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SHORT-CIRCUIT ELECTRODYNAMIC EFFECTS ON MULTICONDUCTORS BUNDLED

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Abstract

One of objects of tests and computations is to focus the designer on appropriate parameters which influence the behaviour of the structure under different loads.

Short-circuit electrodynamic effects are one of the principal loads which affect the behaviour of the structure, and are nowadays a key factor for the design of open-air substations, especially what concerns flexible connections.

In high voltage systems, the use of bundle conductors (more than one conductor per phase) is necessary. However, during a short-circuit current, the electrodynamic forces, acting on the conductors, cause a fast acceleration of the subconductors towards each other until they clash together.

The pinch effect, caused by maximum attraction of subconductors under short-circuit currents, is a high frequency force, with a consequent mechanical tension and spacer compression increase. These spacers, which are used to maintain the distance between the individual cables in bundle conductors, should be perform properly under all the different conditions.

The aim of this paper is to point out the short-circuit behaviour of multiconductors bundle (more than 2 sub-conductors per phase).

A confrontation between our numerical calculation and the results of experimental tests will be presented. The influence of insulating hardware on snatch effect will also be detailed. We will also exposed the first results of a parametric study.

INTRODUCTION

Mechanical effects of short-circuit current in systems of flexible conductors are continuing to be the subject of many researches and investigations. The object of these studies is to develop a simple practical methods, for modelling such system, for the design of the structure. These approaches must take into account all the parameters which influence the behaviour of the structure.

In high voltage systems, the use of bundle conductors is necessary to resolve the corona loss and radio noise problems. The physic of the bundle conductors behaviour, under short-circuit currents, has already described and analysed in the literature [1, 2, 3].

In fact, during short-circuit currents, electrodynamic forces, caused by the current flowing in bundle conductors in the same direction, are generated. These forces, acting on the subconductors, cause a fast acceleration of the conductors towards each other until they clash together. The fast conductors sticking begin in the middle of the subspan and propagate towards spacers. This wave causes an increase of the subconductors stresses.

these stresses are transmitted to the whole of the structure (tower, insulating hardware, fitting, spacers). All components of this structure must support this increase of tension.

We have generalised the model, developed in SAMCEF [4] and based on finite elements theory, for the case of multiconductors bundle in any spatial configurations. This model permits the dynamic study of pinch effect phenomenon.

Our investigations are focused on the validation of this model by confrontations between calculation results and tests. Also, in the object to point up some important parameters which influence bundle dynamic behaviour, we will presented the influence of insulating hardware on the snatch effect and the first results of a parametric study.

APPLICATION

The dynamic study of the phenomenon of pinch effect, in the case of multiconductors bundled and in any spatial configuration, is too complex. In fact, we must subdivide the structure in many elements and ensure perfect impact between these elements. Also, we must take into account all elements of the structure (insulating hardware, droppers, ...). Added to the fact that the constraints characterising the impact of subconductors must be advisedly established.

To ensure perfect impact and reduce computing time, we have chosen, for determining the impact of subconductors, an approach based on crossing of conductors [5]. This approach consist to choice a constant integration time step until the crossing of conductors. Then, we adopt an automatic evaluation of time integration step. The detection of the crossing is based on the change of the direction of the relative displacement of nodes.

In order to validate the model developed, we have treated many types of structures. We will dressed the confrontation between our calculations and test results.

Electrodynamic forces on conductors without contact :

The following application is focused on the evaluation of the peak tensile force, acting on the conductors, without contact. A comparison with the test results is presented. These results are relatives to the structure (figure 1) tested at Furukawa in Japan [6]. It's a case with triple bundle pinch without contact (triple triangle, peak upwards). The short-circuit intensity was 68KA (167 KA peak) with a time constant of 60 ms. The length of the span was 35 m with 2 m of subspan. Two insulator chains of 320 Kg, length 7 m, in V configuration anchor the busbar. The static tensile force is Fst = 14.6 daN.

The following figures show the comparison between the results of our calculation and test.

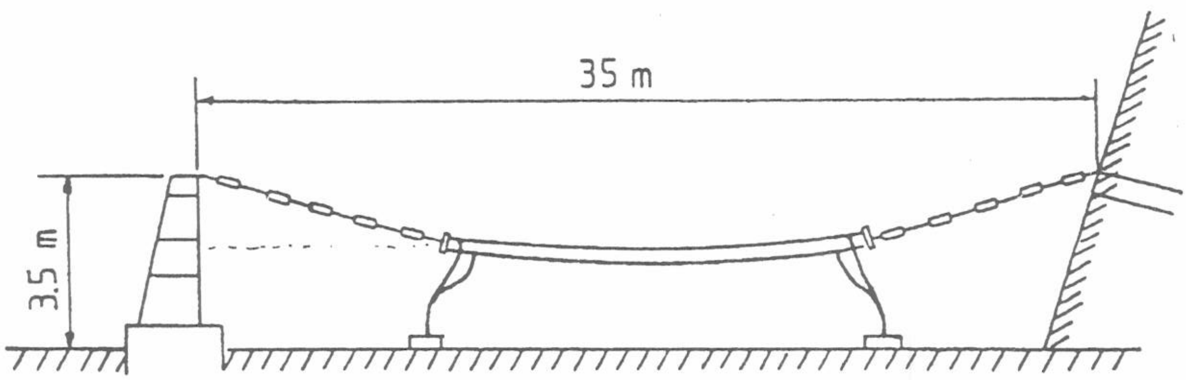

Figure 1 : Bus-bar geometry for bundle pinch test performed in Japan

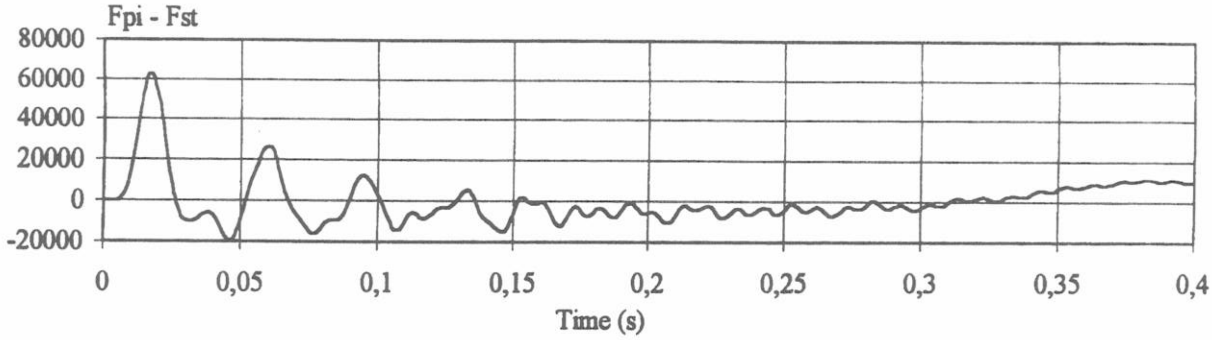

Figure 2 : Calculated time evolution of relative mechanical tension.

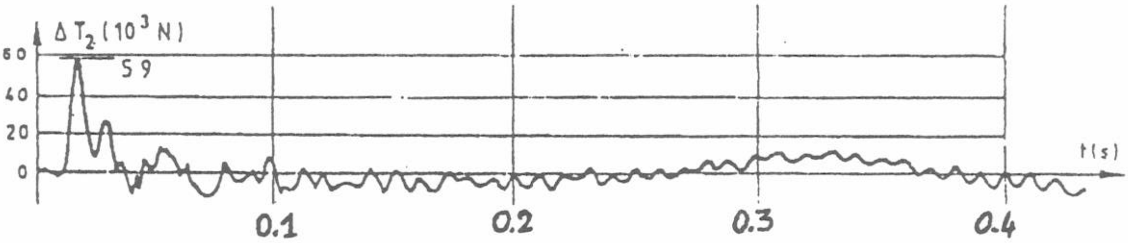

Figure 3 : Oscillogram of test result. ΔT for relative bundle pinch.

The relative increase of the mechanical tension, produced at 20 ms approximately, was in this case $\frac{F_{pi}}{F_{st}} \cong 4.2$.

This case show the importance of the relative constraint even the contact don't occur. This is owing, probably, to the short length of the subspan and the high value of short-circuit current. After transient, mean value of the tension oscillates and stabilises around mechanical tension initial value. This effect is caused by insulator chain longitudinal displacement.

The experimental confrontation is very satisfactory: both maximum peak of tensile force and apparition time of this maximum are respected.

Influence of insulating hardware on snatch effect:

In the object to point out the influence of insulating hardware on the peak tensile force, we have treated the preceding case for different configurations :

case 1 : calculation results with a real configuration

case 2 : case of one subspan with fixed ends (no insulator chains)

We present, in the following figures, the results of this comparison.

We note that the maximum peak of the tension, in the cable, is more important in the case 2 (no chains), and the tension don't oscillate around the initial value. So, we must take into account the insulating chains for calculate the maximal tensile force during pinch effect phenomenon.

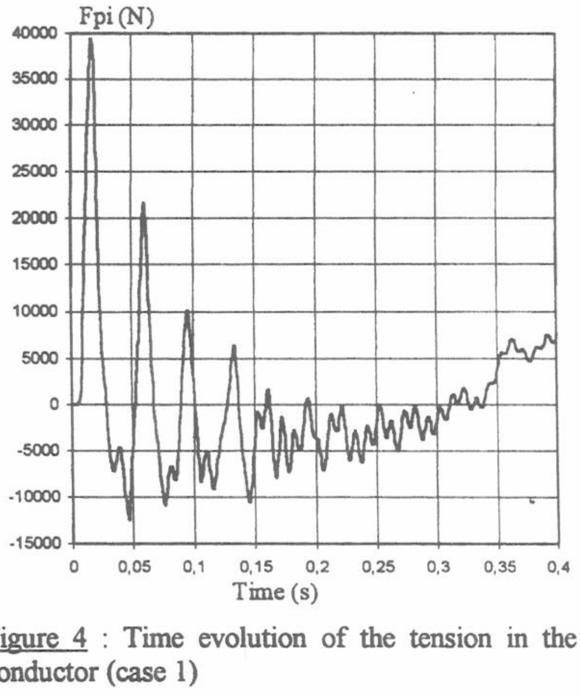

Figure 4 : Time evolution of the tension in the conductor (case 1)

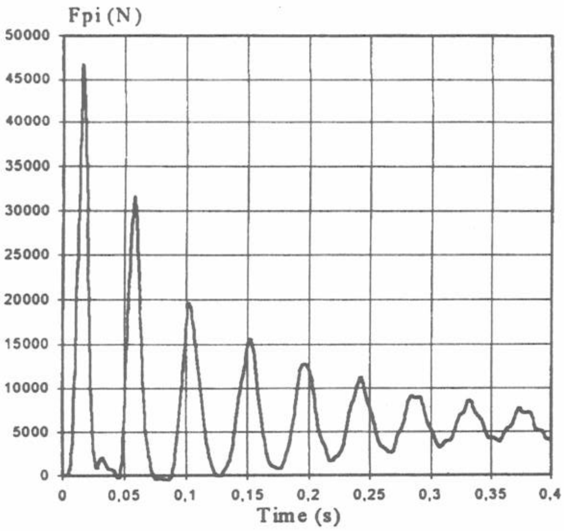

Figure 5 : Time evolution of the tension in the conductor (case 2)

PARAMETRIC STUDY

In reason of the complexity of the pinch phenomenon, owing to the no linearity and to the fact that this phenomenon depends of very numerous physical parameters, we could not deduce a general behaviour of this phenomenon by studying, separately, the influence of each of these parameters. The aim of the parametric study is to summarise the phenomenon by a few number quantities without dimension.

We will present the first results relatives to a first choice of the base parameters. Our aim is to obtain some graphics, representing the relative constraint in the cable versus a parameter P3 and for different values of a parameter P2. These graphics must be independent of cases studied.

Choice of the parameters

For the relative constraint, we could use the following expressions : $\dfrac{F_{pi} - F_{st}}{m_s\, g\, l_s}$; $\dfrac{F_{pi}}{F_{st}}$ or other expressions.

For the first parameter P3, we could use :

$$P_3 = \frac{l_s}{a_s - \phi}$$

$$P_3 = 200.\sqrt[3]{\frac{m_s\, g\, l_s^2}{(a_s - \phi)^2}\left(\sin\frac{\pi}{n}\right)^2 \frac{l_s}{E\,A}} \ ; \ldots$$

This last expression of the parameter P3 is deducted from the equality of the deformed length of conductor expressed by geometric method :

$$l = l_s\left(1 + \frac{F_{p_i} - F_{st}}{E\,A}\right)$$

and the one by the theory of the springiness:

$$l = \sqrt{l_s^2 + (d_s - \phi)^2}$$

where $d_s = \dfrac{a_s}{\sin(\pi / n)}$

The second parameter P2 could be chosen as the relationship between the Laplace force and the force of gravity : $P_2 = \dfrac{F_{os}}{m_s\, g}$

where $F_{os} = 0.2\left(\dfrac{I}{n}\right)^2 \dfrac{\sqrt{n-1}}{d_s}$.

The study of a lot of various cases in which we modify the value of different parameters is necessary to obtain a parametric formulation. In fact, a first choice of parameters P2 and P3 was already applied to a particular base case [3]. We try to improve this study by chosen other expressions of the parameters P2, P3 and by applying it to different cases of structures.

The following figures show the evolution of the constraint $\dfrac{F_{pi}}{F_{st}}$ versus the parameter

$$P_3 = 200.\sqrt[3]{\frac{m_s\, g\, l_s^2}{(a_s - \phi)^2}\left(\sin\frac{\pi}{n}\right)^2 \frac{l_s}{E\,A}}$$

for different values of the parameter $P_2 = \dfrac{F_{os}}{m_s\, g}$.

Relative constraint in the cable :

For this application, we have treated the case of a structure with two subspans of 18 m. The intensity of short-circuit current was 25 kA. Conductor size was ACSR 2x587 mm^2. The distance between subconductors was 0.2 m and the mass, per unit length, of conductor 2 Kg/m.

The same base case was treated with IEC 865 formulation [8, 9, 10], in object to compare IEC calculations to our advanced numerical computation [5], and to treat, easily, lot of cases of structures in a very short time.

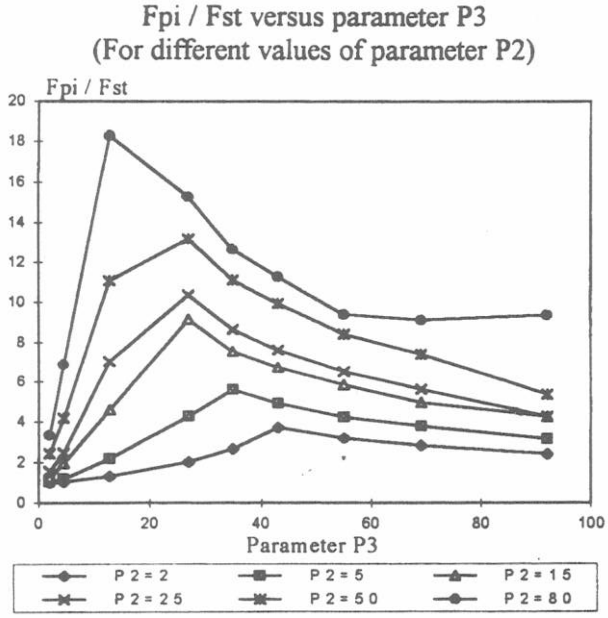

Figure 6 : Relative constraint (Fpi / Fst) calculated by an advanced model [4].

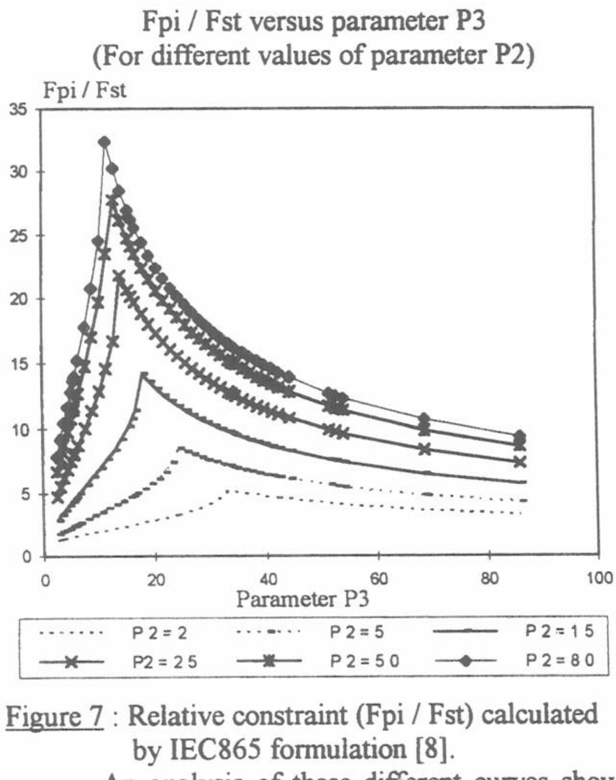

Figure 7 : Relative constraint (Fpi / Fst) calculated by IEC865 formulation [8].

An analysis of these different curves show that there is two zones, radically distinct, limited by maximums of the constraints. The zone limit is corresponding to the curve joining a maximum of the constraints for every value of the parameter P2.

In the first zone, an increase of the parameter P3 corresponds to a fast increase of the constraints. In the second zone, we have an opposite effect : decrease of the relative constraint when we increase the parameter P3.

In comparing these two graphics, we note that they have, practically, the same zone limit. However, the maximal constraint is more important in the case treated by IEC865 formulation. This difference is owing to the simplified hypothesis adopted by IEC formulation. Note that the difference between the maximums, determined by the two methods, increases when we approaches the zone limit.

CONCLUSION

Bundle behaviour, during short-circuit current, is an important factor for the design of structures.

In this paper, we have presented the results of the dynamic study of pinch effect phenomenon, in the case of multiconductor bundled. A comparison between our numerical calculations and test results is also presented. These results are fundamentally good and respect the physic of the phenomenon.

In the case of multiconductors bundled, other confrontations must be done in the object to point out the behaviour of different bundle configurations, and to take into account all components of structures (droppers, tower,...).

Our advanced model is used to develop a parametric study which permits us to deduce a simplified formulation. This formulation can be established from the relationship between the relative constraint and the parameters P2, P3. This parametric study can also be developed by using the formulation CEI 865 and a detailed comparison between these methods must be done.

Insulator chains have a big decreasing effect for the stress. To point up this effect, we have presented the comparison results for different cases: case of real structure and the case of one subspan or all the span but with fixed ends.

These results show that the insulating hardware must be taken into account in the calculation of pinch effect. This, in the object to respect the frequency content of the structure, the maximum constraint peak and the tensile oscillation around the initial value.

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LEXIQUE

Fpi : Peak of tensile force due to the pinch effect.
Fst : Static tensile force in flexible main conductor.
ms : mass, per unit length, of subconductor.
ls : length of the subspan.
g : constant of the gravitation.
as : effective distance between subconductors.
ds : diameter of main flexible conductor.
E : Young's modulus.
A : Cross-section of subconductor.
I : Tri-phase initial symmetrical short-circuit current.
n : Number of subconductors of main conductor.
Φ : Diameter of subconductor.