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Short-circuit on overhead lines with bundle conductors.

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SUMMARY

This paper will be focused on the behaviour of twin bundle with very long subspan length. Some qualitative and quantitative behaviour is detailed.

A comparison with equivalent single conductor is detailed for interphase effects.

The common hypothesis to neglect the so called "pinch effect" in overhead lines and to replace the two subconductors by an equivalent single conductor is showed to be a very bad approach.

Computations of the "pinch effect" during two-phase short-circuit of 20 kA is detailed

Tests and computation are in good agreement as it has been detailed in the literature [2] with the well-known case of Manuzio [5] (the same structure but during one-phase fault).

Recommendations for future work will be suggested.

2. INTRODUCTION

Overhead lines with bundled conductors are more often subject to one-phase short-circuit than multi-phase ones.

Added to the fact that clearance between phases are much bigger than in substations, we may affirm that bundled line are more sensible than single lines to short-circuit effects.

In fact at classical 400kV level a minimum of about 50kA is needed for the line to be disturbed in its behaviour (mainly for clearance reduction and not for mechanical tension increase) [5]. To be complete we must say that up-to-date idea of line compaction could reduce this critical value to about 23kA for the same voltage level [5].

In bundle line, equipped with spacers - as usual -, even a one-phase fault will cause attraction of subconductors with consequent mechanical tension increase and spacer compression.

3. EVALUATION OF RISKS

The physics of transient movement has already been described and analysed in the literature [1,2,3,4]. Imagine that the situation could be such that subconductors must follow the shape of subspan until the last end close to the spacer and then to follow the spacer up to fixation point.

In such a situation we can balance the values :

1) initial length (l_0) augmented of elastic deformation which is (E is elasticity modulus and A the cross section):

$$l = l_0 \cdot \left(1 + \frac{T - T_0}{EA} \right)$$

T is actual tension in the conductors, T_0 is initial static pull.

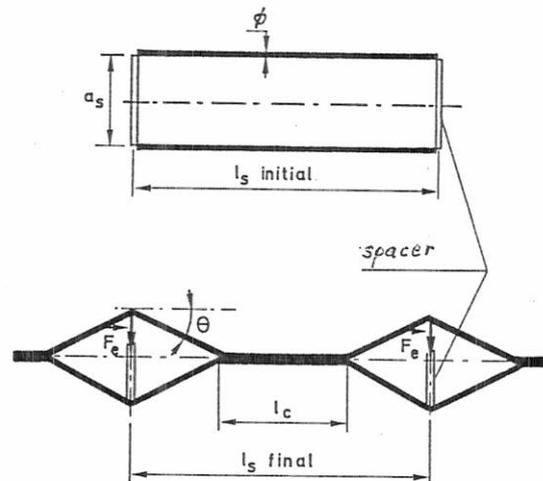


Fig. 1 Bundle geometry before and during short-circuit.

2) geometric length which is subspan length plus spacer length. (a_s is spacer length or subconductor separation, L_s is subspan length)

$$l = L_s + a_s$$

Equating (1) and (2) we can get the mechanical tension increase in the cable ($l_0 = L_s$)

$$l_0 \frac{T - T_0}{EA} = a_s \text{ or } \Delta T = a_s \frac{EA}{l_0}$$

Which of course gives a tremendous value. That is the value you need to increase the length of the cable of about the length of the spacer (imagine that you have to extend a 50 meters cable length of 620 mm² of about 45 cm !)

Happily this is not true on practical situation. That is because

1) the equilibrium position of cable depends on electromagnetic force and generally contact stopped between several tenth of centimeters and several meters far from the spacer

2) end-point of a subspan slightly moves to reduce subspan length, due to vertical movement of the span and insulators displacement at span fixation points.

3) spacers have compression stiffness (depending on the type of spacer)

4) the bending stiffness of the cable is no more negligible for very strong bending forces close to the spacer.

all these contributions tends to decrease the maximum theoretic elevation of mechanical tension during the pinch effect.

As an example, let's fix a 50 m subspan length with a 45 cm separation twin bundle. Imagine it is a 2x620 mm² AMS conductor.

the elasticity of the subconductor itself is :

$$EA/L_s = 0.67 \cdot 10^6 \text{ N/m}$$

maximum increase of tension (theoretic) : $2 \times 0.45 \times 0.67 \cdot 10^6 = 600000 \text{ N} !!$

taking into account diameter of subconductor : 560000N

In the case of small free length " $(L_s - l_c)/2$ " close to the spacer, we can write down :

$$\Delta T = \frac{EA}{l_0} \cdot \left((L_s - l_c) + 2 \cdot \sqrt{\left(\frac{L_s - l_c}{2}\right)^2 + \left(\frac{a_s}{2}\right)^2} \right)$$

so that increase of length is limited to $a_s^2/4(L_s - l_c)$ (as soon as $(L_s - l_c)$ is bigger than a_s which is the case in practice) which is more realistic than $2a_s !!$

taking into account 40 cm free span close to the spacer : 69000 N

taking into account 5 m free span close to the spacer : 5850 N

Moreover this value must be decreased by end-point movement and spacer compression.

taking more into account 5mm of end-points movement or spacer compression : 65000 N

taking into account 5 cm of end points movement : 1756 N

Such twin is normally tensioned at about 30000 N for 400 m span length.

The risk for the overhead line is an increase of mechanical tension close to twice the static pull in the cable. That is because this can occur in very hard conditions (high wind, low temperature) and because tower integrity will no more be ensured in such conditions.

As a result of discussions we can say now that :

mechanical tension increase in bundled conductors is a function of :

- elasticity modulus (an Alac conductor will be more stressed than an aluminium-alloy conductor)

- subspan length : the shorter subspan length will give a higher tension increase.

- elasticity of component : a flexible spacer is better.

- subconductor separation : a smaller separation will reduce the increase of tension

This situation has been already discussed in [1,2] but in the vue of substations where the situation is much more dangerous, due to very short subspan length. Nevertheless in substation, the pitching effect induces very high frequency peak so that structures are not to be designed for the peak value.

The way how the free distance close to the spacer is varying with short-circuit current is not easy. Manuzio [4] proposed one for symmetrical short-circuit. But the transient is so that contact occur during short-circuit and dynamic aspects of the phenomenon is very complex. Other simplified

methods are proposed in [1,2,3] but they must be considered as qualitative only.

As an example the wave propagation on the non-contact zone will produce pulsing effect which are very sensitive to asymmetry and time constant of the short-circuit. This could have increasing factors of more than 2 in some cases.

The danger of pitching effect in overhead lines is that the frequency spectrum of the pitching effect is at more lower frequencies than those observed in substations. So that design must be done for peak value in the majority of cases.

4. THE SIMULATIONS

The problem of pitching phenomena has been approached qualitatively in the preceding chapter. This one will be focused on quantitative approach.

Due to the complexity and dynamic aspects of the phenomenon, we have preferred a finite element approach to solve the problem.

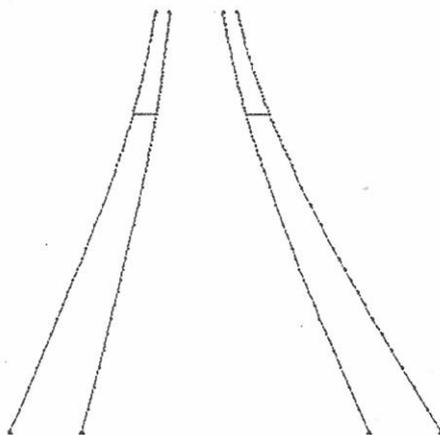


Fig.2 The simulation test. A two-phase twin bundle configuration (2 x 594 mm²), 40 cm separation, two subspan of 65 m, initial tension of 49000 N/subconductor.

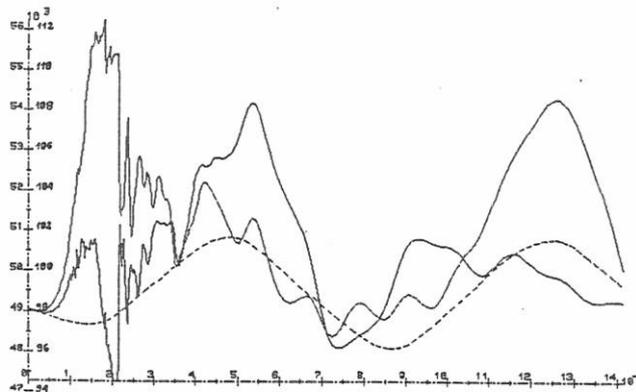


Fig. 5 Traction time evolution in the two subconductors (thick lines) and in the equivalent single conductor (dotted line). (all in Newtons)

The following application is focused on the behaviour of a twin bundle with two subspans. A two-phase fault has been applied and a comparison with equivalent single conductors is detailed.

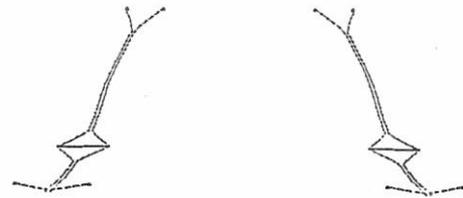


Fig.3 The same configuration as fig.2 during two phase short-circuit (20 kA, 0,2 s, no asymetry). Visualisation at about 0.15 s

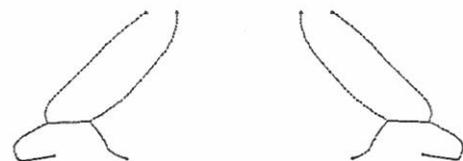


Fig. 4 The same configuration as fig2 after short-circuit end. Visualisation at about 0.55 s

The relatively low short-circuit value has been chosen to be in similar conditions as in Manuzio tests[4].

The tension oscillations is quite classical with a big increase after 0.15 s (impact after 0.11s) and the swing out maximum after 0.5 s and the falling down maximum after 1.2 s.

The dotted line is the same case with equivalent single conductor. The decrease of tension at the beginning is due to temperature heating effect.

It is remarkable to notice the very different tension oscillation in both subconductors, which is emphasised on the speed time evolution (fig. 6)

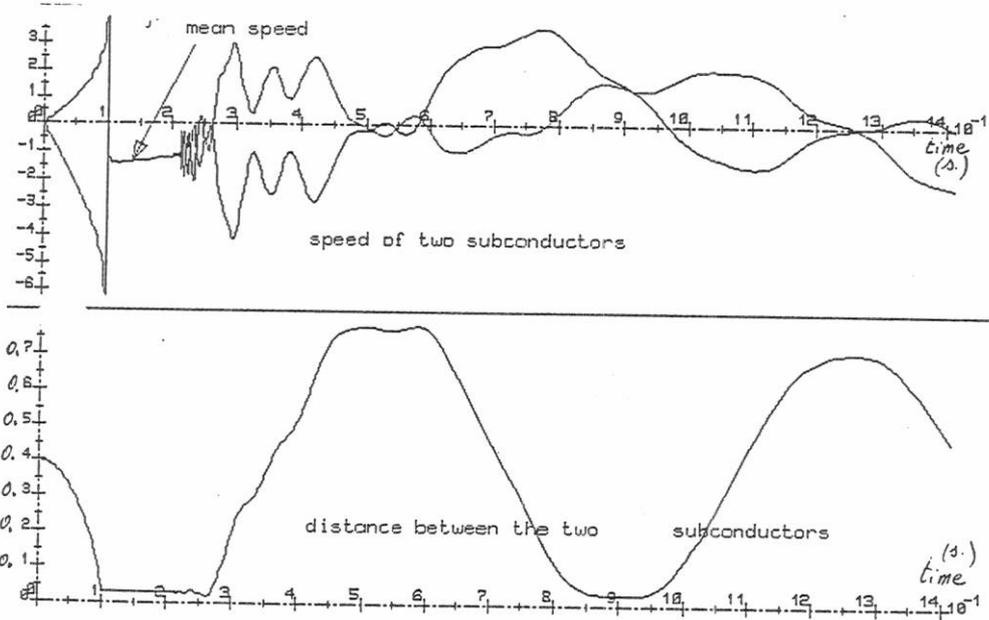


Fig. 6 Upper part : speed time evolution of the two subconductors (m/s). Lower part : time evolution of the distance between the two subconductors at mid-span of one subspan. (m)

The last figure show spacer compression. Comparisons with Manuzio tests on single span has already been detailed in [2] for longer short-circuit time.

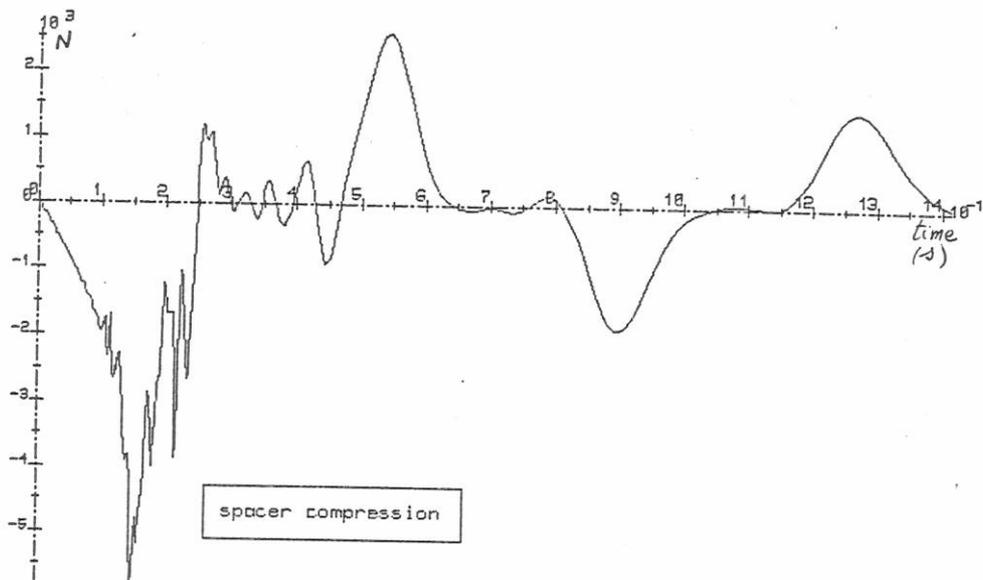


Fig.7 Spacer compression (- is compression, + is traction).

Despite the fact that the tension increase is rather limited in this case, we must bear in mind that the short circuit level was limited to 20 kA without asymmetry. Other simulations could point out the effects of higher short-circuit current, different asymmetry, time constant, etc...

5. RECOMMENDATIONS FOR FUTURE

Emphasis must be given to short-circuit on overhead lines. In the next future, problems will occur.

General recommendations could be done on the base of qualitative approach. But quantitative approach is needed to quantify what are the real effect. Tests are necessary but they must be coupled with computations in which parameters effects can easily be separated. Only finite element approach taking into account all the structure (at least all subspans, insulators and some fitting) could be of some help to solve this complex problem.

Activity in that field has been reduced in the last years due to the lack of international experts meeting. Reactivation of such working groups will be of some help to discuss this complex problem including the interactions with supporting structures.

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