Environmental Issues

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Originally published by Cigré, 2014, under the ISBN 978-2-85873-284-5. Republished by Springer International Publishing Switzerland with kind permission.

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K.O. Papailiou (ed.), *Overhead Lines*, CIGRE Green Books,
DOI 10.1007/978-3-319-31747-2_6

6.1 Introduction

Overhead Lines and Environmental Issues and their interaction have been under consideration within Cigré for many years. The issues covered have ranged from permit procedures, environmental impact assessments and consultation methodologies for Overhead Line projects to mitigation of environmental impacts be they visual, ecological, on land use or of construction and maintenance. The development of reduced visual impact designs and aesthetic designs has been traced and all issues associated with field effects inclusive of the debates on EMF and mitigation measures have been investigated. Life Cycle Assessment for Overhead Lines has been reported on. Many utilities and TSOs have addressed and provided information on all these issues.

Cigré Study Committee B2 *Overhead Lines* (formerly SC22) investigated the question of Overhead Lines and Environmental Issues initially in the eighties and a report was produced. It included material on EMFs and alleged health affects but because of sensitivities in that debate at that time it was never published as a Cigré TB. Matters moved on and attitudes changed. Overhead Lines and Environmental Issues were later dealt with through a number of dedicated working groups from the mid-nineties into the mid two thousands. These were WG 14, *Environmental Concerns and Regulatory Controls*, and WG 15, *Life Cycle Assessment and Environmental Concerns*.

A number of Cigré TBs were produced as listed below:

- Cigré TB 147 *High Voltage Overhead Lines - Environmental Concerns, Procedures, Impacts and Mitigations* (Oct 1999) (Cigre 1999).
- Cigré TB 265 *Life Cycle Assessment for Overhead Lines* (Dec. 2004) (Cigre 2004).
- Cigré TB 274 *Consultations Models for Overhead Line Projects* (June 2005) (Cigre 2005a).

An Electra article on *Environmental Management Plans (EMPs) for Activities Associated with OHLs* (Fitzgerald 2004) was also published.

Reports on Overhead Lines and Environmental Issues were produced for preferential subject (PS) 2 for the Cigré Paris Session in 1996 (Reports of Cigre 1996), for preferential subject 3 for the Paris Session in 2002 (Reports of Cigre 2002), preferential subject 2 for the Paris Session in 2004 (Reports of Cigre 2004a), preferential subject 3 for the Paris Session in 2004 (Reports of Cigre 2004b) and for preferential subject 1 for the Paris Session in 2010 (Reports of Cigre 2010a). These issues will be returned to in the 2014 B2 Paris Session in Preferential Subject 1 *Minimising the Impact of new Overhead Lines*.

With the reorganisation (and relabeling) of Cigré Study Committees in 2003 a new Study Committee, C3, System Environmental Performance, was set up. Henceforth all environmental matters would dealt with by working groups in this SC. and various TBs were produced by their working groups which are relevant to Overhead Lines as part of broader power systems developments. The C3 TBs relevant to Overhead Lines are.

- Cigré TB 487 Strategic Environmental Assessment for Power Developments (Feb 2012) (Cigre 2012a).
- Cigré TB 548 Stakeholder Engagement Strategies in Sustainable Development - Electricity Industry Overview (Aug. 2013) (Cigre 2013).

Cigré C3 Paris session reports from 2004 Preferential Subject (PS) 2 (Reports of Cigre 2004c), 2006 PS 2 (Reports of Cigre 2006), 2008 PS 2 (Cigre 2008), 2010 PS 1 (Reports of Cigre 2010b), 2010 PS 2 (Reports of Cigre 2010c), 2012 PS 1 (Reports of Cigre 2012) and 2012 PS2 (Cigre 2012b) contain many reports of interest in the area of Overhead Lines and Environmental Issues. These issues will be returned to in the 2014 C3 Paris Session in Preferential Subject 2 *Integrated Sustainable Approaches for T & D Development* and Preferential Subject 3 *Acceptance of High Voltage Transmission Assets near Urban Areas*.

A number of other C3 working groups also dealt with Environmental Issues and Overhead Lines. One was C3.04 *Corridor Management*. This working group was to review environmental issues relating to Overhead Lines corridor management for the whole of life for high voltage networks. Cigré TB, *"Corridor Management: An overview of international trends for high voltage networks"* Is expected to be published sometime in 2014. Another C3 WG, 08 *Internalising the External Environmental Costs of OHLs*, has essentially completed its work. A final mature draft is awaiting approval and a Cigré TB should be published in 2014.

Other working groups in B2 and some in other study committees also produced Cigré TBs relevant to Overhead Lines and Environmental Issues and impacts. The B2 ones are:

- Cigré TB 278 Influence of Line Configuration on Environment Impacts of Electrical Origin (Aug. 2005) (Cigre 2005b).
- Cigré TB 416 Innovative Solutions for OHL Supports (June 2010) (Cigre 2005c).

Other Study Committee's TBs from WGs or JWGs of interest are:

- Cigré TB 373 Mitigation Techniques For Power Frequency Magnetic Fields (Feb. 2009) (Cigre 2009).
- Cigré TB 473 Electric Field and Ion Current Environment of HVDC Overhead Transmission Lines (Aug. 2011) (Cigre 2011).

A Joint Working Group C3/B1(Cables)/B2 was set up in 2010. The terms of reference covered reviewing and updating of many of the issues dealt with in B2 TB 147 *High Voltage Overhead Lines - Environmental Concerns, Procedures, Impacts and Mitigations* (Oct 1999) (Cigre 1999). The JWG would address issues which relate to the processes, procedures and environmental impact assessment to obtain permits for transmission lines including the cases of proximity of electricity transmission lines and built development. It would also cover how transmission companies and organisations plan the routes of new transmission lines and design the lines to reduce environmental and visual impact in rural areas and near residential and commercial buildings. It would investigate how transmission companies and organisations deal with requests to underground proposed new overhead lines and with requests to relocate (or underground) existing lines when residential or commercial development is planned, or is newly built, near existing lines (It may be noted that in this Cigré B2 Green Book this latter topic of underground cables or overhead lines is dealt with in a separate Chapter 19). However a Cigré TB is unlikely to emerge from this JWG before 2015.

This chapter, in line with the general direction given, is based on summaries of the above Cigré TB with updates in some key areas, including Field Effects, Corona and other phenomena.

6.2 Environmental Procedures and Assessment - Guidelines

6.2.1 Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment (SEA) is a form of environmental assessment that is meant to evaluate the effects of major new policies or planned developments on the environment, sustainability and stakeholder needs of large areas. Being a relatively new kind of assessment, it has emerged in several different forms and applications, such as:

- Environmental assessment for policies, plans and programs
- Regional assessments, referring to the environmental assessment of plans drawn up for a specific geographical area and
- Sector environmental assessment, designed for specific economic activities, such as energy. The latter is a common type, mainly due to the demands of multilateral financing agencies, who have required the use of this type of instrument for project approvals.

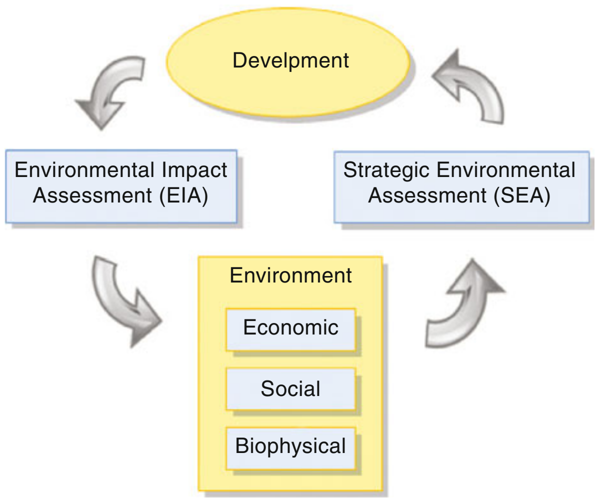

Figure 6.1 Illustration of the main difference between EIA and SEA.

SEA is often assumed to be simply an Environmental Impact Assessment (EIA) for large areas. One possible reason for this is that SEA shares its origins and common principles with EIA. However, there are significant differences between these two assessment methodologies. As illustrated in Figure 6.1 the fundamental difference between the two is that EIA most often focuses on the effects of a proposed development on the environment, while SEA aims to anticipate the effects of new developments on the environmental resources, sustainability and stakeholder needs in an area at a more conceptual stage. The SEA will help confirm the viability of the development concept and may contribute to the design or formulation of the development itself.

As a result of the similarities between EIA and SEA, the approach to SEA assessments has taken some common forms. One is the EIA-based approach, which involves applying the same kind of assessment procedures as in a traditional EIA, except on a broader scope and usually at an earlier stage of planning. The second is the sustainability-based SEA, in which an attempt is made to study the carrying capacities of the environment and the collective desire of the stakeholders for a preferred level and type of regional development.

6.2.1.1 SEA General Structure

The SEA legislation developed in 1969 in the US (with NEPA) stated the necessity to provide analyses of programmes, activities and regulations brought in by federal, state and local governments with reference to the effects these activities may have on the environment and the conservation and use of natural resources. In Europe, each country, within the EU, has enacted or legislated its own version of the SEA Directive 2001/42/CE. Each country has also created regulations and guidelines as to how the assessment will be administered, and how often it will be revised.

On March 21, 2003, during the Convention of Assessment of Environmental Impact, better known as the Kiev Protocol, fellow-members of the United Nations Economic Commission for Europe signed the Protocol of Strategic Environmental Assessment. Only in Spain, Portugal, Italy, Belgium and the Netherlands is an SEA mandatory for grid development planning or other plans in the power sector.

There are some countries, such as Brazil, South Africa, China and Australia, where SEA studies are not regulated by legislation, and, therefore, are not mandatory. Some countries have published guideline documents for undertaking SEA (e.g. South Africa and Canada). In other countries, SEA studies are being developed voluntarily or through informal agreements. The following generic stages are usually part of the process for conducting an SEA study

- Screening: identifying the need for SEA
- Scoping: setting targets and boundaries for the study
- Identification and assessment of alternative scenarios
- Report: analysis and report preparation and review
- Decision: consultation and decision making
- Monitoring: measure report, monitoring and follow-up.

The first step – Screening - is to determine if an SEA is actually needed. The entity responsible for developing the plan or programme (promoter) consults the authorities, with specific environmental responsibilities, to confirm if the plan or programme needs an SEA procedure. This is followed by a scoping process, which consists of identifying the issues to be addressed and the targets and boundaries that are pertinent to these issues. Alternatives for the plan or development are then considered.

For each alternative under consideration, the expected impacts are predicted, as is the significance of each impact on the environment, social conditions and sustainability of the area. Cumulative effects are also investigated for the areas involved. A preliminary report is prepared. The choice of a preferred plan or development option then takes into account the findings and suggestions of the SEA report. This process is accompanied by consultations with the authorities and with the public. Once approved, a monitoring process is put in place. The preliminary report is then made available to the public, and to those authorities with specific environmental responsibilities, in order to ensure an adequate review. Once the review period is concluded, the promoter must then take into account these results and draft the final version of the plan or programme.

SEA for transmission has been applied to plans and programmes, such as National Development Plans. It has also been applied as the first step of the planning process for regional and international power system interconnections. In these cases, the planning process provides the assessment of a region with the intent to select a "corridor" for the transmission line. A "corridor" is understood as the section of territory where technical, environmental and territorial conditions meet the requirements for routing power transmission lines and related plants. Alternatives are analysed based on indicators, and the best alternative is determined, as shown in Figure 6.2. When plans are implemented, monitoring of significant environmental

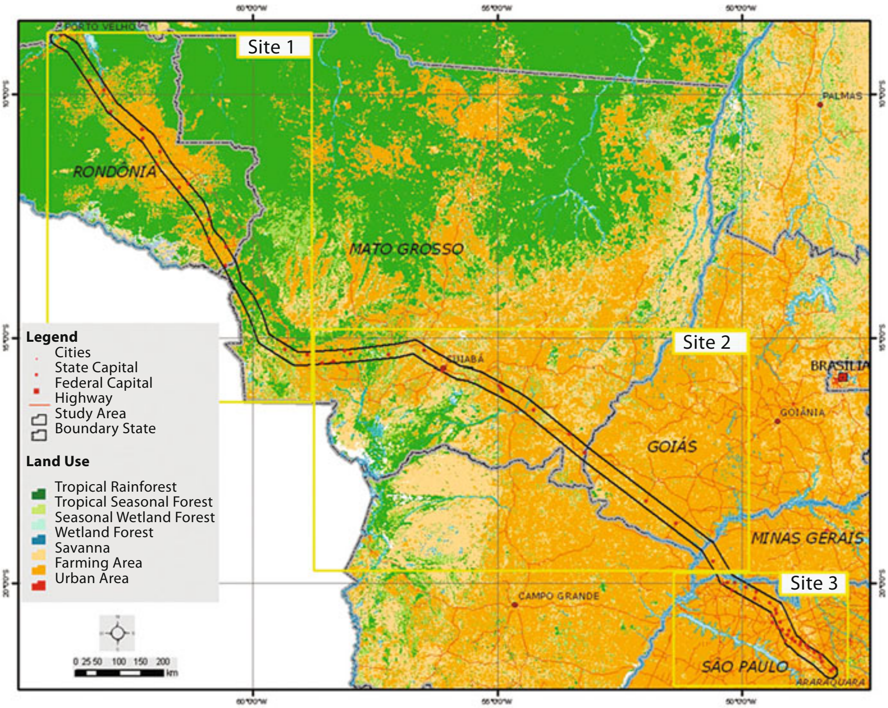

Figure 6.2 Transmission Line Corridor.

effects must be carried out to ensure that during the course of project development unanticipated effects are identified and the appropriate measures are taken.

One of the main steps in the SEA methodology is the development of indicators relevant to the selected objectives. Although many studies have used indicators, those used for SEAs are often interrelated in order to evaluate the effects of the plan or programme on the carrying capacities and sustainabilities of the resources found in the specific area. Therefore, the list of indicators may present significant variations depending on the country or the type of plan or programme being studied. Indicators can differ from country to country and may be different for generation and transmission.

6.2.1.2 Description of the Cigré TB 487 (2012a), SEA for Power Developments

Cigré TB 487, produced by WG C3.06 is divided into an Introduction and seven sections. An Executive Summary synthesises the TB. The Introduction presents the general concepts of SEA, the main characteristics of this type of environmental study and highlights its strategic level.

Section 1: Presents the main environmental and SEA concepts and definitions.

Section 2: Presents a specific comparison of SEA and Environmental Impact Assessment (EIA) studies, indicating the main differences between them.

Section 3: Describes general examples of SEA application and examines its major objectives, the reasons for developing SEA studies, existing legislation and the main responsibilities and accountabilities.
Section 4: Summarises the specific application of SEA studies for generation and transmission systems.
Section 5: Presents an overview of the indicators and other measurement techniques.
Section 6: Provides guidelines and recommendations for SEA in the power sector.
Section 7: Closes the TB with a brief conclusion.
Appendix 1: Presents a summary of SEA studies from each country participating in the Working Group.
Appendix 2: Presents a list of acronyms and abbreviations.

6.2.1.3 Guidelines

- It is imperative to conduct an SEA for major Plans and Programmes
- In all cases, SEAs should be strategic and comprehensive studies
- SEA should be included in national and regional long-term plans both for generation and transmission
- Define specific objectives and the scope of the study on which the assessment will be based and choose an appropriate method of measurement in accordance with the environmental authorities
- Identify different alternatives and analyze their effects
- Include analysis of environmental, social, economic, sustainability, accumulative effects and stakeholder needs
- Identify the stakeholders in the earlier stages of the process
- Take into account the results of public consultation
- SEA studies should result in meaningful deliverables, including proposals for mitigation, compensation and monitoring measures
- Make the results of the study and public consultation available in a Final Report
- Conduct a monitoring phase to provide feedback and to identify the value of lessons learned for the next SEA process.

6.2.1.4 Recommendations

- An appropriate communication plan should be established.
- Modelling tools should be developed to support the analysis of policies and plans, as well as decision making.
- Geographical Information Systems (GIS) should be used, particularly to analyse the cumulative and synergetic effects of the plan or programme.
- Build capacity and training on the SEA skills, which should be implemented.

6.2.2 Permit Procedures and Environmental Impact Assessment

6.2.2.1 Introduction

A survey was carried out by WG 14 on these issues (including others on OHLs and Environmental Issues, see sections below) and was reported on in Cigré TB

147 *High Voltage Overhead Lines - Environmental Concerns, Procedures, Impacts and Mitigations* (Oct 1999) (Cigre 1999). The relevant Section 2 of the Cigré TB gave information on the regulations, procedures, appeal processes, elements of EIA and outline of EIA processes in a range of countries at that time. Nevertheless it should be emphasised that national conditions vary considerably, as may the regulatory controls and environmental impact assessment processes in each country. Which procedures or practices to adopt therefore will depend to some extent on prevailing regulatory regimes in each country and on their unique cultural and environmental climates and it may depend also on the particular features of each project.

It was noted that it was evident that regulatory controls and associated EIA requirements were undergoing regular review and changing frequently. This is continuing and the position for any particular country needs to be confirmed directly or by way of more recent Cigré publications. Guidelines appropriate to the then situation are given below and many are still applicable.

6.2.2.2 Guidelines

- Efficient management of the licensing process is vital. Unnecessary reiteration in the licensing process should be avoided.
- It is desirable to develop a strategy which, while providing full justification for the project and meeting all environmental and consultation requirements, also anticipates that all decisions and procedures will be challenged.
- In the phase of recognition of the necessity and public interest of overhead line projects it is not desirable to have an open ended process. Co-ordination of licensing procedures should be undertaken to minimise delays in the whole process
- In the case of Overhead Lines with a national function a special regulatory process may be beneficial.
- Appeals procedures should have fixed time spans. While processes vary considerably and may involve operating through a number of levels it is essential for utilities to take all precautions and perform all necessary checks to ensure that any risk of losing the permit or licence is absolutely minimised.
- The use of environmental or community compensation schemes for communities affected by Overhead Lines should be considered, particularly where communities perceive only impacts and no specific benefits to them from a project. Various models exist which may prove appropriate depending on local circumstances.
- Models exist of changes to regulatory systems which involve earlier consultation, environmental compensation, commitments to further efforts to minimise overhead line impacts - particularly in the context of overall network lengths and development strategies - and design reviews. These may have relevance to evolving situations elsewhere depending on the stage of development of networks.
- Environmental requirements should be made clear in advance (e.g. in the Environmental Impact Assessment legislation) and confirmed in consultation with authorities. Nevertheless new requirements may arise in relation to the environmental impact studies or their methods of evaluation and it is desirable to try to anticipate these in so far as possible.

- Environmental specialists should be used to provide expert inputs on the overhead line impacts relating to their particular areas of expertise for inclusion in environmental impact statements. Various successful organisational frameworks exist for assimilating these.
- Comprehensive Environmental Impact Assessments should be carried out inclusive of all consultation requirements and environmental impact statements should cover the full range of necessary subjects, description of impacts and mitigation measures.

6.3 Environmental Impacts and Mitigations - Guidelines

TB 147 *High Voltage Overhead Lines - Environmental Concerns, Procedures, Impacts and Mitigations* (Oct 1999). Cigre (1999) reviewed the different types of impacts of Overhead Lines on the Environment under the heading listed below and in Section 6.4 and reported on them and on mitigations measures.

6.3.1 Visual Impact

Assessment and routing including different methodologies for routing for minimal visual impact were described. Routing guidelines were given and methods and tools for visual impact assessment described. Overhead line designs for minimal visual impact were dealt with including structures, conductors, insulators and fittings and methods of camouflage of full overhead lines or the principle elements.

The use of compact lines and pole structures to minimise right of way and impacts was outlined. The development of the “first generation” of aesthetic line designs in a number of countries such as France and Finland, and other solutions to reduce visual impact such as in Sweden (T Tower, see Figure 6.3) and in Hydro Quebec and South Africa (Chainette Cross Rope) were described and examples shown. Some of the aesthetic designs were developed through public competition. Such aesthetic or “landscape tower” designs have continued to multiply.

TB 416 *Innovative Solutions for OHL Supports* (June 2010) (Cigre 2005c) deals with the further development of such designs, be they intended for full lines routes, segments of line routes or used as special structures in particular locations. It gives designs from seventeen countries. Monopole supports are covered and more information is given on the Finnish and French (see Figure 6.4) aesthetic designs mentioned in Cigré TB 147 and developments since in those countries. Quite a few examples of the design of towers as artworks or transformation of some towers into artworks are given. A new Danish 400 kV single pole design with a stainless steel tube head framework supporting the insulator V assemblies in a delta formation is shown and Icelandic studies and competition results outlined.

TB 416 concludes “Demand for electricity has grown dramatically and the need for electricity will continue to grow. As a consequence, different regions of the world will face different challenges, concerning the environmental impacts, to

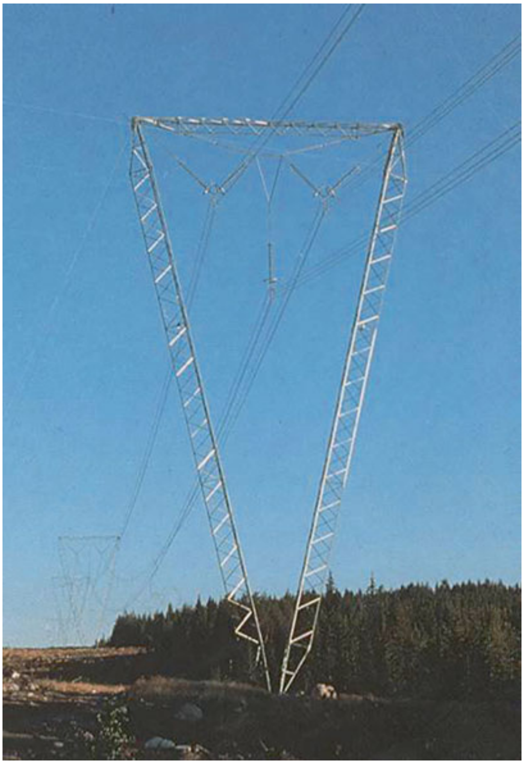

Figure 6.3 Swedish Reduced Visual Impact T Tower, which also reduces EMF.

supply more power. As far as transmission lines are concerned, some Utilities will have to construct long (up to 2500 km) UHV OHLs in the near future. For such lines, as reported in Cigré TB 416, the so called "aesthetic solutions" will be designed based on simplicity, invisibility, slenderness, compactness, all together driven by costs. On the other hand, in other regions of the world, the construction of new lines arouses more environmental and aesthetic concerns. With the growing demand, there will be more requests for alternative design solutions, i.e., for visually attractive landscape towers. In the majority of the cases, the desirable solution is to hide the structures, making them invisible or camouflaged. When, for any reason, this is not feasible, it is always possible to make them more aesthetic, more beautiful".

6.3.1.1 Guidelines on Visual Impact (Cigré TB 147, 1999)

- With regard to the visual impact of Overhead Lines the different approaches of trying to integrate an overhead line within the landscape or to assert the line within it may be used depending on the type of landscape, see Figure 6.5. The essential purpose of visual impact assessment is to describe the change in visual quality associated with the landscape setting and this assessment may be carried out by qualitative or quantitative methods.

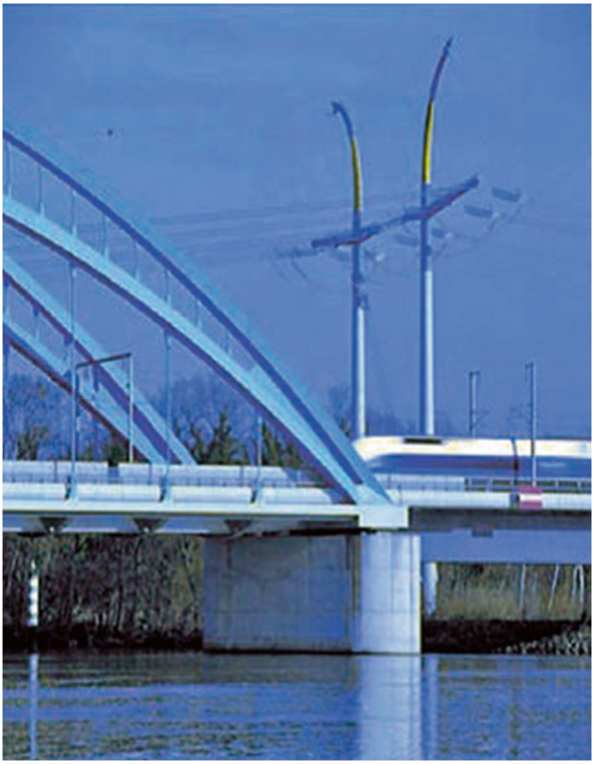

Figure 6.4 Aesthetic Structure, France (I. Ritchie, K. Gustafson).

- Various qualitative systems are available and quantitative methods have been developed and are still undergoing development. Qualitative techniques are generally preferred for dealings with the public while quantitative methods are more in use for expert assessment but are being developed for use with authorities and perhaps the public.
- Careful routing of an overhead line is a most important aspect in reducing the visual impact of a proposed line. Utilities should have a set of well-developed routing guidelines. The possible use of power corridors or joint transportation corridors and power line corridors should be covered.
- The routing guidelines should outline, in some detail, the practical steps to be taken to route a line for minimal visual impact taking account of other constraints and should also include recommendations for optimum location of structures along a line route.
- The chosen methods of visualisation will depend on the audience being targeted. Selected methods are not so important as long as the results are lifelike and understandable to most people, not only experts. This is very important in the planning and permit process phase of the project.
- Photomontages are still the most suitable method for visual presentation to the public. The accuracy of structure location and placement within the terrain is

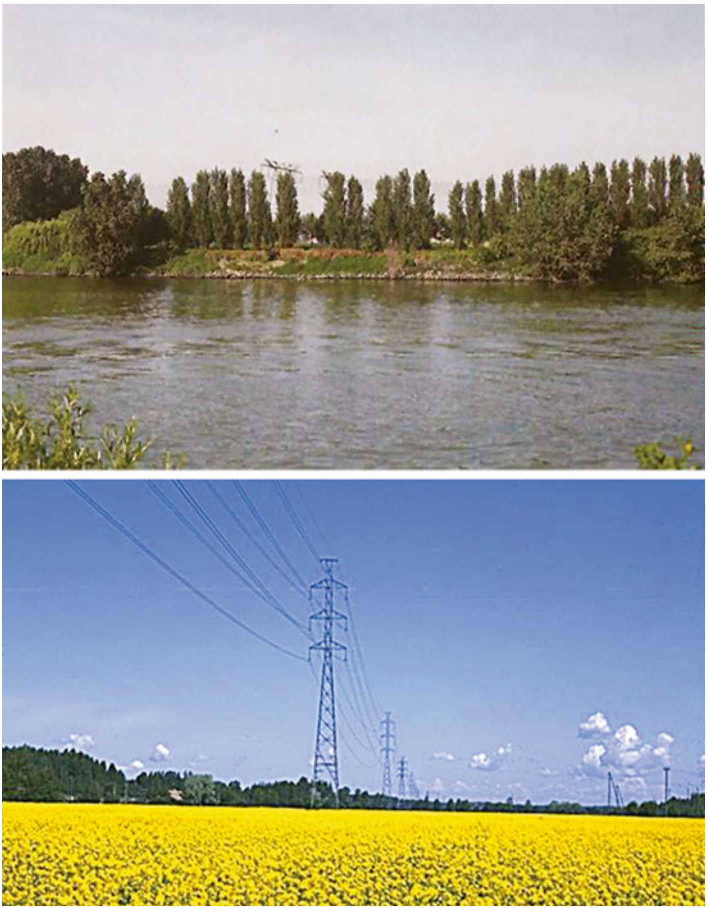

Figure 6.5 Landscape will determine whether integration within a landscape or assertion is the best approach.

crucial to public acceptance. They are also helpful in illustrating camouflage techniques and different designs.

- Digitised terrain models in themselves are not very effective for public presentation but if they are overlaid with digitally reconstituted photographs a basic visual presentation can be achieved. It is preferable to use photographs in conjunction with the terrain model.
- Digitised terrain models using GIS and Google Earth in combination with computer designed towers is a good tool to use for internal use in route selection as it can give an indication of the visibility of the line and structures from many different points of view. It is best suited where digitised maps are available.
- With regard to designs for minimal visual impact there is a strong tendency towards the use of compact lines as a mitigation measure to reduce visual impacts as well as for other reasons. Many utilities use multi-circuit towers to cater for

increasing environmental constraints however in regard to visual impact alternatives would have to be evaluated in each particular case.

- In the case of lattice towers cold formed steel and tubular sections instead of angle members have been used for reduced visual impact. For higher voltage levels lattice towers are considered to have less visual impact than other structures - while poles are used on the lower voltage levels for the same reason. Guyed towers, if acceptable, may reduce visual impact.
- Aesthetic designs of towers and unconventional structure designs have been developed. Many of these latter are used in *once off* or special situations. Their use was confined to limited applications initially but more recent designs have more widespread application.
- Camouflage of structures (using suitable colours) has been successfully used to reduce visual impact in certain locations in some countries but may not be permitted universally. Specially treated conductors are also effective measures that have been used successfully by utilities to reduce overall line impact, a significant portion of which can be attributed to conductor brilliance.
- Various insulator configurations can be used to reduce the visual impact of insulator assemblies. The use of composite insulators of suitable colour can be of advantage, as can specific colours of porcelain and glass insulators.
- Many of the above design options to reduce visual impact have cost debits and these should be balanced against their benefits.

Many of the latest designs are driven by the need to connect renewable energy sources.

New designs of reduced visual impact structures have emerged since the publication of Cigré TB 147 (1999) and TB 416 (2005c) such as the Danish Eagle Double Circuit Tower design with double crossarms below in Figure 6.6. About 160 km of this design has been built, replacing a single circuit 1150 MW 400 kV line with 2× 1800 MW. This design will form the backbone of the refurbished Danish 400 kV grid.

Other new designs are the Dutch Wintrack Pylon and the UK T Pole design with a prismatic arrangement of insulator assemblies (a test line built).

Composite Fibre insulated pole designs are being investigated. These pose many challenges.

Information is available on many of these new designs and investigations on the websites of the TSOs. An interesting development in the European Union is a touring exhibition showcasing pioneering structure design www.gridexpo.eu. This appeared in quite a few European cities in 2013 and more exhibitions are scheduled for 2014.

6.3.2 Impact on Land Use

- The impact of Overhead Line corridors on land use or the restrictions on the use of land near them will vary, depending on their earlier use and on the regulations relevant to them in the various countries.

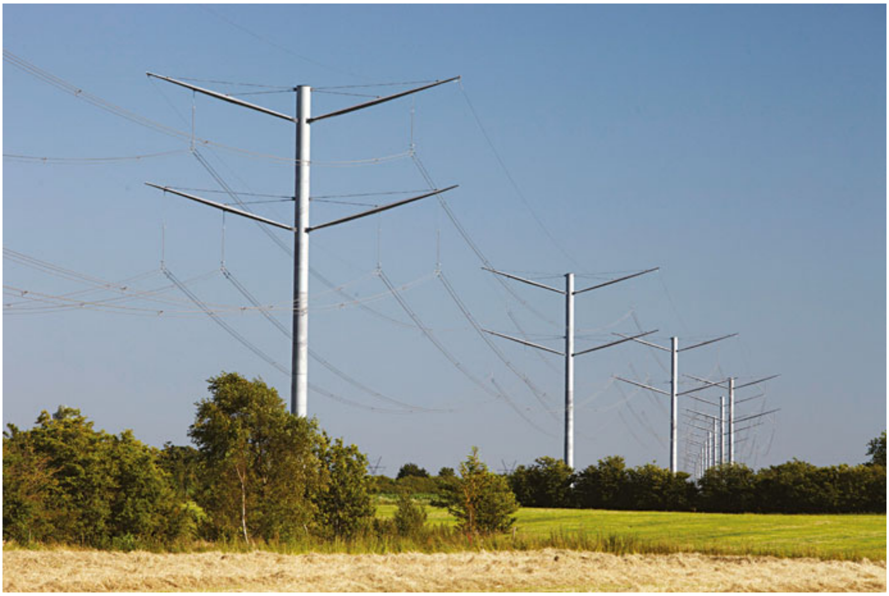

Figure 6.6 Danish Double Crossarm Eagle Tower.

- In forestry Overhead Line corridors will prevent timber production except for seeding stand and Christmas trees but loss of production should be compensated for. Corridors may have a positive effect (bio-diversity).
- In agricultural areas Overhead Lines do not hinder normal agricultural production however precautions may need to be taken with the use of some types of machinery or in performing some operations and structures may cause some interference. Optimising structure locations (if feasible) in such areas can mitigate impact and residual impacts or unavoidable construction and maintenance impacts can be compensated for.
- In industrial and urban areas impacts will depend on whether allowance was made for the line corridor or it was encroached upon and on the national regulations with regard to proximity of Overhead Lines to industrial buildings and to housing. In any case the effect of the line can be minimised by using the line corridors for car parking (see Figure 6.7), access corridors, bicycle paths, community gardens etc.
- If Overhead Lines are permitted in conservation, recreation or wilderness areas, and avoidance is not feasible, special precautions should be taken to minimise impacts. On the other hand line corridors adjacent to other infra-structural developments, such as roads or railways, could be beneficial.

6.3.3 Impact on Ecological Systems

- Route planners should identify sensitive sites, important for endangered species, and areas of special environmental and ecological significance, so that any

Figure 6.7 A double circuit 110 kV line corridor used as a car park in an industrial area (Ireland).

proposed Overhead Line can be routed away from these areas. If avoidance is impossible or very difficult, sufficient mitigation measures should be used after consultation with environmental experts and the environmental authorities.

- Consultation should be undertaken with an ornithologist to verify if vulnerable bird species can be influenced by the line and registration performed of primary ornithological functions or uses of the area to avoid key areas for birds and avoid separating these areas.
- Topographical features which are guiding lines and flight paths for migrating birds and/or are important for local movements of resident species and topographical elements such as cliffs and rows of trees that force birds to fly over power lines should be carefully mapped.
- Shieldwire or conductor marking (see Figure 6.8) should be carefully considered in areas with species known to be potential collision victims, and the design of such should be the result of an analysis of the biology and ecology of the target species.
- Special consideration should be taken when planning Overhead Lines in areas with wild herds. The route planning and the choice of construction period should be chosen after consultation with biologists and environmental authorities.

Figure 6.8 An example of a bird flight devices on the ground wire. A special trolley was developed to install the devices automatically on the wire (Spain).

- With regard to vegetation control, the preferred method to use depends on the actual situation. Mechanical control would normally be preferred from an environmental point of view. However, in some areas, especially with fast growing hardwood, chemical treatment will be preferred as a supplement to the mechanical control. If chemical control is necessary, it should be recommended to discourage high volume application of herbicides. A low volume of selective herbicides on target species should be recommended.
- Use of biological treatment, by using mushrooms on the cut surface of leafy stems, should also be seriously considered. This method has been recently developed. By lengthening the mechanical intervention cycle and avoiding chemical treatment, this method seems to constitute an efficient approach to problems of vegetation control and to the protection of the forest and wildlife environment.

6.3.4 Impact of Construction and Maintenance

- While many of the construction and maintenance impacts and issues appear to be common around the world, each project and its possible impacts should be viewed as unique. The possible impacts of a project must be specifically assessed and the possible mitigation measures determined.
- The impact of the removal of vegetation from the right of way depends on the terrain and vegetation traversed. Sensitive or valued areas should be avoided. Mitigation measures can include limited removal and retention where clearances allow it, the use of helicopters in sensitive areas, stepped removal, and replanting with lower height vegetation.

- In the case of access tracks impact can be reduced considerably if agreement with local landowners or land agencies can be achieved to use existing tracks or roads or access across lands. Tracks should follow the natural contour of the terrain and care should be taken to avoid erosion or impact on water-courses. Special temporary access systems or special temporary roadways can be used if necessary (Figure 6.9).
- On foundation and structure erection soil erosion should be guarded against. The placement of excavated material needs to be appropriate to surrounding land use and topsoil should be stored separately. All restoration work should be done in accordance with the requirements of the property owner, occupier or agency.
- During stringing activities with increased movement along the line route additional precautions should be taken to prevent any possible spread of decease or weeds in sensitive areas and helicopter stringing may be an option to reduce impacts. Conductor drum sites should be carefully chosen to minimise impact and restored as required after construction.
- The impacts of maintenance are generally less significant and apart from inspections or upgradings the main one is the on-going management of the right of way. Impacts and mitigation will be similar to those for vegetation removal. Precautions should be taken during helicopter patrolling to ensure no danger to live stock or blood stock in the vicinity of the line route.
- Environmental Management Plans provide the methodology and systems to link the measures proposed to reduce construction and maintenance impacts to action plans and site specific mitigation activities. Project specific quality plans should

Figure 6.9 Special Temporary Trackway (England).

be established and approved prior to the commencement of construction activities (see subsection below).

- Generally an overhead line is constructed to exist within an environment and operate securely and economically for many years. Any mitigation measures adopted for the construction and maintenance of the overhead line should take this requirement into account.

6.3.5 Environmental Management Plans

Where developments have been approved, there has been an increasing tendency for these approvals to be conditional on requirements for:

- Further environmental studies of the affected areas pre-construction,
- the introduction of environmental safeguards during construction and, in some cases,
- the carrying out of environmental audits post construction.

These are the main elements of an Environmental Management Plan (EMP). A survey carried out by a Task Force of B2WG15 reported in Electra (Fitzgerald 2004) on this whole area. The structure of EMPs was outlined and the report highlighted the methods and context of use of EMPs and some of the positives and negatives of their use. Significantly the survey also demonstrated that those companies that do not use or recognise a formal EMP process have increasingly strong controls externally directed to or internally applied to the environmental impacts of transmission line projects. A check list for an EMP was provided.

6.4 Fields, Corona and other Phenomena, Impacts and Mitigations

Electric and Magnetic Fields (EMFs) are physical phenomena which occur when electricity is flowing in power lines. In the last decades, health issues related to EMFs at Extremely Low Frequency (ELF) have emerged significantly and are important concerns for power system operators. Questions about possible health impacts of ELF-EMFs are often discussed animatedly during the consultation and dialogue phases of the planning and building process of new electricity transmission lines. After more than 50 years of research on this subject, the scientific community could not provide any solid evidence about any health hazard on living organisms associated with a prolonged exposure to ELF-EMFs at a lower level than the international recommendations.

Another phenomenon associated with transmission lines is the Corona effect which may have different consequences depending on many parameters (voltage level, weather conditions, conductors' configuration, pollution…). The main impacts of the Corona effect will be discussed along with audible noise, radio and television interferences and modification of the chemical composition of the atmosphere. Aeolian noise will also be addressed.

6.4.1 Electric and Magnetic Fields at Extremely Low Frequency (ELF-EMFs)

The following section deals with EMFs at power frequencies (mainly 50 Hz in Europe, Asia and Africa or 60 Hz in North America, Japan, Brazil…) which both are classified as Extremely Low Frequencies. Electric Field (ELF-EF) and Magnetic Field (ELF-MF) phenomena will be detailed in subsections 6.4.2 and 6.4.3.

The expression "electromagnetic radiation" is used to describe a fundamental physics phenomenon of electromagnetism: the transmission of radiant energy is carried by photon wave particles at the speed of light. It is also associated with an electromagnetic wave coupling magnetic and electric fields and propagating at the velocity of light. The 3 fundamental parameters describing this phenomenon (the wavelength λ, the frequency the electromagnetic oscillations *f* and the velocity of light c) are associated according the following formula:

$$\lambda = c / f$$

For power frequency (e.g. $f = 50$ Hz) and considering that $c = 300000$ km/s in a vacuum, then it comes $\lambda = 6000$ km. For such a long wavelength, the concept of propagation of electromagnetic waves is not relevant and the phenomena can be considered as quasi-static. As a consequence, in this frequency range, electric and magnetic fields can vary independently from each other. Neither is it relevant at extremely low frequencies, to refer to ionizing radiation. This is a non-ionizing radiation: the electromagnetic energy carried by each quantum is not sufficient to cause ionization of atoms (breaking chemical bonds in molecules) nor to be able to heat biological material.

6.4.2 Electric Field at Extremely Low Frequency ELF- EF

The electric field generated by a power line is related to the voltage expressed in Volts (V or kV). The strength of the electric field is expressed in V/m or kV/m. At ground level, it is at its maximum for a minimum clearance to ground of the overhead conductors, i.e. typically under the line at mid-span. Physical phenomena related to the ELF-EF are described in documents Cigre (2009) and Cigre (1980) and the calculation principles, especially "Equivalent charges method", are detailed in Cigre (1980).

6.4.2.1 Application to Transmission Lines

Many parameters influence the strength of the ELF-EF.

The electric field increases with the voltage level. Its strength reaches its maximum value under the line and rapidly decreases with increasing distance from the line. The electric field decreases to approximately one-third to one-tenth at 30 m from the axis of a single-circuit line, depending on its geometry, and to approximately one-hundredth of its maximum value after a few tens of meters more. Consequently, if the voltage level of the sources directly influences the value of the

Table 6.1 Electric-field strengths in the immediate environment (representative values at 1 m above ground)

Distance from the axis of the line	kV/m
Below a 400 kV, horizontal configuration, single-circuit line	1-5
30 meters from the axis of a 400 kV line	0.5-1.5
65 meters from the axis of a 400 kV line	0.1-0.4

electric field the distance between the sources and the spot measurement is another important parameter. The ELF-EF is also further reduced by grounded objects (e.g. trees, house, bushes…).

Typical measurements of electric field strengths values are given in Table 6.1 for a 400 kV line.

6.4.2.2 Recommendations for Electric Field ELF-EF Mitigation

Electric fields generated by an overhead transmission line can be reduced by modifying geometric or conductors' parameters.

Geometric Parameters

Reducing the phase-to-phase distance, i.e. compacting lines, is one of the most efficient methods to reduce the electric field. A compact line is an overhead line with voluntarily reduced dimensions in phase-to-phase and phase-to-metallic parts distances, (and consequently reduced length of the spans, and height of the poles) compared to a traditional line with an equivalent voltage, respecting (with a reduced –but still acceptable- safety margin) required minimal distances for safety of the public and the minimal internal distances so as to not degrade the quality of the service (Figueroa and Rault 2013).

Increasing the distance between the electric source and the area of exposure is naturally an efficient way to reduce the electric effects. Consequently, increasing the height of conductors in specific places is also effective to reduce ELF-EF exposure. There are different methods to increase the height of conductors:

- Increasing the horizontal mechanical stress of conductors
- Increasing the height of the pylons.

For double-circuit lines, low impedance configuration is strongly recommended for EF mitigation (optimized phase arrangement).

For single circuit lines, delta and triangle configurations give lower values of EF than vertical and flat ones (Cigre 2005b).

Conductor Parameters

Conductor configuration influences ELF-EF levels:

- Decreasing the sub-conductor cross section will increase the electric fields at the surface of the conductors and consequently will reduce ELF-EF levels at ground

Table 6.2 Influence of line parameters on EF-ELF mitigation

	Increase of phase to phase distance	Increase of conductor height above ground	Increase of number of sub-conductors	Increase of sub-conductor spacing	Increase of cross section of sub-conductors
Influence on the EF-ELF at ground level	↗↗	↘↘	↗	↗	↗

level. The effect is small for multi conductors' bundles and, in addition, it increases the Corona effect.

- The number of sub-conductors in a bundle is a significant parameter for electric field mitigation. As the number of sub-conductors increases, the EF at the surface of the conductors decreases which increases the ELF-EF at ground level.
- In the same way, increasing the spacing between sub-conductors will increase the ELF-EF at ground level.

More generally, all options for reducing the Corona effect will reduce the electric field at the surface of the conductors, and will consequently increase the electric fields at ground level. Table 6.2 sums up the influence of different line parameters on the ELF-EF values (Cigre 2005b):

Besides these mitigation techniques, it must be underlined that ELF-EF is easily reduced by any conductive object, even when poorly conductive such as trees, fences and usual building materials. As a consequence, whatever the magnitude of the external ELF-EF, the resulting exposure can often be neglected inside buildings.

6.4.3 Magnetic Field at Extremely Low Frequency ELF-MF

The magnetic field generated by a power line is related to the current expressed in Amps (A) flowing into the electrical circuits: this is a magneto static phenomenon. Physically the magnetic field strength "H" is expressed in Amps per meter (A/m) and is the strength of the magnetic field vector **H** related to the magnetic flux density **B** which is expressed in Tesla (T) or Gauss (G): 1 T = 10 000 G. Physical phenomena related to the ELF-MF are described in Cigre (2009). The relationship between H and B is: $B = \mu.H = \mu_0.\mu_r.H$. The permeability μ is the product of the vacuum permeability "μ_0" ($\mu_0 = 4\pi.10^{-7}$ H/m ~ $1{,}25.10^{-6}$ H/m) and the relative permeability "μ_r" related to the physical environment where the ELF magnetic field is studied. For information, $\mu_r = 1$ in most of physical environments except in ferromagnetic material where μ_r is significantly higher (e.g. Cobalt: $\mu_r = 250$, steel: $\mu_r = 10\,000$) and so, in most environments, H and B simply derive from 1 A/m = 1.25 μT. Considering this simple relation valid in most material including living tissues, it is a common practice to merge the two and simply call the magnetic flux density B as "magnetic field", and express it in Tesla (T) and more often in μT (1 μT = 10^{-6} T) considering the usual range of magnitudes of ELF-MF generated by power lines.

Methods used to calculate the ELF-MF are detailed in Cigre (1980).

6.4.3.1 Application to Transmission Lines

The main parameter influencing the ELF-MF strength is the current flowing in the conductors. Applied to the overhead line case, and assuming that weather parameters are constant, an increase of current will lead to a thermal expansion of conductors and then an increase of the sag. The magnetic field source is then closer to the ground, what results in an additional increase of the field magnitude at ground level. Respectively, at a few tens of meters from the line this sag variation effect can be neglected. Table 6.3 gives typical measured values of ELF-MF around transmission lines:

Figure 6.10 represents the ELF-MF pattern calculated at 1000 Amps along a perpendicular axis to the line at the middle of the span for a spot located at 1 meter above ground.

6.4.3.2 Recommendations for Magnetic Field ELF - MF Mitigation

Contrary to the ELF-EF, the ELF-MF cannot be reduced by conductive objects, except for highly conductive or ferromagnetic ones.

Magnetic field generated by an overhead transmission line can be mainly reduced using compensation methods or modifying geometric parameters. Unlike the electric field, the conductor configuration (number and spacing of sub-conductors or

Table 6.3 Magnetic flux densities in the immediate environment (representative values at 1 meter above ground level)

Distance from the axis of the line	μT
Below a 400 kV, horizontal configuration, single-circuit line	5-25
30 meters from the axis of a 400 kV line	0.5-5
60 meters from the axis of a 400 kV line	0.2-1

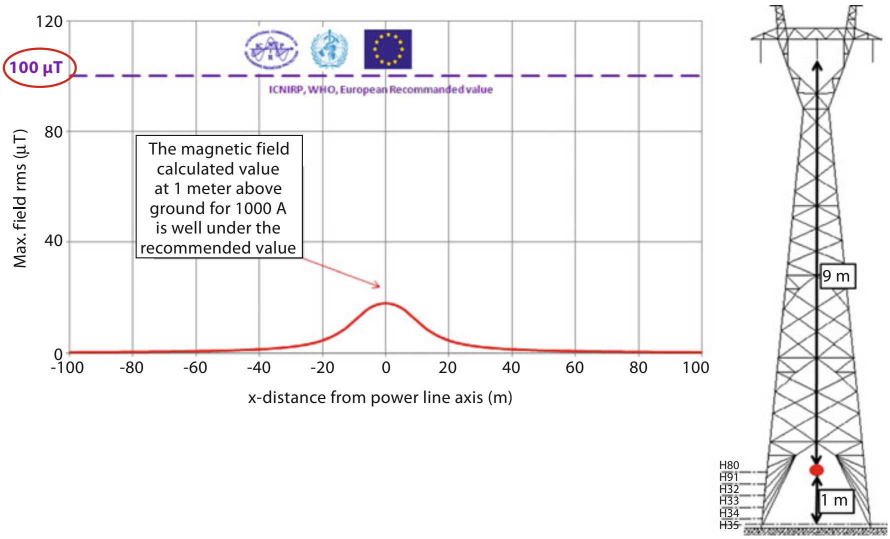

Figure 6.10 Typical ELF-MF pattern related to transmission lines.

total conductors cross section) has no influence on magnetic field magnitude at ground level. Phase splitting and phase cancellation are some very efficient solutions for ELF-MF mitigation. Ferromagnetic shielding solutions won't be described in the following parts as they are designed mostly for underground cables.

Geometric Parameters

Reducing distances between phases is the best way to mitigate ELF-MF. Thus the transmission line right of way is decreased which reduces the distance between the ELF-MF source and the spot measurement (Figure 6.11). Besides compacting lines increases the magnetic field compensation between the different phases of the circuit(s). This solution is very efficient especially for spot measurement in the vicinity of transmission line.

Increasing the distance between a measurement spot and the magnetic field source can be also carried out by increasing the height of conductors which is a simple way to locally reduce magnetic field exposure (note: "simple" here means easy to understand, but this does not mean that raising up towers or wires is a simple engineering process).

Table 6.4 sums up the influence of different line parameters on the ELF-MF values (Cigre 2005b).

Phase Splitting

The basis of the phase splitting principle is to convert a single-phase two conductor circuit into a single phase four conductor circuit in order to create a quadrupole which is a low field configuration as the ELF-MF decays at $1/r^3$ rate.

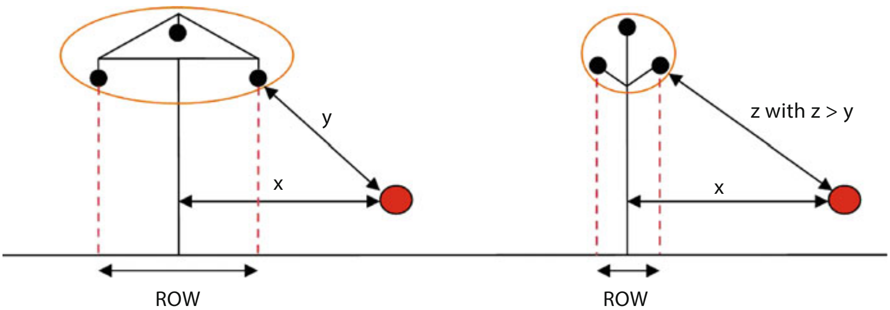

Figure 6.11 Compact line: MF-LF mitigation.

Table 6.4 Influence of line parameters on ELF-MF mitigation

	Increase of phase to phase distance	Increase of conductor height above ground	Increase of number of sub-conductors	Increase of sub-conductor spacing	Increase of total cross section
Influence on the ELF-MF	↗↗	↘↘	=	=	=

Concerning three-phase configurations, the splitting of phases aims at increasing the symmetry of the whole circuit, what can be done by splitting 2 phases or 3 phases (Cigre 2009): the resulting field will decay at $1/r^3$ rate rather than $1/r^2$.

Phase Cancellation

Phase cancellation is only applicable to multi-circuit configurations and is based on the same physical principles as phase splitting. Practically, it also applies the principle of increasing the symmetry of multi-circuit system. For double circuit' cases, phase arrangement of conductors influences the ELF-MF strength. It depends of the geometrical arrangement of the phase conductors in relation to the support (conductor configuration). The phase cancellation will be all the more efficient as the currents in the two circuits are balanced and flowing in the same way.

Compensation Methods

ELF-MF can be compensated using 2 technical methods:

- *Passive compensation:* this mitigation technique is related to Faraday-Lenz Law: "the induced electromotive force ε in any closed circuit is equal to the negative of the time rate of change of the magnetic flux through the circuit φ".

$$\varepsilon = -\frac{\mathrm{d}\varphi}{\mathrm{d}t}$$

Consequently when a coil or loop is placed close to an overhead transmission line and is subjected to ELF-MF, induced current flows in the coil and generates a magnetic field which compensates the original ELF-MF (Cigre 2009).

The efficiency of this solution will be influenced by several parameters including:

- Shape of the coil
- Location of the coil
- Electrical parameters of the coil
- Number of coils

- *Active compensation:* this mitigation technique uses an external power source in order to inject an appropriate current in the coil to optimize the field compensation. Current magnitude and phase has to be calculated according to the variation of ELF-MF in the space of interest due to the variation of current flowing into the conductors (Cigre 2009).

6.4.4 Assessment of the Exposure to Magnetic Field for Epidemiological Studies

For a given transmission line, magnetic field strength permanently varies over the time depending on the variation of the current flow. Human exposure to the magnetic field also depends on the time spent at a given distance from the line (Cigre 2007).

Table 6.5 Yearly current ratio proposition

Yearly current ratio (or field ratio)	Conservative	Very conservative
95%/rated	0.5	0.7
Mean/95%	0.5	0.7
Mean/rated	0.25	0.5

The dispersion of the magnetic field in a given set of values is assessed using standard deviation.

Other mathematical parameters may be used: the percentiles of the field values, I.E. the field value not exceeded during a given percentage of time. The median value is the 50th percentile. The 95th percentile of the field distribution is often considered as the annual maximum value during normal exploitation conditions.

Cigré (2007) has proposed values in order to assess the 95th percentile of the current distribution in the absence of any accurate information on this distribution, using a percentage of the rated value of the line (Table 6.5). The rated condition is defined as the maximum expected current load for a given transmission line taking into account regulations, several technical parameters, and territory constraints and are standardized at a national level.

6.4.4.1 Capacitive and Induced Effects

Electric field causes a displacement of electric charges in conductive objects such as vehicles, metal roofs or irrigation pipes and even in human bodies. The alternating field therefore generates an induced current inside the conductive objects, which magnitude is influenced by the shape and size of the exposed objects. The electric field inside the body is close to null due to the small potential difference generated by the induced current (a few μA) and the electric resistivity of human body (a few Ω/m). Consequently, whereas the external electric field generated by an overhead power line may be in kV/m range, the field induced in the body is much lower than 1 V/m. Corresponding induced currents are not detected by the person because they are several order of magnitude lower than the threshold of perception. Nevertheless, this induced current is sufficient to make a fluorescent tube glow.

When a person is exposed to an electric field and is in established contact with a conductive structure, several consequences may occur depending on their insulation from the ground (Cigre 1991).

Induced voltages are also a phenomenon related to electric fields. If a conductive object is not earthed, the electric field will induce a floating potential, which depends on the field magnitude and on the size of the object. During the transitory phase of establishing contact, when the distance between the object and the person is small enough and the voltage difference is sufficient, a small spark is generated. Once the contact is made, an induced (steady-state) current will flow as described previously.

As seen in 6.4.3, the magnetic field induces a 50 Hz current in conductive objects. The magnitude of the induced current is influenced by the magnetic field strength, the volume of the conductive object, and its impedance. Therefore the internal electric conductivity of the body is essential to determine the magnitude of the magnetically induced currents. Such currents inside the body cannot be felt by exposed persons and are well below electrical safety thresholds.

Concerning long metallic structures not well earthed, such as metallic fences or pipelines, which are built along transmission lines, an induced voltage is generated. If a person touches this conductive structure, an electrical loop (composed by the structure, the body and the ground) will be constituted. The induced voltage is proportional to the magnetic field magnitude and the size of the loop.

Usually the induced voltage level felt by a person touching the metallic structure remains low (a few volts), but this voltage level depends on how long the metallic structure is lying parallel to the line. This induction effect is a major electrical risk for electrical workers during maintenance tasks on parallel circuits. When contact is established, an induced current flows through the body, which might be dangerous during wet conditions, i.e. when the contact impedances are low.

6.4.4.2 Research on Biological and Alleged Health Effects

During more than 50 years of research on potential biological effects of electric and magnetic fields, the scientific community has published many collective expertise reports about the possible influence of a chronic low-level exposure to ELF-MF on human health. Although some epidemiological results have recurrently observed an association between exposure to ELF-MF and childhood leukaemia, it is widely recognized that the association with other illnesses (including solid adults and childhood cancers and adult leukaemia) is much weaker, if present at all. It is also recognized that, after more than 30 years of research on ELF-MF experimental studies have not evidenced any biological mechanism which would support the epidemiological observations.

Nevertheless, the research on potential biological effects of ELF-EMF is still progressing and international committees such as ICNIRP,[1] SCENIHR,[2] and national and international authorities, such as HPE[3] and WHO[4] regularly update their reports, advices, and health guidelines. The classification of ELF-MF as "possibly carcinogenic" with regard to childhood leukaemia was published by IARC[5] in 2001 and has not been challenged since then, which also means that no new study published since 2001 has changed this classification.

In contrast to the still unproven long term effects, acute effects of high electric and magnetic fields are well documented and scientifically established. Based on these known acute effects, international organization such as ICNIRP, IEEE[6] and international authorities such as the WHO have proposed exposure thresholds for

[1] *International Commission on Non Ionizing Radiation Protection*

[2] *Scientific Committee on Emerging and Newly Identified Health Risks (working for the European institutions)*

[3] *Health Protection England (formerly HPA)*

[4] *World Health Organization*

[5] *International Agency on Research on Cancer, affiliated to the WHO*

[6] *Institute of Electrical and Electronics Engineers*

protecting the public and the workers, which have been endorsed by national or international legislations, such as in Europe.

In 2010, ICNIRP has updated its Health Guidelines regarding low frequency fields (up to 100 kHz) and has raised the reference level for the public up to 200 μT for power frequency magnetic field, and up to 1000 μT for workers, which was adopted by the European directive for limiting the occupational exposure to EMF.

Reference levels are contrasted with the usual range of higher exposures in epidemiological studies, which are well below 1 μT. Although all scientific committees (and notably the WHO) agree on the fact that the epidemiological evidence is much too limited to be used as scientific basis for legislation, the issue is debated in a lively fashion with important media coverage. Under the media and social pressure, some countries have adopted precautionary approaches based on lower values than the ones scientifically recommended at international level.

6.4.5 DC-EF and Ion Current Phenomena

6.4.5.1 Electric Field and Ion Current for Direct Current

Issues of static Electric Fields (DC-EF) and Ion Current (IC) in relation to High Voltage Direct Current (HVDC) Overhead Transmission Line will be described in this section. This sub-chapter will describe physical phenomena, calculation methods, impacts on humans and natural environment.

ICNIRP has set a limit only for DC magnetic field (DC-MF) at 40,000 μT. As the DC-MF generated by HVDC is around 50 μT (approximately the same level as the earth's magnetic field), it is almost 1000 times lower than the ICNIRP limit. Consequently DC-MF won't be detailed in the following parts. DC-EF and ion current phenomena are described in Cigre (2011).

Unlike ELF-EMF, Direct Current Electric and Magnetic Fields (DC-EMF) are not varying quickly over time (but they may have quasi-static variations). As for overhead networks working at power frequency, DC overhead grid will produce Corona effect but the ions generated by Corona effect will have different evolutions:

- For a positive polarity conductor: negative ions will be attracted toward the conductor and are neutralized on contact. Positive ions will move away from the positive conductor which will then be seen as a positive ions source.
- For a negative polarity conductor: positive ions will be attracted toward the conductor and are neutralized on contact. Negative ions will move away from the negative polarity conductor, which will then be seen as a negative ions source.

Consequently, for a unipolar DC transmission line, the region (accordingly called "space charge region") between the line and the ground is filled with ions having the same polarity as that of the conductors. For a bipolar DC transmission line, 3 space charge regions are created: a positive region under the positive conductor, a negative region under the negative conductor and a bipolar region between the positive and negative conductors.

Three physical quantities are closely related to each other regarding the electrical environment of a HVDC transmission line.

- Electric field E
- Ion current density J
- Space charge density ρ.

6.4.5.2 Recommendation for DC-EF and Ion Current Density Mitigation

As with a HVAC line, a HVDC transmission line may be designed in order to mitigate DC-EF and ion current density. Table 6.6 sums up the influence of geometric and conductors' parameters on EF-DC and IC.

6.4.5.3 Research on Biological and Alleged Health Effects

Static Electric Field

Unlike AC fields, no currents and fields are induced inside the body.[7] Depending of its strength, the electric field can be sensed by the movement of hair. The average threshold of perception is 40 kV/m.

But when the ion current concentration is higher, the threshold of perception will be lower as the hair can get electrically charged by collecting air ions. The reported threshold of electric field detection is around 25 kV/m under an HVDC transmission line.

Psychophysical experiments have examined the behavioural and psychological response of humans and animals exposed to high static electric fields. No effect has been reported.[8]

Biological impacts on animals have also been studied: no damaging effect have been reported regarding experiments on rat and their offspring, longevity of mice or neurotransmitter activity of rats.

Table 6.6 Influence of line parameters on DC-EF and IC mitigation

	Increase of conductor height above ground	Increase of number of sub-conductors	Increase of bundle spacing	Increase of total cross section
Influence on the DC-EF (E)	↘↘	↘↘	↗	↘↘
Influence on the IC (J)	↘↘	↘↘	↗	↘↘

[7] *It is not formally true as when the body is moving in a static field, induction effects may also occur. Nevertheless, they can be neglected here considering the magnitude of the electric and magnetic fields generated by HVDC links, which remain in the same order as natural static fields*

[8] *It should also be noted that high static electric fields can occur naturally, notably under stormy clouds.*

Consequently, as no behavioural, biological and psychophysical impact have been reported regarding electric field experiments, and as the typical threshold of detection for humans is close to 25 kV/m, then most of guidelines have set recommended limiting exposure to EF-DC to 25 kV/m.[9]

Air Ions

HVDC transmission lines are sources of air ions and also generate ozone gas. A typical value of ions concentration under fair weather conditions under the line is around 20,000 ions/cm^3, which is lower than ions concentration in large towns (up to 80,000 ions/cm^3). Double blind experiments have been conducted in order to determine physical response to air ions concentration. Small symptoms have been reported such as headache, husky voice, sore throat and dizziness for subjects exposed to 32,000 positive ions/cm^3. However respiratory irritation symptom cannot be associated with ionic current exposure levels, even at 500,000 ions/cm^3.

Besides, no evidence has been reported concerning impacts of long term exposure to ions current (neither positive nor negative) on asthma or hay fever.

In order to determine if an agent is the source of an increased risk of human cancer, IARC has convened task groups composed of expert scientists to review the published studies. The task group regarding impacts of DC-EF exposure concluded there is no evidence of carcinogenicity in humans and classified DC-EF as a potential carcinogenic agent.

6.4.6 Corona

6.4.6.1 Physical Phenomenon

Corona is an electric phenomenon related to high voltage Overhead Lines which may have different impacts on the environment considering characteristics of the line and weather conditions. The main ones are: audible noise, interferences at high frequency and atmospheric chemistry.

Corona is associated with the electric field level on conductors' surface. When this field exceeds the critical surface voltage gradient E_c of a cylindrical conductor, Corona occurs depending on weather conditions. E_c is calculated using the Peek's formula which is valid for smooth surfaces and cylindrical object.

In practice, the onset gradient is lower than E_c. Indeed, conductors are made of strands, and the irregularities on surface due to the manufacturing and the stringing of the conductors, induce a local increase of the electric field on surface. Weather is also a significant parameter, especially during rainy, foggy or dew conditions. Drops of water increase irregularities on the surface of the conductor. All this parameters produce a strong local increase of the electric field.

A surface state coefficient m ($m < 1$) can be defined on the basis of experiments to take into account these parameters. Consequently, for real conductors, Corona

[9] *Advisory Group on Non-ionising Radiation (AGNIR) "Particle deposition in the vicinity of power lines and possible effects on health". NRPB, 2004*

phenomenon occurs when the electric field on conductor surface E exceeds the critical surface voltage gradient E_c weighted by the surface state coefficient m:

$$E > m\ E_c$$

The physical manifestations of Corona are (Cigre 1974):

- Corona discharges in the air surrounding conductors' surface and fittings
- Discharges and sparking in stressed areas of insulators
- Sparking caused by imperfect contacts.

6.4.6.2 Corona Noise

Source of Corona Noise

Corona noise may be usually generated by overhead lines exceeding 220 kV (Cigre 1991). As seen in 6.4.6.1, the onset of Corona and its intensity are greatly influenced by the weather conditions. Therefore, audible noise level is higher during rainy or foggy conditions but not necessarily more perceptible due to the background noise of the rain. Mostly during fair weather period, noise is generated by any kind of pollution deposited on the cable or insulators (grease, insects, corrosion…).

The spectral analysis of the Corona noise shows there are several components (CISPR/TR 18-1 ed2.0 IEC 2010):

- A low frequency hum close to power frequencies
- A high frequency buzzing or crackling.

Humming is discrete tones occurring at multiples of the power frequency and is dominant at twice of this frequency (the noise is generated for each maximum and minimum value of the AC voltage).

Crackling is a broadband noise, characteristic of the Corona phenomenon, due to the significant energy contained in the mid and high frequency (f > 500 Hz), contrary to the environment noises where the main energy is contained in the low frequencies (Cigre 1991).

Measurement of Noise

The human ear spectrum is defined as the range of frequencies that can be heard by humans or animals. In average this spectrum is from 20 Hz to 20 kHz for humans, but may vary significantly from one person to another. Infrasound is a sound pressure wave oscillating at lower frequency than 20 Hz and ultrasound is a sound pressure wave oscillating at higher frequencies than 20 kHz.

Frequencies contained in the hearing range are sensed differently by the human ear. Indeed its sensitivity depends of the magnitude and the frequency of the sound pressure wave. The human ear is a highly sensitive receiver which can detect a large range of magnitudes. Therefore the sound pressure is expressed in decibels (dB) which is a logarithmic scale. To take into account the frequency characteristics of the ear, a noise is usually measured by A-weighted noise measurement devices.

Frequency A-weighting is defined by the international standard IEC 61672-1[10] which also defined sound level meters specifications. Thus, the noise is expressed in dBA. The threshold of hearing is 0 dBA and the threshold of pain is around 120 dBA.

Due to variations of noise in everyday life (nature, cars, industries, construction works…), the duration of measurement is crucial to assess the noise incidence. Several times the average levels of the fluctuating noise over the measurement period can be defined. The main one is called "Equivalent Sound Level" or L_{EQ}, expressed in dBA and is used by most regulations. Other means can be defined as L_{50} which is the equivalent sound pressure exceeded during 50 % of the time measurement.

Calculation of Audible Noise Levels

Several research centers studied Corona noise calculation and proposed empirical formulas during heavy rain conditions and for a single phase conductor. All the formula used the same variables such as the value of the electric field on conductor surface, the number and the diameter of sub-conductors. In order to assess the audible noise generated by a three-phase circuit, these formulas have to be applied for each conductor. Then the resultant sound pressure generated by the circuit is the logarithmic addition of the three sound pressures and is expressed in dBA. For a linear noise source, the sound attenuation is proportional to the logarithm of the distance to the source. Consequently, when the distance between the source and the measurement spot is doubled then the sound pressure decreases by approximately 3 dB. In practice the attenuation is influenced by many environmental parameters such as the nature of ground, vegetation, buildings (Cigre 1999).

Recommendations for Corona Noise Mitigation

Audible noise has to be studied when designing a new transmission line or upgrading the line voltage, especially for lines of voltage 220 kV or more. The voltage level of the line is the first parameter which has a direct impact on the Corona activity. As seen in Calculation of Audible Noise Levels above, increasing the distance between the noise source and the measurement point reduces the noise perception. Increasing the height of conductors does not have a strong impact on the noise mitigation. There are different ways to reduce Corona activity. Conductors' parameters have a significant influence on the Corona noise: increasing the number of sub-conductors or increasing conductor diameter has a significant influence on the Corona noise mitigation. Contrary to magnetic field mitigation (see 6.4.3) compact lines have a negative impact on the Corona activity and consequently on the noise generated by the line.

Table 6.7 sums up the influence of different line parameters on the Corona noise values (Cigre 2005b).

As explained in 6.4.9 (Physical Phenomena) above, pollution may be a significant parameter on the Corona activity. Several noise measurements highlighted that there may be higher noises close to towers, especially near angle towers compared to noise measurement at mid-span. The explanation is that the pollution on insulators and fittings increases the Corona activity, inducing local discharges. Consequently,

[10] *"Electroacoustics - Sound level meters - Part 1: Specifications" IEC, 2013*

Table 6.7 Influence of line parameters on audible noise mitigation

	Increase of phase to phase distance	Increase of conductor height above ground	Increase of number of sub-conductors	Increase of sub-conductor spacing	Increase of total cross section
Influence on audible noise	↘↘	↘	↘↘	↗	↘

washing fittings, insulators and conductors are an easy way to mitigate Corona noise on existing lines in a polluted environment. Suitably designed fittings should be used.

6.4.7 Radio and Television Interferences

6.4.7.1 Active Interferences

Radio and television interference, expressed in decibel (dB), generated by power lines, are not considered as an important environmental issue. However, in some case, interferences have to be studied regarding installations using frequency systems which are implanted in the vicinity of the line.

Transmission lines may cause radio interferences because of Corona, discharges and sparking at highly stressed area of insulators and sparking at imperfect contacts. These phenomena produce different shapes, amplitudes and repetition rates of current pulses generated by the ionisation of the air surrounding the conductors, and have different impacts on the radio interferences (Cigre 1991). The latter are characterized by:

- Frequency spectra
- Modes of propagation (along the wires or directly radiated)
- Statistical variations (depending on weather conditions).

Interferences produced by Corona are characterized by frequency range from 0.15 MHz to a few MHz. Most of the time, TV frequencies are not perturbed. These disturbances are mainly guided along the line and are attenuated according to the line configuration and the properties of the ground. Indeed, the electromagnetic radiation generated by current pulses does not contribute directly to the noise level. However the magnetic and electric fields associated with the spectral components of currents, propagate along the wires. The noise level is determined by the aggregation effect of the fields generated by the discharges along the line.

Polluted or wet insulators may produce interferences up to some tens of MHz and may have an impact on the bands of television broadcasting. Disturbances are directly radiated. The only efficient way to reduce this phenomenon is to wash insulators periodically.

Sparking at imperfect contacts may be a local source of frequency perturbations, but water may have a positive effect on bad contacts which can become bridged and as a consequence, the noise interferences are reduced.

The annoyance of radio and TV perturbations are determined by the "signal to noise ratio" at the receiving installation (Cigre 1974). Cigré proposed a scale in order to quantify the quality of reception perturbed by Corona disturbances and discharges on insulators (see Table 6.8).

The variation of the noise field according to the distance to the axis of the line is a decreasing function depending of the studied frequency and the configuration of the line (see Figure 6.12). The noise also decreases according to the distance to the line, but the decreasing rate depends of the line configuration (see Figure 6.13). This figure has been traced by taking a distance of 15 m as reference, horizontally from the point directly below the conductor. These figures have been established considering 500 kHz as the reference frequency (Cigre 1974).

Table 6.8 Quality of the signal according to the signal-to-noise ratio

Signal-to-noise ratio	Quality of reception – Subjective impression
30	Inaudible interference
24	Perception of interference
18	Audible interference
12	Bad quality for music, but speech is intelligible
6	Speech understandable with concentration
0	Speech unintelligible

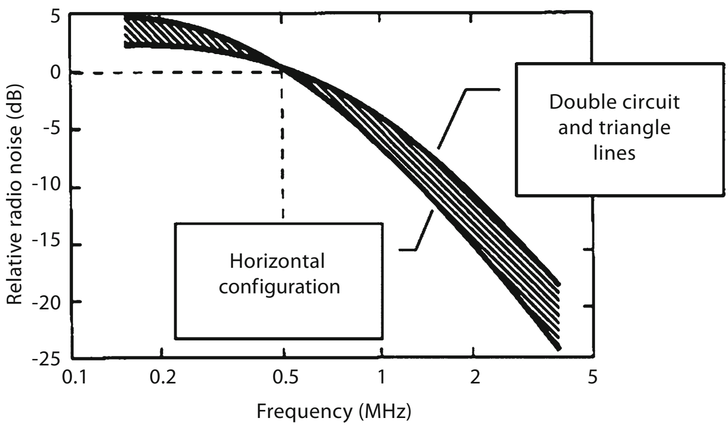

Figure 6.12 Noise level (dB) according to the frequency (MHz), depending of the line configuration.

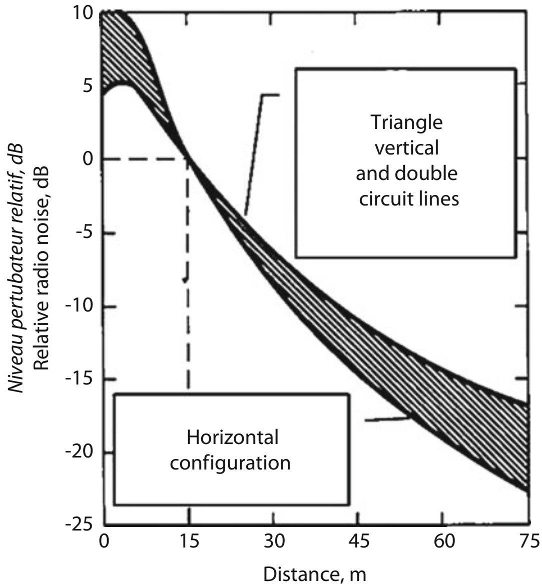

Figure 6.13 Noise level (dB) according to the distance to the line, depending of the line configuration.

Table 6.9 Influence of line parameters on radio interferences mitigation

	Increase of phase to phase distance	Increase of conductor height above ground	Increase of number of sub-conductors	Increase of sub-conductor spacing	Increase of total cross section
Influence on radio interference	↘	↘	↘↘	↗	↘

CISPR[11] is the international committee specialized in radio frequency interference and is part of the IEC.[12] This committee has been founded to define standards to limit frequency perturbations. The standard CISPR/TR 18-1 (2010) gives more information on the radio noise generated by the AC power lines in frequency ranges from 0.15 MHz to 30 MHz (AM broadcasting) and from 30 MHz to 300 MHz (FM and TV broadcasting). Radio interferences over 300 MHz generated by the line are not significant enough to be taken into account.

Table 6.9 sums up the influence of different line parameters on the radio interferences (Cigre 2005b), the results are very similar to the ones in Table 6.7, for the audible noise.

[11] *International special committee on radio interference*

[12] *International Electrotechnical Commission*

6.4.7.2 Passive Interferences

The interferences discussed above are directly produced by the power line so they are described as active interferences. In this case, lines may be seen as sources of disturbances. However transmission lines (such as large structures such as buildings, towers…) may be source of passive interference by reflecting and reradiating broadcast radio signals. When the tower is close to a broadcasting system, it may act as a secondary antenna, modifying the radiation characteristics of the broadcasting station (Cigre 1991). This problem can be solved by changing the position of the source or by improving the signal.

6.4.8 Atmospheric Chemistry (Ions and Ozone)

Corona discharges generate chemical reactions in the air surrounding the conductors. Ions and ozone are the main chemical components related with the Corona activity.

6.4.8.1 Ions

Ions are electrically charged atoms or molecules. It may be a positive ion (formed by the removal of electron(s)) or a negative ion (formed by the gain of electron(s)). Ions are naturally present in the air, formed by phenomena such as natural radioactivity, cosmic rays or thunderstorms or human activity such as exhaust gas emissions. The usual concentration of ions in the air varies between 100 and 2,000 ions/cm^3.

Table 6.10 shows typical air ion concentrations (Cigre 2011).

In the case of alternative power lines, the amount of ions generated by Corona discharges is relatively low. Indeed the electric field generated at the conductors' surface has an influence on ions movements. Due to the alternative shape of the field, ions will be continually attracted and repelled in the air surrounding the conductors. Moreover ions may collide with ions of the opposite polarity and are mutually neutralized. Consequently ions generated by AC power lines at ground level are much lower than natural ion concentration in the air (Cigre 1991).

Ions generated by DC transmission lines can reach a few tens of thousands of ions per cm^3: around 20,000 ions/cm^3 under the line at ground level (see 6.5.4.3).

6.4.8.2 Ozone

Ozone (or trioxygen) is a natural triatomic molecule constituted by 3 oxygen atoms (0_3). The human activity has a significant influence on the ozone concentration in the air: in a natural environment ozone concentration is around 50 ppb (50 ozone

Table 6.10 Typical ion concentration according different locations

Location	Air ion concentration (ions/cm3)
Fair weather open space	70 - 2000
In a large town	Up to 80000
30 cm above a burning match	200000 – 300000
1.5 m downwind of vehicle exhaust	50000

Table 6.11 Production of Ozone and Chemical Reactions on French Grid (400 kV)

Production (kg/h)	French 400 kV grid (21,000 km)	Global production in France (Natural and anthropogenic)
Ozone 0_3	72.7	13.6 10^6
Nitrogen dioxide NO_2	1.9	1.8 10^5
Hydrogen peroxide H_2O_2	0.24	5.3 10^4

molecules for 1 billion of air molecules) and may exceed a few hundred ppb in large town during a few hours. Corona discharges generate ozone in the vicinity of the conductors. Then ozone immediately reacts with other components in the air such as nitrogen oxides and hydrocarbons.

Mathematical models have been developed to assess ozone formed by Corona discharges taking into account multiple factors including atmospheric conditions, wind or ozone decay rate. These models conclude that most transmission lines around 345 kV do not generate detectable ozone levels. An alteration of the natural ozone concentration has been evaluated for lines exceeding 765 kV during adverse conditions (heavy rain, light wind and at a few meters from the conductors) (Cigre 1991). Calculations applied on the French EHV grid (400 kV) have estimated the production of ozone and its chemical reactions as given below in Table 6.11 (Cigre 1999).

These results show the global French EHV grid is negligible on a national scale. Measuring ozone directly under the line at ground level is difficult due to the variations of the background level of ozone in the environment which are far higher than the amount of ozone generated by Corona discharges.

6.4.9 Aeolian Noise

Aeolian noise is very uncommon phenomenon produced by overhead lines under very particular wind conditions. This phenomenon is independent of the voltage level or the current flowing into the line. Aeolian noise is the result of the wind blowing over conductors, insulators, through lattice towers or hollow fittings and depends of the speed and the direction of the wind.

The noise generated by wind on the conductors results from the shedding of air vortices. When the wind speed exceeds 10 m/s and if the wind is unfavourably oriented, this may cause a rumbling noise reaching a few tens of dBA (Cigre 1999). This noise can be mitigated by wrapping a wire along the cable in order to modify the shedding of air vortices or the use of specially shaped conductors.

Under well-defined conditions, the wind blowing over insulators can produce a high intensity pure tone noise of a few hundred of hertz. The reduction of this noise can be achieved by fitting rubber bushes within the insulators strings or by replacing some insulators with new ones with particular shapes.

6.4.10 Conclusions/Guidelines

- After more than 50 years of research on the subject of possible health impacts of ELF-EMFs, the scientific community could not provide any solid evidence about any health hazard on living organisms associated with a prolonged exposure to ELF-EMFs at a lower level than the international recommendations.
- However the ELF-EMF issue is a key one in the debate on new overhead line projects. It is recommended to continue to monitor EMF developments closely and to submit good quality information to the public, local authorities and utilities' own personnel.
- In contrast to the still unproven long term effects, acute effects of high electric and magnetic fields are well documented and scientifically established. Based on these, international organizations and authorities such have proposed exposure thresholds for protecting the public and the workers, which have been endorsed by national or international legislations, such as in Europe.
- Electric fields generated by an overhead transmission line can be reduced by modifying geometric or conductors' parameters. Magnetic field generated by an Overhead Transmission Line can be mainly reduced using compensation methods or modifying geometric parameters
- Overhead Line designs have been developed which lead to reduced magnetic fields. Some of these designs have been implemented. Their feasibility and costs have to be studied with respect to the issues involved in the area of magnetic fields
- The capacitive and induced effects of Overhead Lines are well known and adequate mitigation measures exist to deal with them.
- Audible noise aspects must be taken fully into account when designing new overhead transmission lines. The fact that this is the case does not always mean that they are of minor importance in regard to impacts and particular solutions must be sought. Effective design mitigation measures exist such as increasing the diameter of conductors and the number of sub-conductors.
- In the case of aeolian noise where conductor aeolian noise problems have arisen new techniques have been developed which reduce the audible noise level down to a low level compared to ambient noise levels. Insulator aeolian noise problems can usually be solved.
- Measures required to minimise radio and television interference are the same as for the reduction of audible noise. Difficulties from "passive" interference can generally be alleviated by improving the receiving aerial or its position.
- In the case of alternating currents there is no measurable ion density differential compared to the earth's natural ion density. In the case of direct current lines while ion density increases at ground level substantial research has not indicated any health effects.
- The increase of the ozone concentration in the vicinity of power lines is negligible.

6.5 Concerns and Issues, Consultation Models for OHL Projects and Stakeholder Engagement Strategies

6.5.1 Introduction

The survey carried out by 22WG14 revealed thirteen concerns and issues facing utilities for new lines and existing lines (both for upgrading and refurbishment and for operation and maintenance) and these were tabulated in Chapter 3 of Cigré TB 147 (1999). The top five were EMF Health Concerns, Visual Impact, Landowner Negotiations and Access, Community Opposition and Property Values. These would seem to be as valid today as then. Guidelines are given below in 6.5.2.

The work of SC22.15 produced TB 274 *Consultations Models for Overhead Line Projects* (June 2001) (Cigre 2005a). This is summarised and guidelines given in 6.5.3. The WGC3.04 dealt with similar issues in a somewhat broader context and Cigré TB 548 *Stakeholder Engagement Strategies in Sustainable Development – Electricity Industry Overview* (Cigre 2013) was produced by them. A summary and Guidelines are given in 6.5.4. These reflect and reinforce those of Cigré TB 274.

6.5.2 Concerns and Issues Facing Utilities -Guidelines

- Planning and environmental issues associated with both new projects and existing assets are major business issues for electricity utilities. As such they need to be given a suitably high priority so that, like all business risks, they are managed effectively. Environmental issues are increasingly important for companies and the communities they operate in. Visual amenity and EMF head the list of public concerns
- Good, appropriate communication is an inherent part of successful management of the issues. Each utility must decide what is most appropriate to suit its circumstances but the general guideline would be to ensure that active consideration is given to strategies required to meet business success and expectations of the public.
- Good practice in different forms and means exists worldwide. Examples are communication programmes or centres aimed at explaining the use of electricity and the environmental effects of overhead lines. It is up to utilities to benefit from others' experience.
- The fostering of good relations with landowners and occupiers affected by proposed overhead lines and with those on whose lands existing networks are in place is essential.
- Codes of Practice or Landowners/Occupiers Charters should be put in place to comprehensively cover all aspects of utility dealings with landowners. These should include access, construction and maintenance issues and also possible future changes in land use.

- These Codes or Charters should deal with the standards to be maintained in communication, consultation and workmanship as well as in personal contact.
- Early communication is vital to inform landowners of all aspects of the project including financial compensation methods and to optimise the route and location of towers on their property. The necessary resources should be dedicated to maintaining good communication throughout any construction or refurbishment project and to ensuring that general and individual agreements are honoured. (See Sections 6.5.4 and 6.5.5).

6.5.3 Consultation Models for OHL Projects

6.5.3.1 Introduction

In drawing up proposals for new overhead transmission lines, undertaking environmental impact assessment (EIA) and seeking rights, permits and consents to construct, transmission companies are increasingly, whether legally required or voluntarily, undertaking more stakeholder consultation. Community involvement can be key to the success of often controversial new transmission infrastructure proposals, requiring the use of innovative and "best practice" approaches. Public Hearings are a key feature of most processes, see Figure 6.14 A Public hearing.

It was hoped that Cigré TB 274 (2005a) would provide a useful reference for Cigré members and those working in electrical power systems, providing an overview of best practice approaches to consultation for overhead line projects and possibilities for improvement in this challenging area.

Figure 6.14 A Public Hearing.

Working Group B2.15 set about examining “best practice” consultation approaches in 2001, with an international survey of member countries. Responses were gathered to a series of questions relating to the type and nature of consultations undertaken, the extent of legislative requirements, timescales, key ingredients for success and whether consultation was undertaken in the ongoing management of transmission line assets. Further questions relating to the impact of market restructuring, society expectations and the use of new and emerging technologies were added in 2002. It was then decided that the results warranted production of a Cigré TB, which could usefully also include a number of “best practice” case study examples from around the world.

In addition to explaining the particular consultation approaches adopted in the case study examples briefly described below, Cigré TB 274 includes the full findings of the international survey and captures overall key ingredients for success.

6.5.3.2 Case Study 1: Austria

This first case study concerned a proposal for a new 95 km 380 kV double-circuit, lattice steel overhead line through predominantly rural parts of Austria, the planning of which started in the 1980s. Significant opposition was encountered from the public, politicians, community groups and local government.

Whilst there is no legislative requirement to undertake consultation (the permitting authority decides whether to consult on consent applications), Verbund Austrian Power Grid went to considerable lengths to engage with a wide range of stakeholders and adopted a range of approaches in the process, with considerable success.

6.5.3.3 Case Study 2: Canada

The second case study explained the consultation approaches taken when, in 1998, Hydro- Québec announced the construction of a new 140 km 735 kV overhead line, urgently needed to secure supplies to households left without power following a major ice storm. Special decrees were adopted by Government to amend certain laws and exempt the Company from others, including bypassing the normal public inquiry process for the initial 100 km section of the route, to be substituted instead by an information and consultation committee established by the Government.

Intense opposition, lobbying and legal challenge from well organised residents closest to the first section of line route ultimately resulted in a successful legal challenge to the Government decrees and normal regulations were subsequently reinstated for the remaining 40 kilometre section of overhead line. The Company therefore had to repeat the entire consultation process in 1999.

6.5.3.4 Case Study 3: Japan

The third case study explained the consultation approaches adopted by Tohuku Electric Power Co., Inc for a new 84 km 275 kV double-circuit overhead line to connect a coastal nuclear power plant with an inland switching station in Japan. Consultations started in the early 1990’s and construction, which took 2½ years, commenced in 1998. See Figure 6.15 Basic Route Selection Work (Japan).

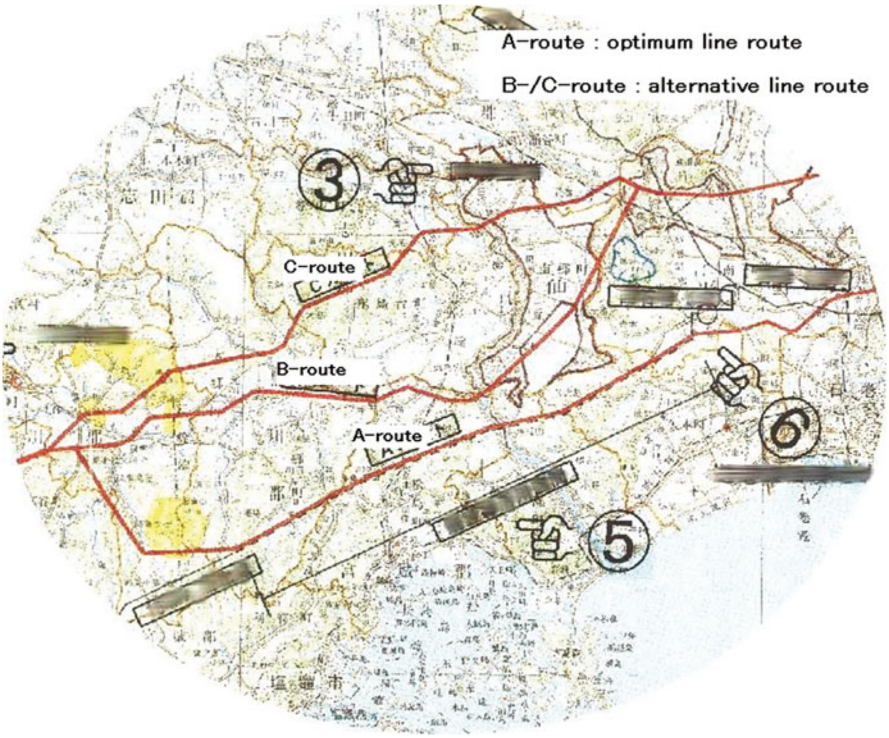

Figure 6.15 Basic Route Selection Work (Japan).

The new line passed quite close to urban areas and scenic spots such as a quasi-national park and a prefectural natural park. Nesting places of endangered bird species, Golden Eagles and Hodgson's Hawk Eagles, were discovered following ecological survey along the planned route corridor.

Line routing difficulties and risk of delays due to opposition on EMF, visual impact and/or nature conservation grounds were at the fore of the Company's concerns as they set about the planning of the project and undertaking consultation.

6.5.3.5 Case Study 4: UK

The fourth case study outlined the very effective use made by National Grid Transco of interactive virtual reality computer modelling when undertaking consultation in 2000 about options for a new sealing end compound. This formed part of a much larger and very contentious overhead line project in the north of England, the planning of which had started in 1990 and two major public inquiries had sat during the early-mid 1990s. The affected local planning authorities had always maintained their objections to the new line and the task of consulting on options for a sealing end compound was set about amidst considerable public opposition.

6.5.3.6 Case Study 5: South Africa

In explaining the approaches adopted by Eskom in South Africa, the fifth case study considered the consultation models that can effectively and usefully applied during the environmental impact assessment process, taking account of the particular legal system and the interests, concerns and culture of the various groups that are consulted. The case was made to explain why the development of a comprehensive public participation model should take due regard of the need for a sound public participation process, fair compensation and the final recourse to rights of expropriation by the transmission company.

6.5.3.7 Consultation Requirements Associated with Project Financing

Before outlining the findings of the international survey questions and drawing conclusions on the key ingredients for success in "best practice" consultation approaches, Cigré TB 274 gives examples and practical advice about instances where consultation can form an essential mandatory requirement when seeking project funding assistance financial institutions. By way of example, an overview of the consultation requirements of the European Bank for Reconstruction and Development associated with an electrical interconnector project between Romania and Hungary is provided, highlighting the need to plan for and fully comply with such requirements when seeking project funding assistance around the world.

6.5.3.8 Conclusions/Guidelines

The main findings of the Working Group, explained more fully in Cigré TB 274, were as follows:

- Most companies undertake much more consultation than legislation requires. Mandatory consultation requirements often only exist in environmental assessment legislation. Whilst consultation takes time, it helps identify likely concerns and possible points of objections; helps refine proposals, address concerns and smooth the eventual permitting process.
- Companies should establish a consistent approach to mapping stakeholders and understanding their viewpoints, needs and expectations.
- Use of independent specialists when considering options, preparing consultation information and assisting at advisory meetings, increases the credibility of the information presented and helps secure understanding and co-operation from stakeholders.
- Present as much information as possible, trying to get the balance right and tailoring information to suit the audience. Communicate via the best methods available (e.g. Company web-site, detailed publications or brochures, periodic newsletters, advertorials in local newspapers, etc).
- Conduct open and engaging consultation with a broad range of representative and interested groups. Different forms of consultation may be appropriate with

different bodies at different stages in the planning process. Initial consultations typically involve the permitting authorities. Public consultation frequently follows at least some initial EIA work to identify route options. Include governmental, non-governmental, permitting authorities, special interest environmental organisations, community, landowners and the public.

- Too often companies will wait until opposition organises and issues negative statements on the project. Early in the project it important that communities know how the project will benefit them in terms of increasing the reliability of the electrical network, in monetary compensation schemes and in job creation.
- Companies have to be pro-active in dealing with opposition and must give immediate information on issues related to EMF/Health, visual impact mitigation and nature conservation management.
- Provide full information about alternatives (e.g. routing, tower designs, rationalisation/removal of lower voltage lines etc) and where appropriate, allow some choices by stakeholders. Whilst consultation may provide some opportunity to influence decision-making, for example in route selection, this may not apply to all aspects of a project, such as undergrounding. In some senses, therefore, it is also about informing.
- Start consultations as early as possible. Consider engaging the public and other stakeholders in the scoping of the project EIA, consideration of the need for the line, transmission alternatives, the identification of route corridor options and ranking of route selection criteria. Thereafter, maintain engagement and feedback with stakeholders, openly sharing findings of option studies, environmental and social impact assessment studies.
- Consider opportunities to involve representatives of the permitting bodies as observers – can help reduce time subsequently taken to determine consent applications and gives the permitting body the opportunity to suggest adjustments to the communication strategy.
- Consider use of new and emerging computer based technologies that may assist the environmental impact assessment and consultation processes (e.g. virtual reality modelling). See Figure 6.16 Virtual Reality Model - Sealing End Compound (UK).
- Where seeking project finance assistance from funding institutions, check specific consultation requirements. Useful advice can be found in an IFC publication "Doing Better Business Through Effective Public Consultation and Disclosure" – A Good Practice Manual' (1998).
- Use "best practice" mitigation measures to minimize temporary construction and permanent environmental impacts. The costs of such measures often represent a very small percentage of overall project cost and assist enormously in securing community support.
- Specify environmental requirements in construction contracts and include penalties for non-compliance. Plan communication requirements during the construction phase of a project. Keeping the affected community and wider interests informed of the planned works and developing mechanisms for doing so throughout the construction phase can contribute enormously to the successful delivery of a new overhead line project.

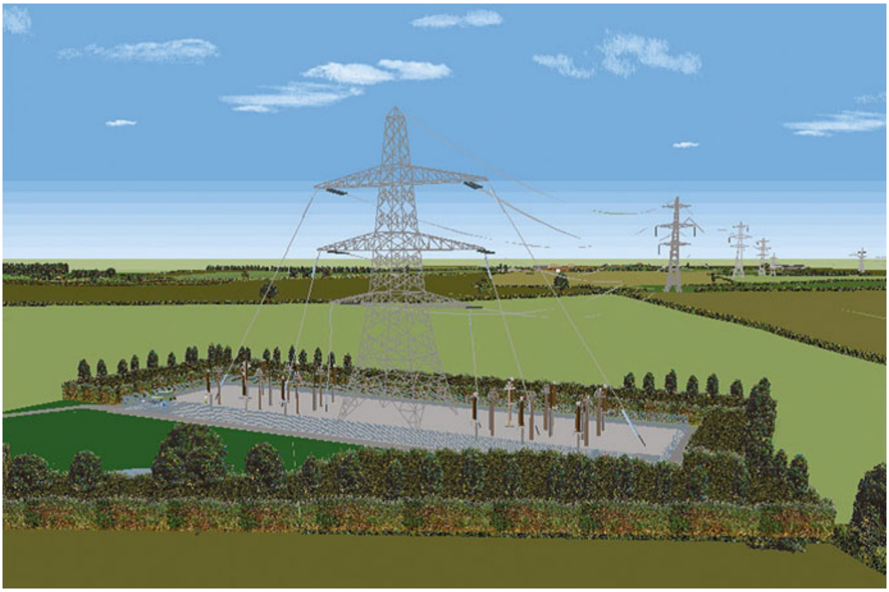

Figure 6.16 Virtual Reality Model - Sealing End Compound Option (UK).

- Approaches to publishing the results of consultation were found to vary. Consider outlining the results of consultations in environmental impact assessment reports explaining how it has influenced routing decisions or modifications to proposals.
- Where electricity markets have been opened up, lead times for projects may be shorter, requiring approaches that allow for more intense, albeit greater, public consultations. Opening up of markets can lead to less willingness to accept transmission proposals as being "in the public interest".
- Most companies are facing increasing expectations within society for greater and earlier consultations to be undertaken, particularly with regard to new construction and replacement or diversions of existing overhead lines.
- Most companies use photomontages to provide clearly understandable visualisations, together with web-sites to provide information about projects.

6.5.4 Stakeholder Engagement Strategies

6.5.4.1 Introduction

The results of a survey of electricity organisations, and other recent experience, present an encouraging picture about stakeholder engagement in the sector. Electricity organisations worldwide were surveyed on their attitudes to, and experiences of stakeholder engagement, particularly in relation to the development of electricity construction projects, within the context of sustainable development.

The past few decades have seen large organisations respond more proactively to environmental issues, and increasingly now to societal pressures – two of the three legs of sustainable development (the other being, economic or financial). There has been a growing voice within communities to be heard and to seek to influence government or organisational decisions which affect them.

This pressure has been evident too within the electricity sector, particularly where electricity organisations are seeking to expand or change their networks or build new infrastructure. There is increasingly less acceptance by populations and communities that the electricity sector is acting completely in the public interest and therefore that their proposals should go non-scrutinised or unchallenged. This is especially true where organisations are no longer state owned.

Electricity organisations have been responding to this challenge by being more open and transparent in how they relate to the public. The traditional relationship has been one of "producer and consumer"; increasingly it is becoming additionally one of "organisation and stakeholder".

The relationship between organisation and stakeholder is primarily driven by legal and regulatory obligations, however the results of the survey show that the level of voluntary stakeholder engagement is increasing, which has the potential to unlock value and increase organisational performance as well as increasing public acceptance and enhancing reputation as socially responsible, trustworthy organisations.

6.5.4.2 Survey Findings

The survey found that stakeholder engagement policies are less common than environmental policies in electricity organisations. Environmental studies and detailed design are considered the most important stages of the project life cycle in which to undertake stakeholder consultation.

Legal obligations, reputation, values and ethical issues are the main drivers for stakeholder consultation and engagement. While formal environmental statements, major projects and legal requirements are key prompts for stakeholder consultation, policy development is not.

It is not surprising that legal requirements are the main motivation to undertake stakeholder consultation, but many companies choose to carry out consultation significantly beyond the minimum level required in order to improve relationships with stakeholders and gain public acceptance. Although many stakeholders are consulted or involved on a voluntary basis by most companies, there is no global common practice evident in identifying stakeholders. There was no single existing standard strategy amongst electricity organisations relating to stakeholder engagement.

A number of methods to engage stakeholders are used such as local meetings, newspapers and website links. Individual face-to-face meetings and community meetings are viewed as the most effective consultation method, followed by the use of websites. Most organisations report back to stakeholders on consultation results voluntarily See Figure 6.17 Stakeholder Consultation Session.

This provides clarity and transparency to stakeholders and gives organisations a greater insight into stakeholders "key concerns". Some electricity organisations monitor the outcomes of stakeholder engagement and communicate these internally to improve business process.

Figure 6.17 Stakeholder Consultation Session.

Electricity organisations believe that stakeholders are most concerned about nature conservation, visual impact and EMF/health issues.

A wide range of methods of engagement and stakeholder groups result in the need for a tailored, targeted approach to stakeholder engagement which should be influenced by the nature of the project, the stage of the project lifecycle, stakeholder groups and organisational constraints. Examples of good practice can also be found in the Case Studies in the Cigré TB 274.

The survey does not claim to be representational. The respondents to the survey may be those organisations which embrace engagement rather than those which have yet to see the benefits. Without further work, there is no way of establishing how representative the findings of the survey are.

6.5.4.3 Conclusions

Electricity organisations are increasingly recognising the benefit of stakeholder engagement, not only because of their commitments to sustainable development, but for the benefit of electricity infrastructure projects themselves, and for all the benefits of building relationships with key environmental and citizen organisations. Companies have indicated that they are prepared to learn from their stakeholder consultation and engagement exercises, and use the results to build best practice and improve processes within their organisations. The case studies show the wide variety of stakeholder engagement which is taking place for electricity projects.

Stakeholder consultation may be backed by legislation in many countries, but it is clear that many companies go considerably beyond the minimum, recognising the benefits of engagement. Even so, there remains a perception amongst some to consider the process as a regulatory obligation with which they must comply, rather than an essential component of the planning and delivery of a scheme. If consultation activities are driven principally by legal or regulatory requirements, there is a risk that organisations will not fully recognise stakeholder or customer drivers in their businesses, and not optimally respond to the needs of the societies they serve.

Many companies clearly recognise the business and reputational risks that come from poor stakeholder relations, and place a growing emphasis on social responsibility and transparency and reporting. In this context, good stakeholder relations are a prerequisite for good risk management. There is increasing emphasis within the electricity industry on good stakeholder engagement through creating transparency in key activities and ensuring the promotion of social responsibility.

However, it is clear that there is little common methodology in consultation or engagement across the sector. Electricity companies are more likely to develop their own processes, than look to the experience of others in the sector. Similarly, they are much more inclined to use engagement in the development of projects rather than in the development of policy or programmes.

The Working Group recognises the value of the use of stakeholder engagement strategies for electricity infrastructure projects within the context of sustainable development. Good engagement facilitates the sustainability of decisions made about projects, ensures social issues are considered as well as environmental ones, ensures that electricity organisations understand and consider the wider implications of their project decisions, and helps to ensure that trust with stakeholders is developed. Good engagement has the characteristics of being timely and transparent, so that stakeholders can influence the project decisions.

Critically, organisations must not see stakeholder engagement as a form of justification for projects by attempting to disguise "selling" tactics as "asking" or consulting. Therefore, meaningful early engagement and integration of stakeholders issues into project design from the beginning of the decision making process is key to ensuring that issues are tackled from the outset of a proposal, and acceptance of the project by stakeholders afterwards. Considerable amounts of time and resources are involved with setting up and running the process of stakeholder engagement through the project lifecycle.

Interestingly, time was found to be the key constraint for electricity organisations, ranking ahead of resources or finance. This infers that project programmes are considered to be very important. It therefore becomes more critical that consultation and engagement strategies are worked up as early as possible, and designed to produce effective outcomes. Early and good engagement can actually help project programmes.

Whilst a flexible approach to stakeholder engagement is beneficial, there is a global need for a standard set of principles for communication, consultation and engagement.

6.5.4.4 Key Principles/Guidelines for Stakeholder Engagement

The Working Group produced a set of 8 key principles for stakeholder engagement in the electricity sector, and believes that these key principles provide valuable guidelines for electricity companies when developing and implementing stakeholder engagement strategies.

Approach to Stakeholder Engagement

The approach to stakeholder engagement should be fundamentally consistent for all of a company's construction projects. This approach could be flexible, varying according to the scale and type of the project, but should still be consistent.

Consistency should occur across stakeholder groups and localities. The aim must be to establish trust among stakeholders.

Project Scoping (Proportional Approach)

The value from engagement should be optimised by scoping the requirements for the project. Be clear about the real constraints of the project – what engagement and communication can assist with, and what is out of scope. Be aware of what project phases are to be the subject of engagement. A lot of effort and resource on engagement at the margins of a project may realise limited additional benefit. It may also be beneficial to engage key stakeholders (particularly those representing different community interests) at the start of a project to establish their views on what they would consider to be a "proportionate approach".

Stakeholder Identification (Identify and Understand your Stakeholders)

Establish a consistent approach to mapping stakeholders and understanding their likely viewpoints, needs and expectations from engagement, and the potential value that could be realised from engaging them. There should be a clear commitment to community engagement at a local level. It is also important to define the "voiceless" or "hard to reach" stakeholders such as those with mobility difficulties, sight or hearing loss, literacy difficulties, alternative language requirements, etc; or people too busy to engage with traditional consultation methods. Identify and target these groups specifically.

Start Engagement Early

Early engagement in a scoped manner will help to build project awareness and understanding, so helping to reduce the risk of "surprise" later. Engage key stakeholders early in the scoping phase to enable them to contribute to the development of effective solutions. They may have information and views that will be of benefit to the proposal, and securing their endorsement for an approach to stakeholder engagement, and for securing data will be of considerable value. Stakeholders must have the opportunity to comment and influence at the formative stage. Be clear about the stage of the project when engaging: stakeholders should not expect all project details to be available at the early stages, and should appreciate that they are being involved in formative stages.

Targeted Mix of Consultation/Engagement Methods

A combination of methods for stakeholder engagement should be considered and chosen depending on the stage of the project, the stakeholder groups involved and their individual concerns, needs and priorities. Methods should be tailored to the required output, such as awareness building, gaining understanding, inviting comments, or enabling constructive debate. Methods could include provision of information through news media; published information sheets or leaflets; exhibitions; websites; on-line questionnaires; discussion events; workshops, perhaps independently facilitated; community panels, etc. Dedicated community liaison and engagement staff could be utilised. Regular engagement with key stakeholders will enable relationships to be developed and maintained.

Create an Open and Transparent Process

It is important to manage the expectations of stakeholders by clearly stating the objectives and scope of the engagement from the outset. Some aspects of a project will be "out of scope" for consultation, such as legislative or regulatory obligations, however it should be recognised that there may be different ways of satisfying these obligations. Similarly, timescales should be clearly defined at the outset. The engagement or project process should be openly publicised, and be clear, so that as many obstacles to engagement are removed as possible. Project information should be tailored for audiences in format and style, for example, non-technical material or specialist, detailed material.

Provide Feedback to Stakeholders (Monitor and Evaluate)

It is important that stakeholders can see how their comments have been taken into consideration. Feedback mechanisms should be developed to demonstrate how views have been considered and addressed. This is not necessarily a simple task for complex or controversial projects where large numbers of comments may be received. It is important to demonstrate not only that engagement has taken place, but that it has been an effective part of the process. It is important to be clear about how views are reflected in, or used to influence, subsequent decisions, processes and plans. When comments have been considered but the proposals have not changed, it is good practice to explain why not.

Engagement should be Proactive and Meaningful

Stakeholder engagement should be appropriate for the purpose and the target audience and should be proactive and meaningful. Stakeholders should generally be involved at project stages where they are able to influence an outcome or decision. The approach to the engagement of citizen communities should be proactive, accessible and inclusive.

6.6 Life Cycle Assessment (LCA) for OHLs

6.6.1 Introduction

Working Group B2.15 was set up in 2000 to examine Life Cycle Assessment (LCA) issues as applied to Overhead Lines and to study aspects of overhead line relating to Environmental Concerns. With regard to LCA the specific terms of reference were:

- To analyse LCA methods and existing tools and to ascertain their range of application for overhead lines.
- To develop methodologies as appropriate for Life Cycle Assessment of Overhead Lines, establishing recommendations to provide as complete a picture as possible of the interactions of an overhead line with the environment and to provide decision makers with information which identifies opportunities for environmental improvement.

For clarity it is useful to give here the definition of LCA from the Society for Environmental Toxicology and Chemistry (SETAC):

> *"The Life Cycle Assessment is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying, and quantifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements.*
>
> *The assessment includes the entire life cycle of the product, processor activity, encompassing extracting and processing raw materials, manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal.*
>
> *The Life Cycle Assessment addresses environmental impacts of the system under study in the areas of ecological health, human health and resource depletion. It does not address economic considerations or social effects. Additionally, like all other specific models, LCA is a simplification of the physical system and cannot claim to provide an absolute and complete representation of every environmental interaction."*

The working group undertook a broad examination of LCA and LCA methodologies. A summary is given of how LCA developed and how it is classified and outlined in the ISO 14040 series. A full review was included of work done in Scandinavian countries on LCA on power systems and overhead lines. A very detailed explanation and comparison was provided of various LCA software packages, how they operate and their benefits.

To develop working group documents on LCA the approach adopted was to examine the main components of Overhead Lines – structures and foundations, conductors and insulators – and to initially assess in a qualitative manner the impact of these components on the environment through the production, use and disposal phases.

Furthermore a series of detailed quantitative LCA studies were carried out on the main Overhead Line components (using Japanese LCA software). The results of some studies (in Japan and Denmark) dealing with the Overhead Line as a system were also included. Finally conclusions and recommendations were presented.

Electric and magnetic fields(EMF), audible noise and other interference issues connected to transmission lines were not covered by Cigré TB 265 (2004), since they have already been dealt with in detail in Cigré TB 147 (1999), from SC 22.14, as well as by other working groups in Cigré and they, like visual impact, cannot be analysed using LCA methodologies. Some of the studies reported on were driven by demands of customers in deregulated markets for more information on the environmental effects of overhead lines.

This brochure should certainly assist in that regard. It is hoped that the information contained in Cigré TB 265 (2004) will be of benefit to Cigré members and those working in electrical power systems in providing an overview of Life Cycle Assessment, its application to Overhead Lines and the possibilities for environmental improvement. It could also serve as a model of the application of life cycle assessment to other components of an electric power system.

6.6.2 LCA Development and Early Applications

Chapter 2 of Cigré TB 265 (2004) is devoted to the description of the LCA development and early applications and also give an outline of ISO 14040 series. The introduction of LCA and an historic overview to LCA are briefly reviewed. The current applications of LCA are also examined.

Cigré TB 265 (2004) states that LCA is increasingly recognised as a potentially powerful environmental management tool and is increasingly being used in environmental management systems of companies as well as by governments in the policy-making process. References to application of LCA in the electrical industry are explored also in this chapter. Some studies have been carried out involving overhead lines.

6.6.3 Power System and Overhead Line LCA in Scandinavia

Chapter 3 summarised the Scandinavia LCA studies on power and transmission system. Vattenfall performed the first one in Sweden in the mid 1990s. Danish power companies have completed a similar, more recent study. The Scandinavian studies are the most comprehensive involving overhead lines, with available reports combined with accessible sources.

The results show:

- The methods were largely the same, and the results are expressed in the same functional unit (environmental impact per 1 kWh of electricity delivered to the consumer).
- The most significant environmental impact of the total electrical system is due to generation while the contribution from transmission is relatively small (0.3 % in Denmark).
- Network losses are a major source of environmental impact from power lines.
- The Swedish study shows that the transmission losses to a national grid customer amount to 2 % while for household customers (distribution) they are 9 %. See Figure 6.18.

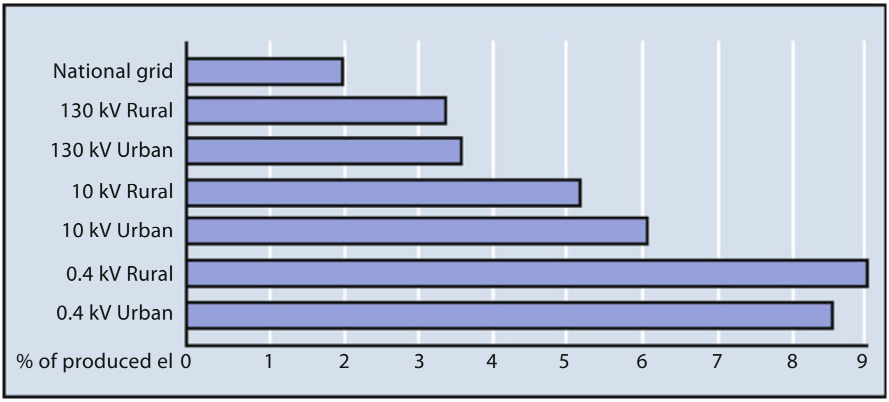

Figure 6.18 Transmission Losses in Electricity Supply Networks (Sweden).

6.6.4 Comparison of LCA Software

Chapter 4 of Cigré TB 265 (2004) describes the outline and what LCA software packages (JEMAI, TEAM, SIMAPRO) can do in general, and also compares some of their features. These software have similar functions, however because of their different origins (Japan, France, Netherlands) there are some differences. See Figure 6.19 General procedure for the calculation of Eco-indicators (Eco-indicator 99 [Netherlands]).

Therefore, it seems that consistent results cannot be obtained between different LCA software packages, and there is little meaning in comparing the final values of results derived from several different LCA software packages. Taking these differences between software packages into consideration, it is recommended that impact assessment comparison (between an original project and an improved one) should be carried out using the same LCA software.

In order to choose appropriate software for a specific LCA study, it is recommended to examine whether the function of the software as well as the database suitable for the intended LCA study.

6.6.5 LCA, Overview for OHL Components, Construction and Maintenance

An Overhead Line is a large system, which consists of several subsystems made up of various components, their transportation, construction work, maintenance activities, dismantling, recycling, transmission losses, and so on. Considering that elementary flows for the transmission system are the sum total of each sub-system, it is necessary to regard these sub-systems as one of the product systems to be studied.

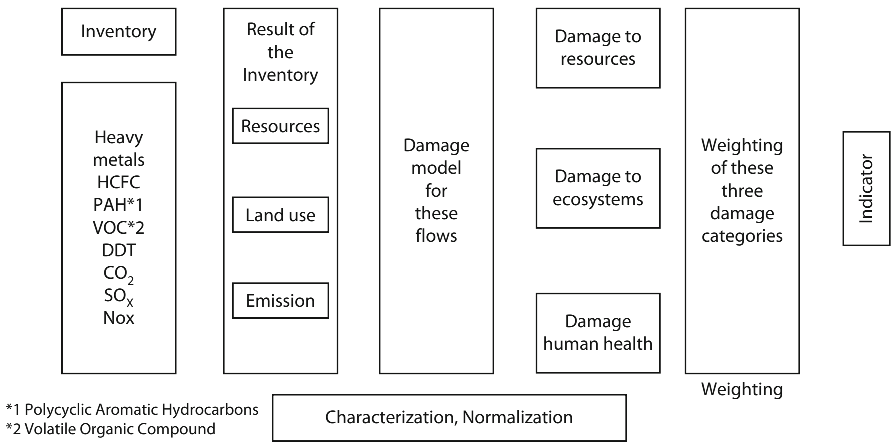

Figure 6.19 General procedure for the calculation of Eco-indicators (Eco-indicator 99 [Netherlands]).

Chapters 5 and 6 of Cigré TB 265 (2004) are devoted to the description of the major components or activities related to OHL, in terms of their material used (raw or recycling), corrosion protection, dismantling, recycling and scrapping. These chapters conclude with the listing of conclusions and recommendations to reduce the environmental impact of each component or activity in terms of LCA studies.

LCA, studies on some OHL components Chapter 7 of Cigré TB 265 (2004) shows some concrete calculations of LCA for several processes for OHL components (lattice tower, conductor (ASCE), porcelain insulator) based on the procedure specified in the ISO 14040 series. An actual analysis is carried out using the LCA software "JEMAI –LCA" which was developed by the Japan Environmental Management Association for industry (JEMAI).

6.6.6 LCA, Studies on OHL

Finally, Chapter 9 provides two detailed calculations of LCA for an Overhead Line. The first one covers a 154 kV overhead line build in Japan and was carried out using the LCA software "JEMAI – LCA". From this study, the WG recommend to reduce environmental impacts caused from OHL (excluding power transmission losses). The recycling of aluminium of the conductor seems the most effective way and efforts should continue in promoting aluminium recycling. Concerning transmission losses, the development of low resistance conductors seems an effective option. It should be noticed that this study was conducted based on the data mainly obtained in Japan and environmental impacts stemming from power transmission losses are largely influenced by its power generation sources.

In Denmark, as in Japan electricity production is largely based on fossil fuels. Their study show that only 0.3 per cent of the environmental impact of the Danish power system is related to the component of transmission overhead lines (Figure 6.20).

An interesting study, outside the WG, was presented in Cigré Paris C3 session 2012, Wang. W and A. Beroual, T. Mehiri, G. Tremouille 2012, *Life Cycle Assessment on a 765 kV AC transmission system*, Cigré Paris, Report C3-208 (Wang et al. 2012).

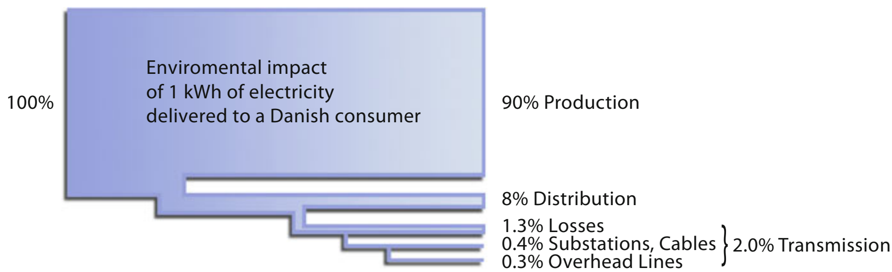

Figure 6.20 Breakdown of Environmental Impact of 1 kWh of Electricity delivered to a Danish Consumer.

In this paper, an LCA study was conducted, using SimaPro (one of the LCA software packages compared with two others in 6.6.4 above) on one 765 kV AC transmission system in Venezuela, with the aim of investigating the potential environmental impacts of a transmission system and locating the major sources of environmental burdens from one electrical transmission system.

The system consisted of the transmission lines, composed of conductors, ground wires, towers, foundations and insulators and the four substation fed by them. In the investigation of the substations, the considered components included major equipments such as power transformers, circuit breakers, current transformers, voltage transformers, shunt reactors, surge arresters, disconnects, etc, of course including their supporting frames and foundations; and constructions such as gantries, access roads, gravels in substations, etc.

Through the LCA study, it was shown that energy losses in transmission lines and power transformers and SF6 emissions of circuit breakers are the major sources of environmental impacts, while the materials production cannot be ignored.

6.6.7 Conclusions/Recommendations

Based on the work across the range of LCA issues investigated and informed by the studies undertaken within the working group and elsewhere, conclusions are presented in Cigré TB 265 and recommendations as given below were made.

- Life Cycle Assessment studies for overhead lines and overhead line components should be performed using the ***ISO 14040 Environmental Management - Life Cycle Assessment*** series. The goal and scope of any study, be it environmental reporting, product improvement or product comparison should be clearly set out, including identification of the intended audience.
- The product system and its boundaries must be properly defined and modelled. These will depend on whether the overall grid, an overhead line or overhead line components are being studied. This will also apply to the choice of functional unit and a relationship can be established between different units depending on the system boundaries.
- No matter which system is going to be analysed and how it is modelled, the allocation criteria should always be similar. Regardless of which product system is chosen, the representativeness of the population studied is one of the major requirements, if the results of the LCA study are to be taken seriously.
- With regard to Life Cycle Impact Assessment the choice of the impact categories to be considered should be justified in relation to the goal and should be initially included in the scope of the LCA study. The choice of characterisation indicators is critical at this stage.
- An LCA software package appropriate to the country or region in which the assessment is being performed should be used.
- The comparison between different LCA software packages shows that consistent results cannot be obtained, and there is little meaning in comparing the final

values of results derived from several different LCA software packages. Therefore taking differences between software packages into consideration, it is recommended that impact assessment comparison (such as a comparison between an original product and an improved one) should be carried out using the same LCA software.

- The overview of Overhead Line components showed that well established methods exist for recycling of some of the major overhead line components particularly steel towers and conductors. These methods should be availed of and efforts increased to recycle all overhead line components.
- Efforts should be made to keep the duration of Overhead Line construction to the minimum as significant environmental impacts can arise at this stage. It is recommended that Environmental Management Plans should be developed and used. If required by the authority or by the landowner, access roads should be removed and recycled. Maintenance activities should be organised and scheduled to eliminate or minimise environmental impact particularly painting of towers.
- The results of actual LCA studies carried out on some of the principal overhead line components lead to the following recommendations
  - To reduce environmental impact, especially to reduce resource exhaustion impact, it is strongly recommended that lattice steel towers should be recycled. It could reduce the amount of iron reserves consumption as well as zinc reserves consumption. Figure 6.21 shows Lattice Steel Tower impact on resource exhaustion for the different reserves as percentages within the total. In the case study, it was presumed that zinc is recycled; however recycling

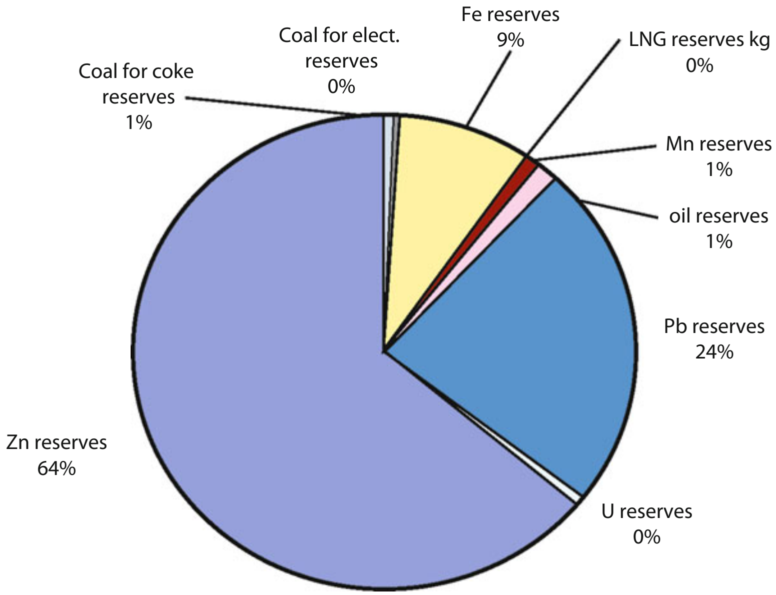

Figure 6.21 Lattice Steel Tower – Impact on Resource Exhaustion (Japan).

zinc is not as common as recycling steel. The extent of zinc deposits in the world is much less than those of iron and taking this situation into consideration it is also recommended that zinc recycling processing should be widely adopted.

- To reduce environmental impacts, such as gas emission related impacts as well as resource exhaustion impact, it is strongly recommended that conductors should be recycled. It is commonly known that the energy required for recycled aluminium is about 3 % of original aluminium production. The electrolysis process to extract alumina from bauxite for original aluminium production needs a large amount of electricity, while the aluminium recycling process basically consists of melting and moulding processes, which need less energy than the electrolysis process.
- Another way to reduce environmental impact is to reduce transmission losses. In this respect the development of low resistance conductor seems an effective way that could be recommended. Upgrading to a higher voltage power system may also seem to be effective; however a more comprehensive analysis of the whole power system would be needed to draw this conclusion.
- With regard to insulators only a small percentage of removed insulators are experimentally recycled as construction materials and a porcelain insulator recycling system is not fully established. Knowing that more energy is consumed in the insulator manufacturing processes of insulators than in the raw material manufacturing processes, establishment of the reuse of removed insulators as value added materials is desirable since material production itself for insulator production is not so energy consuming and it seems important to effectively reuse insulators which have already consumed energy in their manufacturing process.
- Another approach to reduce environmental impacts might be to extend the function as insulators as long as possible. In this respect development of efficient and reliable diagnostic methods as well as life span extension technology is recommended.

• The recommendations from the study on a 154 kV overhead line section in Japan reinforce those noted above.
  - To reduce environmental impacts caused from OHLs (excluding power transmission losses), recycling aluminium of the conductor seems the most effective way and it is recommended that efforts should continue in promoting aluminium recycling.
  - Furthermore in terms of natural resource preservation, recycling lattice towers especially zinc recycling, is effective. However zinc-recycling systems have not been established sufficiently compared to steel recycling systems, this might be another area to be focused on.
  - Concerning transmission losses, the development of low resistance conductors seems an effective option to recommend. Upgrading of OHLs to higher voltage ones might be another option, however further more detailed LCA studies, which would cover the broader power system, would be needed to conclude this.

  - It should be noted that this study was conducted based on the data obtained mainly in Japan and environmental impacts stemming from power transmission losses are largely influenced by its power generation sources. Knowing that, it is recommended that the situation (such as power generation sources) in each country should be reviewed when interpreting LCA results in each country.
- These are complemented by the recommendations from the Danish study on 1 km of 400 kV OHL which also included a comparative study on the use of new structure designs (single circuit) as against the traditional double circuit lattice steel tower design.
  - Using LCA studies to reduce the environmental impact requires an overview of the entity that the LCA study forms part of. This is particularly the case if a utility is willing to invest money in order to reduce the environmental impact. Otherwise, it is very likely that investment would not be made efficiently.
  - Technically, a reliable way to reduce the environmental impact from overhead lines is to ensure that a transmission tower is designed for two or more circuits. In this way the environmental impact related to concrete foundations and towers tends to be minimised per 1 kWh of electricity transported. New foundation design and construction could be another effective way to minimise the environmental impact.
  - LCA studies of components in the power system are still evolving. As far as models for the transmission grid are concerned results from the studies can be used as a supplement in evaluation of, for example, different types of towers or foundation technologies.
  - The lifetime of the different components of the overhead line should be estimated individually.
- The results of the study on the Venezuelan 765 kV transmission system points to the eco-design of a transmission system, that is to say, if ways to decrease a transmission system's environmental impacts are to be considered, focus should be put on the methods of reducing energy losses of conductors of transmission lines and power transformers and decreasing the SF6 emissions of circuit breakers. Besides, ways of minimising materials used in equipments are also beneficial to the reduction of environment load.

Life Cycle Assessment is a very valuable tool for overhead lines engineers, planners and utilities to assist in the evaluation of the impact or interaction of overhead lines and the environment. It can be used and developed across a range of applications from environmental reporting to product improvement and comparison. However it should be noted that its use has some restrictions.

LCA does not prioritise impacts; there is no differentiation between local impacts and those diluted in time and space. For instance it is not possible to differentiate between a large pollution over a short time period and smaller pollution over a longer period. It should also be noted that other tools and techniques exist to assess and reduce overhead line impacts on the environment and LCA results should always be evaluated in this broader context.

6.7 OHL and Sustainable Development

Taking account of the above Chapters on Overhead Line environmental impacts and mitigations, consultation models and Life Cycle Assessment the following may be stated with regard to Overhead Lines and Sustainable Development in the context of the three main pillars of sustainability: environmental protection, social progress and economic growth.

A transmission system allows the separation in space of electric power generation sites from consumption areas. A transmission network can use the advantage of a generation base which is widespread and diversified, and thus reduces the impact of generation on the environment. It is notable that an overhead transmission network enables easier and profitable use of renewable energies such as hydro and wind. Its structure allows the delivery of quality electrical power to each consumer safely.

This system optimises the use of generation, both nationally and internationally to ensure the balance between supply and demand at any time.. The meshed network pools power plants, optimises production costs and minimises environmental impacts including carrying a low carbon energy footprint (hydro, nuclear, wind, solar). The network is a link of solidarity that can accommodate renewable energy (wind in particular) which is not predictable enough to be operated independently of other energy sources.

The transmission network allows a fair distribution of electricity throughout a country which is essential for good development and regional planning. In this sense, the transmission grid is one of the pillars of sustainable development. Overhead Lines are (with underground cables and substations) the main component of the network and as such they make an important contribution to sustainable development.

- Only Overhead Line technology can design electricity transmission links with large capacities and capable of operating over long distances, in an economic fashion
- An Overhead Line can operate at high voltages in excess of 1 million volts, and allow several Giga Watt of power flow without increasing intensities and losses, A Direct Current (DC) OHL can carry many GW over several thousands of km. Comparative economics of OHL/UGC is favourable to OHL for the higher capacities (over 1 GW)
- An OHL project design takes into account the expectations of residents in addressing the following
  - A route is chosen after a consultation process, sensitive areas are avoided, suitable reduced impact designs are used and aesthetic towers as appropriate, 3D techniques are employed to ensure integration in the landscape.
  - Noise Reduction is ensured
  - EMF mitigation is applied
  - Row management is optimised
- In its operational phase, an OHL provides the expected performance in the long term and respects the environment. It ensures:
  - Low electrical losses,
  - Easy and fast fault location and fault repair

And the following are achieved
- Improved anticorrosion maintenance of supports
- Optimised vegetation maintenance of the row
- Increased biodiversity in the row

With appropriate maintenance and replacement of components or refurbishment, the life of an OHL can be greatly extended. Hence, an OHL is an asset that can be managed with flexibility. To maintain, refurbish or replace are all possible choices depending on the available resources of the society.

- An Overhead Line network can adapt to changes, even major work (with costs and difficulties being limited):
- The need to increase network transmission capacity due to increased consumption and new generation sites (wind farms) can be accommodated by refurbishment of Overhead Lines with the replacement of conductors, and strengthening of supports if necessary, or by voltage uprating.
  - If changes in climatic conditions or design philosophy have to be catered for towers can be strengthened mechanically.
  - In the case of a change of land use, an Overhead Line can be rerouted.
- Overhead Line materials are easily recycled at the end of life and have no significant residual impact.

The metals of towers and conductors can be fully recovered and recycled. The residual impact of an OHL is limited to foundations which consist mainly of neutral materials with respect to the ground (concrete).

6.8 Highlights

- Overhead Lines and Environmental Issues have been addressed within Cigré for many decades. Developments in a wide range of areas have been investigated and reported on. The ever present need for more efficient permit processes for overhead line projects and associated developments has been outlined.
- The emergence of Strategic Environmental Assessment and its broader role in ensuring sustainable development has been presented. Recommendations for its implementation are listed. The framework of Environmental Impact Assessment has been outlined and various broad guidelines given.
- Environmental Impacts of Overhead Lines and methods to mitigate them are described. In the case of visual impact this covers routing guidelines and mitigations for landscape as well as the development of reduced visual impact designs and aesthetic designs from across the globe.
- Impacts and mitigation measures and guidelines were presented for ecology and land use. The impacts of construction and maintenance of overhead lines are described and guidelines for their mitigation given. The development of Environmental Management Plans was pointed to.

- The impacts and mitigations of Fields, Corona and other elated phenomena were dealt with in regard to: Electric and Magnetic Fields, Research on Bio Effects and Alleged Health Effects, Electric and Magnetic Field Reduction, Noise and Interference and Atmospheric Chemistry. After more than 50 years of research on the subject of possible health impacts of ELF-EMFs, the scientific community could not provide any solid evidence about any health hazard on living organisms associated with a prolonged exposure to ELF-EMFs at a lower level than the international recommendations.
- The pressing requirements for gaining public and community acceptance of overhead lines have been described. Concerns and issues facing utilities and TSOs have been given. Methodologies of community and landowner consultation and stakeholder engagement have been presented. Examples of good practice consultation models and guidelines on stakeholder engagement polices have been given.
- The work done on Life Cycle Assessment was summarised in the following areas: early applications, power system and overhead lines LCA in Scandinavia, comparison of LCA software, LCA, overview for OHL components, construction and maintenance and LCA, studies on OHL. Conclusions/Recommendations were presented.
- The benefits of Overhead Lines and transmission networks in contributing to sustainable development have been summarised. It can certainly be said that over recent decades there has been a high level of development on all issues associated with Overhead Lines and Environmental Issues by Cigré, utilities and TSOs, resulting in improved processes, minimisation and mitigation of environmental impacts and continuous efforts to gain acceptance for overhead lines.

6.9 Outlook

- Overhead Lines Environmental Issues will continue to be of prime importance and indeed it can be forecast that they will increasingly dominate in many projects.
- Strategic Environmental Assessment (SEAs) studies will grow and develop. SEAs will be strategic and comprehensive studies and increasingly will be included in national and regional long-term plans both for generation and transmission. Modelling tools will be developed to support the analysis of policies and plans, as well as decision making.
- Regulatory regimes will continue to evolve in response to the urgent need to streamline processes. The use of community compensation schemes and commitments to reduce overall impact of networks will increase.
- Efforts will both continue and increase to mitigate the overall visual impact of overhead lines and more companies will introduce reduced visual impact designs or new aesthetic overhead line designs.
- Increased efforts will be made to further reduce and mitigate overhead line impacts on ecological systems and land use. Use will be made of Environmental Management Plans.

- With regard to EMF and Corona phenomena the expectations of society regarding the increase of its standard of living have to be taken into consideration by TSOs. EMF and disturbances related to Corona phenomena may be important concerns for people living in the vicinity of overhead transmission lines.
- These electric phenomena are currently taken into account by TSOs, by studying new transmission line designs which increase the fields compensation, or by working with manufacturers on new materials in order to decrease the Corona activity. Another aspect which is being developed by TSOs is the pedagogical approach on these particular subjects. The way to communicate (e.g. websites or dialogues with residents living close to the line) will be one of the keys to improve the acceptance of power lines.
- Consultation Models will be developed which will see companies undertake more consultation than required by legislation. They will conduct open and engaging consultation with a broad range of representative and interested groups.
- Companies will have to be pro-active in dealing with opposition and must give immediate information on issues related to EMF/Health, visual impact mitigation and nature conservation management.
- Electricity organisations will increasingly recognise the benefit of stakeholder engagement, not only because of their commitments to sustainable development, but for the benefit of electricity infrastructure projects themselves, and for all the benefits of building relationships with key environmental and citizen organisations.
- Many companies will clearly recognise the business and reputational risks that come from poor stakeholder relations, and place a growing emphasis on social responsibility and transparency and reporting. In this context, good stakeholder relations will be a prerequisite for good risk management.
- More companies are likely to undertake Life Cycle Assessment and to appreciate that it is a very valuable tool for overhead lines engineers, planners and utilities to assist in the evaluation of the impact or interaction of overhead lines and the environment.
- There will be an increasing appreciation of the role of Overhead Line networks in ensuring sustainable development.
- Cigré Study Committees and working groups will be active in supporting all the above developments.

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