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VOLTAGE SAG CHARACTERISTICS OF COVERED CONDUCTOR FEEDERS

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ABSTRACT

The voltage sag characteristics of rural medium voltage (MV) networks having covered conductors are studied in this paper. Only sags caused by faults in MV networks are taken into account. Results of a fault statistics survey of covered conductors are presented. Study cases covering the sag analysis of typical rural MV networks of covered and traditional bare conductor overhead line feeders are performed. The results of the sag analysis show that when serving sag sensitive customers a considerable improvement can be reached by using covered conductor lines.

INTRODUCTION

Traditionally, interruptions have been the major concern when assessing power quality. Now the focus is moving from longer to shorter interruptions and also to voltage sags. The area affected by voltage sags as well as sag characteristics are influenced by several factors, for example, system configuration, system earthing, system and fault characteristics, transformer connections and system protection practices, as well. Especially in rural overhead line areas, faults in MV networks represent an important share of the voltage sags experienced by a low voltage customer [1]. Thus, any means that affect the number and type of faults occurring in MV networks are an important tool in limiting the influence of voltage sags.

Typically, MV networks have underground cables in urban areas and bare conductor overhead lines in rural areas. From the 1980's the use of covered conductor lines has been expanding in MV networks throughout the world. One reason for this is that covered conductor lines are more compact and environmentally friendly than bare conductor lines. In addition, the fault frequency of covered conductor feeders is lower than in bare overhead line networks. This development also has an influence on sag characteristics and is one important aspect when serving sag sensitive customers.

In this paper, the voltage sag characteristics of MV networks consisting of covered and bare conductor lines are studied and compared. In particular, the differences in impedances, fault frequencies, fault types, and fault clearing types, and their influence on sag distribution are of interest.

COVERED CONDUCTOR LINES

The development of covered conductor systems in Finland started as early as in the 1970's. The driving force to the development was the possibility to improve the reliability and safety of bare overhead lines by using a thin insulating covering over the bare metallic conductor. Finally, covered conductor systems evolved to what they are today in many European countries such as Finland, the United Kingdom, Italy, Poland, the Czech Republic, the Baltic countries etc.

Conductor

The most widely used construction for covered conductors consists of a stranded and compacted aluminium alloy conductor with a weather resistant XLPE covering (Fig. 1). The conductor has proven to be reliable in very severe conditions and will sustain, for example, the lying of fallen trees for days, both mechanically and electrically.

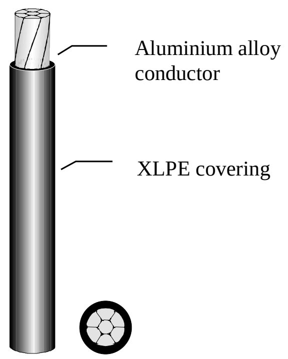

Fig. 1. Covered conductor.

Covered conductor system

Because of the covering, covered conductors are not so vulnerable when conductors touch each other or temporary contact with trees or tree branches occurs. This enables the phase spacing of covered conductors to be reduced to only one third of the phase spacing of bare overhead lines. Furthermore, the line corridor may be left narrower in forested areas than in areas with bare overhead lines.

To utilise fully the advantages of covered conductors, special top-pole arrangements may be used (Fig. 2). In addition, some other special accessories have been developed for varying conditions, such as terminating clamps, arc-protection devices, and vibration dampers.

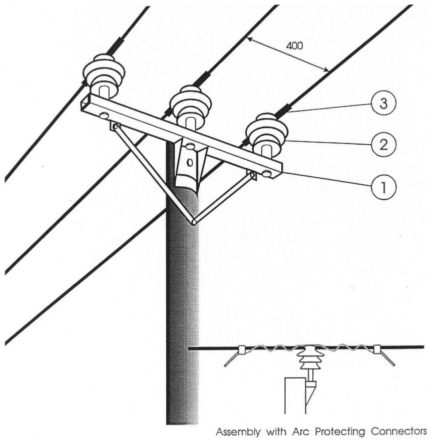

Fig. 2. Covered conductor system, pole top arrangement.

VOLTAGE SAGS

According to standard EN 50160, a voltage sag is a sudden reduction of the supply voltage to a value between 1%…90% of the nominal or declared voltage, followed by a voltage recovery after a short period of time [2].

In this paper, only sags caused by faults in radially operated MV networks are considered. When a fault occurs in one radially operated MV feeder the sagged voltage on the substation busbar will be caused by the voltage drop in the system feeding it and in the primary transformer. The remaining voltage on the substation busbar during the fault, as the per unit value of the source voltage, can be calculated by the ratio of the impedance from the MV busbar to the fault location and the total impedance of the fault current path (1).

$$\underline{U}_{Sag}(\,p.u.) = \frac{\underline{Z}_L + \underline{Z}_F}{\underline{Z}_S + \underline{Z}_T + \underline{Z}_L + \underline{Z}_F} \qquad (1)$$

where $\underline{U}_{Sag}$ is the remaining voltage on the busbar, $\underline{Z}_L$ the feeder impedance from the substation to the fault location, $\underline{Z}_F$ the fault impedance, $\underline{Z}_S$ the source impedance, and $\underline{Z}_T$ the impedance of the primary transformer.

If the sag is caused by a power system fault, the protection practices determine the voltage sag duration. The estimation of sag frequency requires a probabilistic approach and network reliability data. Traditionally, when power distribution companies report their MV fault statistics, they include only data from permanent faults. However, this data is not adequate in voltage sag calculations, where data of faults cleared by autoreclosure sequences and respective shares of different fault types should also be known.

SAGS CAUSED BY FAULTS IN OVERHEAD LINE FEEDERS

To be able to compare the influence that the use of covered conductor feeders instead of bare conductors has on voltage sags, differences in impedances (Eq. 1), fault frequencies, and fault types are needed.

Impedance

The feeder impedance has an influence on the sag magnitude: the smaller the feeder impedance the lower the remaining voltage on the substation busbar (Eq. 1) or the larger the area of vulnerability. For example, the impedance of the covered conductor PAS120 is r = 0.31 Ω/km, x = 0.30 Ω/km: the same values for the bare Al132 conductor are r = 0.24 Ω/km, x = 0.36 Ω/km. As can be seen in Fig. 3, no significant difference in sag influence can be obtained based on the difference in impedances of the feeders.

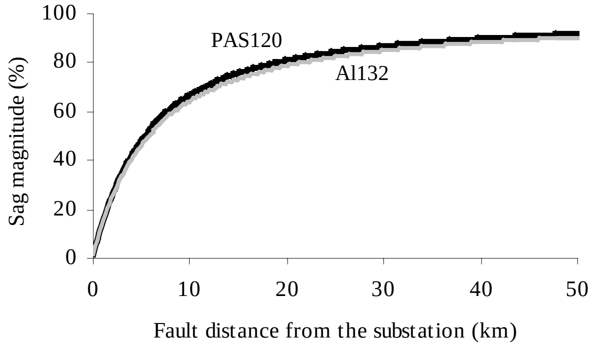

Fig. 3. Voltage sag magnitude as a function of fault distance, $\underline{Z}_S$ = i 0.45 Ω, $\underline{Z}_T$ = i 2.0 Ω, Z_F = 0 Ω.

Causes of faults in overhead lines networks

In Finland, about 70% of the permanent faults that occur in rural MV networks are caused by animals and weather conditions, like thunder, snow, icing, storm, hard wind and fallen trees (Table 1) [3]. By using covered conductors instead of bare overhead lines, it is expected that the number of faults caused by animals and weather can be reduced. A certain share of the faults caused by the lines touching each other, tree branches or fallen trees are avoidable. On the other hand, faults that occur, for example, on outdoor pole mounted transformers in places like air gaps, surge arresters, insulators, bare conjunction connections, will still exist and can not be affected by the selection of a conductor type.

Table. 1. Causes of permanent faults of rural MV networks.

	faults/ 100km/year	%
Thunder	0.51	5.3
Snow and ice	0.38	4.0
Tree falled by snow	0.76	7.9
Wind and storm	4.46	46.6
Other weather conditions	0.09	0.9
Animals	0.28	2.9
Careless tree felling	0.20	2.1
Excavating	0.02	0.2
Other outsiders work	0.14	1.5
Vandalism	0.01	0.1
Misuse	0.03	0.3
Mistakes in installation and planning	0.06	0.6
Malpractice	0.06	0.6
Overload	0.04	0.4
Construction failure	0.52	5.4
Unknown	2.02	21.1
Total	9.58	100

Fault data

In Finland, Sener, the Finnish Electricity Association, collects fault statistics of MV faults [3]. These statictics include, for example, figures for the average number of interruptions over the total MV feeder length (1/100km). The typical frequency of permanent MV faults in overhead line networks has varied between 3-13 faults per year per 100 km during the past years.

In sag analysis, the fault frequency is needed. The use of a single value for permanent faults for this purpose is inadequate because if autoreclosure sequence is used for protection, only a small share of faults is permanent. Typically, the share of faults cleared by high-speed autoreclosure (h-s) is about 70% and by time-delayed (t-d) autoreclosure 20%. If applying only a single value of permanent fault frequency to sag analysis, the sag frequency would be considerably underestimated. In addition, different fault types are associated with different sag characteristics. Thus, without taking this into account, the sag frequency would be considerably overestimated.

The shares of different fault types in different fault clearing types should also be known. For example, in [4] the results of a detailed survey showed that in faults cleared by h-s autoreclosure the share of earth faults was 75% while in faults cleared by t-d autoreclosure and in permanent faults the share was 50%. The probability of two-phase short circuits was four times the probability of three-phase short circuits.

Fault statistics survey of covered conductor feeders

The history of covered conductors is not long, only a couple of decades. One major advantage of the covered conductor feeders should be the lower fault frequency. In [5] and [6], it is reported, that in a case of permanent faults the fault frequency of covered conductor feeders is 25 - 50% of the fault frequency of bare overhead line feeders.

To find more detailed fault statistics for covered conductor feeders another study of MV faults was performed. One major problem in the analysis was that power distribution companies seemed not to have feeders with only covered conductors. A typical feeder construction was a mixture of both bare overhead line and covered conductor on the same feeder. The analyzed material included 2650 faults that occurred during 4.5 years in 42 medium voltage feeders of total length 1151 km. These feeders have 832 km of bare conductors and 254 km of covered conductors. The share of covered conductor / feeder varies typically between 10 – 50%. Autoreclosure is in use. The main results of the survey were:

1. 73% of the faults were cleared by h-s, 6% by t-d autoreclosure and 21% remained as permanent faults.
2. The fault type and fault place (bare conductor / covered conductor / distribution transformer / etc.) were only known in the case of a permanent fault.
3. In permanent faults, the share of earth faults was 75%.
4. In permanent faults, the fault frequency of covered conductors was 72% of the fault frequency of bare conductors.
5. All the permanent faults at covered conductor feeders were earth faults.

The obtained fault frequency of permanent faults of covered conductors is lower than the fault frequency of bare conductor lines. In addition, one important advantage from the use of covered conductors is the scheduling of repairing permanent faults. For example, in a case where there is a fallen tree on a covered conductor feeder but no mechanical or electrical problems exist, the supply can be continued despite the tree. However, at a later time, an interruption will be needed when the tree is removed from the line. Thus, in faults caused by fallen trees, the number of permanent faults in covered conductor feeders is about the same, but the scheduling of tree removal and supply interruption can be arranged to be performed at the most convenient time.

In the case of faults cleared by autoreclosures, the higher the share of covered conductors, $CC_{p.u.}$, the lower the fault frequency (Fig. 4). Further, the higher the share of covered conductors in a forest $CC_{forest,\ p.u.}$, the higher the fault frequency (Fig. 5). The obtained equations for the fault frequencies (faults/100km/year) of faults cleared by t-d and h-s autoreclosure as a function of the share of covered conductors per feeder are the following:

$$f_{t-d}(CC_{p.u.}) = 9.1 - 16.4CC_{p.u.} \tag{3}$$

$$f_{h-s}(CC_{p.u.}) = 34.9 - 49.7CC_{p.u.} \tag{4}$$

Equations (3) and (4) are valid when $0.1 < CC_{p.u.} < 0.5$.

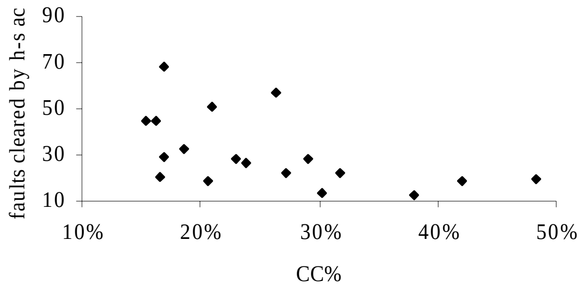

Fig. 4. The h-s fault frequency (faults/100km/year) as a function of the share of covered conductors in an overhead line feeder.

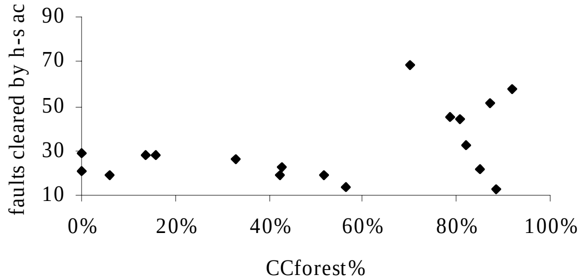

Fig. 5. The h-s fault frequency (faults/100km/year) as a function of the share of covered conductors in the forest.

With these analyses, the question of what the fault frequency of a feeder consisting of purely covered conductors ($CC_{p.u.} = 1.0$) would be cannot be answered. Further, this analysis does not give any result regarding the share of different fault types in faults cleared by autoreclosure sequence. This would be very important in sag analysis because the earth faults in unearthed MV networks do not cause any sags on the low voltage side

STUDY CASE

A study case was performed to calculate the sag distributions of substations supplying either bare conductor or covered conductor feeders. It was assumed that the substation has a 10 kA short circuit current on the 110 kV side, with one 16 MVA transformer supplying five overhead line feeders of total length 250 km. The fault data is according to Table 2. In Table 2, f is the fault frequency of permanent faults, $p_{sc,pf}$ is the share of short circuits in permanent faults, $p_{sc,td}$ in faults cleared by t-d autoreclosure, and $p_{sc,hs}$ in faults cleared by h-s autoreclosure. n_{pf} is the number of permanent faults, n_{td} the number of faults cleared by t-d autoreclosure, and n_{hs} the number of faults cleared by h-s autoreclosure. Finally, $p_{sc,3}$ is the share of three-phase short circuits in all short circuit faults. Further, by applying the method presented in [4], the sag distributions can be calculated.

Table 2. Fault data.

	bare	covered
f	7.0	5.0
$p_{sc,pf}$	50	0
$p_{sc,td}$	50	50
$p_{sc,hs}$	25	50
n_{pf}	10	20
n_{td}	20	30
n_{hs}	70	50
$p_{sc,3}$	25	25

The fault characteristics of covered conductor feeders contribute to the lower number of voltage sags (Fig. 6). It has to kept in mind, that the fault data in Table 2 includes faults from all over the overhead lines (feeders, overvoltage protection, distribution transformers, etc.), not only faults occurring on the bare or covered overhead line sections.

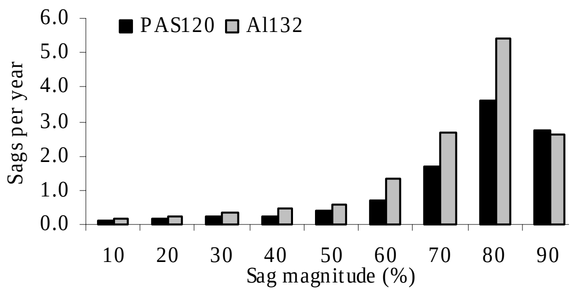

Fig. 6. Non-cumulative number of sags.

CONCLUSIONS

The use of covered conductors is expanding. The main advantages are that covered conductors are compact and environmentally friendly. In addition, in severe storms the supplies can be continued despite of trees leaning on the covered conductors if no mechanical problems exist. Thus, the scheduling of repairing these kinds of permanent faults is flexible in the case of covered conductors.

The use of covered conductors also has its influence on voltage sags. In a case of a single fault, there is no significant difference in sag magnitudes, but the lower fault frequencies and different fault types contribute to lower sag frequencies. The fault frequency of permanent faults is slightly lower with covered conductors. In addition, a considerable advantage can be achieved in the case of faults cleared by autoreclosure sequences.

The nearer to the point of common coupling (PCC) the faults occur the more serious is the sag influence. Thus, the means to lower the sag impact should be focused in the neighbourhood of the PCC. The whole overhead line system includes lines, distribution transformers, overvoltage protection, insulators, covers for animals, tree trimming, etc. The fault frequency of the whole system should be planned to be as low as possible. The choice to use covered conductors is one part of this entire planning task.

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