Ratio old/new design wind load: 1.4-2.1. Weight: Δ = 18-30%	-
BR5	88→138 kV. 50→70°C. Conductor change	60
BR6	Restringing 18→20% due to low clearance/road crossings. 50→55°C	-
BR7	T: 15→150 y. Weakness detected in tower design (lack of wind data)	-
BR9	69→138 kV. Substitution of wood poles. Live line works	20
BR10	69→138 kV. 2→1 circuit. Single→twin by conductor regrouping	25
BR11	ACSR→TACSR (125°C). TACIR in some spans with low clearance	-
CA1	Unacceptable failure rate due to severe icing. Increased Return Period	-
CA2	ACSR 795→ACSS 1113 (high temperature conductor)	-
FR1	480→570 Pa wind pressure on conductors. Anti-cascade supports	-
GE1	River crossing. Wind pressure: Δ = 35%. Ice load: Δ = 100%	-
GE2	Wind pressure: Δ = 27%. Ice load: Δ = 100%. Twin→Quad (same area)	-
GB1	4 x ACSR 400→3 x AAAC 700 (same total diam.). Poor condition	70
GB2	ACSR: 50→75°C; AAAC: 75→90°C	.25
GB3	75→170°C. 2 x ACSR 400→2 x GZTACSR 620 (Gap type cond.)	100
IT1-3	132 kV. Reconductoring: AAAC 153 & 196→AAAC 460 x 2	-
IT4-5	70→132 kV. Reconductoring: ACSR 93→AAAC 153 or 460	-
JA1	2nd cct: ACSR 160 & 240→SBACSR 210 & 320 (smooth-same Ø)	19
NO1	2 cct 132 kV→1 cct 300 kV. 50→80°C. I→V insulator set	10
PO1	ACSR 377/86→AAL 400. Temperature: 55→60°C & ext renovation	-
PO2	ACSR 349/79→AAL 400. Temperature: 55→106°C & ext renovation	-
PO3	ACSR Condor→AAL 400. Temperature: 55→70°C & ext renovation	-
SA1	50→76°C & RTM at 400 kV crossing	-
SA2	275→400 kV. Re-tensioning. Re-insulation	-
SA3	66→132 kV. Re-tensioning	-
SM1	Danube crossing. ACS 126→189	20

SM2	Danube crossing. ACSR 273→ACS 362	15
SM3	ACSR 175→AA 212	50
SM4	ACSR 160→AA 186	50
SP1	400 & 220 kV: 50→85°C	-
SW1	400 & 220 kV: 50→70-80°C	5-10
US1	34 kV→115 kV. 336 MCM→398 MCM	-
US2	115 kV→230 kV	-
Item	1	2

The information in Column 1 of Statistical Table 8.3 about the main works carried out has been collected mainly from the replies to Question Q3 and Table T1 of the Questionnaire. For the purpose of this Statistical Table 8.3 the description has been summarized in only one line in order to have a quick overview. For more details, we refer to the following Statistical Tables. Three more cases than in Statistical Table 8.2 (42 cases instead of 39) are considered, because case BR1, BR3 and IT1-5 have now been split into two separate cases. The information in the last Column 2 about the costs of the Uprating/Upgrading is mostly (18/42 cases or 43%) expressed in percentages with respect to the construction costs of a new line. The range is quite large. It varies from 0.25% to 100%. One of the 100% values is dealing with the replacement of the existing conductors with a Gap-type conductor where the transversal cross-sectional area is higher, the other value of 100% with a very short line. It is stressed that this value of 100% does not take into account the costs for the authorization process and time needed to obtain permits. The first case of only 0.25% deals with a temperature increase.

The mean value for the Uprating/Upgrading costs in comparison with the construction of a new line is 33%, but the median value is only 20%.

8.4 Typical Uprating/Upgrading works carried out

Table 8.4 - Typical Uprating/Upgrading works carried out

Item	Uprating (without Upgrading) (R)	Uprating with upgrading (R+G)	Upgrading (without Uprating) (G)	Upgrading with Uprating (G+R)	Increasing current rate	- Increasing conductor temperature	- Increasing attachment point	- Re-tensioning	- Reconductoring	- Compact/Smooth conductor	- High temperature conductor	Increasing voltage level	Upgrading due to wind pressure/ice load	Upgrading due to higher cond. diameter	Poor condition of foundation	Life extension due to poor condition
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AN1	-	x	-	-	x	x	x	x	x	-	x	-	-	-	-	x
BE1	-	-	-	x	x	-	-	-	x	x	-	-	x	x	-	-
BE2	x	-	-	-	x	x	x	x	-	-	-	-	-	-	-	x
BE3	x	-	-	-	x	x	x	x	-	-	-	-	-	-	-	-
BR1a	x	-	-	-	x	x	-	-	x	-	x	-	-	-	-	-
BR1b	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-
BR2	x	-	-	-	x	-	-	x	-	-	-	-	-	-	-	-
BR3a	x	-	-	-	-	-	-	-	-	-	-	x	-	-	x	x
BR3b	x	-	-	-	x	x	-	-	-	-	x	-	-	-	x	x
BR4	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x
BR5	-	x	-	-	x	x	x	-	x	-	-	x	-	x	-	x
BR6	x	-	-	-	x	x	-	x	-	-	-	-	-	-	-	x
BR7	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x
BR9	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x	x
BR10	x	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x
BR11	x	-	-	-	x	x	-	-	x	-	x	-	-	-	-	-
CA1	-	-	-	x	x	-	-	-	x	x	-	-	x	-	-	-
CA2	-	x	-	-	x	x	-	-	x	-	x	-	-	x	-	-
FR1	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-
GE1	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x
GE2	-	-	-	x	-	-	-	-	x	-	-	-	x	x	-	x
GB1	-	-	-	x	x	-	-	-	x	-	-	-	-	-	x	x
GB2	x	-	-	-	x	x	-	x	-	-	-	-	-	-	-	-
GB3	-	x	-	-	x	x	-	-	x	-	x	-	-	x	-	x
IT1-3	-	x	-	-	x	-	-	-	x	-	-	-	-	x	-	-
IT4-5	-	x	-	-	x	-	-	-	x	-	-	x	-	x	-	-

JA1	x	-	-	-	x	-	-	-	x	x	-	-	-	-	-	-
NO1	-	x	-	-	x	x	-	-	-	-	-	x	-	-	-	-
PO1	x	-	-	-	x	x	-	-	x	-	-	-	-	-	-	x
PO2	x	-	-	-	x	x	x	-	x	-	-	-	-	-	-	x
PO3	x	-	-	-	x	x	-	-	x	-	-	-	-	-	-	x
SA1	x	-	-	-	x	x	-	x	-	-	-	-	-	-	-	x
SA2	x	-	-	-	-	-	-	x	-	-	-	x	-	-	-	x
SA3	x	-	-	-	-	-	-	x	-	-	-	x	-	-	-	x
SM1	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x
SM2	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x
SM3	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x
SM4	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x
SP1	x	-	-	-	x	x	x	x	-	-	-	-	-	-	-	-
SW1	x	-	-	-	x	x	x	-	-	-	-	-	-	-	-	x
US1	-	x	-	-	x	-	-	-	x	-	-	x	-	x	-	x
US2	x	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

In order to assess this important Statistical Table 8.4 above, it has been repeated in Statistical Table 8.5 with the same data, but using the following preferential sequence:

- According to the type of Uprating/Upgrading works carried out:
    - Uprating without Upgrading (R in Column 1) (we remind that for the purpose of this report the life extension has not been considered as Upgrading; tower extension for compensating increase of sag has also not been considered as an upgrading action);
    - Uprating combined with Upgrading where Uprating was the objective and the Upgrading was necessary for instance either to keep or even to improve the reliability level (R+G in Column 2);
    - Upgrading without Uprating (G in Column 3);
    - Upgrading combined with Uprating where Upgrading was the principal objective and the Uprating an opportunity (G+R in Column 4);.
- According to the type of Uprating:
    - Increasing current rate (Column 5);
    - Increasing voltage level (Column 12);
- According to the tool used for increasing the current rate:
    - Increasing conductor temperature (Column 6);
    - Reconductoring (Column 9);
- Finally according to the alphabetical sequence of the countries.

8.5 Classification of Uprating/Upgrading works carried out

Table 8.5 - Classification of Uprating/Upgrading works carried out

Item	Uprating (without Upgrading) (R)	Uprating with Upgrading (R+G)	Upgrading (without Uprating) (G)	Upgrading with Uprating (G+R)	Increasing current rate	- Increasing conductor temperature	- Increasing attachment point	- Re-tensioning	- Reconductoring	- Compact/Smooth conductor	- High temperature conductor	Increasing voltage level	Upgrading due to wind pressure/ice load	Upgrading due to higher cond. diameter	Poor condition of foundation	Life extension due to poor condition
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
BE2	x	-	-	-	x	x	x	x	-	-	-	-	-	-	-	x
BE3	x	-	-	-	x	x	x	x	-	-	-	-	-	-	-	-
BR1a	x	-	-	-	x	x	-	-	x	-	x	-	-	-	-	-
BR3b	x	-	-	-	x	x	-	-	-	-	x	-	-	-	x	x
BR6	x	-	-	-	x	x	-	x	-	-	-	-	-	-	-	x
BR11	x	-	-	-	x	x	-	-	x	-	x	-	-	-	-	-
GB2	x	-	-	-	x	x	-	x	-	-	-	-	-	-	-	-
PO1	x	-	-	-	x	x	-	-	x	-	-	-	-	-	-	x
PO2	x	-	-	-	x	x	x	-	x	-	-	-	-	-	-	x
PO3	x	-	-	-	x	x	-	-	x	-	-	-	-	-	-	x
SA1	x	-	-	-	x	x	-	x	-	-	-	-	-	-	-	x
SP1	x	-	-	-	x	x	x	x	-	-	-	-	-	-	-	-
SW1	x	-	-	-	x	x	x	-	-	-	-	-	-	-	-	x
BR2	x	-	-	-	x	-	-	x	-	-	-	-	-	-	-	-
JA1	x	-	-	-	x	-	-	-	x	x	-	-	-	-	-	-
SM1	x	-	-	-	x	-	-	-	x	-	-	-	-	-	x	x
SM2	x	-	-	-	x	-	-	-	x	-	-	-	-	-	x	x
SM3	x	-	-	-	x	-	-	-	x	-	-	-	-	-	x	x
SM4	x	-	-	-	x	-	-	-	x	-	-	-	-	-	x	x
BR3a	x	-	-	-	-	-	-	-	-	-	-	x	-	-	x	x
BR10	x	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x
SA2	x	-	-	-	-	-	-	x	-	-	-	x	-	-	-	x
SA3	x	-	-	-	-	-	-	x	-	-	-	x	-	-	-	x
US2	x	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-
AN1	-	x	-	-	x	x	x	x	x	-	x	-	-	-	-	x
BR5	-	x	-	-	x	x	x	-	x	-	-	x	-	x	-	x

CA2	-	x	-	-	x	x	-	-	x	-	x	-	-	x	-	-
GB3	-	x	-	-	x	x	-	-	x	-	x	-	-	x	-	x
IT1-3	-	x	-	-	x	-	-	-	x	-	-	-	-	x	-	-
IT4-5	-	x	-	-	x	-	-	-	x	-	-	x	-	x	-	-
NO1	-	x	-	-	x	x	-	-	-	-	-	x	-	-	-	-
US1	-	x	-	-	x	-	-	-	x	-	-	x	-	x	-	x
BR9	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x	x
BR1b	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-
BR4	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x
BR7	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x
FR1	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-
GE1	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x
BE1	-	-	-	x	x	-	-	-	x	x	-	-	x	x	-	-
CA1	-	-	-	x	x	-	-	-	x	x	-	-	x	-	-	-
GB1	-	-	-	x	x	-	-	-	x	-	-	-	-	-	x	x
GE2	-	-	-	x	-	-	-	-	x	-	-	-	x	x	-	x
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Statistical Table 8.5 above summarizes particularly the works carried out for Uprating overhead lines through increasing the current rate, the voltage level or both.

The Uprating/Upgrading actions for the 42 cases can be ranked as follows:

- 57% or 24 cases - Uprating (without Upgrading) (R in Column 1)
- 21% or 9 cases - Uprating with Upgrading (R+G in Column 2)
- 12% or 5 cases - Upgrading (without Uprating) (G in Column 3)
- 10% or 4 cases - Upgrading with Uprating (G+R in Column 4)

Uprating is considered in 37 cases (88%) (R, R+G and G+R); Upgrading in 18 cases (43%) (R+G, G, G+R). Uprating and Upgrading are combined in 13 cases (31%) (R+G, G+R).

For Uprating actions, increasing current rate (Column 5) is significantly more popular than increasing voltage level (Column 12):

- 71% or 30 cases for increasing current rate;
- 24% or 10 cases for increasing voltage level.

Only in 3 cases (7%) they are combined.

For increasing current rate (Column 5), increasing conductor temperature (Column 6) is nearly as popular as reconductoring (Column 9).

- 43% or 18 cases for increasing conductor temperature;
- 50% or 21 cases for reconductoring.

Moreover increasing conductor temperature and reconductoring are combined in 9 cases (21%). For the 21 reconductoring cases, Upgrading could be avoided in 10 cases (48%).

For increasing conductor temperature (Column 6), both increasing conductor attachment point (Column 7) and re-tensioning (Column 8) are as popular:

- 17% or 7 cases for increasing conductor attachment point;
- 17% or 7 cases for re-tensioning.

In 4 cases (10%) they are combined.

Finally it is surprising that Life Extension (LE) (Column 16) due to poor condition is mostly combined with Uprating and/or Upgrading actions (62% or 26 cases). Even for the 24 Uprating cases R (thus without Upgrading) only, the percentage is higher. Consequently, it is extremely interesting to examine more in detail how LE is combined with Uprating and/or Upgrading:

- For the total of 42 cases, LE is combined 26 times or 62%;
- For the 24 R cases, LE is combined 16 times or 67%;
- For the 9 R+G cases, LE is combined 5 times or 56%;
- For the 5 G cases, LE is combined 3 times or 60%;
- For the 4 G+R cases, LE is combined 2 times or 50%.

We may conclude that Life Extension is independent of the action is whether Uprating or Upgrading. It justifies the assumption made in Clause 3.2 to make a distinction between Upgrading and Life extension. The life of the transmission line can be extended by replacement of the deteriorated elements and/or the elements where the rate of deterioration with time is too high (due to corrosion, wear, fatigue, annealing, etc.). This justification will be confirmed by comparing the values of the expected remaining life with the return period for climatic limit loads in Statistical Table 8.9.

The Summary Table 8.5/S below gives for the 42 Questionnaires in both absolute value and in % the number of works carried out to Uprate/Upgrade the overhead lines, and the detail as well for R, R + G, G and G + R.

Table 8.5/S – Classification of Uprating/Upgrading works carried out							
	Classification of Uprating/Upgrading works carried out (Q12)	Uprating		Upgrading		Total	
		R	R+G	G	G+R	Abs	%
	Number of replies	24	9	5	5	42	100
1	Uprating (without Upgrading) (R)	24	-	-	-	24	57
2	Uprating with Upgrading (R+G)	-	9	-	-	9	21
3	Upgrading (without Uprating) (G)	-	-	5	-	5	12
4	Upgrading with Uprating (G+R)	-	-	-	4	4	10
5	Increasing current rate	19	8	0	3	30	71
6	- Increasing conductor temperature	13	5	0	0	18	43
7	- Increasing attachment point	5	2	0	0	7	17
8	- Re-tensioning	9	1	0	0	10	24
9	- Reconductoring	10	7	0	4	21	50
10	- Compact/Smooth conductor	1	0	0	2	3	7
11	- High temperature conductor	3	3	0	0	6	14
12	Increasing voltage level	5	5	0	0	10	24
13	Upgrading due to wind pressure/ice load	0	0	4	3	7	17
14	Upgrading due to higher cond. diameter	0	6	0	2	8	19
15	Poor condition of foundation	6	1	0	1	8	19
16	Life extension due to poor condition	16	5	3	2	26	62

8.6 Uprating works carried out on conductors and insulator strings

Table 8.6 - Uprating works carried out on conductors and insulator strings

Item	Uprating works carried out	Increasing current rate	- Increasing temperature	- Reconductoring	- Clearance increased	- Some support extensions	- Suspension to semi-strain	Increasing voltage level	- Insulation level modified	- Insulators replaced by new ones	- Insulators added	- New attachments to cross-arm	- New cross-arm/changed	Shield wire modified	Earthing modified
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AN1	x	x	x	x	-	x	x	-	-	x	-	x	-	-	-
BE1	x	x	-	x	-	-	x	-	-	x	-	-	-	-	-
BE2	x	x	x	-	x	x	x	-	-	-	-	-	-	-	-
BE3	x	x	x	-	x	x	x	-	-	-	-	-	-	-	-
BR1	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR2	x	x	-	-	x	-	-	-	-	-	-	-	-	x	-
BR3	x	-	-	-	-	-	x	x	x	x	x	x	x	x	x
	x	x	x	-	-	x	x	-	-	-	-	x	x	x	x
BR4	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-
BR5	x	x	x	x	x	x	x	x	x	x	-	-	-	-	-
BR6	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-
BR7	-	-	-	-	-	-	-	-	-	-	-	-	x	-	x
BR9	x	-	-	-	-	-	-	x	x	-	x	x	x	-	-
BR10	x	-	-	-	-	-	-	x	x	-	x	x	x	x	-
BR11	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-
CA1	x	x	-	x	-	-	-	-	-	x	-	-	x	x	-
CA2	x	x	x	x	-	-	-	-	-	x	-	-	-	-	-
FR1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GE1	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
GE2	x	-	-	x	-	-	-	-	x	x	-	x	-	x	-
GB1	x	x	-	x	-	-	-	-	-	x	-	-	-	x	-
GB2	x	x	x	-	x	-	x	-	-	-	-	-	-	-	-
GB3	x	x	x	x	-	-	-	-	-	x	-	-	-	x	-
IT1-3	x	x	-	x	-	-	-	-	x	-	-	-	-	x	x
IT4-5	x	x	-	x	-	-	-	x	x	-	-	-	-	x	x
JA1	x	x	-	x	-	-	-	-	-	-	-	-	-	-	x
NO1	x	x	x	-	-	-	-	x	x	-	x	x	-	x	x

PO1	x	x	x	x	-	-	-	-	-	x	-	-	-	x	x
PO2	x	x	x	x	-	x	-	-	-	x	-	-	-	x	x
PO3	x	x	x	x	-	-	-	-	-	x	-	-	-	x	x
SA1	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-
SA2	x	-	-	-	x	-	-	x	x	x	-	-	-	-	-
SA3	x	-	-	-	x	-	-	x	x	-	x	-	-	-	-
SM1	x	x	-	x	x	-	-	-	-	x	-	-	-	x	-
SM2	x	x	-	x	x	-	-	-	-	x	-	-	-	-	-
SM3	x	x	-	x	x	-	-	-	-	x	-	-	-	-	-
SM4	x	x	-	x	x	-	-	-	-	x	-	-	-	x	-
SP1	x	x	x	-	x	x	x	-	-	-	-	-	-	-	-
SW1	x	x	x	-	-	x	-	-	-	-	-	-	-	x	-
US1	x	x	-	x	-	-	-	x	x	x	-	-	-	-	-
US2	x	-	-	-	-	-	-	x	-	-	-	-	-	-	-
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

In the Statistical Table 8.6 above we can find more information about the modifications on conductors and insulators for the Uprating of overhead lines.

We just mention some significant percentages:

- 43% or 18 cases: shield wire modified;
- 43% or 18 cases: insulators replaced by new ones;
- 26% or 11 cases: insulation level modified;
- 24% or 10 cases: earthing modified;
- 12% or 5 cases: insulators added.

Reconductoring of phase conductors is in 11 cases (26%) combined with replacement of shield wire and in 16 cases (38%) with replacement of insulators.

The Summary Table 8.6/S below gives for the 42 Questionnaires in both absolute value and in % the number of works carried out on conductors and insulators to Uprate the overhead lines, and the detail as well for R, R + G, G and G + R.

Table 8.6/S - Uprating works carried out on conductors and insulators							
	Uprating works carried out on conductors and insulators (Q 3)	Uprating		Upgrading		Total	
		R	R+G	G	G+R	Abs	%
	Number of replies	24	9	5	4	42	
	%	57%	21%	12%	10%		100
1	Uprating works carried out	24	9	0	4	37	88
2	Increasing current rate	19	8	0	3	30	71
3	- Increasing temperature	13	5	0	0	18	43
4	- Reconductoring	10	7	0	4	21	50
5	- Clearance increased	13	1	0	0	14	33
6	- Some support extensions	6	2	0	0	8	19
7	- Suspension to semi-strain	6	2	0	1	9	21
8	Increasing voltage level	5	5	0	0	10	24
9	- Insulation level modified	4	6	0	1	11	26
10	- Insulators replaced by new ones	9	5	0	4	18	43
11	- Insulators added	3	2	0	0	5	12
12	- New attachments to cross-arm	3	3	0	1	7	17
13	- New cross-arm/changed	3	1	2	1	7	17
14	Shield wire modified	10	4	1	3	18	43
15	Earthing modified	6	3	1	0	10	24

8.7 Upgrading works carried out on supports and foundations

Table 8.7 - Upgrading works carried out on supports and foundations

Item	Upgrading works carried out	Original design criteria for Upgrading	- (Slightly) Reviewed design criteria	- Statistical/Probabilistic design	Some/all supports modified/reinforced	- Due to higher total conductor diameter	- Due to higher wind pressure/ice load	- Due to poor condition (corrosion)	Some/all supports replaced/added	Some/all foundations modified	- Due to higher overturning moment	- Due to poor condition	- Adequate after recalibration
Item	1	2	3	4	5	6	7	8	9	10	11	12	13
AN1	x	-	x	-	x	-	-	-	x	-	-	-	-
BE1	x	-	x	x	x	x	x	-	-	-	-	-	x
BE2	-	-	x	x	-	-	-	-	-	-	-	-	-
BE3	-	-	x	x	-	-	-	-	-	-	-	-	-
BR1	-	-	-	-	-	-	-	-	-	-	-	-	-
	x	x	-	-	x	-	-	-	-	-	-	-	-
BR2	-	x	-	-		-	-	-	-	-	-	-	-
BR3	-	-	x	x	x	-	-	-	x	x	-	x	-
	-	-	x	x	x	-	-	-	x	x	-	x	-
BR4	x	-	x	x	x	-	x	-	-	-	-	-	x
BR5	x	x	-	-	x	x	-	-	x	x	x	-	-
BR6	-	x	-	-	-	-	-	-	x	x	-	x	-
BR7	x	-	x	x	x	-	x	-	-	-	-	-	x
BR9	x	-	x	x	-	-	-	-	-	x	-	x	-
BR10	-	-	x	-	x	-	-	-	-	x	-	-	x
BR11	-	-	x	-	-	-	-	-	-	-	-	-	-
CA1	x	-	x	x	x	-	x	-	x	x	-	-	x
CA2	x	x	-	-	x	x	-	-	x	x	-	-	x
FR1	x	-	x	-	x	-	x	-	x	x	x	-	-
GE1	x	-	x	-	x	-	x	-	-	x	x	-	-
GE2	x	-	x	-	x	x	x	-	-	x	x	-	-
GB1	x	-	x	x	x	-	-	x	x	x	-	x	-
GB2	-	-	-	-	-	-	-	-	-	-	-	-	-
GB3	x	-	x	x	x	x	-	x	-	x	x	-	-
IT1-3	x	-	x	-	-	x	-	-	x	x	x	-	-
IT4-5	x	-	x	-	-	x	-	-	x	x	x	-	-

JA1	-	x	-	-	-	-	-	-	-	-	-	-	-
NO1	x	x	-	-	x	-	-	-	-	-	-	-	-
PO1	-	x	-	-	-	-	-	-	-	-	-	-	-
PO2	-	x	-	-	-	-	-	-	x	-	-	-	-
PO3	-	x	-	-	-	-	-	-	-	-	-	-	-
SA1	-	-	x	x	-	-	-	-	-	-	-	-	-
SA2	-	-	x	x	-	-	-	-	-	-	-	-	-
SA3	-	-	x	x	-	-	-	-	-	-	-	-	-
SM1	-	x	-	-	x	-	-	-	-	x	-	x	-
SM2	-	x	-	-	x	-	-	-	-	x	-	x	-
SM3	-	x	-	-	x	-	-	-	-	x	-	x	-
SM4	-	x	-	-	x	-	-	-	-	x	-	x	-
SP1	-	x	-	-	-	-	-	-	x	x	x	-	-
SW1	-	x	-	-	-	-	-	-	-	-	-	-	-
US1	x	-	-	-	-	x	-	-	x	-	-	-	-
US2	-	-	x	x	-	-	-	-	-	-	-	-	-
Item	1	2	3	4	5	6	7	8	9	10	11	12	13

Statistical Table 8.7 above and Table 8.7/S below summarize the works carried out for Upgrading lines. The percentages for strengthening and substituting some supports in a line are comparable (respectively 50% and 33%). It means that in many cases when some supports have to be strengthened, some other supports (mostly dead-end or angle supports) have also to be replaced. The number of Upgrading actions for higher total conductor diameter and higher wind pressure or ice load are comparable (respectively 19% and 17%). Surprisingly in some cases the reinforcement of foundations can be avoided. Thanks to local soil investigation they are mostly considered adequate after recalibration (14%).

Table 8.7/S - Upgrading works carried out on supports and foundations

	Upgrading works carried out on supports and foundations (Q3)	Uprating		Upgrading		Total	
		R	R+G	G	G+R	Abs	%
	Number of replies	24	9	5	4	42	
	%	57%	21%	12%	10%		100%
1	Upgrading works carried out	0	9	5	4	18	43
2	Original design criteria for Upgrading	12	3	1	0	16	38
3	- (Slightly) Reviewed design criteria	10	5	4	4	23	55
4	- Statistical/Probabilistic design	8	2	2	3	15	36
5	Some/all supports modified/reinforced	7	5	5	4	21	50
6	- Due to higher total conductor diameter	0	6	0	2	8	19
7	- Due to higher wind pressure/ice load	0	0	4	3	7	17
8	- Due to poor condition (corrosion)	0	1	0	1	2	3
9	Some/all supports replaced/added	5	6	1	2	14	33
10	Some/all foundations modified	9	6	2	3	20	48
11	- Due to higher overturning moment	1	4	2	1	8	19
12	- Due to poor condition	7	1	0	1	9	21
13	- Adequate after recalibration	1	1	2	2	6	14

8.8 Results of Uprating works

Table 8.8 - Results of Uprating works

Item	Transmission capacity before Upr. (MVA)	Transmission capacity after Upr. (MVA)	Transmission capacity increase (ratio)	Operation temperature before Upr. (°C)	Operation temperature after Upr. (°C)	Av. electrical unavailability before (h/year)	Av. electrical unavailability after (h/year)	Number of outages before (1/100km.year)	Number of outages after (1/100km.year)	Unchanged performance
Item	1	2	3	4	5	6	7	8	9	10
AN1	-	-	-	-	-	-	-	-	-	-
BE1	39	-	-	75	75	-	-	-	-	x
BE2	97	203	2.6	40	75	-	-	-	-	x
BE3	13	36	2.6	40	75	-	-	-	-	x
BR1	270	350	1.4	-	-	-	-	-	-	-
BR2	94	94	1.0	75	75			13	13	x
BR3	-	-	-	-	-	-	-	15	4	-
	-	-	-	55	75	-	-	2	2	x
BR4	2000	-	-	-	-	-	-	-	-	-
BR5	40	80	2.0	50	75	0	0	-	-	-
BR6	52.3	64.5	1.2	50	55	-	-	-	-	x
BR7	-	-	-	-	-	30	10	1.5	1.0	-
BR9	18	72	4.0	-	-	-	-	-	-	-
BR10	2x18	144	4.0	-	-	-	-	-	-	-
BR11	234	300	1.3	-	-	-	-	-	-	x
CA1	-	-	-	-	-	6	0.1	3.1	2.6	-
CA2	-	-	-	-	-	-	-	-	-	-
FR1	-	-	-	-	-	-	-	-	-	x
GE1	-	-	-	-	-	2	2	3	3	-
GE2	2700	3600	1.3	80	80	12	6	1	1	-
GB1	5560	6140	1.1	50	50	16	4	-	-	-
GB2	1390	1710	1.2	50	75	-	-	-	-	x
	2010	2210	1.1	75	90					
GB3	3420	6200	1.8	75	170	-	-	-	-	x
IT1-5	260	560	2.2	-	-	-	-	-	-	-

JA1	51	51+58	1.1	-	-	0	0	6.1	0.4	-
NO1	357	1215	3.4	50	80	-	-	-	-	-
PO1	196	214	1.1	55	60	12	0	-		-
PO2	374	800	2.1	55	106	-	-	-	-	-
PO3	194	268	1.4	55	70	0	0	-	-	-
SA1	680	1100	1.6	50	76	-	-	1	1	x
SA2	500	1000	2.0	50	50	-	-	2	2	x
SA3	30	50	1.7	-	-	-	-	<2	<2	x
SM1	-	-	-	-	-	-	-	-	-	-
SM2	-	-	-	-	-	-	-	-	-	-
SM3	-	-	-	-	-	-	-	-	-	-
SM4	-	-	-	-	-	-	-	-	-	-
SP1	1330	1629	1.2	50	85	-	-	-	-	-
	342	421	1.2							
SW1	680	1110	1.6	50	70-80	-	-	-	-	x
	1340	1420	1.1							
US1	-	-	-	-	-	-	-	-	-	-
US2	-	-	-	-	-	-	<1	1.5	1.5	-
Item	1	2	3	4	5	6	7	8	9	10

The results of the Uprating works are revealed in Statistical Table 8.8 above.

For 26 cases the value of the increase of transmission capacity has been mentioned (Columns 1-3):

- The increase of power transmission capacity varies between 1.1 and 4.0;
- The mean value is 1.8;
- The median value is 1.5.

For 15 cases the value of the increase of the operation temperature has been mentioned (Columns 4-5):

- The increase of operation temperature varies between 5°C and 95°C;
- The mean value is 29°C;
- The median value is 26°C.

Unfortunately we received very few information about the improvement of the line performance (Columns 6-9). Only for 7 cases the values given show improvement of the number of outages (1/100 km.year) or the unavailability (h/year) after Uprating/Upgrading.

8.9 Results of Upgrading works

Table 8.9 - Results of Upgrading works												
Item	Basic wind speed before (m/s)	Basic wind speed after (m/s)	Return period wind load before (years)	Return period wind load after (years)	Return period ice load before (years)	Return period ice load after (years)	Mechanical unavailability before (h/years)	Mechanical unavailability after (h/years)	Number of supports failed before (per year)	Number of supports failed after (per year)	Expected remaining life before (years)	Expected remaining life after (years)
Item	1	2	3	4	5	6	7	8	9	10	11	12
AN1	-	-	-	-	-	-	-	-	-	-	-	-
BE1	27	27	50	50	10	100	-	-	-	-	25	25
BE2	27	27	50	50	-	-	-	-	-	-	5	10
BE3	27	27	50	50	-	-	-	-	-	-	20	20
BR1	-	-	-	-	-	-	-	-	-	-	-	-
BR2	-	-	-	-	-	-	-	-	0	0	40	40
BR3	-	-	-	50	-	-	-	-	-	-	-	-
BR4	-	33	-	150	-	-	-	-	1.5	0	10	30
BR5	31	28	-	50	-	-	0	0	0	0	10	30
BR6	-	-	-	-	-	-	-	-	0	0	20	30
BR7	26	30	15	150	-	-	23	2	0.2	0.1	10	30
BR9	25	25	3	5(1)	-	-	50	20	1.0	0.4	5	15
BR10	31	31	-	25	-	-	-	-	-	-	20	30
BR11	34	34	50	50	-	-	-	-	-	-	-	-
CA1	-	-	50	50	10	50	-	-	-	-	-	50
CA2	-	-	50	50	-	-	-	-	-	-	30	30
FR1	-	-	-	-	-	-	-	-	-	-	-	-
GE1	31	36	35	300	40	500	-	-	-	-	30	50
GE2	24	27	50	150	-	-	-	-	-	-	40	80
GB1	24	24	50	50	-	-	-	-	-	-	4	40
GB2	-	-	-	-	-	-	-	-	-	-	20	20
GB3	24	24	50	50	-	-	-	-	-	-	14	40
IT1-5	-	-	-	-	-	-	-	-	-	-	-	40
JA1	40	40	50	50	-	-	-	-	-	-	50	50
NO1	35	35	50	50	-	-	-	-	-	-	50	50

PO1	20	21	-	50	-	-	-	-	-	-	10	35
PO2	-	-	-	50	-	-	-	-	-	-	10	35
PO3	20	21	-	50	-	-	-	-	-	-	10	35
SA1	40	40	50	50	-	-	-	-	-	-	25	40
SA2	40	40	50	50	-	-	-	-	-	-	20	40
SA3	30	30	50	50	-	-	-	-	-	-	15	30
SM1	-	-	-	-	-	-	-	-	-	-	10	40
SM2	-	-	-	-	-	-	-	-	-	-	5	40
SM3	-	-	-	-	-	-	-	-	-	-	5	30
SM4	-	-	-	-	-	-	-	-	-	-	5	30
SP1	-	-	-	-	-	-	-	-	-	-	-	-
SW1	-	-	50	50	-	-	-	-	-	-	20	25
US1	-	-	35	50	-	-	-	-	-	-	15	50
US2	-	-	-	-	-	-	-	-	-	-	-	-
Item	1	2	3	4	5	6	7	8	9	10	11	12
Safety factor 1.5												

The results of the Upgrading works are revealed in Statistical Table 8.9 above.

We received information about the:

- Reference wind speed:
  - The value is mentioned for 20 cases (or 51% for a total of 39 cases);
  - The value varies between 21 m/s and 40 m/s (after upgrading);
  - The mean value is 29 m/s;
  - The median value is 30 m/s;
  - Only in 5 cases (13%), the reference wind speed increases.

- Return period for wind limit loads:
  - The value is mentioned for 25 cases (or 67% for a total of 39 cases);
  - The value varies between 25 years and 300 years (after upgrading);
  - The mean value is 71 years;
  - The median value is 50 years;
  - Only in 5 cases (13%), the return period for wind loads increases.

- Only for 3 cases the return period for ice loads was mentioned separately. The results are not significant, except when they differ from the return period for wind load and even when they are higher.

- Expected remaining life:
  - The value is mentioned for 32 cases (or 82% for a total of 39 cases);
  - The value varies between 10 years and 80 years;
  - The mean value is 36 years;
  - The median value is 35 years;
  - In 23 cases (59%), the expected remaining life increases;

- This increase varies between 5 years and 40 years; the mean value of the increase is 22 years; the median value is 20 years.

The expected remaining life is significantly lower than the return period for the climatic limit load. The ratio of the remaining life to the return period (after Uprating/Upgrading) varies between 20% and 120% (we eliminated the highest value of 300% because the "return period" was valid for a safety factor of 1.5). The mean value of the ratio is 65% and the median value is 70%.

The fact that the remaining life is significantly lower than the return period is another reason why in this report both are considered separately.

8.10 Operation and maintenance costs

Table 8.10 - Operation and maintenance costs

Item	Cost per line per year (before)	Cost per line per year (after)	Cost per line length per year (before)	Cost per line length per year (after)	Cost per MW per year (before)	Cost per MW per year (after)	Additional comments	Other cost parameters
Item	1	2	3	4	5	6	7	8
AN1	-	-	-	-	-	-	-	
BE1	1	.2	1	.2	-	-	-	
BE2	1	.8	1	.8	1	.4	-	
BE3	1	.8	1	.8	1	.4	-	
BR1	x	x	-	-	-	-	x	No change
BR2	-	-	-	-	-	-	-	
BR3	-	-	-	-	-	-	-	
BR4	-	-	-	-	-	-	-	
BR5	-	-	-	-	-	-	-	
BR6	-	-	-	-	-	-	-	
BR7	1	.8	1	.7	1	.7	-	
BR9	-	-	-	-	-	-	-	
BR10	-	-	-	-	-	-	-	
BR11	-	-	-	-	-	-	-	
CA1	x	-	-	-	-	-	-	
CA2	-	-	-	-	-	-	-	
FR1	-	-	-	-	-	-	-	
GE1	-	-	-	-	-	-	-	
GE2	-	-	-	-	-	-	-	
GB1	-	-	-	-	-	-	x	Difficult to quantify. However savings are significant due to lower thermal losses and unplanned outages.
GB2	1	<.5	-	-	-	-	x	Transmission constraint costs eliminated.
GB3	-	-	-	-	-	-	x	Uprating aim is not maintenance elimination
IT1-5	-	-	-	-	-	-	-	
JA1	-	-	-	-	-	-	x	% given for second circuit (42%)

NO1	-	-	-	-	-	-	x	No change
PO1	x	-	-	-	-	-	-	
PO2	-	-	-	-	-	-	-	
PO3	-	-	-	-	-	-	-	
SA1	1	1	1	1	1	.6	-	
SA2	1	1	1	1	1	.6	-	
SA3	-	-	-	-	-	-	-	
SM1	-	-	-	-	-	-	-	
SM2	-	-	-	-	-	-	-	
SM3	-	-	-	-	-	-	x	Maintenance period: 2 years instead of 1 y
SM4	-	-	-	-	-	-	x	Same as SM3
SP1	x	-	-	-	-	-	-	
SW1	-	-	-	-	-	-	-	
US1	-	-	-	-	-	-	-	
US2	-	-	-	-	-	-	x	No change
Item	1	2	3	4	5	6	7	8

As already mentioned earlier we received very few information about the operation and maintenance costs. Probably they are difficult to quantify.

However savings are significant after Uprating due to either lower thermal losses or elimination of transmission constraint costs.

8.11 Decision factors on Uprating and/or Upgrading works

Table 8.11 - Decision factors on Uprating and/or Upgrading works

Item	Lower investment of the works	Lower LCA costs (inv + losses	Unacceptable reliability (mech./electr.)	Political costs of unavailability	Real return periods lower than design	Additional information	Others
Item	1	2	3	4	5	6	7
AN1	-	-	-	-	-	-	
BE1	x	x	x	x	x	x	Unacceptable number of conductor failures due to severe ice load. Delay. Risk Management.
BE2	x	x	-	-	-	x	Important link.
BE3	x	-	-	-	-	x	Difficulty permits for new lines. Ageing.
BR1	-	-	-	-	-	x	Lower transmission capacity.
	-	-	-	-	-	x	Failure probability too high.
BR2	-	-	x	-	-	x	Lower clearance.
BR3	x	x	-	-	-	-	
BR4	-	-	x	x	x	-	
BR5	x	x	-	-	-	-	
BR6	x	-	x	-	-	-	
BR7	x	-	-	-	x	x	Preventing line switch. Correcting weaker points. Available resources.
BR9	x	-	x	-	-	-	
BR10	x	-	-	-	-	-	
BR11	x	x	-	-	-	-	
CA1	-	-	-	-	-	x	Large number of failures due to severe icing.
CA2	x	x	-	-	-	-	
FR1	x	-	x	-	-	x	Continuity of service. Strengthening policy.
GE1	-	-	x	-	x	x	Reduction of environmental impacts. Noise.
GE2	-	-	x	-	x	x	Reduction of environmental impacts. Noise.
GB1	-	x	x	x	-	-	
GB2	x	x	-	-	-	x	To avoid constraint costs of under-capacity. Only carried out if refurbishment cost is small.
GB3	x	x	-	-	-	x	To alleviate a transmission constraint on the system. The amount of enhancement needed

							required a new line or gap type conductor.
IT1-5	-	-	-	-	-	x	Reliability comes to a limit.
JA1	x	x	-	-	-	x	Stringing of second circuit avoids live line works.
NO1	x	x	-	-	-	-	
PO1	x	x	x	-	-	x	Line importance. Capacity. Unavailability. Age.
PO2	x	x	x	x	-	-	
PO3	x	x	x	-	-	x	Line importance. Capacity. Unavailability. Age.
SA1	x	x	-	-	-	x	Losses reduced by connecting substations.
SA2	x	x	-	-	-	x	After failure of major power stations.
SA3	x	x	-	-	-	x	Total system losses reduced by linking power stations.
SM1	x	x	-	-	-	x	Low transmission capacity and clearances
SM2	x	x	-	-	-	x	Same as SM1
SM3	x	x	x	-	x	x	Same as SM1
SM4	x	x	x	-	x	x	Same as SM1
SP1	-	-	-	-	-	x	Power transmission capacity to increase.
SW1	x	x	-	-	-	x	Power transmission capacity to increase.
US1	-	x	-	x	-	-	
US2	-	-	-	-	-	x	Acceptable performance based on study costs.
Item	1	2	3	4	5	6	7

The decision factors on Uprating and/or Upgrading works from Statistical Table 8.11 above and Summary Table 8.11/S below are ranked here under according to the preference:

1. 68% (27 votes): Lower investment of the works;
2. 58% (23 votes): Lower LCA costs (investments, losses, O&M costs);
3. 35% (14 votes): Unacceptable mechanical or electrical reliability;
4. 18% (7 votes): Real return periods lower than design;
5. 13% (5 votes): Political costs of unavailability.

There are also useful additional comments for 27 cases (68%). Large number of failures or too low transmission capacity are mentioned.

Table 8.11/S - Decision factors on Uprating/Upgrading works

	Decision factors on Uprating/Upgrading works (Q8 and T5)	Uprating		Upgrading		Total	
		R	R+G	G	G+R	Abs	%
	Number of replies	23	8	5	4	40	100
1	Lower investment of the works	19	5	2	1	27	68
2	Lower LCA costs (inv + losses +O&M)	16	5	0	2	23	58
3	Unacceptable reliability (mech./electr.)	7	1	3	3	14	35
4	Political costs of unavailability	1	1	1	2	5	13
5	Real return periods lower than design	2	0	3	2	7	18
6	Additional comments	18	2	4	3	27	68

8.12 Decision factors on Uprating/Upgrading rather than a new line

Table 8.12 - Decision factors on Uprating/Upgrading rather than a new line									
Item	Lower initial investment of the works	Political costs of unavailability	Increasing mechanical reliability	Increasing electrical reliability	Extending remaining life of the line	Increasing power transmission capacity	Coping with new legislation or standards	Additional Comments	Others
Item	1	2	3	4	5	6	7	8	9
AN1	-	-	-	-	-	x	-	x	Conductor replacement. Cost benefit. Poor condition. Lines replaced or refurbished.
AU1	-	-	x	-	-	x	x	x	Uprating 220>380kV impossible (loads). Conductor change insufficient for new transmission capacity. New line shorter than uprated line.
BE1	x	-	x	-	x	x	x	x	Difficulty authorization for new lines.
BE2	-	-	-	-	-	-	-	x	Same as BE1.
BE3	-	-	-	-	-	-	-	x	Same as BE1.
BR1	x	x	x	x	x	x	-	-	
BR2	x	-	x	x	x	x	x	x	Difficulty to obtain RoW.
BR3	x	-	-	x	x	-	-	-	
BR4	x	x	x	-	-	-	x	-	
BR5	x	-	-	-	-	x	-	-	
BR6	-	-	-	-	-	-	-	x	Same as BR2.
BR7	x	-	x	-	x	-	-	x	Possibility of establishing a schedule for modifications along a long time period. Starting with weakest/critical points. Increase of line performance (availability) at min cost. Availability of resources.
BR8	x	x	-	x	x	x	-	-	
BR9	-	-	x	-	x	x	-	-	
BR10	x	-	x	-	-	x	-	-	
BR11	x	x	-	-	-	x	x	-	

CA1	-	-	-	-	-	-	-	x	Damage cost based on historical information. Break Even Index where upgrading cost is balanced against expected damage cost. Societal cost for lost services. Public's perception. Higher design load due to unacceptable number of failures.
CA2	x	-	-	-	-	x	-	-	
DK1	-	-	-	-	x	-	-	x	Extending life (painting, re-galvanizing).
FR1	x	x	x	-	x	x	x	x	Environment
FI1	-	-	-	-	-	-	-	x	Application of higher voltage level or bigger conductors is impossible without change of (guyed) supports. So old 110 kV lines are replaced with new ones.
GE1	-	-	x	x	-	x	x	x	Lack of ROW for new lines.
GE2	-	-	-	-	-	-	-	x	Same as GE2.
GB1	-	-	-	-	-	-	-	x	Line nearing end of design life. Poor condition.
GB2	x	x	x	x	x	x	-	x	Difficulty to build new lines.
GB3	-	-	-	-	-	-	-	x	Gap type is an alternative to new lines. Same cost, but a new line requires high costs associated with obtaining planning permission, and take a long time.
IT1-5	-	-	x	x	x	x	-	-	
JA1	-	-	-	-	-	-	-	-	
NO1	x	x	x	x	x	x	-	-	
PO1	-	-	-	-	-	-	-	x	Same as PO2.
PO2	x	x	x	x	x	x	-	x	Uprating is the only way as 220 kV network is no more extended. Ageing.
PO3	-	-	-	-	-	-	-	x	Same as PO2.
SA1	-	-	-	-	-	-	-	x	Same as SA3.
SA2	-	-	-	-	-	-	-	x	Same as SA3.
SA3	x	-	x	x	x	x	-	x	Lower system losses.
SM1	x	-	x	x	x	x	-	x	Ageing. Key factors: lower investment costs; difficulty authorization new lines
SM2	x	-	x	x	x	x	-	x	Same as SM1
SM3	x	-	x	x	x	x	-	x	Same as SM1
SM4	x	-	x	x	x	x	-	x	Same as SM1
SP1	-	-	-	-	-	x	-	x	Changes in new regulatory market → Change of Power Plan (location of power stations; bottlenecks on lines).
SW1	x	-	-	-	-	x	x	x	Permits.
US1	x	x	-	-	-	x	-	-	
US2	x	-	-	-	-	x	-	-	Only study costs to change 115→230kV
Item	1	2	3	4	5	6	7	8	9

The decision factors in Statistical Table 8.12 above and the Summary Table 8.12/S below, to carry out Uprating and/or Upgrading works, rather than building a new line are ranked hereunder according to the preference:

1. 60% (26 votes): Increasing power transmission capacity;
2. 53% (23 votes): Lower initial investment of the works;
3. 44% (19 votes): Increasing mechanical reliability;
4. 42% (18 votes): Extending remaining life of the line;
5. 33% (14 votes): Increasing electrical reliability;
6. 21% (9 votes): Political costs of unavailability;
7. 19% (8 votes): Coping with new legislation or standards.

There are also many useful additional comments for 29 cases (67%).

We notice that final decisions are more based on the qualification of costs and transmission capacity than on the real need of upgrading, life extension, uprating and line performance.

Table 8.12/S - Decision factors on Uprating/Upgrading rather than a new line

	Decision factors on Uprating and/or Upgrading rather than a new line (Q10)	Uprating		Upgrading		No	Total	
		R	R+G	G	G+R	R/G	Abs	%
	Number of replies	23	8	4	4	4	43	100
1	Lower initial investment of the works	14	4	3	1	1	23	53
2	Political costs of unavailability	4	2	2	0	1	9	21
3	Increasing mechanical reliability	10	3	4	1	1	19	44
4	Increasing electrical reliability	10	2	1	0	1	14	33
5	Extending remaining life of the line	10	3	2	1	2	18	42
6	Increasing power transmission capacity	14	7	2	1	2	26	60
7	Coping with new legislation or standards	3	0	3	1	1	8	19
8	Additional comments	17	2	3	4	3	29	67

8.13 Quantification methods for decision on Uprating/Upgrading

Table 8.13 - Quantification methods for decision on Uprating/Upgrading

Item	Initial Investment Costs	Comparisons with the costs of a new line	Additional comments	Others
Item	1	2	3	4
AN1	x	-	x	Condition. Outage length. Impact on Landowners.
BE1	x	x	x	Risk Mgt. Outage limitations. Use of structural capacity excess.
BE2	-	-	x	Same as BE1.
BE3	-	-	x	Same as BE1.
BR1	x	x	-	
BR2	-	x	x	Lower available time to build a new line.
BR3	x	x	-	
BR4	-	-	-	
BR5	x	x	-	
BR6	-	-	-	
BR7	x	x	x	1. Availability/Reliability analysis. 2. New capacity. 3. Econ. Evaluation. Optimum is lowest cost of investments + losses.
BR8	x	x	-	
BR9	-	x	-	
BR10	x	x	-	
BR11	x	x	-	
CA1	-	-	x	Expected damage cost. Significant higher design load (New ice data with revised Gumbel distribution plot).
CA2	x	-	-	
FR1	-	-	x	Few economic factors for evaluation.
GE1	x	-	x	Minimum investment to cope with reliability requirements.
GE2	-	-	x	Same as GE1.
GB1	-	-	-	
GB2	x	x	-	
GB3	-	-	-	

IT1-5	-	-	-	
JA1	-	-	-	
NO1	x	x	-	
PO1	-	-	x	Same as PO2.
PO2	x	x	x	See 2004 Paris paper B2-102. Uprating Costs. Life expectancy. Line importance.
PO3	-	-	x	Same as PO2.
SA1	-	-	-	
SA2	-	-	-	
SA3	x	x	-	
SM1	x	x	x	Recording OH line condition (defect, degradation rate, possibility of Uprating/Upgrading)
SM2	x	x	x	Same as SM1
SM3	x	x	x	Same as SM1
SM4	x	x	x	Same as SM1
SP1	x	-	x	Determined by TSO. Enquiry period too long.
SW1	-	x	x	Problem of permits for new line, even in corridors.
US1	-	x	-	
US2	-	-	-	
Item	1	2	3	4

Regarding the quantification methods for decisions on Uprating/Upgrading in Statistical Table 8.13 above and the Summary Table 8.13/S below, the number of votes in favour of the two possibilities are identical:

- 50% (20 cases): Initial investment costs;
- 50% (20 cases): Comparisons with costs of a new line.

There are also useful additional comments for 19 cases (48%).

Table 8.13/S - Quantification methods for decision on Uprating/Upgrading

	Quantification methods for decision on Uprating/Upgrading (Q11)	Uprating		Upgrading		No	Total	
		R	R+G	G	G+R	R/G	Abs	%
	Number of replies	23	8	4	4	1	40	100
1	Initial Investment costs	12	4	2	1	1	20	50
2	Comparisons with costs of a new line	13	4	1	1	1	20	50
3	Additional comments	12	1	3	3	0	19	48

8.14 Influence of operation and maintenance costs on decision

Table 8.14 - Influence of operation and maintenance costs on decision					
Item	O&M costs recorded globally	O&M costs taken into account	O&M costs not taken into account	Additional comments	Others
Item	1	2	3	4	5
AN1	-	-	-	x	Least cost solution. Impact on landowners.
BE1	x	x	-	x	Cost ratio uprating works/new line. Condition monitoring.
BE2	x	x	-	x	Cost ratio works/possible risks and increased O&M.
BE3	x	-	x	-	
BR1	-	x	-	-	
BR2	x	-	x	-	
BR3	-	-	-	-	
BR4	-	-	-	-	
BR5	x	-	x	-	
BR6	-	-	-	x	Same as BR2.
BR7	x	x	-	x	Live line possibility. Ease of modification constructions.
BR8	x	-	x	-	
BR9	x	x	-	x	Works rejected if unacceptable regarding maintenance.
BR10	x	x	-	-	
BR11	-	-	-	-	
CA1	-	-	x	x	Damage costs. Societal cost for lost services. Public perception.
CA2	x	x	-	x	O&M costs not transparent and easy to extract.
DK1	x	-	x	-	
FR1	-	-	-	-	
GE1	x	-	x	x	High loads on foundations→high costs.
GE2	-	-	-	x	Same as GE1.
GB1	-	-	-	x	O&M costs difficult to quantify, but considerable savings.
GB2	-	-	-	x	Complex. See 2004 Paris paper. Cost of works/resources.
GB3	-	-	-	x	Elimination of transmission constraint costs.
IT1-5	x	-	x	-	
JA1	-	-	-	-	

NO1	x	x	-	x	O&M cost will be taken into account in the future.
PO1	x	-	-	-	
PO2	x	x	-	x	Mostly failure costs. Ageing of elements (insulators and earthwire).
PO3	x	-	-	-	
SA1	-	-	-	x	Same as SA3.
SA2	-	-	-	x	Same as SA3.
SA3	x	-	-	x	0.2% of capital replacement cost per year.
SM1	x	x	-	x	Cost compared with cost new line. Condition monitoring.
SM2	x	x	-	x	Same as SM1
SM3	x	x	-	x	Same as SM1
SM4	x	x	-	x	Same as SM1
SP1	-	-	x	-	
SW1	x	-	-	x	Only known by TSO.
US1	x	-	-	x	Steps to solve problem if unacceptable failure number.
US2	-	-	-	x	Limited Right of Way is the determining factor.
Item	1	2	3	4	5

Statistical Table 8.14 above and Summary Table 8.14/S below summarize the replies to Question Q12 of the Questionnaire. In 59% of the cases the Operation and Maintenance (O&M) costs are registered, mostly by the Transmission System Operator. But only in 32% of the cases they are taken into account for the decisions on Uprating and/or Upgrading. Probably, as mentioned by one responder, they are not registered per line, but globally. From the additional comments to Question Q12 of the Questionnaire (61% of the responders) and the previous comments, it is clear that the O&M costs are only one of the various possible criteria. Mostly they are not significant or at least not transparent. Nevertheless, there is a general agreement that O&M costs decrease sharply after Uprating/Upgrading. In this context reduction of transmission constraint costs, damage and failure costs can lead to considerable savings in O&M.

Table 8.14/S - Influence of operation and maintenance costs on decision

	Influence of O&M Costs (Q12)	Uprating		Upgrading		No	Total	
		R	R+G	G	G+R	R/G	Abs	%
	Number of replies	23	8	4	4	2	41	100
1	O&M costs recorded globally	13	6	2	1	2	24	59
2	O&M costs taken into account	8	3	1	1	0	13	32
3	O&M costs not taken into account	3	2	1	1	2	9	22
4	Additional comments	13	6	2	4	0	25	61

9. Conclusion of the statistical tables

Most of the Statistical Tables are followed by some conclusions and a summary table per item and per specific Uprating/Upgrading activity.

9.1 Uprating/Upgrading statistics

For a total of 42 cases we counted 24 cases (57%) of Uprating without Upgrading (R), 9 cases (21%) of Uprating where Upgrading was necessary to keep at least the same reliability level (R+G), 5 cases (12%) of Upgrading without Uprating (G) and 4 cases (10%) of Upgrading where Uprating was an opportunity (G+R) (Table 9.1). Uprating and Upgrading are often combined (31%), except when Uprating and Upgrading are typical cases such as respectively increasing operation temperature and strengthening structures to increase the structural reliability level.

Table 9.1 – Combination of Uprating and Upgrading

Main action	Uprating	Upgrading	Total
No combination	Uprating only 57% (24 cases)	Upgrading only 12% (5 cases)	69% (29 cases)
Combination	Uprating with Upgrading 21% (9 cases)	Upgrading with Uprating 10% (4 cases)	31% (13 cases)
Total	78% (33 cases)	22% (9 cases)	100%(42 cases)

For Uprating actions, increasing current rate is significantly more popular than increasing voltage level:

- 71% or 30 cases for increasing current rate;
- 24% or 10 cases for increasing voltage level.

For increasing current rate, increasing conductor temperature is nearly as popular as reconductoring:

- 43% or 18 cases for increasing conductor temperature;
- 50% or 21 cases for reconductoring.

Moreover increasing conductor temperature and reconductoring are combined in 9 cases (21%). For the 21 reconductoring cases, Upgrading could be avoided in 10 cases (48%).

For increasing conductor temperature, both raising conductor attachment point and re-tensioning are as popular:

- 17% or 7 cases for raising conductor attachment point;
- 17% or 7 cases for re-tensioning.

For 26 cases the increase of transmission capacity has been mentioned. The factor of this increase varies between 1.1 and 4.0. The mean value is 1.8 and the median is 1.5.

For 15 cases the increase of the operation temperature has been mentioned. This increase varies between 5°C and 95°C. The mean value is 29°C and the median is 26°C.

The return period for limit wind loads varies between 25 and 300 years (after upgrading). For ice loads the return periods are sometimes higher (up to 500 years). Only in 5 cases (13%), the return period for climatic loads increases. The number of Upgrading actions due to higher wind pressure or ice load (7 cases) and higher total conductor diameter (8 cases) are comparable.

9.2 Life extension and line performance statistics

The values of the expected remaining life are mentioned for 32 cases (82%). The value varies between 10 years and 80 years. The mean value is 36 years and the median 35 years. In 23 cases (59%), the expected remaining life increases after Uprating/Upgrading. This increase varies between 5 years and 40 years. The mean value of the increase is 22 years, the median is 20 years.

It is surprising that Life Extension (LE) is mostly combined with Uprating and/or Upgrading actions (62% or 26 cases). Even for the 24 Uprating cases R without Upgrading the percentage is higher. Consequently it is extremely interesting to examine more in detail how LE is combined with Uprating and/or Upgrading actions.

For the total of 42 cases, LE is 26 times or 62% (Table 9.2a) combined with Uprating and/or Upgrading. For the 24 Uprating (R) cases, LE is combined 16 times or 67%; for the 9 Uprating with Upgrading (R+G) cases, LE is combined 5 times or 56%; for the 5 Upgrading (G) cases, LE is combined 3 times or 60% and for the 4 Upgrading with Uprating (G+R) cases, LE is combined 2 times or 50%.

Table 9.2a – Probability that Life Extension is combined with Uprating/Upgrading

Main action	Uprating	Upgrading	Total
No combination	Uprating only 67% (16/24 cases)	Upgrading only 60% (3/5 cases)	66% (19/29cases)
Combination	Uprating with Upgrading 56% (5/9 cases)	Upgrading with Uprating 50% (2/4 cases)	54% (7/13 cases)
Total	64% (21/33 cases)	56% (5/9 cases)	62%(26/42 cases)

We may conclude that Life Extension is irrespective of whether the action is Uprating or Upgrading. It justifies the assumption made in Clause 3.2 to make a distinction between Upgrading and Life extension.

The expected remaining life is significantly lower than the return period for the climatic limit load. The ratio of the remaining life to the return period (after Uprating/Upgrading) varies between 20% and 120%. The mean value of the ratio is 65% and the median is 70%.

Table 9.2b summarizes for various indicators the number of answers received, the range of values (min. to max.) and the mean and median values.

Table 9.2b – Indicators for the results of Uprating/Upgrading and Life Extension					
Indicator	Number	Min	Max	Mean	Median
Increase of transmission capacity (-)	26	1.1	4.0	1.8	1.5
Increase of operation temperature (°C)	15	5°C	95°C	29°C	26°C
Reference wind speed (m/s)	20	21 m/s	40 m/s	29 m/s	30 m/s
Return period of limit wind load (years)	25	25 a	300 a	71 a	50 a
Expected remaining life (years)	32	10 a	80 a	36 a	35 a
Increase of remaining life (years)	23	5 a	40 a	22 a	20 a
Ratio: remaining life/return period (%)	23	20%	120%	65%	70%

Unfortunately we received very few information about the improvement of the performance of the line. Only for 7 cases the values given show improvement of the number of outages (1/100 km.year) or the unavailability (h/year) after Uprating and/or Upgrading.

9.3 Decision factors

The decision factors on Uprating and/or Upgrading works are ranked hereunder according to the preference (total votes 40):

1. 68% (27 votes): Lower investment of the works;
2. 58% (23 votes): Lower LCA (Life Cycle Assessment) costs (investments, losses, O&M costs);
3. 35% (14 votes): Unacceptable mechanical or electrical reliability;
4. 18% (7 votes): Real return periods lower than design;
5. 13% (5 votes): Political costs of unavailability.

There are also useful additional comments for many cases (68%). Large number of failures or too low transmission capacity are mentioned. We notice that final decisions are more based on the qualification of costs and transmission capacity than on the need of upgrading, life extension, uprating or line performance.

In about 59% of the cases the Operation and Maintenance (O&M) costs are registered, mostly by the Transmission System Operator. But only in 32% of the cases they are taken into account for the decisions on Uprating and/or Upgrading. Probably, as mentioned by one responder, they are not registered per line, but globally. There is a general agreement that O&M costs decrease sharply after Uprating/Upgrading. In this context reduction of transmission constraint costs, damage and failure costs can lead to considerable savings in O&M.

The Uprating/Upgrading costs are mostly compared with the construction of a new equivalent line. The range is quite large: from 0.25% to 100% with a mean value of 33% and a median of 20%.

10. General conclusion

With the answers to the Questionnaire sent abroad, CIGRE WG B2.06 TF03 was able to collect and compare worldwide best practices on Uprating and/or Upgrading works of overhead transmission lines to assess the reasons, the design requirements and the results achieved.

11. References

[1] IEC 60826, "Design Criteria of Overhead Transmission Lines", Edition 3, October 2003

[2] WG 22.06, "Probabilistic Design of Overhead Transmission Lines", CIGRE Technical Brochure No. 178, February 2001

[3] Ghannoum Elias, "Increasing Structural reliability and Security using IEC 60826 Principles", Report R9-03, Colloquium on Overhead Lines Revitalization, Belgrade, May 6-10, 2003

[4] WG 22.13, "Management of Existing Overhead Transmission Lines", CIGRE Technical Brochure No. 175, December 2000

[5] WG B2.12, "Conductors for the Uprating of Overhead Lines", CIGRE Technical Brochure No. 244, April 2004

Appendix - Questionnaire sent abroad

CIGRE WG B2.06 TF 03
Questionnaire on Uprating and/or Upgrading of Overhead Transmission Lines

(It is requested to prepare one set of answers to the questions of First Part, for each line separately. For the Second Part, only one set of answers is reqired)

First Part: Specific questions related to lines which have been uprated/upgraded
(Questions 1 to 9)

1. **Did you already uprate or upgrade overhead transmission lines in your Company (Utility)?**

   Answer: Yes or no.
   If No, jump to questions 10 to 12.
   If Yes, answer the Questions 1 to 9 for every line you have data.
   Name of the *line/set of lines* subjected to Uprating/Upgrading
   Answer:

2. **General information and data of the original line, which has been subjected to Uprating/Upgrading**

2.1 Line length?
Answer: km;

2.2 Date of original commissioning and start-up of operation after Uprating /Upgrading?
Answer:

2.3 Type of circuit before/after Uprating/Upgrading?
Answer:

2.4 Basic line data before and after Uprating/Upgrading?
Answer:
Fill in Table 1.

3. **Provide a short description of the uprating and/or upgrading works carried out for the overhead transmission line described above, which underwent such activities**

3.1 Design criteria? Were these based on deterministic or statistical approaches? Which standards were used in the original design and also in the design of the uprating/upgrading of the line? Original criteria/New criteria?
Answer:

3.2 Supports? What were the original support types, and were they modified during uprating/upgrading?
Yes or no.
If yes, describe briefly the modification carried out and add illustrative drawings.
Answer:

3.3 Conductors? What were the original conductor types, were they replaced or their design temperature raised during uprating/upgrading?
Yes or no.
If yes, describe briefly the modifications carried out.
Answer:

3.4 Shield wires? What were original shield wire types, and were they modified during uprating / upgrading?
Yes or no.
If Yes, describe briefly the modification carried out.
Answer:

3.5 Insulation level? Which insulator type was used originally? Was the line re-insulated, and if so was the same type of insulator used? Which were the new insulation levels adopted? Describe briefly the modifications carried out, adding illustrative drawings, if available.
Answer:

3.6 Earthing system? What earthing system type was used, and was it modified or improved? Add illustrative drawings, if available.
Answer:

3.7 Foundations? What types of foundation were used originally, and were any modifications made?
Yes or no.
If yes, describe briefly the modification carried out.
Answer:

Detailed questions (4, 5, 6 and 7) are related to each OHTL which was uprated or upgraded and basically describe the results obtained from these operations. Please provide the data available, if possible filling in Tables 1, 2, 3 and 4.

4. Information on the line parameters and characteristics, both as originally constructed and following Uprating and/or Upgrading of the line

Please fill in Table 1 or supply any other available data or information on line parameters before and after line uprating and/or upgrading.

Table 1: Line parameters before and after Uprating/Upgrading

Line component	Before	After
Typical Support		
Conductors		
Nº of insulators per string/Basic Insulation Level (BIL)		
Creepage distance per string		
Swing angle / Minimum Conductor-tower clearance		
Transmission capacity (MW)		
Average earth resistance		
Other changed parameters (1)		

(1) Please indicate other parameters, if considered more appropriate for the relevant case.

5. Costs of uprating

If there was power transmission increase, inform the relative costs of the uprating works as compared to the construction of a new line.

6. Electrical and mechanical reliabilities before and after Uprating/Upgrading

Answer: Fill in Tables 2 and 3, or supply other available information on the subject.

Table 2: Electrical reliability parameters assessed or occurred before and after Uprating/Upgrading

Electrical reliability parameter	Before	After
Fast front performance (1)		
Slow front performance (2)		
Power frequency performance (3)		
Pollution level for selecting insulation		
Average unavailability/year		
Other indices (please indicate) (4)		

(1) Number of line outages / 100 km.year, for lightning overvoltages;
(2) Risk of Failure or Probability of Flashover (PFO) for switching surge overvoltages;
(3) Failure rate in the period of line life;
(4) Please indicate other indices, if considered more appropriate for the relevant case.

Table 3: Mechanical reliability parameters assessed or occurred before and after Uprating/Upgrading

Mechanical reliability parameter	Before	After
Return period (Years) of design loads		
Reliability level (1)		
Basic wind speed (10m, 10 min)		
Nº of tower failures occurred (total and percentage)		
Nº of foundation failures occurred (total and percentage)		
Mechanical unavailability		
Other indices (please indicate) (2)		

(1) If applicable. If not, quantify the reliability at the way you name it;
(2) Please indicate other indices, if considered more appropriate for the relevant case.

7. Operational and maintenance costs before and after uprating /upgrading

Answer: If enough information is available, fill in Table 4.
If not, please supply other data or comments applicable.

Table 4: Operational and maintenance costs before and after Uprating/Upgrading

Option of Cost Data	Before	After
Real cost per line (Euro$/line.year) or (%) /line.year (1)		
Cost per line length (Euro$/km.year) or (%)/km.year (1)		
Cost/MW transmitted per year or (%)/MW.Year (1)		
Other cost parameters (2)		

(1) The comparative unit costs before and after uprating/upgrading (in %) are a sufficient information;
(2) Please indicate other cost parameters, if considered more appropriate for the relevant case.

8. **What main factors influenced the decision by the line owner or utility to uprate or upgrade the line?** *(Indicate in Table 5 the applicable options. If any answer is yes, please supply additional information/comments)*

Table 5: Factors influencing the decision to uprate/upgrade.

Option	Answer (Yes/No)
Lower investment of the works carried out	
Lower whole lifetime costs (initial investment + losses + maintenance costs converted to present day value)	
Unacceptable reliability of line (mechanical, electrical or both)	
Political costs of unavailability	
Occurrence of Return Periods lower than established in design criteria for mechanical failures of line	
Others	

Additional information/Comments:

9. **Provide please an estimation of the remaining life of the line assessed before and after the uprating/upgrading process.**

Answer:
- **Before uprating/upgrading: …… years**
- **After uprating/upgrading: …… years**

Additional information/Comments:

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(Supply just one answer)

Second Part: Information on general uprating/upgrading policies
(Questions 10 to 12)

10. On which factors/parameters is the decision to uprate or upgrade rather than construct a new overhead line made? (*Indicate in Table 6 all options as applicable. If any answer is yes, please supply additional information*)

Table 6: Decision factors/parameters

Option	**Answer (Yes/No)**
Lower initial investment of the works to be carried out	
Political costs of unavailability	
Increase mechanical reliability of the line	
Increase electrical reliability of the line	
Extend line life time	
Increase power transmission	
Cope with new legislation/standards	
Others	

Additional information/Comments:

11. What are the methods adopted for quantifying each process? Indicate in Table 7 the quantifying methods.

Table 7: Quantifying methods

Option	**Answer (Yes/No)**
Initial investment costs for uprating/upgrading the line	
Comparison of uprating/upgrading costs with costs for building a new line	
Others	

Additional information/Comments:

12. Are operation and maintenance costs of overhead lines measured and recorded in your Utility? How are they taken into account, when analyzing the alternative of uprating and/or upgrading an overhead line? Please provide comments.

Answer:

Additional information /Comments:

Instructions for filling the Questionnaire

First Part: Specific questions related to lines which have been uprated/upgraded

Question 1: If yes, provide the name of the line for which data will be supplied.
Question 2: Provide the data required and fill in Table 1.
Question 3: Supply main data on components uprated, if possible presenting illustrative drawings on towers, insulator strings etc. Describe the original and new design criteria used in the uprating carried out.
Question 4: Complete Table 1 with the parameters before and after uprating/upgrading. For the case of uprating, it is important to inform line transmission capacity (power) before and after.
Question 5: Data on costs, absolute values or relative are important, in order to permit evaluation of uprating as compared to the construction of new lines. Even for upgrading, it is of paramount importance to know the costs for increasing the reliability of the line.
Question 6: What was the influence of the uprating/upgrading works in both electrical and mechanical reliability parameters of the line? Fill in Tables 2 and 3, using the best available or estimated values of the parameters.
Question 7: It is a very sensible and difficult question. Supply what is available or estimated in matter of maintenance and operation costs **before** and **after** uprating/upgrading. Fill in what is possible in Table 4.
Question 8: Specify the factors that influenced the decision of uprating/upgrading each of the lines object of the answers.
Question 9: Indicate or estimate the line life that was foreseen before and the new life after the uprating/upgrading. A rough estimate may be enough.

Second Part: Information on general uprating/upgrading policies

Question 10: Inform or estimate the main factors that your Company has used or intend to use in the future for taking the decision of uprating/upgrading overhead lines
Question 11: Indicate the quantifying process, for instance cost comparison between uprating or building a new line
Question 12: Provide some hints or information on maintenance costs of lines and their eventual influence on uprating/upgrading lines.

Definitions

Uprating: comprises actions carried out in an existing line to increase its transmission capacity (power transmitted);
Upgrading: comprises actions carried out in an existing line to improve its reliability.

Notes:
a) Uprating and upgrading are frequently carried at the same time in an existing line;
b) A real example of a filled Questionnaire has already been sent to all respondents;
c) Answer Questions 1 to 10 so many times as possible depending on the number of lines for which data are available.

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