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BUNDLE BEHAVIOUR DURING SHORT-CIRCUIT FAULT
Influence of insulating hardware on snatch effect

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KEYWORDS *Short-circuit current - bundle - substations - overhead lines - spacer - electrodynamic forces - dynamic behaviour - supporting structure*

ABSTRACT

Two experimental confrontations with numerical simulation will be detailed. Complementary informations obtained from the calculations can help to the physical interpretation of the phenomenon and clearly put into evidence some unobvious influences like insulating hardware longitudinal movement and others. One other application in other range of practical use will complete our approach.

INTRODUCTION

Normal ampacity in HV systems, corona loss and radio noise requirements typically can only be satisfied through the use of more than one conductor per phase. Currents flowing in conductors generate forces acting between the conductors. The relatively close bundle spacing and typically large short circuit currents can result in very significant conductor forces. The forces acting on the conductors cause a rapid acceleration of the conductors towards each other until they clash together. This rapid pinching together of the conductors causes an effective shortening of the conductor length available for the bus span which results in a rapid increase in conductor tension. We call it "the snatch effect".

STATE OF ART

The behaviour of bundle conductors under high fault current has been studied for a long time [1,2,3]. A lot of the publications, f.e. [6,8,10], only concern experimental tests. Some other (we know only two [4,5]) gave details about numerical approach but without experimental confrontations nor phenomenologic explanation.

Some simple modelling [2,3,7,9] try to give ,sometimes with success, an approach for determination of the first peak of mechanical tension due to the snatch effect in the short begining after fault ignition. Unhappily none of them, except [2], make relations between the obtained results and the physics of the phenomenon , which of courses make the results focused on specific cases. [2] f.e. is limited to long span without insulators and relatively low short-circuit current. Important influence can be ignored in such a way.

We have already proposed a general approach based on parametric study [9] from which two very simple formula give an access to the first peak of mechanical tension and the main factors influencing that peak.

OBJECTIVE OF AN ACCURATE MODELLING

For an accurate design of supporting structure, the time evolution of the snatch effect must be reproduced in good correlation with real case. That means not only the peak but also the frequencies of apparition of successive peaks and general time evolution must be well simulate. If not, overdesign based on high frequence maximum value can increase the cost of a significant factor.

Hypothesis and limitations of bundle modelisation

1. bending stiffness of cable are neglected. This effect will cause some local effects (near spacer) without influence on general behaviour, and thus will not affect mechanical tension time evolution.

3d ESCC, Sulejów, Oct 25-27, 1988 Proceeding, pp 89-93

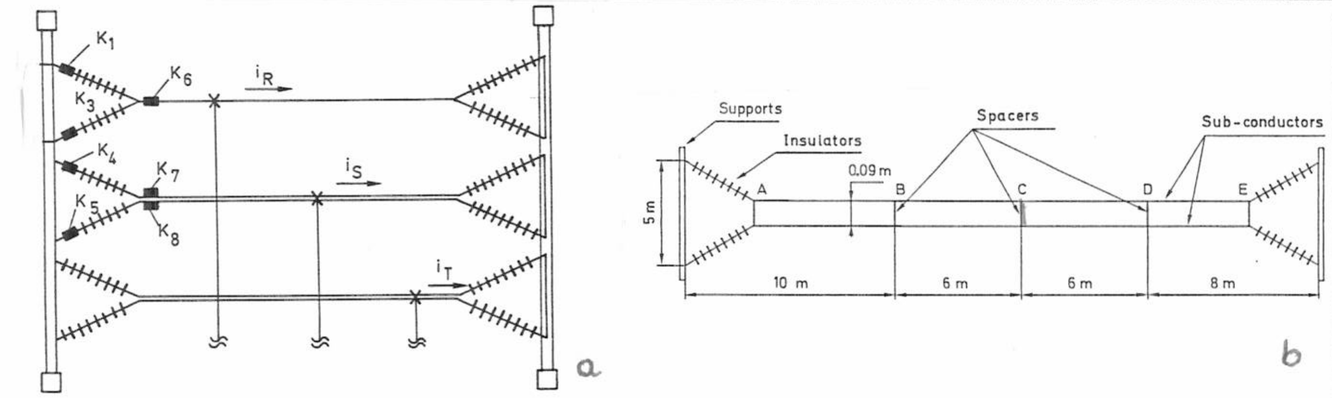

Figure 1. Substation configuration tested in KEMA [8]:
a) geommetry (Ki = measuring devices)
b) details on phase S

2. the shock between cable will absorb all relative kinetic energy. That means a speed and an acceleration reduced to the mean values just at the time before impact, for all nodes coming in contact.

The model follow the explanation described in [11] except that impact is now included. As a practical low cost approach (although it is not a limitation of the model) bundle effects can be calculated without the interphase effect : both effects might be superposed because time constant of the two phenomenon are fully different (snatch effect last about 0.1 s, interphase effect allways occurs far after that time due to time to swing)

APPLICATIONS

A 420 kV substation flexible busbar with anchoring V insulators

Fig. 1a and 1b show the structure tested in KEMA, taken from [8] . The short-circuit intensity was 50 kA rms (137 kA peak) with a time constant of 65 ms. It was a two phase short-circuit (S and T), input current came through isolator. So only half a span (S) was carrying current (from C to E on fig. 1b). CAnductor size was ACSR 1055/45 twin bundle with 9 cm separation. Two insulator chains (see fig. 1) of 225 kg, length 5.4m in V configuration anchor the busbar.

Fig. 2 to 5 give the numerical simulation and experimental confrontation (fig 5).

what are the main critical observations ?

1. the mechanical tension (case 1,fig 2)and spacer compression (fig 3) follow the electromagnetic force (fig. 4)

2. Due to that the first peak is much influenced by asymmetry of the current

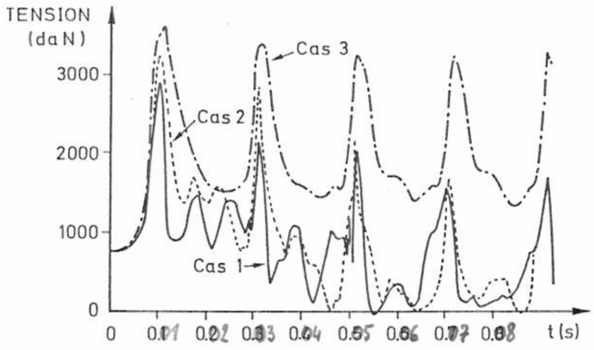

Figure 2. calculated time evolution of mechanical tension in a subconductor (see text for differentiation between case 1 to 3)

3. the first peak of mechanical tension (at 10 ms) (fig. 2 and 3) is consequent to a 0.8 mm longitudinal displacement of the insulator chain and a 0.3 mm horizontal displacement of the first spacer. From these

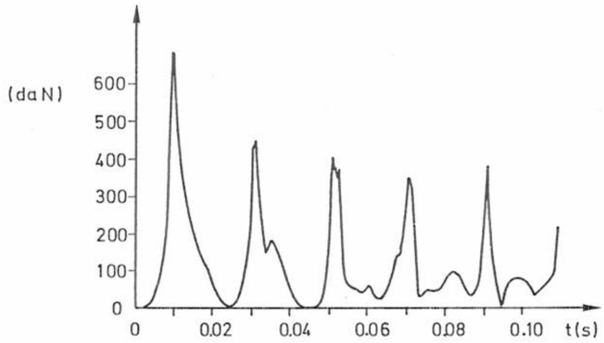

Figure 3. calculated time evolution of spacer compression

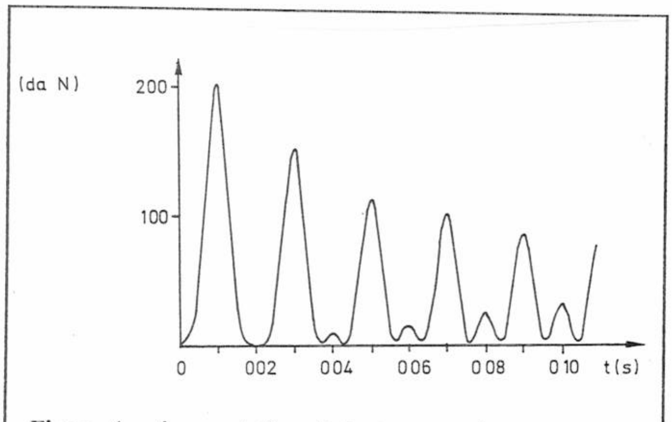

Figure 4. time evolution of electromagnetic force

results the so called "equivalent dynamic stiffness" [9] can be estimated by :

$$S_d = \frac{\text{first peak of tension}}{\text{displacement of end points of a subspan}} = \frac{2 \times (30500 - 7500)}{(8+3)10^{-4}} = 2\ 10^{7}\ \text{N/m}$$

4. vertical displacement at mid-span (reduction of sag) is very low and has no significative effect on snatch phenomenon.

5. relative increase of the mechanical tension in the busbar was in this case 30000/7500 = 4

6. after transient, mean value of tension oscillates around initial tension (fig. 2, case 1)

7. the experimental confrontation is very satisfactory (fig. 5) except after the transient where probably the behaviour of supporting structure (not included in this calculation) will limit the amplitude of the forced vibrations.

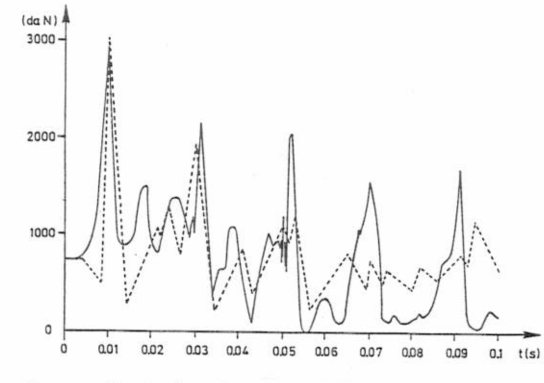

Figure 5. confrontation between full scale tests(dotted line) and calculations(solid line) on mechanical tension time evolution.

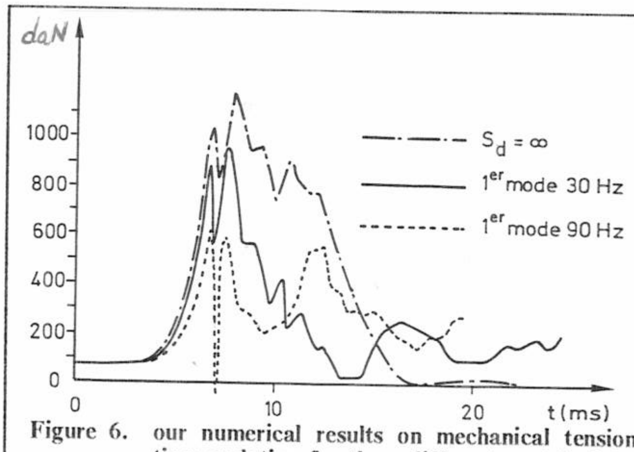

Figure 6. our numerical results on mechanical tension time evolution for three different model of the structure.

8. fig. 2 compare the preceeding case with two other calculations :

   a. case 1 : real case
   b. case 2 : real configuration but with symmetric condition at mid-span. This is not the reality because input current was given by isolator at mid-span, thus only half a span carried current.
   c. case 3 : only one subspan with fixed ends(no insulator chains).

It is not so obvious to explain why the mean value of case 1 will not oscillate around mechanical tension initial value. But it is clear that this effect is caused by insulator chain longitudinal displacement. To take this fact into account will severely limit the strain in the structure and in the spacer.

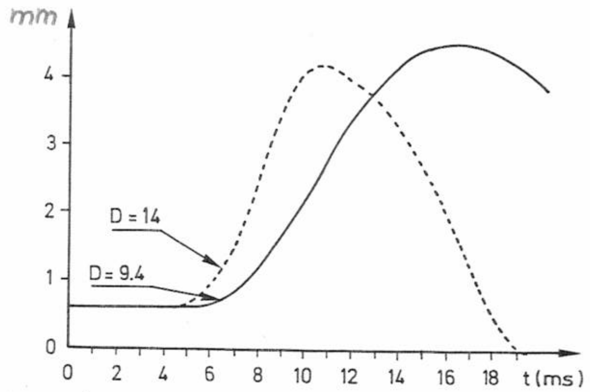

Figure 7. top insulator longitudinal displacement time evolution

A high voltage short connection between insulator support

This application refering to [6] is a flexible short connection (span of 15 m) between two insulator support (spring constant = 2.5 10^6 N/m, first eigenfrequence at 30 Hz) The short-circuit current was 40 kA (102 kA peak) with a time constant of 65 ms. Conductor was Al/St 537/53 mm² twin bundle with 6 cm separation, two subspan of 7.5 m each. No more informations were available.

But it is clear from published results that another frequence was excited during snatch effect. In fact begining of bending moment at the bottom of the insulator support clearly starts in opposite direction as applied force. This is typical of a higher mode (second one f.e.) excitation.

Fig. 6 shows the numerical simulation during the first 20 ms. It is of some interest to compare the three computations:

1. case 1 :with fixed end points (infinite stiffness for the support)
2. case 2 : with given static stiffness (0.25 10^7 N/m) and fisrt mode at 30 Hz.
3. case 3 : same as case 2 but the first mode was raised to 90 Hz

Between two extreme cases, maximum amplitude is reduced by a factor 2. This can be explained by the fig. 7 giving displacement at the top of the insulator support. In case 1 it is of course zero. In case 2, at the instant of the maximum peak (=7 ms), relative increase of displacement (fig.8) was (0.94-0.6)= 0.34 mm ; and in case 3, it was (1.4-0.6) = 0.8 mm. Let's point out that maximum displacement of the top of insulator is about the same in the two cases (about 4 mm) (fig.8) but will not occure,of course,at the same time. Our so called " equivalent dynamic stiffness "can be calculated :

1. case 2 :

$$S_d = 2 \times (9500 - 740)/0.00034 = 5.2\ 10^7\ \text{N/m}$$

2. case 3 :

$$S_d = 2 \times (6000 - 740)/0.00080 = 1.3\ 10^7\ \text{N/m}$$

Note the complete difference between S_d and static stiffness (the same for case 2 and 3 = 2.5 10^6 N/m It is obvious that a greater horizontal displacement at the top of insulator at the instant of maximum collapse, will produce a lower stress in the bus. Let's remember that this reduce of mechanical tension will also affects the compression of the spacer.

Experimental time evolution of the mechanical tension was closer to our case 3 (maximum experimental value of 6550 N). It is impossible to compare other value due to lack of data on insulator support. In fact probably that second mode of tested insulator support was closer to 90 Hz which would explain the better confrontation for this mode (case 3).

In this application maximum peak tension increases by a factor 8.8 from initial static value.

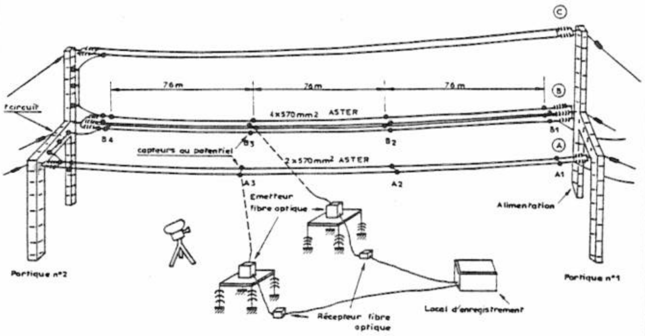

Figure 8. **Overhead line EDF test structure(by courtesy of B. DALLE)**

$m_S = 1{,}824\,\%$

Third case : a 400 kV overhead line

Fig 8 shows the structure tested in EDF, taken from [10]. The short-circuit intensity was 60 kA (163 kA peak) with a 120 ms time constant. Conductor size was ASTER 2x570 mm2 with 40 cm separation, 4 subspan of 57 m. Insulator chain mass of 327 kg, length 4.64 m.

Fig. 9 and 10 give confrontations with tests and calculations during the first 70 ms. Relative increase of mechanical tension is limited to 80/35 = 2.28.

Due to the 40 cm between subconductors, spacer compression is rather big (1500 daN). For this application we deduce $S_d = 2\dfrac{(40000 - 18400)}{(20 - 10)10^{-3}} = 4.3\ 10^6$ N/m .

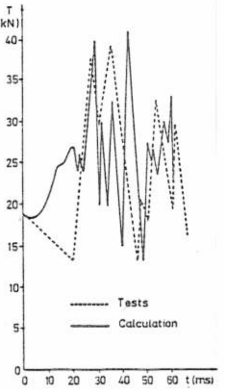

Figure 9. **Mechanical tension time evolution in a subconductor , confrontation with experimentation.**

CONCLUSION

Bundle behaviour during short-circuit fault is an important topic for the design of high voltage substations (flexible busbars and connections) and overhead lines.

$P_{15} = 51{,}3$
$P_5 = 143$
$\alpha = 3.85$
F_p 46000.
$F_1 = \frac{2.15}{t_c}$
$t_c = 25$ ms
8248

The behaviour of the bundle during fault is a very quick come together of all subconductors which causes a high increase of the mechanical tension in the conductors and in the spacer. (the increase can be 10 times the initial value as seen during experiments, but sometimes this increase can be reduced to some percent). Such an increase can cause severe damage to the supporting structure.
The influencing parameters of this phenomena are sometimes surprising. This paper point out some of them which can increase maximum stress by a factor of 2 if neglected during the design by too simple approach.

For a given structure strain increases proportionally with the current, and because snatch effect is a high frequence phenomenon, it is related to instantaneous value of the current. So asymmetry of the current can increase the strain by a factor of 2.8 for network time constant greater than 60 ms.The only way to reduce this effect is to decrease subconductor separation and increase subspan lengh, keeping in mind corona effect and subspan oscillation.

Insulator chain have a very big decreasing effect for the stress, but supporting structure has more limited influence due to higher inertia. In simple approach, insulating hardware can be replace by an equivalent stiffness . Some order of amplitude have been given in the paper, say 10^{7} N/m. This conclusion only valid for snatch effect is in complete opposition with the conclusion for interphase effects(low frequence phenomenon)where supporting stucture had a very big influence.

For short connections between insulator supports, the dynamic behaviour of the support has a very big impact on the stress. Generally the dynamic characteristics (eigenfrequences, modal shape) are not given by manufacturer. Something must be done in that field.

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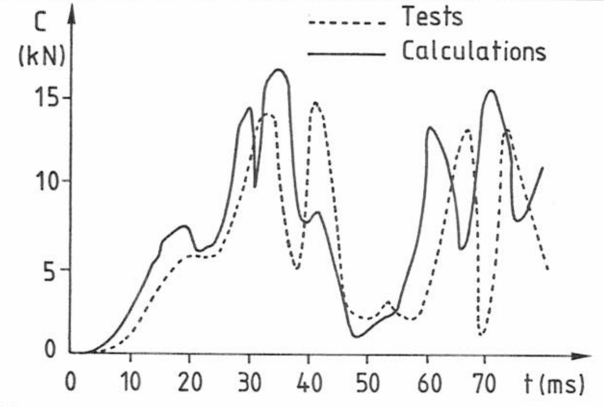

Figure 10. Mechanical tension time evolution in a spacer , confrontation with experimentation.

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