Construction of Transmission and Distribution Lines

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EXECUTIVE SUMMARY:

For more than a century we are using electricity. T&D lines are used to distribute electricity to places often far away from where it has been produced. Today demand is still on the increase causing constant modifications, extensions and development of the current networks.

The financial risk involved might be transferred to insurers.

In this document are laid out the different Insurance aspects concerning design and construction of T&D lines. You will find typical MPL sceneries and a study of how today’s engineering insurance overages applies to this sector of industrial activity.
1 Technical description of Transmission and Distribution Lines

1.1 Introduction

To get a good understanding of the subject it is needed to know the surrounding and the context of the T&D lines. First of all, the lines are operating as an element of transmission of power, that is meaning that without a global network with production and consumer the T&D line does not exist anymore. Saying that fact, we shall introduce the grid notion. The line is a transfer item to carry the power from one point to another point. To avoid blackout of the power, lines are interconnected, it is a grid. The basic grid is, one power plant, one T&D line and then one consumer, the most sophisticated are the international grids with simultaneously loops, and tree configurations. The grid notion allow to understand a great part of the T&D lines problem, locations, nominal power of the line, design, and construction and operating trends.
1.2 Historical / future development:

The first transmission of electrical impulses over an extended distance was demonstrated on July 14, 1729 by the physicist Stephen Gray, in order to show that one can transfer electricity by that method. The demonstration used damp hemp cords suspended by silk threads (the significance of metallic conductors not being appreciated at the time).

Before the advent of electricity, mills, forges and manufactories – i.e. the "large" power consumers in those days – had to be located near the water mills or windmills generating mechanical power, as it could only be transmitted over very short distances. Power generation and consumption were localised and mechanically interconnected; maximum possible consumption was always dictated by the supply of mechanical power available at any given moment. The first electricity generating plants replacing such water mills or windmills tended to be built in the immediate vicinity of local power consumers.

However the first practical use of overhead lines was in the context of telegraphy. By 1837 experimental commercial telegraph systems ran as far as 13 miles (20 km). Electric power transmission was accomplished in 1882, one year after the first international electricity exhibition in Paris, the founder of the “Deutsches Museum”, Oskar von Miller, organized a trade fair in Munich which was intended to be coequal with the show in Paris. For this reason he commissioned together with the Frenchman Marcel Depréz the erection of a direct current high voltage transmission line over a distance of 35 miles from the town Miesbach to Munich, an outstanding world record at that time. A steam engine rated 1.5 hp in Miesbach produced electricity which was transmitted at a voltage of 2 kV to the exhibition in Munich where an artificial waterfall was driven. Although the efficiency of the line was only 25%, the visitors were euphoric about this proof that electrical energy can be transmitted over long distances.

1891 saw the construction of the first three-phase alternating current overhead line on the occasion of the International Electricity Exhibition in Frankfurt. Miller built a three phase current 200 hp transmission over a distance of 110 miles with an efficiency of 75% between Lauffen and Frankfurt.

In 1912 the first 110 kV-overhead power line entered service followed by the first 220 kV-overhead power line in 1923. In the 1920s RWE AG built the first overhead line for this voltage and in 1926 built a Rhine crossing with the Pylons of Voerde, two masts 138 meters high. The following spread of electricity lines and networks meant that it was no longer necessary for producers and consumers to be located side by side. An electricity network or "power grid" is created when several producers and consumers are connected by power lines. Regional small-area grids are known as island grids.

In the first half of the 20\textsuperscript{th} century, the pioneering technical inventions regarding insulation and transformation allowed these island grids to expand appreciably and merge into larger "interconnections" permitting the exchange of electrical power between different grids. This development was driven by the following advantages in relation to island grids:

- The impact of activation and deactivation by individual producers and consumers is mitigated by their large number. Unforeseen load fluctuations caused by a sudden loss of generating capacity or by a high temporary demand can be handled more easily.
- Power plant capacity can be utilised more uniformly; different types of power plant can be optimally operated as base load, mid-load or peak load plants in accordance with their power generation cost structure.
- Power can be transported over large distances from the producers to the consumer centres. Power stations can be erected where production conditions are best and not where their power is consumed.
Network operation is more reliable. Redundancies and reserves can be minimised without loss of reliability.

In Germany in 1957 the first 380 kV overhead power line was commissioned (between the transformer station and Rommerskirchen). In the same year the overhead line traversing of the Strait of Messina went into service in Italy. Starting from 1967 in Russia, and also in the USA and Canada, overhead lines for voltage of 765 kV were built. In 1982 overhead power lines were built in Russia between Elektrostal and the power station at Ekibastusz, this was a three-phase alternating current line at 1200 kV (Power line Ekibastuz-Kokshetau). In 1999, in Japan the first power line designed for 1000 kV with 2 circuits were built, the Kita-Iwaki Power line. In 2003 the building of the highest overhead line commenced in China, the Yangtze River Crossing. Nowadays enormous continent-wide grids with numerous international interconnections have been established in all developed areas of the world.

In view of the advantages of electricity use, growing number of electric appliances and provided the industrialization of emerging economies will continue, an ongoing growth of T&D networks worldwide in the next decades can be predicted despite the energy saving efforts which focus mainly on the reduction of the use of primary energy. Beside the widely used high voltage three-phase current systems we can expect also a substantial growth of the high voltage direct current transmission technology. The latter has played a niche role but has advantages regarding reduction of transmission losses over very long distances.

An important subject is to understand why AC or DC for the T&D lines according to the type of line?

A key feature of electricity is that unlike all other forms of energy, it cannot be stored, even for a fraction of a second. A sophisticated system of control is therefore required, to ensure electric generation always matches demand. If supply and demand are not in balance, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout, such as occurred in California and the US Northwest in 1996 and in the US Northeast in 1965, 1977 and 2003. To reduce the risk of such failures, electric transmission networks are interconnected into regional, national or continental wide networks thereby providing multiple redundant alternate routes for power to flow should (weather or equipment) failure's occur. Much analysis is done by transmission companies to determine the maximum reliable capacity of each line which is mostly less than its physical or thermal limit, to ensure spare capacity is available should there by any such failure in another part of the network.

Then according to history and progress of the technology, transmission lines mostly use three phase alternating current (AC). High-voltage direct current (HVDC) technology is used only for very long distances (typically greater than 400 miles); undersea cables (typically longer than 30 miles); or for connecting two AC networks that are not synchronized.

Electricity is transmitted at high voltages (that is to say, 110 kV or above) to reduce the energy lost in long distance transmission. Underground power transmission has a significantly higher cost and greater operational limitations but is sometimes used in urban areas or sensitive locations.

Transmitting electricity at high voltage reduces the fraction of energy lost to resistance. For a given amount of power, a higher voltage reduces the current and thus the resistive losses in the conductor. For example, raising the voltage by a factor of 10 reduces the current by a corresponding factor of 10 and therefore the losses by a factor of 100, provided the same sized conductors are used in both cases. Even if the conductor size (cross-sectional area) is reduced 10-fold to match the lower current the losses are still reduced 10-fold. Long distance transmission is typically done with overhead lines at voltages of 115 to 1,200 kV. At extremely high voltages, more
than 2 MV between conductor and ground, corona discharge losses are so large that they can offset the lower resistance loss in the line conductors.

The power of the resistance lost is calculated as follow:

- \( P = R \cdot I^2 \) where, \( P \) = power loses; \( R \) = resistance; and \( I \) the current intensity.
- The losses coming from the Joule effect as above mentioned are depending of two parameters, the resistance and the current. The HT using allow to below the I effect through the “equivalent carried power” \( P = U \cdot I \) where \( U \) is the HT used.
- Then to reduce the \( R \) factor as lower as possible, the only solution is to below the resistivity of the conductor, by using raw materials with lower resistivity, or play with the diameter through the section \( S \), as the length of the cable is fixed by the line itself.

\[
R = \frac{l}{\rho S}
\]

When a current is operating on a line, due to the above losses, the temperature will increase, the designer and T&D line operator shall take into account the losses themselves, the increasing of the temperature but also the effects on the material, ie the thermal expansion, and tensile test limit of the raw material to avoid plastic deforming and then permanent defect. For the Al the max admissible temperature is 100°C.

In France these losses are estimated to 2.5% of the total consumption (13 TWh) per year. Then to reduce again these losses the alternative is to multiply the number of the conductors on one line, sometime with cables at few centimetres distance from the others.

As an example, Transmission and distribution losses in the USA were estimated at 7.2% in 1995. In general, losses are estimated from the discrepancy between energy produced (as reported by power plants) and energy sold to end customers; the difference between what is produced and what is consumed constitute transmission and distribution losses.

As of 1980, the longest cost-effective distance for electricity was 7,000 km (4,300 mi), although all present transmission lines are considerably shorter.

In an alternating current circuit, the inductance and capacitance of the phase conductors can be significant. The currents that flow in these components of the circuit impedance constitute reactive power, which transmits no energy to the load. Reactive current flow causes extra losses in the transmission circuit. The ratio of real power (transmitted to the load) to apparent power is the power factor. As reactive current increases, the reactive power increases and the power factor decreases. For systems with low power factors, losses are higher than for systems with high power factors. Utilities add capacitor banks and other components (such as phase-shifting transformers; static VAR compensators; physical transposition of the phase conductors; and flexible AC transmission systems, FACTS) throughout the system to control reactive power flow for reduction of losses and stabilization of system voltage.

Then High voltage direct current (HVDC) is used to transmit large amounts of power over long distances or for interconnections between asynchronous grids. When electrical energy is required to be transmitted over very long distances, it is more economical to transmit using direct current instead of alternating current. For a long transmission line, the lower losses and reduced construction cost of a DC line can offset the additional cost of converter stations at each end. Also, at high AC voltages, significant (although economically acceptable) amounts of energy are lost due
to corona discharge, the capacitance between phases or, in the case of buried cables, between phases and the soil or water in which the cable is buried.

HVDC is also used for long submarine cables because over about 30 km length AC can no longer be applied. In that case special high voltage cables for DC are built. Many submarine cable connections - up to 600 km length - are in use nowadays.

The amount of power that can be sent over a transmission line is limited. The origins of the limits vary depending on the length of the line. For a short line, the heating of conductors due to line losses sets a thermal limit. If too much current is drawn, conductors may sag too close to the ground, or conductors and equipment may be damaged by overheating. For intermediate-length lines on the order of 100 km (62 mi), the limit is set by the voltage drop in the line. For longer AC lines, system stability sets the limit to the power that can be transferred. Approximately, the power flowing over an AC line is proportional to the sine of the phase angle of the voltage at the receiving and transmitting ends. Since this angle varies depending on system loading and generation, it is undesirable for the angle to approach 90 degrees. Very approximately, the allowable product of line length and maximum load is proportional to the square of the system voltage. Series capacitors or phase-shifting transformers are used on long lines to improve stability. High-voltage direct current lines are restricted only by thermal and voltage drop limits, since the phase angle is not material to their operation.

Up to now, it has been almost impossible to foresee the temperature distribution along the cable route, so that the maximum applicable current load was usually set as a compromise between understanding of operation conditions and risk minimization. The availability of industrial Distributed Temperature Sensing (DTS) systems that measure in real time temperatures all along the cable is a first step in monitoring the transmission system capacity. This monitoring solution is based on using passive optical fibres as temperature sensors, either integrated directly inside a high voltage cable or mounted externally on the cable insulation. A solution for overhead lines is also available. In this case the optical fibre is integrated into the core of a phase wire of overhead transmission lines (OPPC). The integrated Dynamic Cable Rating (DCR) or also called Real Time Thermal Rating (RTTR) solution enables not only to continuously monitor the temperature of a high voltage cable circuit in real time, but to safely utilize the existing network capacity to its maximum. Furthermore it provides the ability to the operator to predict the behaviour of the transmission system upon major changes made to its initial operating conditions.

1.3 Technical description:

An overhead power line is an electric power transmission line suspended by towers or poles. Since most of the insulation is provided by air, overhead power lines are generally the lowest-cost method of transmission for large quantities of electric power. Towers for support of the lines are made of wood (as-grown or laminated), steel (either lattice structures or tubular poles), concrete, aluminium, and occasionally reinforced plastics. The bare wire conductors on the line are generally made of aluminium (either plain or reinforced with steel or sometimes composite materials), though some copper wires are used in medium-voltage distribution and low-voltage connections to customer premises.

The invention of the strain insulator was a critical factor in allowing higher voltages to be used. At the end of the 19th century, the limited electrical strength of telegraph-style pin insulators limited the voltage to no more than 69,000 volts. Today overhead lines are routinely operated at voltages exceeding 765,000 volts between conductors, with even higher voltages possible in some cases.
Overhead power transmission lines are classified in the electrical power industry by the range of voltages:

- **Low voltage** – less than 1000 volts, used for connection between a residential or small commercial customer and the utility.
- **Medium Voltage (Distribution)** – between 1000 volts (1 kV) and to about 33 kV, used for distribution in urban and rural areas.
- **High Voltage (Sub-transmission if 33-115kV and transmission if 115kV+)** – between 33 kV and about 230 kV, used for sub-transmission and transmission of bulk quantities of electric power and connection to very large consumers.
- **Extra High Voltage (Transmission)** – over 230 kV, up to about 800 kV, used for long distance, very high power transmission.
- **Ultra High Voltage** – higher than 800 kV.

For our purpose and clarify the perimeter of our subject, we will stick on the 3 last above types of T&D overhead lines.

This paper will not focus on underground Transmission Lines as the subject can be handled mainly as Pipes laying or similar works. For sea cables, the works are considered in most cases as off shore and shall be handled as such.

**Color Key:**
- Black: Generation
- Blue: Transmission
- Green: Distribution

**Diagram:**
- Generating Station
- Transmission lines: 765, 500, 345, 230, and 138 kV
- Substation Step Down Transformer
- Subtransmission Customer 26kV and 69kV
- Primary Customer 13kV and 4kV
- Secondary Customer 120V and 240V

Above the split of elements of Electric power global arrangement

Below is the basic scheme of a transmission line

The purple cable is the guard cable for lightning protection of the power T&D line. Theses pylons are carrying two three-phase systems, the red one and the blue one. Each phase is hanged through one isolating device.
1.3.1 Direct current and Three-phase current or Alternating current

In alternating current (AC, also ac) the movement (or flow) of electric charge periodically reverses direction. An electric charge would for instance move forward, then backward, then forward, then backward, over and over again. Direct current (DC) is the unidirectional flow of electric charge.

1.3.2 Description of the equipment (line with pylon, cables and substation with transformers, switch yard…)

1.3.2.1 The structures, the pylons

Structures for overhead lines take a variety of shapes depending on the type of line. Structures may be as simple as wood poles directly set in the earth, carrying one or more cross-arm beams to support conductors, or "armless" construction with conductors supported on insulators attached to
the side of the pole. Tubular steel poles are typically used in urban areas. High-voltage lines are often carried on lattice-type steel towers or pylons. For remote areas, aluminium towers may be placed by helicopters. Concrete poles have also been used. Poles made of reinforced plastics are also available, but their high cost restricts application.

Each structure must be designed for the loads imposed on it such as conductors, wind, ice, etc, however this is a well-known design which answer to specific local national regulation. A large transmission line project may have several types of towers, with "tangent" ("suspension" or "line" towers, UK) towers intended for most positions and more heavily constructed towers used for turning the line through an angle, dead-ending (terminating) a line, or for important river or road crossings. Depending on the design criteria for a particular line, semi-flexible type structures may rely on the weight of the conductors to be balanced on both sides of each tower. More rigid structures may be intended to remain standing even if one or more conductors is broken. Such structures may be installed at intervals in power lines to limit the scale of cascading tower failures.

<table>
<thead>
<tr>
<th>Type of pylon by function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor pylons or strainer pylons</td>
<td>Are employed at branch points as branch pylons and must occur at a maximum interval of 5 km, due to technical limitations on conductor length.</td>
</tr>
<tr>
<td>Branch pylon</td>
<td>Is a pylon that is used to start a line branch. The branch pylon is responsible for holding up both the main-line and the start of the branch line, and must be structured so as to resist forces from both lines.</td>
</tr>
<tr>
<td>A tension tower with phase transposition of a traction current line for single phase AC 110 kV, 16.67 Hz</td>
<td></td>
</tr>
<tr>
<td>Type of pylon by material used</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---</td>
</tr>
<tr>
<td><strong>Wood pylons:</strong> For support pylons a straight trunk impregnated with tar is usually used, which carries one or more cross beams with the conductor cables on the top. For anchor pylons constructions looking like a V or an A are used, because these can stand higher forces. Because of the limited height of available trees the maximum height of wood pylons is limited (approx. 30 metres). In Germany wood pylons are used as a rule only for lines with voltages up to approximately 30 kV, while in the U.S. wood pylons are used for lines with voltages up to 345 kV.</td>
<td><img src="image" alt="Wood pylon" /></td>
</tr>
<tr>
<td><strong>Concrete pylon:</strong> or concrete pole, is an electricity pylon made from reinforced concrete. Concrete pylons are manufactured at the factory and put up at the power line’s right of way. Concrete pylons, which are not prefabricated, are also used for constructions taller than 60 meters. One example is a 66 meters tall pylon of a 380 kV power line near Reutter West Power Plant in Berlin. Such pylons look like industrial chimneys and some of these structures are also used as chimneys. In China some tall pylons of power line crossings of wide rivers were built of concrete. The tallest of these pylons belong to the Yangtze Power line crossing at Nanjing with a height of 257 meters.</td>
<td><img src="image" alt="Concrete pylon" /></td>
</tr>
<tr>
<td><strong>Steel tube pylon:</strong> is a pylon, which is manufactured from a steel tube. This type of pylon is generally assembled at the factory and set up on the power line’s right of way with a crane.</td>
<td><img src="image" alt="Steel tube pylon" /></td>
</tr>
<tr>
<td>A lattice steel pylon is an electricity pylon consisting of a steel framework construction. Lattice steel pylons are used for power lines of all voltages. For lines with operating voltages over 50kV, lattice steel pylons are the form of pylon used most often. Lattice steel pylon is usually assembled from individual parts at the place where it is to be erected. This makes very high pylons possible (generally up to 100 meters — in special cases even higher)</td>
<td><img src="image" alt="Lattice steel pylon" /></td>
</tr>
</tbody>
</table>
### Conductor arrangements

**single-level**

**Two-level pylon** is a pylon at which the circuits are arranged in two levels on two crossbars. Two-level pylons are usually designed to carry on the lowest crossbar four and at the upper crossbar two conductors, but there are also other variants, e.g. such carrying six conductors in each level or two conductors on the lowest and four on the upper crossbar.

**Three-level pylon** is a pylon designed to arrange conductor cables on three crossbars in three levels. For two three-phase circuits (6 conductor cables), it is usual to use fir tree pylons and barrel pylons. Three-level pylons are taller than other pylon types

### 1.3.2.2 The Foundations

**Foundation**

**Gravity foundation of reinforced concrete slabs** common foundation in normal ground. Difficulty to make cast large quantities of concrete. Different temperature can be observed during the solidification causing thermal cracks and exposing the steel structure to corrosion.

**Pile foundation with concrete slab** used in difficult ground conditions (bored, tube driven into ground). Challenges related to the making of the piles with possibility dislocation. Limited control possibilities towards the quality of the pile.
Sheet pile foundation with concrete slab
used in difficult ground conditions (sheet piles driven / vibrated into ground).
Tendency to replace pile foundation as cheaper process without long running experience.

1.3.2.3 Insulators, Bushings and Arresters

Insulators must support the conductors and withstand both the normal operating voltage and surges due to switching and lightning. Insulators are broadly classified as either pin-type, which support the conductor above the structure, or suspension type, where the conductor hangs below the structure. Up to about 33 kV (69 kV in North America) both types are commonly used. At higher voltages only suspension-type insulators are common for overhead conductors. Insulators are usually made of wet-process porcelain or toughened glass, with increasing use of glass-reinforced polymer insulators.

Suspension insulators are made of multiple units, with the number of unit insulator disks increasing at higher voltages. The number of disks is chosen based on line voltage, lightning withstand requirement, altitude, and environmental factors such as fog, pollution, or salt spray. Longer insulators, with longer creepage distance for leakage current, are required in these cases. Strain insulators must be strong enough mechanically to support the full weight of the span of conductor, as well as loads due to ice accumulation, and wind.

Porcelain insulators may have a semi-conductive glaze finish, so that a small current (a few milli-amperes) passes through the insulator. This warms the surface slightly and reduces the effect of fog and dirt accumulation. The semiconducting glaze also insures a more even distribution of voltage along the length of the chain of insulator units.

Insulators for very high voltages, exceeding 200 kV, may have grading rings installed at their terminals. This improves the electric field distribution around the insulator and makes it more resistant to flash-over during voltage surges.

Here below the details on the equipment

**Insulators, Bushings and Arresters (Surge arresters) types**

Basic Insulators used to separate electrical conductors. Insulators are required at the points at which they are supported by utility poles or pylons.
Surge arresters are used to avoid damage to the electrical equipment through controlled conduction of the excess voltage (ex. lightning) either through flashover (preferred) or through the arrester itself by grounding.

All of them are exposed to height mechanical stress after excess voltage damaging the mechanical structure of the arrester. Therefore particular attention is paid to avoid rupture after such event. The centre rod is the core part and continuously further developed.

Different designs are known.

<table>
<thead>
<tr>
<th>Tube design</th>
<th>Cage design</th>
<th>Wrap design</th>
</tr>
</thead>
<tbody>
<tr>
<td>(core - Fibre Reinforced Plastic tube)</td>
<td></td>
<td>(core – Metal Oxide Varistor)</td>
</tr>
<tr>
<td></td>
<td>Cage design</td>
<td>Wrap design</td>
</tr>
<tr>
<td></td>
<td>(core - Fibre Reinforced Plastic rods)</td>
<td>(core – Metal Oxide Varistor)</td>
</tr>
</tbody>
</table>

Bushings are specific insulators that required where the wire enters buildings or electrical devices, such as transformers or circuit breakers, to insulate the wire from the case. They are hollow insulators with a conductor inside them.

**Materials, design**

- glass, porcelain, or composite polymer materials
- Cap and pin design is to keep parts of the insulator dry to increase the insulation capacity in wet conditions and avoid flashover

1.3.2.4 Conductors

Aluminium conductors reinforced with steel (known as ACSR) are primarily used for medium and high voltage lines and may also be used for overhead services to individual customers. Aluminium
conductors are used as it has the advantage of better resistivity/weight than copper, as well as being cheaper. Some copper cable is still used, especially at lower voltages and for grounding.

While larger conductors may lose less energy due to lower electrical resistance, they are more costly than smaller conductors. An optimization rule called Kelvin's Law states that the optimum size of conductor for a line is found when the cost of the energy wasted in the conductor is equal to the annual interest paid on that portion of the line construction cost due to the size of the conductors. The optimization problem is made more complex due to additional factors such as varying annual load, varying cost of installation, and by the fact that only definite discrete sizes of cable are commonly made.

Since a conductor is a flexible object with uniform weight per unit length, the geometric shape of a conductor strung on towers approximates that of a catenaries. The sag of the conductor (vertical distance between the highest and lowest point of the curve) varies depending on the temperature. A minimum overhead clearance must be maintained for safety. Since the temperature of the conductor increases with increasing heat produced by the current through it, it is sometimes possible to increase the power handling capacity (up-rate) by changing the conductors for a type with a lower coefficient of thermal expansion or a higher allowable operating temperature.

Bundled conductors are used for voltages over 200 kV to avoid corona losses and audible noise. Bundle conductors consist of several conductor cables connected by non-conducting spacers. For 220 kV lines, two-conductor bundles are usually used, for 380 kV lines usually three or even four. American Electric Power is building 765 kV lines using six conductors per phase in a bundle. Spacers must resist the forces due to wind, and magnetic forces during a short-circuit.

Overhead power lines are often equipped with a ground conductor (shield wire or overhead earth wire). A ground conductor is a conductor that is usually grounded (earthed) at the top of the supporting structure to minimize the likelihood of direct lightning strikes to the phase conductors. The ground wire is also a parallel path with the earth for fault currents in earthed neutral circuits. Very high-voltage transmission lines may have two ground conductors. These are either at the outermost ends of the highest cross beam, at two V-shaped mast points, or at a separate cross arm. Older lines may use surge arrestors every few spans in place of a shield wire, this configuration is typically found in the more rural areas of the United States. By protecting the line from lightning, the design of apparatus in substations is simplified due to lower stress on insulation. Shield wires on transmission lines may include optical fibres (OPGW), used for communication and control of the power system.

Medium-voltage distribution lines may have the grounded conductor strung below the phase conductors to provide some measure of protection against tall vehicles or equipment touching the energized line, as well as to provide a neutral line in Wye wired systems.

While overhead lines are usually bare conductors, rarely overhead insulated cables are used, usually for short distances (less than a kilometre). Insulated cables can be directly fastened to structures without insulating supports. An overhead line with bare conductors insulated by air is typically less costly than a cable with insulated conductors. A more common approach is "covered" line wire. It is treated as bare cable, but often is safer for wildlife, as the insulation on the cables increases the likelihood of a large wing-span raptor to survive a brush with the lines, and reduces the overall danger of the lines slightly. These types of lines are often seen in the eastern United States and in heavily wooded areas, where tree-line contact is likely. The only pitfall is cost, as insulated wire is often costlier than its bare counterpart. Many utility companies implement covered
line wire as jumper material where the wires are often closer to each other on the pole, such as an underground riser/Pothead, and on re-closers, cut-outs and the like.

### Conductors

<table>
<thead>
<tr>
<th>Suspended wires for electric power transmission are bare, except when connecting to houses, and are insulated by the surrounding air. Cooper has been replaced by Aluminium with steel wire core to provide the material strength.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground cable – insulated</td>
</tr>
<tr>
<td>Sea cable – insulated</td>
</tr>
<tr>
<td>Surge arresters connection detail</td>
</tr>
</tbody>
</table>

1.3.2.5 Substations

A transmission substation decreases the voltage of incoming electricity, allowing it to connect from long distance high voltage transmission, to local lower voltage distribution. It also reroutes power to other transmission lines that serve local markets. A transmission substation may include phase-shifting or voltage regulating transformers.

This distribution is accomplished with a combination of sub-transmission (33 kV to 115 kV, varying by country and customer requirements) and distribution (3.3 to 25 kV). Finally, at the point of use, the energy is transformed to low voltage (100 to 600 V, varying by country and customer requirements).
2 Construction process and costs

2.1 First step impact study, routing

One of the major problems of the lines are the using of the area below. The first step for the project is to define according to the possible consequences the best routing in term of costs and result for the crossed areas.

Use of the area below an overhead line is restricted because objects must not come too close to the energized conductors. Overhead lines and structures may shed ice, creating a hazard. Radio reception can be impaired under a power line, due both to shielding of a receiver antenna by the overhead conductors, and by partial discharge at insulators and sharp points of the conductors which creates radio noise.

In the area surrounding overhead lines it is dangerous to risk interference; e.g. flying kites or balloons, using ladders or operating machinery. In add some studies are showing that life of organism can be influenced by the electrical field. The view of the lines can also be another difficulty due to the tourism presence and real estate area in the vicinity.

Overhead distribution and transmission lines near airfields are often marked on maps, and the lines themselves marked with conspicuous plastic reflectors, to warn pilots of the presence of conductors.

Construction of overhead power lines, especially in wilderness areas, may have significant environmental effects. Environmental studies for such projects may consider the effect of brush clearing, changed migration routes for migratory animals, possible access by predators and humans along transmission corridors, disturbances of fish habitat at stream crossings, and other effects.

All these subjects shall be anticipated in the first phase of the project, then we can summarize as follow taking account of quality and reliability requirements:

Rough determination of the route, taking account of the following criteria:

- Environmental compatibility
- Low impact on nature
- Most cost-effective construction possible
- Efficient operation (small losses)
- Consideration of natural or man-made obstacles (e.g. lakes, mountains and mountain ranges, cities, conservation areas, etc.)
- Possible locations of transformer substations
- Possible locations of assembly yards
- Maintenance costs in the operating phase

2.2 Detailed planning of the transmission route

For the detailed planning, routing is carried out – an operation which involves recording and assessing the features of the terrain in particular. This routing is carried out in stages, in ever more detail.
Example of the route taken by a 380 kV line

2.3 Detailed design and execution drawings

Taking account of the results of the routing, a detailed execution plan for the overhead line is worked out. Besides a detailed geological survey (soil testing), this also includes the design planning of the pylons. This essentially depends on topological conditions (minimum clearances from objects and trees), scenic aspects (low mast height in built-up areas wherever possible) and meteorological effects (influence of wind, ice load, avalanche hazard), as well as on the number of conductor systems.

In order to ensure the highest possible level of operational safety, a thorough study of wind conditions is carried out along the entire route. Individual wind zones are established in the course of this study and the pylons are dimensioned accordingly. Particular attention must be paid to critical sections in which the topography is such that it can give rise to "funnel effects" characterised by high wind speeds. The crossing of mountain tops is also to be regarded as critical.

Sectioning into ice-load zones (if there are) is likewise carried out. In Europe this is based on a pan-European standard with individual national appendices. In critical areas, the design of pylons and conductors should be reinforced.

In areas at risk from avalanches, pylons must be provided with special protection (e.g. by means of avalanche wedges, intended to steer the avalanche forces around the pylon).

A project flowchart is drawn up for the realisation of the project. With longer lengths of transmission lines, the project as a whole is divided into individual lots (e.g. 20 km).
From the underwriter's point of view, particular attention must be paid to appropriate compliance with quality requirements, as the frequent use of parts made from the same materials means that there is a corresponding problem of serial losses. Taking into account the above the designer shall also define precisely the length of the conductors. They shall take into account the location, areas, mountains, temperature effect and thermal expansion etc. one well-known method is finite elements system applied on pulley and cable element, as indicated in “Code ASTER” which give a realistic model of the T&D line cable length calculation.

2.4 Construction phases / time schedule

In this chapter we will focus only on the T&D lines itself erection, the construction of other element as substations are well-known.

2.4.1 Preliminary work on construction

Once the detailed planning has been carried out and the approval process completed, a start can be made with the actual on-site construction work. However, considerable preliminary work is needed before the actual work of erecting overhead lines can begin. This preliminary work includes:

- Tree-felling work on routes running through forests
- Road building work
- Site facilities (usually about every 20 km)

2.4.2 Foundations

Foundations for tower structures may be large and costly, particularly if the ground conditions are poor, such as in wetlands. Each structure may be considerably strengthened by the use of guy wires to resist some of the forces due to the conductors.

Ground conditions play an important part in terms of the size of the foundation. A geotechnical ground survey should be made in order to determine the properties of the earth. In this respect, we specifically focus on the following factors:

- Level of groundwater table
- Ground conditions/ground properties – sand, clay, etc.
- Aggressive ground conditions.
In case the earth is extremely aggressive, special concrete must be used to avoid damage in the foundation. In extreme climatic circumstances a foundation must be stronger and bigger. If you are to build closely to the coast, you must consider that the wind conditions are stronger there than in the middle of the land mass. Where you are, determines the terrain class. The size of the pylon is also an important factor in the evaluation of the load on the foundation and consequently the size of the foundation.

When the foundation size is determined, the digging begins and the cast of the foundation is initiated.

For this purpose the following methods can be applied:

- The earth is dug up normally and in keeping with the size of the foundation, after which the foundation is cast.
- Bunging/Sheet piling method is applied in narrow spaces. Interlocking sheets of steel are pressed down at all four corners and the cast of the foundation starts step by step from there. The earth will not fall into the pit during the dig, since it is held by plates.
- Piling method this method is used for building an especially strong foundation. The method is suitable for places where the ground does not have a strong adhesion (sandy earth). Concrete piles are thrust into the ground into e.g. 10 metres depth with approximately half a meter to one meter above the ground. The upper part of the concrete pile is then blasted off and the iron inside the pile bent into the top layer of the foundation, which is being cast on top. Thus the foundation is anchored in the best possible way into the ground and has great static carrying capacity. The time frame depends on the size of the foundation, but it typically takes one week to cast a foundation of 5x5 metres.
- The drying of foundation depends on the time of the year and the weather. In Summer the foundation is ready for use after 1 – 2 weeks, whereas in Winter the foundation dries for about 3 – 4 weeks.

2.4.3 Pylon assembly / switch yard erection

Whereas concrete and round steel masts are supplied complete, lattice pylons are usually delivered in individual pieces and assembled into segments on site – on the ground. The pylon segments and arms are then fixed together (pylon assembly). Depending on the local conditions, this is done using either cranes or – especially in rough terrain – helicopters.

According to the type and size of the elements the preassembling is scheduled. The location of the T&D line and weight of the elements can drive to a mixed solution.
2.4.4 Cables hanging

After the erection of the steel structure and the fitting of the surge arresters, isolators, and cable reels are preassembled on the ground then they are attached to the pylon. The cable reels allow the pilot rope, pulling rope and conductors to be installed.

Parallel to this, the cable-drum and winch sites are constructed and anchored appropriately. The cable reels and cable winches are then fastened onto them. The usual and simple method is the use of drawing machine tool.

Where the transmission route crosses transportation routes such as motorways or railway lines, safety scaffolding is set up in the crossing area to prevent danger to the traffic running below in the event of any cables falling.
The pilot ropes (usually nylon ropes 10-15 mm in diameter) are then hoisted up, using helicopters. These pilot ropes are up to 6 km long and are used for attaching the cable pulling ropes.

It will allow initiating the drawing of the conductor at its place.
The pulling rope is a steel-wire rope with enough tensile strength to be able to hoist up the final conductor and the earthing conductor (lightning protection cable).

After the pulling rope, finally the (operating) conductors and, depending on the voltage level and lightning protection, one or two earthing conductors are hoisted up.
The cables are then adjusted. This involves tensioning the cables to the relevant tension and adjusting to provide the necessary sag. The cables are then braced in the case of angle pylons and clamped in the case of support pylons.

The final work consists of fitting the spacers of the individual conductor bundles (field spacers), installing the bird warning and aircraft warning spheres, and attaching the cable loops on the pylons.
2.4.5 Tests and acceptance

The test phase is very important, as it should simulate every possible operating condition. Besides visual and mechanical inspections (clamped and screwed connections), earth-fault tests are also carried out, as well as technical tests in the transformer stations. The line section is then taken into operation following a precisely specified start-up programme.

There are tower testing stations for testing the mechanical properties of towers.

2.4.6 Recultivation

Once all the work has been completed, the relevant road removal, reforestation and recultivation work is carried out.

2.5 Values of T&D lines

Investment cost. A high-voltage, direct current (HVDC) transmission line costs less than an AC line for the same transmission capacity. However, the terminal stations are more expensive in the HVDC case due to the fact that they must perform the conversion from AC to DC and vice versa. On the other hand, the costs of transmission medium (overhead lines and cables), land acquisition/right-of-way costs are lower in the HVDC case.

The here below scheme summarize the cost comparison between DC and AC line. It appear that some technical trend, such as material, diameters, and other parameters can influence the diagram, but as they are linked to the mechanical characteristics of the materials, the choice can be driven through the global parameters as mentioned. This fact explains partially the big differences which can occur between price of tow projects.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Country</th>
<th>Location</th>
<th>Power</th>
<th>Nb of systems</th>
<th>cables length</th>
<th>Line length</th>
<th>Location area</th>
<th>Current</th>
<th>Type of line</th>
<th>nb of lines</th>
<th>Duration</th>
<th>nb of workers</th>
<th>type of erection</th>
<th>Total Value ME€</th>
<th>Value in ME€ per Km</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>France</td>
<td>Normandie</td>
<td>400 Kv</td>
<td>6</td>
<td>10000km</td>
<td>150km</td>
<td>Flat</td>
<td>AC</td>
<td>Overhead</td>
<td>1</td>
<td>Unknown</td>
<td>80</td>
<td>Prefab/cranes</td>
<td>380</td>
<td>2,5</td>
<td>No pylon erection</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>North France</td>
<td>400 Kv</td>
<td>4</td>
<td>1200 km</td>
<td>80 km</td>
<td>Flat</td>
<td>AC</td>
<td>Overhead</td>
<td>2</td>
<td>1 month</td>
<td></td>
<td>roling of cables</td>
<td>60</td>
<td>0,7</td>
<td>7 km (4 miles) underground</td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>Middleton Connecticut</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>117km</td>
<td>Mixed flat/mountains</td>
<td>AC</td>
<td>Overhead/underground</td>
<td>1</td>
<td>more than 24 months</td>
<td>Unknown</td>
<td>Prefab/cranes</td>
<td>662</td>
<td>5,65</td>
<td></td>
</tr>
</tbody>
</table>

*in MEUR

Comparaison of costs on T & D over head lines
3 Insurance Aspects

3.1 Material Damages (CAR/EAR)

3.1.1 Natural perils
Transmission and distribution (T&D) lines are characterised by a widespread physical presence. Due to their high susceptibility to natural hazards, especially windstorm and ice, these lines harbour a massive loss accumulation potential. This is why insurers are carefully insuring such risks. The natural hazards accumulation risk is normally controlled by the application of reasonable sub-limits.

Although T&D lines are designed to perform during extreme weather conditions, history has shown, that even worse weather conditions could affect the network resulting in big damage. One such loss example is the big ice storm in 1998 in Canada. The storm affected an area of almost the size of Switzerland and transmission and distribution lines suffered widespread collapse due to massive ice accumulations. From a technical point of view, it is quite clear that transmission lines were not built to withstand such a large amount of ice.

Another hazard is flood exposure of overhead power transmission line foundations during construction. Excavation works for foundations of power transmission lines can suffer severe damage caused by erosion or stagnant water. Pouring of concrete for foundations should occur within a few days following completion of the excavation. The number of excavations open at any one time should be limited to the minimum required for the performance of works according to the local conditions and works programme. Unless compliance is evident a special condition or preferably special exclusion should be added.

The Taiwan EQ in 1999, (21st of September), shown that T&D lines are susceptible to landslide damage following an earthquake.

Bush fire can also represent a large exposure for the T&D lines. This exposure can be reduced by the control of the vegetation and/or adequate routing.

Lightning is also a possible peril, nevertheless, some equipment is fitted to deal with such exposure, during the maintenance this peril and damaged equipment is excluded.

3.1.2 Serial Losses
A transmission line basically consists of masts or poles and wires. Consequently the same kind of losses could be triggered by the same failure of design, workmanship or material. This could be limited by adding a serial loss clause.

3.1.3 Theft and burglary
Because of the recent increase of copper prices, the hazard to theft of copper cables has increased. This can be limited by storing the wires in guarded and fenced in storage areas.
3.1.4 Access roads
T&D lines are found almost everywhere on earth from mountainous areas to the desert, from cities to areas with almost no inhabitants. Especially for remote areas, access to the construction site can be very difficult or even be inaccessible for some time during the year because of snow. In case of damage, this could prolong the repair time, as well as increase the repair costs, after demobilisation of the working construction site and preassembling areas, in particular during the maintenance period.

3.1.5 Inland Transit
The size of transported equipment might cause difficulties because of limited access roads. Inland transit cover should therefore be carefully assessed.

3.1.6 Special equipment
Special equipment such as cranes or helicopters might be needed for the construction of a T&D line. Following a loss, this might trigger additional costs because such equipment is not readily available.

3.1.7 Reliability of electrical power system
The power system should be designed in such a way that no damage occurs in case of a reasonably foreseeable contingency. This means that design criteria take into account natural events of a certain return period (e.g., 50 years). Consequently, one could consider a clause that excludes losses below the design criteria for natural perils.

3.2 Third Party Liability
Third party liability exposure depends very much on the route of the T&D line. It can be very low in remote areas such as mountains but significantly increase in areas of large populations such as cities. Consequently, TPL exposure must be carefully assessed for each individually project.

TPL exposure will be in direct relation to urban density. The lower the voltage, the higher the penetration of urban areas! The most important exposure phases are related to the connection works to the grid and town substations and testing & commissioning period. Damages to crops, forest, and cultures as a consequence of fire could happen in some country areas, and can be controlled by adequate endorsement. Scaffolding and other method of protection shall be provided to minimize and mitigate surroundings exposure.

Employers Liability during construction and erection period should be considered due to the nature of the works.
3.3 Delay in Start Up

3.3.1 General
The sum insured under DSU generally amounts to the difference between expected revenues and the variable costs, ie costs not incurred if the project is inoperative. This is also called the annual gross profit. The insurance can only be triggered by a material damage loss covered under section 1 of the CAR/EAR policy. Indemnity under the policy should be on actual loss sustained basis. For a detailed description of the DSU we refer to the IMIA paper WGP 63 (09).

The main issue in order to establish the scope of this cover is the difficulty in determining the real impact on profit due to interrupted line as usually lines are connected in a grid with alternative routing. Developing countries have a higher exposure due to the lack of development of their grids, therefore the alternative routes cannot be considered in case of a loss.

The delay in restoring and repairing works can be longer depending on the difficulty of access.

3.3.2 Electrical price volatility and leeway clause
The price for electrical energy is very volatile. This is why it is rather difficult to know what the actual loss sustained could be in case of a delayed start up of a plant a few years after policy signing.

The effect of the price volatility of electrical energy can be limited by a leeway clause. This means that a change on the price up to a fixed percentage of the sum insured for DSU could be included. However this should not change that a claim shall always be indemnified on the basis of actual loss sustained. In addition, the maximum indemnity should not exceed the sum insured multiplied
for the leeway stated in the policy. The premium should be adjusted at the end of the policy period accordingly.

3.3.3 Consequential damages
Our world has become extremely dependent on electrical energy. As a consequence, even a small damage to a power line can affect many industrial plants that depend on electricity supplied by the line resulting in large consequential business interruption losses. Needless to say that the consequential damage to an industrial plant that depends for its operation on the T&D line can be very costly. The corresponding exposure should therefore be assessment carefully.

3.3.4 Contingent Business Interruption
DSU can be extended to include contingent events like Denial of Access, Public Authorities, Suppliers and Customers. With regard to these exposures we refer to the IMIA paper WGP 55 (08) Contingent BI in Engineering Insurance. CBI covers are very exposed mainly if NAT/CAT applies.

3.3.5 Increased Costs of Working (ICOW)
One big advantage of electrical power is that it can be easily transported via large distances. The failure of an overhead line does not necessarily mean complete loss of power to a region because there might be possible alternatives that could be used to reroute electrical energy. The costs due to rerouting could be covered by the increased cost of working section.

3.3.6 Risk Management service
The implementation of adequate risk management measures plays an important role when insuring T&D lines.

3.4 Accumulation
Accumulation of T&D lines is mainly an issue of operational covers. The reason for this is, that T&D lines under construction will exit the construction policy as soon as the risk is handed over to the principal or put into operation.
4 MPL Considerations

The Maximum Probable Loss is an estimate of the maximum loss which could be sustained by the insurers as a result of any one occurrence considered by the underwriter to be within the realms of probability. This ignores such coincidence and catastrophes as may be possibilities, but which remain highly improbable”.

The aim of this section is to provide underwriters with the most likely MPL scenario and basic assessment process for T&D lines construction projects according to the above MPL definition by IMIA which is a standard extensively used and accepted for Engineering insurance business.

As MPL assessment depends on several peculiar and geographical instances all the relevant considerations have been dealt with according to criteria governing loss events frequency and severity regardless of specific situations which would certainly affect the MPL rationale but cannot be addressed in details in a general paper.

These factors can be briefly grouped into four categories as follows.

- Policy wording scope (perils covered and extensions);
- External hazards;
- Natural hazards;
- Project intrinsic hazards.

4.1 Policy wording scope

The wording directly applies to material damage MPL assessment to estimate the ultimate exposure under the policy resulting from the combination of technical aspects and insurance related issues (e.g. limits, sub-limits and special covers).

The most common extensions which have to be included in the MPL assessment (full limits summed up to base MPL material damages) are:

- Expediting expenses;
- Removal of debris;
- Escalation/indexation clause;
- Existing Properties;
- Increased cost of working;
- Experts fees
- Third party liability (if the relevant section is part of the policy)

In particular, policy wording and scope of cover can have some relevant impact on MPL assessment as overhead T&D lines are commonly built up as a series of identical elements (e.g. towers). Coverage extensions such as Faulty design and workmanship without Serial losses clause to limit exposure for events triggered by the same recurring cause can result in large claims because of the number of affected items.
ALoP/DSU exposure, if included in the coverage, has to be carefully considered as minor material damages can result in large claims when it takes a long time to repair them (e.g. because of spare parts lack/delivery timing or difficult access to an area during certain periods).

4.2 External hazards

External hazards category refers to perils rising from entities/individuals neither part of the project environment nor involved in its development.

Given the strategic importance of T&D lines (power supply) and the actual impossibility to have continuous watchman service and/or fenced areas all along the construction site, it makes exposure to third party individuals’ actions somewhat critical. Terror attacks (easy target and large consequential damages rising from delay in start up) and consequences of strikes, riots or civil commotions can affect this type of projects with higher frequency than other engineering projects with well-defined and watched locations.

Valuable goods stored at the construction site or partially assembled along the line (copper cables and ceramic insulators) are also exposed to theft notwithstanding the relative difficulties rising from transportation of bulky items.

Finally, other nearby man-made hazards (e.g. upstream dams, airport and motorways) should always be adequately taken into consideration as they could result in an increased exposure to flood and aircrafts/vehicles impact.

4.3 Natural hazards

Natural hazards as already mentioned in our paper, are the most likely MPL scenario for most of the T&D lines projects. The length of these lines (up to hundreds kilometres) and the relative low value per kilometre suggest an event - like earthquake, flood or wind storm - affecting large sections of a line to be the actual MPL scenario.

Material damages severity due to natural hazards mainly depends on the maximum wideness of the T&D line section (it could also be up to the full line for specific hazards like Earthquake) which can be actually affected by a single event.

Partial handover of T&D lines, other than for large projects including different sections part of a network, is usually not possible as a line from A to B can be operated only when it is completely finished and connected to its own substations.

As a consequence, completed sections not in operation remain exposed to natural hazards for the whole construction policy period until the completion of the whole project.

A full list of natural hazards to be considered for T&D lines MPL assessment is included in the Loss Scenario paragraph.

4.4 Project intrinsic hazards

Single elements of a T&D line do not present any key exposure as foundations, tower frames, cables and insulators are well-known and engineered items.
On the other hand, T&D lines can run through remote and impervious areas where site accessibility, erection of high-rise towers and soil conditions can be critical.

Use of special equipment like mobile cranes or helicopters results in additional exposure during erection phases as these equipments are critical to operate and subject to changes in local conditions which could affect their effectiveness (e.g. bad weather, wind, crane stabilizers not appropriately positioned on stable soil) resulting in material damages like partial tower collapse.

4.5 MPL Assessment Process

A general guidance to the MPL assessment process including detailed information on each stage is provided by means of the following flowchart.

Project Information can consistently vary case by case and sufficient information depends on specific features although they should at least grant to identify the construction process (including critical path/key operations) and a breakdown of costs for various items.

Once the most probable hazards have been identified an easy cross-check of Probable Maximum Loss (PML) and Maximum Possible Loss (MPL) helps to better define the cost of reinstating the lost or damaged portion of works under PML scenario. Finally, additional costs because of policy extensions have to be added up to the amount of physical damages to get the MPL which is usually more than the original cost of damaged items.

<table>
<thead>
<tr>
<th>PROJECT INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&amp;D line features</td>
</tr>
<tr>
<td>Construction method</td>
</tr>
<tr>
<td>Project location (morphology, meteorological data, etc.)</td>
</tr>
<tr>
<td>Project time schedule (critical path and local exposures)</td>
</tr>
<tr>
<td>Project value and cost per unit (e.g. per kilometre/section)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RISK EXPOSURE ANALYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most probable hazards to affect the project</td>
</tr>
<tr>
<td>Risk management/mitigation measurers in place</td>
</tr>
<tr>
<td>Policy wording terms and conditions</td>
</tr>
</tbody>
</table>
4.6 MPL and Loss Scenarios

Loss scenarios which can affect T&D overhead lines projects are various and their impact (frequency and severity) varies significantly depending on local conditions. The table below shows the most common scenarios grouped by hazards categories described in previous paragraphs and this can be considered as a rationale irrespective of specific projects features and local external conditions which could be prevailing on other hazards.

The scenarios are a solid base to identify major exposures but they cannot be accounted as completely exhaustive of possible loss circumstances.

<table>
<thead>
<tr>
<th>Hazards</th>
<th>MPL Scenarios</th>
<th>Frequency</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural hazards</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthquake</td>
<td>Total loss of most of the towers (incl. foundations) and cables for projects within 50km from the epicentre.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ice and snow accumulation</td>
<td>Large sections of the line (e.g. highest elevation amsl) can be affected by the same event resulting in towers and cable collapse.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Wind storms</td>
<td>Large sections of the line can be affected (mainly towers) for a continuous period also during cable laying.</td>
<td>2) X</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>Total loss of foundations and earthworks for large sections (e.g. in a valley) plus possible towers collapse.</td>
<td>1) X 3) X</td>
<td></td>
</tr>
<tr>
<td>Landslides and avalanches</td>
<td>Limited sections affected by total losses resulting in consistently increased costs of /time for reconstruction.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Lightning</td>
<td>Lightning storms usually affect limited areas with possible damages to a limited number of substation(s) and/or single towers.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Subsidence</td>
<td>Local effects depending on subsoil conditions affecting towers' foundations (also as consequence of EQ).</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>External Hazards</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aircraft impact</td>
<td>Minor local damages depending on nearby airfields and missing signals during cables laying across valleys.</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td>Bush fires</td>
<td>From limited to large sections affected by bush fires ignited by external causes resulting in damages to towers (jeopardized stability) and cables (efficiency).</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td><strong>Terrorism &amp; SRCC</strong></td>
<td>Local attacks (e.g. explosive devices) to destroy substations or single towers are most likely limited to restricted areas/sections.</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Theft</strong></td>
<td>Theft of minor to moderate quantities of valuable goods (bulky items) stored at the construction site or partially assembled along the line.</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Nearby man-made hazards</strong></td>
<td>Railway lines, motorways, other overhead lines, power plants, dams (basins/tailing facilities) etc. which bring additional exposure due to related activities (e.g. fuel, pressure vessels explosions or flood waves).</td>
<td>X</td>
<td>4) X</td>
</tr>
<tr>
<td><strong>Project intrinsic hazards</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire</strong></td>
<td>The most exposed items are substations and storage areas and PML usually refers to the largest fire unit.</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Faulty design and workmanship</strong></td>
<td>Serial items (e.g. towers, cables or insulators) can suffer losses triggered by the same fault (faulty workmanship) although well-consolidated technologies and material allow considering the exposure as moderate.</td>
<td>X</td>
<td>5) X</td>
</tr>
<tr>
<td><strong>Construction operations</strong></td>
<td>Lifting, erection and cable laying operations are intrinsically risky given special equipments and high rise structures although related to limited sections (e.g. 1 tower total loss because of crane’s jib failure).</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1) Frequency is not included for Natural hazards as it depends on the location of the project.
2) Wind storm severity have to be increased to High in case of projects located in areas subject to heavy snow falls/freezing rain or hurricanes/typhoons. A layer of ice 1 cm thick means an additional weight of almost 100 kg per 100 m and it increases the diameter and, with it, the area of the cable exposed to wind forces.
3) Flood severity can be considered Low where morphology allows to clearly separate different flood areas/chat basins.
4) Nearby man-made hazards have to be increased to High in case of upstream dams or other installations which can trigger events which affects large areas.
5) Faulty design severity has to be increased to Medium in case serial losses limits are not included in the policy wording.
6) Natural hazards:
   a. Earthquake: High exposure during the execution of foundation, substation and pylon erection. Direct and indirect damages and collapse of pylons could happen.
   b. Windstorm: producing losses over the whole project but mainly affecting pylons.
   c. Ice & Snow: Combined effect of ice and wind could change the aerodynamic conditions of the cables as a consequence of the higher charges produced by the deposit of ice and snow on them. Higher exposure at the end of the construction period and during testing. Snow avalanches in hilly areas producing collapse of pylons.
   d. Wild fire: producing damages in the substation and stored equipments.
   e. Lightning: basically affecting substation and eventually one pylon.
   f. Flood: Direct and indirect damages due to landslides affecting excavation works, foundations, access roads and producing pylons collapse.
   g. Thermal Phenomena / Solar wind: Induction current problems due to solar irradiation.
   h. Soil conditions: affecting to excavation works and foundations.

7) Man made hazards:
   o Terrorism: Higher exposure on substation due to accumulation. Some damages have also been produced to pylons.
   o SRCC: damage to substation that is the most exposed part of the project due to accumulation.
   o Theft: Stored equipments (mainly cables) in case of absence of security measures.
   o Operational Errors: basically affecting to substation during testing and commissioning period.
   o Aircraft collision: producing loss or damage in pylons, cables and isolators during maintenance period as a consequence of Maintenance works.
4.7 SUMARY THROUGH RISK MATRIX DEFINITION

**CAR/EAR:**

<table>
<thead>
<tr>
<th>PERILS vs PHASES</th>
<th>Erection/Construction Phase</th>
<th>Testing&amp;Commissioning</th>
<th>Maintenance</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Foundation</td>
<td>Substation</td>
<td>Pylon Erection</td>
</tr>
<tr>
<td>Natural Hazards</td>
<td>Earthquake</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
</tr>
<tr>
<td></td>
<td>Windstorm</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
</tr>
<tr>
<td></td>
<td>Ice&amp;Snow</td>
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<td>Pylon/Cable</td>
</tr>
<tr>
<td></td>
<td>Wild fire</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
</tr>
<tr>
<td></td>
<td>Lightning</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
</tr>
<tr>
<td></td>
<td>Flood</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
</tr>
<tr>
<td></td>
<td>Thermal Phenomena / Solarwind</td>
<td>Substation</td>
<td>Substation</td>
</tr>
<tr>
<td></td>
<td>Soil Conditions</td>
<td>Substation</td>
<td>Substation</td>
</tr>
<tr>
<td>Man made hazards</td>
<td>Terrorism</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
</tr>
<tr>
<td></td>
<td>SRCC</td>
<td>Substation</td>
<td>Substation</td>
</tr>
<tr>
<td></td>
<td>Theft</td>
<td>Substation</td>
<td>Substation</td>
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<tr>
<td></td>
<td>Operational Errors</td>
<td>Substation</td>
<td>Substation</td>
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<tr>
<td></td>
<td>Aircraft collision</td>
<td>Pylon/Cable/Isolator</td>
<td>Pylon/Cable/Isolator</td>
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<tr>
<td></td>
<td>Defaults in design</td>
<td>Substation/Isolator</td>
<td>Substation</td>
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<tr>
<td></td>
<td>Defaults in erection</td>
<td>Substation</td>
<td>Substation</td>
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<tr>
<td></td>
<td>Defaults in material</td>
<td>Substation</td>
<td>Substation</td>
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</table>

<table>
<thead>
<tr>
<th>PERILS vs EQUIPMENTS</th>
<th>Foundation</th>
<th>Pylon</th>
<th>Cable</th>
<th>Isolator</th>
<th>Transformer</th>
<th>Switch</th>
<th>Stored Equipments</th>
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<tr>
<td>Natural Hazards</td>
<td>Earthquake</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
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<td>Windstorm</td>
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<td>Ice&amp;Snow</td>
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<td>Wild fire</td>
<td>Substation/Pylon</td>
<td>Pylon/Cable</td>
<td>Substation/Pylon</td>
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<td></td>
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<td>Pylon/Cable</td>
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<td>Substation</td>
<td>Substation</td>
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</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Defaults in material</td>
<td>Substation</td>
<td>Substation</td>
<td>Substation</td>
<td>Substation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.8 Policy MPL Calculation

Given a certain MPL scenario, the actual policy MPL calculation results from the best estimate of the relevant material damages - also considered as a percentage of the Total Sum Insured or Total Contract Value - and the whole amount of policy extensions according to their own sub-limits.

The escalation index (if included in the policy by means of an escalation or leeway clause) has to be applied to the material damages value for the chosen PML scenario.

4.9 Example

<table>
<thead>
<tr>
<th>Sum Insured/Policy Limits [Euro]</th>
<th>MPL [%]</th>
<th>MPL [Euro]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contract Works</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Damages</td>
<td>250,000,000</td>
<td>27%</td>
</tr>
<tr>
<td>Escalation %</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Escalated Replacement Cost</td>
<td>275,000,000</td>
<td></td>
</tr>
<tr>
<td><strong>Policy extensions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Removal of Debris</td>
<td>10,000,000</td>
<td>100%</td>
</tr>
<tr>
<td>Expert Fees</td>
<td>2,500,000</td>
<td>100%</td>
</tr>
<tr>
<td>Expediting Expenses</td>
<td>2,000,000</td>
<td>100%</td>
</tr>
<tr>
<td>Other</td>
<td>2,500,000</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>292,000,000</td>
<td></td>
</tr>
<tr>
<td><strong>Advanced Loss of Profit /DSU</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indemnity Period</td>
<td>12 months</td>
<td></td>
</tr>
<tr>
<td>Time Excess</td>
<td>30 days</td>
<td></td>
</tr>
<tr>
<td>Gross Profit</td>
<td>24,000,000</td>
<td>11/12</td>
</tr>
<tr>
<td>Claims Expenses</td>
<td>100,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>24,100,000</td>
<td></td>
</tr>
<tr>
<td><strong>Combined PML</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Damages</td>
<td>91,250,000</td>
<td></td>
</tr>
<tr>
<td>ALoP/DSU</td>
<td>22,100,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PML figures above refer to 100% PML calculation (regardless of the share written by a single insurer) and extensions have been included up to their own limits (safe side) while ALoP/DSU loss refers to the full indemnity period excluding the relevant time excess (30 days = 1 month).

Third Party Liability, if covered under CAR/EAR policy by means of a separate section, has to be accounted in the MPL assessment as 100% of its limit for each single event as most of the T&D lines are part of relatively large networks (grid) of interconnecting facilities which belong to third
parties and can be damaged (including consequential damages due to impossibility to sell or buy power through the grid) in case of construction or testing operations of new sections/lines.

The application of similar calculation sheets to the main loss scenarios will show which one results in the highest combined MPL.
5 Recommendations for underwriters and clauses issues

To be in position to handle the risk in a good shape, some subjects shall be carefully weighed:

- Phasing and routing documents are mandatory
- Work in section clause (according to standards)
- Open foundation clause
- Pilling clause
- Serial loss clause
- The flood exposure can be limited by adding an endorsement which gives limitation to the return period.
- Fire fighting facilities
- Creeps and forest for TPL
- Wind speed, and more generally whether limits especially with helicopters and - DSU cover.
- Damages to access to site
- Temporary camps and store
- Partial hand over
6 Examples of losses:

Technically T&D lines are in construction basically standard risk, some subjects shall be handled during risk analysis, a lot of example affected operational risk, construction risk analysis shall take into account the phasing, seasons and mitigate the risk accordingly, that is not possible during operational. This exposure is reinforced on operation due to the old design and old steel on existing T&D lines. The following examples show claims especially during operation of the lines.

Buckled 220 kV pylons following Windstorm Emma about 20 items on the ground (in operation)

Icing on an overhead line (January 2010 during operation)
Erosion of foundation following flooding (operation) Danger from landslide/mudflow (operation)

Potential for terrorist attacks

Danger from avalanches