# DESIGN OF MV AND HV COVERED CONDUCTOR OVERHEAD LINES

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***SUMMARY***

*Covered conductors (CC) have been used in MV electrical distribution networks since 1970's in Finland. In the middle of 1990's the use of covered conductors has been expanded to high voltage level (110 kV). This paper presents newest findings regarding the design of covered conductor overhead lines. First the general features of covered conductor lines are presented. After that the environmental and safety advantages of covered conductor lines are shown. Then the status of European standardisation of covered conductor overhead lines is gone through. Also the topic of safe design tension of a covered conductor is discussed. Furthermore, new accessories that enable more reliable power distribution with covered conductor system are shown. In addition, advantageous solutions in supporting structures that yield to lower cost are presented. Finally, some considerations regarding the future developments of covered conductor lines are given.*

## COVERED CONDUCTOR OVERHEAD LINES

A MV covered conductor is typically composed of a compacted aluminium alloy conductor on top of which a single weather resistant XLPE-insulation is extruded. The construction of a HV covered conductor is more complex containing insulation and semiconducting layers.

Figure 1 shows two covered conductor lines (MV and HV) in Tuusula, Finland.

Figure 1. MV and HV covered conductor lines in Tuusula, Finland.

The basic idea for using covered conductors is to make the line more tolerable against conductor clashing and trees leaning on the conductor, cf. figure 2. Furthermore, covered conductors enable reduced phase distances making the line even more compact when compared to conventional bare conductor overhead line. This feature can be utilised by upgrading an old bare conductor line to a covered conductor line with increased power delivery capacity without need to widen the right of way.

Figure 2. Typical condition faced by MV lines in Finland during wintertime.

Uninterrupted energy supply is nowadays taken for granted by the customers: network companies have to compensate electricity not provided or even indirect damages caused by the outages. This puts heavy demand to the reliability of the network and its components. Over the years covered conductor overhead lines have proven to be a sustainable solution in tough weather conditions.

Recently, the profitability of cabling in MV networks in Finland was studied in [1]. In this study the investment, maintenance and outage costs were included. The results indicated that underground cable is approximately 30 % more expensive in rural population centre and industrial area than covered conductor overhead line.

## ENVIRONMENTAL AND SAFETY ASPECTS

Today environmental and safety issues have grown in importance. More and more pressure is put to network owners to use environmentally acceptable and safer electricity lines. Naturally this creates a challenge to conductor and accessory manufacturers to be able to provide solutions which meet the new demands.

European Commission has launched Integrated Product Policy (IPP) approach in order to reduce the life cycle environmental impacts of products [2]. One of the fundamental issues in IPP is eco-design, which takes into account the product life cycle.

Environmental impacts of different LV and MV energy supply systems were studied in [3]. Studied MV systems included underground cable, bare and covered conductor overhead lines. The results of the life cycle assessment (LCA) indicated that underground cable is the most harmful to the environment with a clear difference to bare and CC lines. Major reason for this is that after usage cable is left into the ground and not recycled. The failure rate, effects of electromagnetic fields (EMF) and landscape were discarded.

The failure rate (number of outages) of covered conductor lines is close to that of underground cables. Furthermore, the phase distances in covered conductor lines are smaller than in bare lines, which will reduce the EMF effect and also allow narrower wayleave. It is evident that if one takes into account also these factors, the covered conductor overhead lines produce smallest environmental impact and thus can be regarded as an *eco-line*.

An additional benefit of using covered conductor lines is increased safety in comparison to bare lines. According to the statistics of Finnish Safety Technology Authority [4] there has been on average one fatal accident per year in recent ten-year period related to bare MV overhead lines (this accounts for ca. 30 % of all fatal electrical accidents). A typical accident is that the boom of the crane hits to the bare overhead line. It is probable that these kinds of accidents could be avoided with CC lines (provided that the covering is not peeled off). In [5] it is suggested that HVCC lines should be used in places where additional safety is needed, e.g. river crossing where one could accidentally touch lines with a fishing rod.

## STANDARDISATION OF COVERED CONDUCTORS

CENELEC is the European Committee for Electrotechnical Standardisation. It has recently issued *EN 50341: Overhead electrical lines exceeding AC 45 kV* [6]. The work for standard concerning medium voltage overhead lines is under process. *EN50XXX: Overhead Electric Lines with Rated Voltages Exceeding AC 1 kV up to and including AC 45 kV* is largely based on EN 50341 and covers only additional requirements and simplifications that apply only to this medium voltage range. In this standard covered conductor lines will be included.

In addition, there are two component standards under preparation, which are dealing with covered conductors for overhead lines and the related accessories for rated voltages above 1 kV AC and not exceeding 36 kV AC

- *prEN 50397-1- Part 1: Covered conductors*
- *prEN 50397-2- Part 2: Accessories.*

So in the future there will be comprehensive standardisation to assist design and construction of MV covered conductor lines.

Since the use of covered conductors in HV lines is a relatively new idea there is no directly applicable standards available. In such cases, the designer must lean on existing standards and experimental testing, some guidance is given in [7].

## SAFE DESIGN TENSION

The first CC lines suffered from aeolian vibration damage due to inadequate damping. Too low damping inherited from excessive conductor tension used in these lines. Today, the applied conductor tensions at 0 °C temperature are in the range of 20…40 MPa. In Finland it is recommended not to use higher EDS tension than 35 MPa [8].

Cigre has published a report concerning safe design tensions of unprotected conductors with respect to aeolian vibration [9]. In this report safe design tensions are given by means of the parameter $H/w$, where $H$ is the conductor tension at the average temperature of the coldest month and $w$ is the conductor weight. Furthermore, the terrain type where the overhead line is situated has influence on the vibration activity: open flat terrain type yields to laminar wind flow (low turbulence) and thus high wind power input to the conductor. This means that higher conductor tension can be tolerated in a terrain type, which has obstructions e.g. trees, buildings etc. in comparison to open flat areas, cf. table 1.

TABLE 1 - Recommended maximum conductor safe design tensions at the average temperature of the coldest month as a function of terrain category (TC) [9].

| TC | Terrain characteristics | $H/w$ [m] |
|---|---|---|
| 1 | Open, flat, no trees, no obstruction, with snow cover, or near/across large bodies of water; flat desert. | 1000 |
| 2 | Open, flat, no obstruction, no snow; e.g. farmland without any obstruction, summer time. | 1125 |
| 3 | Open, flat, or undulating with very few obstacles, e. g. open grass or farmland with few trees, hedgerows and other barriers; prairie, tundra. | 1225 |
| 4 | Built-up with some trees and buildings, e.g. residential suburbs; small towns; woodland and shrubs. Small fields with bushes, trees and hedges. | 1425 |

Table 2 shows safe design tensions for typical covered conductors used in Finland. In the conductor tension calculation it has been assumed that the ruling span of the line is 70 m (150 m for LMF SAX conductors) and the average temperature of the coldest month is –5 °C. The LMF SAX conductors are used in HV lines.

TABLE 2 - Calculated safe design tensions expressed as percentage of ultimate tensile strength (UTS) of the conductor at 0 °C temperature for various covered conductors.

| Conductor | Tension at 0 °C temperature [% of UTS] | | | |
|---|---|---|---|---|
| | TC 1 | TC 2 | TC 3 | TC 4 |
| SAX-W 50 | 11 % | 13 % | 14 % | 16 % |
| SAX-W 70 | 11 % | 12 % | 13 % | 15 % |
| SAX-W 95 | 10 % | 11 % | 12 % | 14 % |
| SAX-W 120 | 10 % | 11 % | 12 % | 14 % |
| SAX-W 150 | 9 % | 11 % | 11 % | 13 % |
| LMF SAX 185 | 16 % | 18 % | 19 % | 23 % |
| LMF SAX 355 | 15 % | 17 % | 18 % | 21 % |

Table 2 suggests that in terrain type 2 the maximum safe design tensions are 11…13 % of the conductor's ultimate tensile strength (UTS) for the studied MV line conductors. Higher tensions can be used if additional damping is introduced to the system, e.g. by means of vibration dampers. Aeolian vibration danger can also be assessed by using analytical methods or by conducting vibration measurements, see [10].

The HV covered conductors can be strung to higher tension than MV covered conductors, cf. table 2. However, in HV lines built in Finland the applied tension has been ca. 13 % of the UTS. It has been demonstrated both analytically and experimentally that this value leads to a sufficient conductor lifetime estimate [10, 11].

## DESIGN CONSIDERATIONS OF CONNECTORS

Connectors are very crucial components in electrical networks. The main purpose of a connector is to transmit electricity from one conductor to another. From the electrical point of view the connector should transmit electricity with smallest possible losses. From the mechanical point of view the connector should be able to hold conductors together without causing damages to them and sustain climatic loading.

In a covered conductor line insulation piercing connectors (IPC) are used. IPC contains aluminium teeth that penetrate through the insulation into the aluminium conductor. A good initial electrical performance can be guaranteed if there is considerable teeth penetration (very good contact). However, this may lead to disastrous fatigue performance of the conductor due to wire breakage and thus finally poor electrical performance.

## NOVEL COVERED CONDUCTOR ACCESSORIES

### Tension Clamp

The ideal solution for covered conductor lines is to use accessories that can be installed without peeling off the insulation. This makes the installation process easier and also improves the watertightness of the whole system.

Figure 3 shows a new type of tension clamp which can be used both with bare and covered conductors. This clamp has an integrated IPC to connect the clamp to the same potential as the conductor eliminating thus possible RI effects. In addition to the normal tensile testing the clamp has undergone a tensile test under cycling temperature and a vibration test to check that adequate lifetime is achieved for the conductor clamp system.

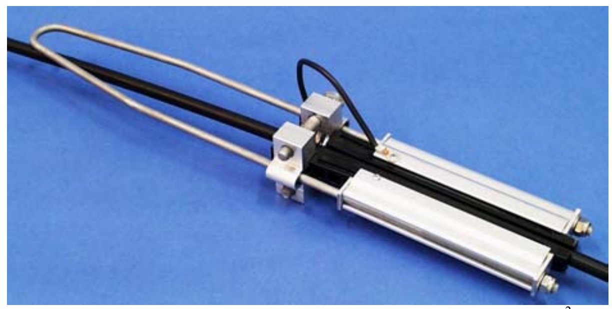

Figure 3. Tension clamp SO 235 for covered conductors up to 70 mm$^2$.

Since this clamp enables adjusting the conductor tension in the line, it can be used for live line work in order to make a disconnection point to the line, cf. figure 4.

Figure 4. Live line disconnection point under work.

### Disconnector

From time to time there arise occasions that some part of the network needs to be disconnected. Typically this happens during repair work, e.g. removing trees leaning on the line or transformer maintenance. Many times ordinary disconnector with breaking capacity is a too sophisticated solution. In order to make the fault recovery time shorter one needs to have several disconnection points (sections) in the line. This is, however, very expensive with conventional disconnectors. On the other hand disconnection point with a jumper, cf. figure 4, might be too slow to operate and needs a full live line crew.

Figure 5 present a simple disconnector that can be easily operated with live line stick phase by phase. This type of solution is ideal for maintenance based disconnection i.e. full breaking capacity is not needed, only idle currents of a line or a cable are broken.

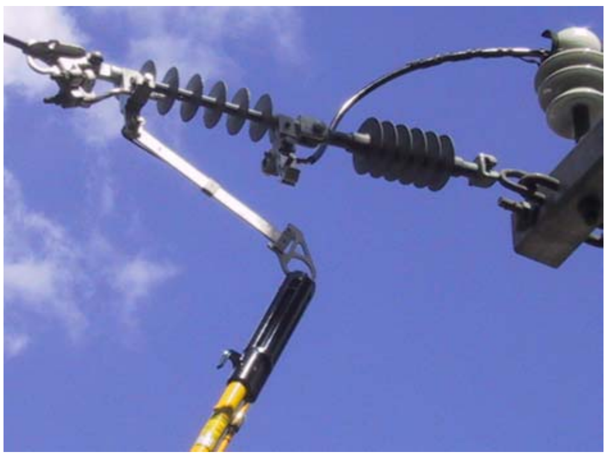

Figure 5. SZ 24 disconnector operated with live line stick.

## ARC PROTECTION OF CC LINES

Lightning produces overvoltages to the overhead lines either striking directly to the line or the neighbourhood of the line. In the cover conductor line the light arc burning point cannot move due to covering and this can lead to damage of the covering or the conductor itself. Light arc damages can be avoided if appropriate protection method is used.

Light arc protection can be arranged in several ways, a comprehensive comparison between various methods is shown in [12].

Light arc protection should be applied e.g. in fields, high spots of terrain where the appearance of overvoltages is probable. Furthermore, it should be applied in lines near the places where people stay or pass frequently [8].

In the study made in [13] it is shown that the use of arc protection systems can be evaluated on economical basis. The cost of repair for permanent line damage and the costs of line failures leading to impaired quality of electricity are compared with the cost of installing arc protection systems. Factors needed to be taken into account are e.g. the lightning density, the height of the trees in the vicinity of the line, the specific resistance of the ground, the relative number of stayed poles, and the presence of other lines near the CC lines.

## SUPPORTING STRUCTURES

As already mentioned covered conductors enable reduced phase distances, normally one can apply one third of the phase distance of a bare line [8].

This means that also more compact supporting structures are enabled. Figure 6 shows typical MV double line construction used in Finland.

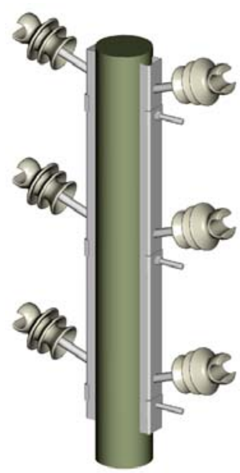

Figure 6. SH 157 double CC line crossarm.

The wooden pole has proven to be the most economical pole solution. Wooden poles can be used even in HVCC lines, see figure 7. Normally wooden poles are directly embedded in to the ground so that no special foundation is needed. According to Finnish experience the lifetime of a CCA treated wooden pole is ca. 40 years and a creosote treated pole more than 50 years.

Recycling of the used pole material (treated wood) is essential to minimise negative environmental impact. Today the used poles are utilised as an energy source in special power plants that can clean combustion gases from metallic compounds.

## FUTURE DEVELOPMENTS

In 2000 a pilot line called Forest-Sax line was taken into trial usage. This 110 kV covered conductor line is equipped with the special fault detection system, which enables e.g. location of tree leaning on the line. Due to this system the line corridor can be made significantly narrower, cf. figure 7. The narrow wayleave introduces savings in land purchase cost to the network company. Furthermore, a compact line is environmentally more acceptable solution.

Figure 7. Falling tree test in Forest-Sax line.

While HV lines with covered conductors are relatively young, the use of covered conductors in MV lines is nowadays standard practice. However, there are still development possibilities to improve the MVCC system even further, e.g. taking advantage of new materials.

## CONCLUSIONS

Network companies are faced with increasing demands to supply energy without any disruptions. Network owners may have to compensate direct and even indirect consequences resulted from undelivered energy to the customers.

This challenge can be tackled by increasing reliability of the network and minimising repair time. Covered conductors provide a cost-effective method to increase overhead line reliability. In the case of network failure, the damage to the customers can be minimised if the network is properly sectionalised so that problem section can be cut out. The number of service breaks can be also decreased with live line work. It is essential that overhead line accessories enable live line work possibility.

In addition to increased reliability covered conductor lines offer enhanced safety and environmental features.

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