

## FINNISH AND SLOVENE EXPERIENCE OF COVERED CONDUCTOR OVERHEAD LINES

**TAPIO LESKINEN\***  
**ELTEL NETWORKS**

**(Finland)**

**VIKTOR LOVRENČIČ**  
**C&G d.o.o. LJUBLJANA**

**(Slovenia)**

### SUMMARY

*Network companies are faced with increasing demands to supply energy without any disruptions. This challenge can be tackled by increasing reliability of the network. Covered conductors (CCs) provide a cost-effective method to increase overhead line reliability. This conclusion is supported by Finnish and Slovene experience.*

*This paper reviews the advantages of covered conductor lines. Furthermore possible problems related to the covered conductor lines are discussed. Also novel covered conductor accessories that enable more reliable power distribution with covered conductor system are introduced. Finally, some considerations regarding the future developments of the covered conductor lines are given.*

### KEYWORDS

Overhead line – Covered conductor – Safety – Environment – Reliability – Aeolian vibration

### 1. INTRODUCTION

The covered conductor technology has been used from 1970's in MV distribution lines. In the 1990's the use of CC lines has expanded to HV overhead lines. Figure 1 shows two covered conductor lines (MV and HV) in Finland.



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

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\* tapio.leskinen@eltelnetworks.com

Standardization of covered conductors in European level is going on, 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: Covered conductors
- prEN 50397-2: 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 are no directly applicable standards available. In such cases, the designer must lean on existing standards and experimental testing; some guidance is given in [1].

## **2. ADVANTAGES OF COVERED CONDUCTORS LINES**

As covered conductor phases tolerate contact with each other and also with other objects there are less outages due to special weather conditions like wind gusts, uneven ice loads, ice shedding or snow covered trees leaning on the line. This feature makes it also possible to reduce the right of way of covered conductor lines. With MV CC lines the line corridor required is about 40% of the bare conductor line. Furthermore, it is possible to build a higher voltage level line using covered conductors in the wayleave of an old bare conductor line. Even though covered conductor line can operate long time with tree leaning on the line, one needs method to locate these trees before breakdown of conductor occurs. Suitable method has been developed based on PD-measurements [2].

The fact that phases can be built closer to each other, means also compact supporting structures. Lighter weight and smaller dimensions make line building work easier and more ergonomic.

Covered conductor lines can be called *eco-lines* [3] as they have several environmental benefits. Compact phase distance decreases EMF-effect in comparison to normal bare lines. Furthermore, analysis based on LCA study [4] shows that the of covered conductor overhead line produce smaller environmental impact than underground cable and bare conductor line.

Another advantage of covered conductor technology is safety. While touching of a bare conductor line cause frequently fatal accidents, this is not the case with a CC line. According to the statistics of Finnish Safety Technology Authority [5] 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 [6] it is suggested that CC 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.

## **3. EXPERIENCES OF USING COVERED CONDUCTORS**

### **3.1 Finland**

As already explained the first MV CC lines were built in Finland in the 1970's. According to Finnish statistics [7] during last five years the annual MV CC network length has increased on average 400 km, which is almost 90% of the total average MV length increase (450 km). However, the overall MV CC network length was only ca. 4 % of the total MV network length in the end of 2002.

Figure 2 shows how the annual outage rate per 100 km has developed in the last 30 years [8]. This figure is valid for rural areas in Finland, meaning that the length of underground cables is less than 10% of the total MV network length. As can be seen from the figure the number of faults has been quite steadily on the level of 5 faults/100 km last 20 years.

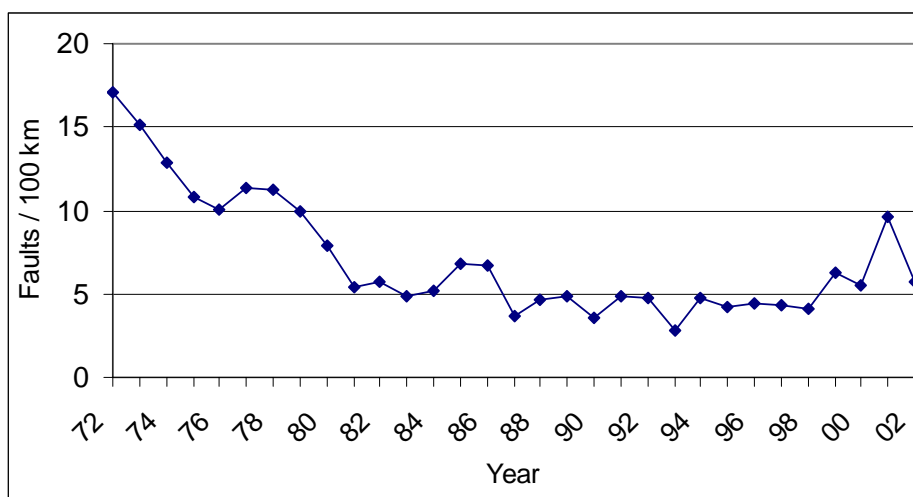


Figure 2. Annual number of faults per 100 km in rural areas of Finland 1972-2002 (all MV line types included) [8].

One contributor to the lowering number of outages has been introduction of covered conductor lines.

Latest studies [9, 10] show that the number of permanent faults in CC lines is about 20% of those in bare conductor MV lines. This is in good agreement with older estimation of 1 fault/100 km in covered conductor lines.

Figure 3 shows how the application of covered conductor lines affects to the number of high-speed and delayed automatic reclosings based on studies in [9, 10].

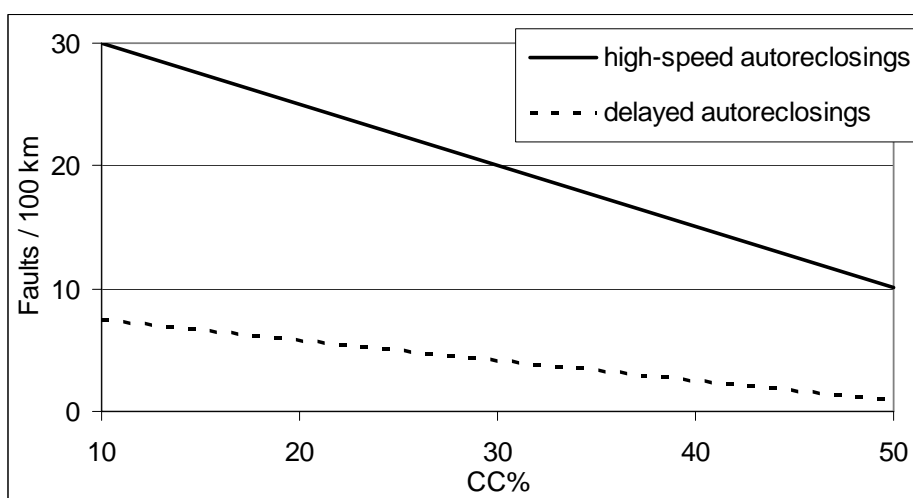


Figure 3. Fault frequency as a function of the CC share in the network [9, 10].

As can be seen from then figure 3 the number of high-speed automatic reclosings reduces to one third when the percentage of covered conductor lines is increased from 10% to 50%. Network owner has now possibility to make a judgement based on the cost of reclosings [11] versus the cost of building covered conductor lines.

### 3.2 Slovenia

The first MV overhead line ROB-PURKARČE [12], using CCs according to the Finnish technology (PAS system) was built by the Slovene utility ELEKTRO LJUBLJANA in December 1993. The past ten years were a very successful test for more than 900 km of built 20 kV overhead lines using CCs. CC lines presented about 8% of all Slovene MV overhead lines.

After introducing of CC system all five Slovene utilities started to use CC mainly changing bare conductors on old lines by new CCs. During the last ten years Slovene utilities annually reconstructed over 100 km of MV lines by CCs. Mainly new lines in last period were built by CC system. The Slovene utilities in the last five years have introduced another technology for MV overhead lines, overhead 20 kV universal cables, there are about 100 km of that type of MV lines.

Slovene statistic for long period show the annual outage rate of MV per 100 km is between 15 and 25. There are not very precise statistics. This figure is valid for rural areas in Slovenia, meaning that the length of underground cables is less than 5% of the total MV network length. That number of faults has been quite steadily on the level less than 10 faults/100 km last 10 years because Slovene utilities reconstructed a lot of old MV lines mainly using CCs or overhead cables or new technology like DAS (distribution automation system), remote controlled load breakers on poles, shunt circuit breakers etc. One contributor to the lowering number of outages has been introduction of CC lines.

Latest studies [13, 14, 15] show that the number of permanent faults in CC lines was until 2000 only 78 on 864 km CC lines in seven years. This is in good agreement with older estimation of maximum 2 fault/100 km in CC lines.

At the end of 2003, after ten years of using CC, all Slovene utilities agreed that the reason for rising number of broken conductors (there are more than 28 faults) must be analysed. The study have to take in to account some of Slovene specifics like; high level of lightning, different type of overvoltage protection (mainly PAD system), concrete poles, aeolian vibration damage, quality of the used material, (non)experienced fitters and other reasons.

### 3.3 Comparison

Table I shows comparison between Finnish and Slovene CC lines. The higher number of faults in Slovenia can be due to more active lightning. Furthermore missing standard and many producers of CCs and related accessories in Slovenia makes the application of CC lines more diverse.

*Table I. Comparison of Finnish and Slovene CC lines.*

Country	Finland	Slovenia
Experience in years	30	10
Annual number of faults per 100 km	1	2
Percentage of CCs in MV network	4	8
Standardisation	Yes	No (only recommendation)
Normal overvoltage protection system	APD (arc protection device)	PAD (power arc device = advanced spark gap)
Supporting structures	Wooden poles Angle structures guyed or A-type	Wooden poles Concrete poles (double lines) Steel poles (rare)
CC fixing type to the insulator	Preformed tie	Top spring swinging clamp (mainly) Preformed tie Top screw swinging clamp (rare)
Isoceraunic level (number of thunder days)	Low (10)	Moderate (30)

## 4. OVERVOLTAGE PROTECTION

Lightning produces overvoltages to the overhead lines either striking directly to the line or in the neighbourhood of the line. Most of the strokes ending to the line strike to the poles on parts which are uncovered. In the covered conductor line the power arc burning point cannot move due to covering

and this can lead to damage of the covering or the conductor itself. Arc damages can be avoided if appropriate protection method is used.

Arc protection can be arranged in several ways, a comprehensive comparison between various methods is shown in [16, 17].

If no disruptions in power delivery are allowed then the overvoltage protection system should be based on surge arresters or the BIL (basic impulse level) of the line should be raised to a level where induced overvoltages are unlikely to cause a breakdown of the line insulation.

Power arc protection should be applied e.g. in fields and in high spots of terrain where the line is most exposed to lightning strikes. Furthermore, it should be applied in lines near the places where people stay or pass frequently [17, 18].

In the study made in [19] 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.

## 5. AEOLIAN VIBRATION

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, which was based on the bare conductor tensions.

Covered conductors require lower stringing tensions than bare conductors. This is basically due to the fact that the covering increases the conductor diameter, which has following effects:

- vibration frequency and thus
- conductor self-damping power reduces for a given wind velocity
- wind power fed into the conductor increases.

For example the 50 sqmm covered conductor used in Finland has diameter ratio of ca. 0.63 (aluminium conductor diameter per overall diameter). For a given wind velocity this means that covered conductor:

- vibrates at the frequency 0.63 times that of uncovered conductor
- self-damping power decreases to level  $0.63^5 \approx 0.1$ , i.e. 10% of the value of the uncovered conductor
- wind power fed into the conductor increases  $0.63^{-1} \approx 1.6$  times compared to conductor without covering.

All this means that covered conductor vibrates with higher vibration amplitude and wire stresses. One must also note that conductor self-damping power and wind power are functions of vibration amplitude so the true comparative values should be calculated based on EBA, see e.g. [20].

Cigre has published a report concerning safe design tensions of unprotected bare conductors with respect to aeolian vibration [21]. 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.

Authors experience is that for covered conductors  $H/w$  limits should be 100...200 m more conservative than those bare conductor limits reported in [21]. Higher tensions can be used if additional damping is introduced to the system, e.g. by means of vibration dampers.

## 6. NOVEL ACCESSORIES

With covered conductors it is recommended to use insulation piercing accessories. There exist cases where normal bare conductor accessories have been used and the covering has been peeled off carelessly with a knife. This creates cuts to the conductor strands, which can be considered as initial cracks. Under cyclic loading of aeolian vibration these cracks then grow until the wire is broken. Figure 4 demonstrates how the lifetime of the conductor strand is affected by an initial cut. E.g. a cut  $a_0$  10% of the strand diameter  $d_w$  reduces the lifetime of the strand to 2% in comparison to a strand with a 1% cut.

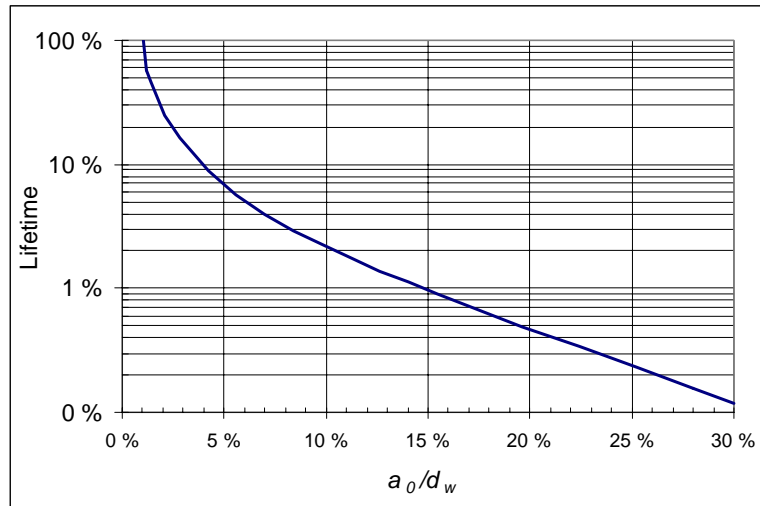


Figure 4. Crack size effect on conductor lifetime [3].

The number of service breaks can be decreased with live line work. It is essential that overhead line accessories enable live line work possibility and do not require peeling off the covering.

Figure 5 shows a new type of tension clamp which can be used both with bare and covered conductors. 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.



Figure 5. Live line disconnection point is made to MV CC line.

## 7. FUTURE DEVELOPMENTS

Covered conductors have been used for decades in 20 kV distribution networks. The application of covered conductors has expanded recently also to 30 kV and 45 kV levels. In addition there is two HV CC lines operated at 110 kV in Finland. Also in Norway there is now a HV CC line.

The other Finnish HV CC line, Forest-Sax line, is built to a very narrow line corridor. It has been equipped with PD-measurement system, which can locate tree fallen on the line. After the fallen tree is detected the operating personnel can arrange the power supply to customers via alternative routes, de-energize the line in a controlled manner and arrange the tree removal. After the tree has been removed the line can be re-energized. Thus, a tree fallen on the covered conductor line should not cause any power supply interruption to the customers [22].

It is apparent that the use of covered conductors is more and more popular. Furthermore, the application is now expanding to higher voltage levels. This creates a challenge to the manufactures of covered conductors.

## 8. CONCLUSIONS

Covered conductors offer several benefits to the network companies. Most important are increased reliability, safety and friendliness to the environment.

Both Finnish and Slovene experience show that covered conductors operate well in the network and reduce remarkably the number of outages.

However, there are important technical issues related to the use of covered conductor which should not be overlooked. Most important are overvoltage protection and the control of aeolian vibration. Furthermore, it is important to use accessories which do not require peeling off the covering.

Authors believe that the use of covered conductors will expand and also find application more in HV lines.

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