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2.2 SHORT-CIRCUIT MECHANICAL EFFECT ON BUNDLED CONDUCTORS IEC865 RECOMMENDATIONS: CONFRONTATIONS WITH TESTS AND NUMERICAL COMPUTATIONS.

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ABSTRACT :

Two approachs are used to determine pinch effect in bundle conductors:

-Experimental tests
-Numerical methods (advanced and simplified).

I.E.C 865 formulation , one of this simplified models, is also able to determine the maximum instantaneous peak load during pinch effect. However a caution must be taken concerning the limitation caused by the method hypothesis.

This paper will focus on comparison between I.E.C 865 formulation and test or numerical computations. Some critical cases will be also addressed.

Finally we applied I.E.C recommendations to more than two hundred configuration cases and we will detail our feeling on the true range of application of actual I.E.C 865 formulation.

All our investigations are focused on the pinch effect, not on other short circuit loads which are prettily well evaluated by I.E.C 865 formulation.

INTRODUCTION :

In high voltage systems, the use of bundled conductors (more than one conductor per phase) is necessary to resolve the corona loss and radio noise problems.

However during a short circuit current, the current flowing in bundle conductors in the same direction, generate electrodynamics forces between the conductors.

The forces acting on the conductors cause a rapid acceleration of the conductors towards each other until they clash together.

The fast conductors sticking begin in the middle of the subspain and propagate toward spacers resulting in rapid increase of the conductors stresses called pinch effect (Fpi).

This stresses are transmitted to the whole of the structures (conductors, spacers, insulating hardware, supports,...).

Pinch effect in bundle conductors was and still be the subject of many investigations:

In the end of Sixties, Manuzio [1] and Alexandrov [2] studied this phenomenon and gave some experimental results.

In the Seventies and the beginning of eighties we witnessed the appearance of various simplified numerical studies of the phenomenon [3, 4, 5].

This models try to calculate, some time with success, the peak of mechanical tension value.

After this date some advanced numerical studies appeared [6, 7], and gave some numerical results but with few experimental confrontation and phenomenological explanation.

We published, for the first time, an advanced numerical [8] study which was confronted to experimental results done by E.D.F [9] and KEMA [10]. A phenomenological explanation and a parametric studies was also done.

It will be a big mistake to close this state of art without talking about CIGRE activities.

CIGRE activity is still in action on this field (WG 23-02 until 1987 and actual WG 23-11 (task force) and published in 1987 a brochure on the subject [11] including some parametrical study of bundle pinch effect.

In summary, the pinch effect evaluation may be done by two ways:

Experimental tests (E.D.F, K.E.M.A, F.G.H ...)
Numerical methods:
* advanced methods (SAMCEF [12], ADYNA [13], ...)
* simplified methods ([3], [4], [5], ...)

Because of the excessive cost requested by test, numerical methods are developed and widely used.

The advantage of advanced method is their ability to take into account all the mechanical and electrical characteristics of the structure, therefore restrictive hypothesis vanish in a large scale. Simplified methods are easily implemented but are limited because of restrictive hypothesis characterising each method.
Our investigation concern the confrontation between I.E.C 865 formulation [14] and tests ([9], [15], [16]).

I.E.C 865 FORMULATION :

The I.E.C 865 formulation theory is widely developed in reference [13]. We give just a summary of this method pointing out hypothesis that we judge restrictive. All parameters definitions are given in annex.

This method is based on the parameter (J) given by :

$$J = \sqrt{\frac{\varepsilon_{pi}}{1+\varepsilon_{st}}}$$

where εpi and εst are the strain factors characterising the contraction of the bundle, and shall be calculated from :

$$\varepsilon_{st} = 1.5\,\frac{F_{st}\ N\ l_s^2}{(a_s - d_s)^2}\,(\sin\frac{180°}{n})^2$$

$$\varepsilon_{pi} = 0.375\,n\,\frac{F_v N\, l_s^3}{(a_s - d_s)^3}(\sin\frac{180°}{n})^3$$

Fv represents the short-circuit current force and is given by :

$$F_v = (n-1)\,\frac{\mu_0}{2\Pi}\,(\frac{I''_{k3}}{n})^2\,\frac{l_s\ v_2}{a_s\ v_3}$$

The parameters v_2 and v_3 are described in the reference [14].

The parameter (J) determines the bundle configuration during short-circuit current flow as follows :

J ≥ 1 : the sub-conductors clash
In this case the tensile force (Fpi) is obtained from :

$$Fpi = Fst\ (\ 1 + \frac{V_e}{\varepsilon_{st}}\,\xi)$$

The parameter (ξ) is given by the real solution of :

$$\xi^3 + \varepsilon st\ \xi^2 - \varepsilon pi = 0$$

J < 1 : the sub-conductors reduce their distance but do not clash. The tensile force (Fpi) is obtained from :

$$Fpi = Fst\ (\ 1 + \frac{V_e}{\varepsilon_{st}}\eta^2)$$

The parameter (η) can be obtained by solving the following cubic equation with non linear coefficients :

$$\eta^3 + \varepsilon_{st}.\eta - \varepsilon_{pi}\ f_n = 0$$

The I.E.C 865 formulation suppose :

1- the first hypothesis concern j factor :

J ≥ 1 subconductors clash

J < 1 no impact between subconductors

2 - the second hypothesis deals with the resultant spring constant of both supports (S). This constant is involved in the formula :

$$N = \frac{1}{S.L} + \frac{1}{n.Es.As}$$

If the exact value of S is not known, then the value $S = 10^5$ N/m should be used for slack conductors. For span with strained conductors specification of S is under consideration.

3- the third hypothesis involve ls, as and ds.

I.E.C formulation suppose that , if :

$$\frac{as}{ds} \leq 2 \quad \text{and} \quad ls \geq 50.as$$

or

$$\frac{as}{ds} \leq 2.5 \quad \text{and} \quad ls \geq 70.as$$

We can neglect pinch effect (Fpi) in comparison with the short - circuit tensile force (Ft).

To dissect this simplified method we have began by a confrontation between I.E.C. 865 formulation and more than two hundred test cases done in reference [17]. Other comparisons are done with KEMA case [15] and EDF [9]. Some comparison results are plotted in curve 1. We have analysed deeply these results and we have deduced the following constatations.

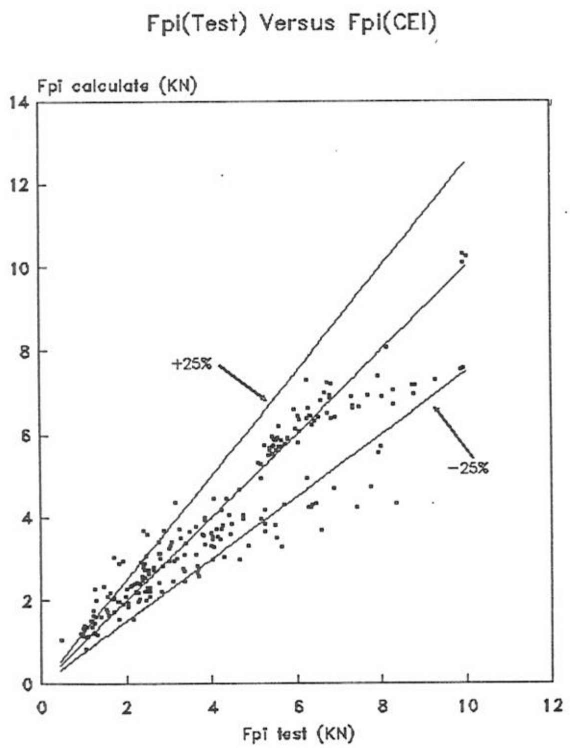

Figure 1 : Comparison results

COMMENTARY :

To show the limitation caused by the J factor (First hypothesis), we have treated E.D.F [3] case with unequal subspan to make j factor vary around the limit value J=1. The I.E.C. 865 formulation give for Fpi versus J factor results which are plotted in Figure 2.

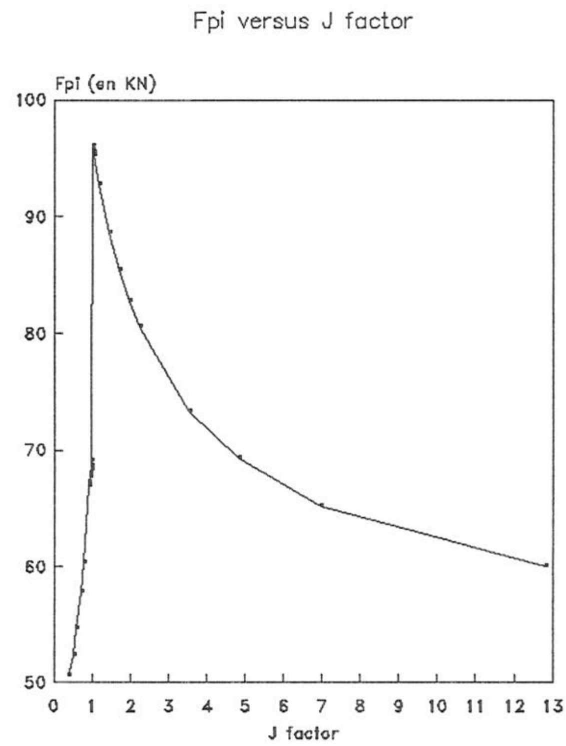

Figure 2 : Fpi versus J factor results

The first remark is the net discontinuity around j= 1. The jump of the pinch effect value is to high in comparison with the same case treated by advanced numerical methods or tests. This variation of Fpi is more dangerous if we know that just one meter more or less in span tip up the case from one side to the other around J=1. in this case Fpi jumps from 69 KN to 97 KN.

The second hypothesis concern spring constant of both supports (S).

This constant is involved in the formula of N.

$$N = \frac{1}{S.L} + \frac{1}{n.Es.As.}$$

Because of the great sensibility of pinch effect Fpi to spring constant "S" [10], the exact value of S must be taken into account, however I.E.C 865 formulation give $S = 10^5$ N/m for slack structure and nothing about strained structure. This impossibility to involve real influence of both supports of spring constant in I.E.C formulation limits the application field of this method.

To illustrate this, we have treated two cases, EDF test [9] and KEMA test [15].

The spring constant influence on Fpi is plotted in the figures 3 and 4.

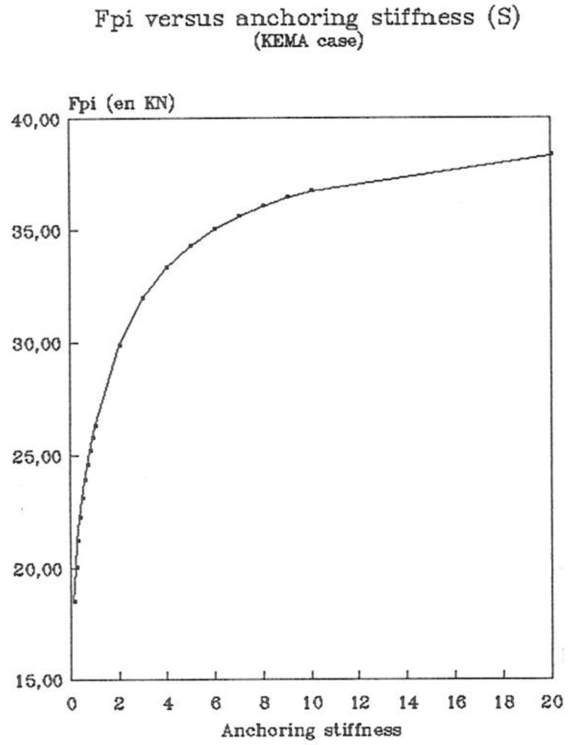

Figure 3: Fpi versus anchoring stiffness results

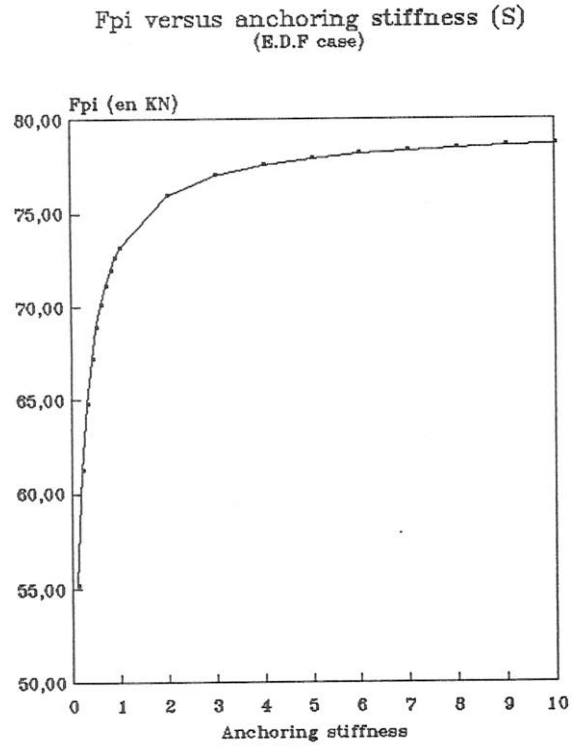

Figure 4: Fpi versus anchoring stiffness results

We can note that $\frac{\Delta Fpi}{\Delta S}$ increases rapidly before saturation zone. Then a small error on the evaluation of S gives an appreciate variation of Fpi. That's why the exact value of S must be known.

The following computation shows that:

For $S=10^5$ N/m .(value taken in default of real value) I.E.C 865 formulation give Fpi = 18,5 KN far from 40 KN given by test For $S=2{,}1\ 10^7$ N/m deduced from [10]. The result is improved and became 38,4 KN (see Table 1).

	Fpi (test)	Fpi (C.E.I)
$S1 = 10^5$ N/m	40 KN	18.5 KN
$S2= 2.1\ 10^7$ N/m	40 KN	38.4 KN

Table 1

To give more details on the spring constant influence on pinch effect, we have observed the ratio Fpi tested over Fpi calculated versus Fst (Figure 5). The most important result that we have deduced is that the same structure, and under same electrical conditions, we can note that the I.E.C formulation give good results for high static tensile force Fst. We think that, for such structure , the spring constant influence is weak .

To illustrate this we have done a parametrical study involving Fpi, Fst and S . Results are plotted in figure 6. we can note that the saturation appear quickly therefore Fpi became insensitive to S variation.

The third hypothesis concern specially substations, where "as" is very small. To show the limit of this hypothesis we have checked the KEMA case (substation) which verify

$\frac{as}{ds} \leq 2.5$ and $ls \geq 70.as$.

The hypothesis stipulate that under such conditions the tensile force Fpi can be ignored in contrast to the tensile force Ft. However test results give for pinch effect KEMA case 40 KN and 26 KN for short-circuit tensile force (Ft) !. good care must be taken in such situations.

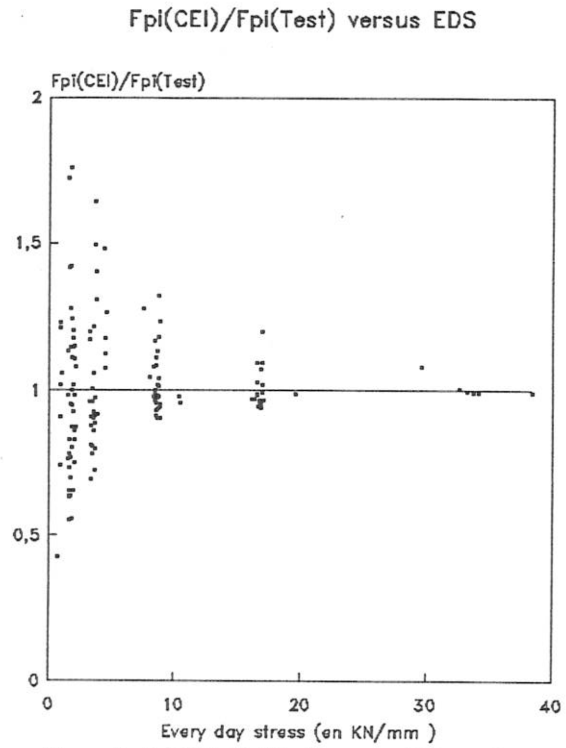

Figure 5: Fpi(CEI)/Fpi(Test) versus EDS results

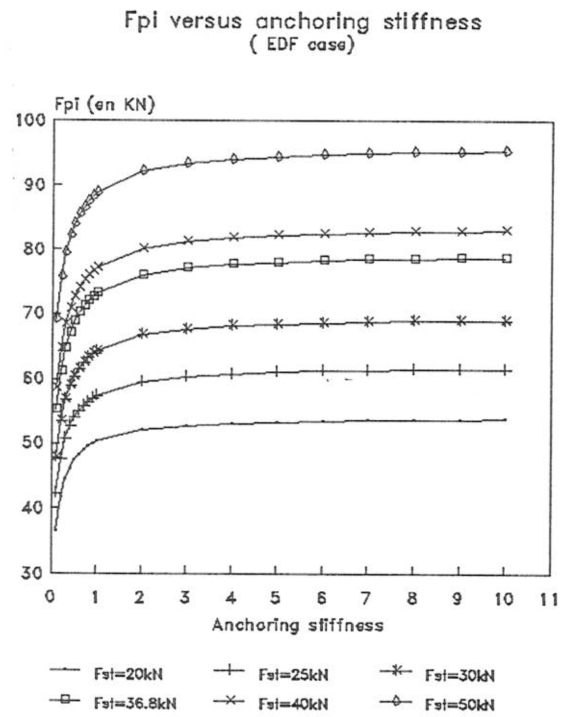

Figure 6: Fpi versus anchoring stiffness results

CONCLUSION AND RECOMMENDATIONS

I.E.C 865 formulation give some times, with success, a quite good results for simple configurations. However, during short circuit the interaction between bundle conductors and the supporting structure (principally insulating hardware) influence in a large scale the peak of mechanical tension due to the snatch effect. To neglect this influence leads to under estimate the stress and to an inadequate design of the substation.

To resolve partially this problem, I.E.C 865 recommendation propose the involvement of a spring constant " S" but the problem remain in the determination of "S".
$S = 10^5$ N/m proposed by the formulation gives often bad results. Our experience gives us the feeling that "S" is near 10^6 to 10^7 N/m.

To take "J" factor value (around J=1) as the only condition which indicate if the subconductors clash or not is too dangerous. To ensure safe decision, this condition must be coupled to other physical considerations.

Other investigations are requested in this field.

In other side, the third hypothesis which stipulate that we can neglect Fpi in comparison with Ft in some cases may lead to neglect more than 50% of the load on structures. Analysing deeply the confrontation results (I.E.C./Test), we have point out that I.E.C formulation do not give good results for cases with low Fst (Jumpers,...). In such cases we must use other methods. Finally, we believe that for most cases advanced methods or tests are necessary. Simplified methods can be used in very simple cases, or can be used to help advanced method to choose an accurate descritisation of the structures.

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Annex

LEXIQUE :

Fst : Static tensile force in flexible main conductor.

N : Stiffness norm of an installation with flexible conductors.

ls : Centre-line distance between connecting pieces or between one connecting piece and the adjacent support.

as : Effective distance between subconductors.

ds : Diameter of flexible conductor.

n : Number of sub-conductors of main conductor.

μ_0 : Magnetic constant, permeability of vacuum.

I"k3 : Tri-phase initial symmetrical short-circuit current.

S : Resultant spring constant of both supports of one span.

L : Center-line distance between supports.

Es : Actual Young's modulus for calculating Fpi.

As : Cross-section of one sub-conductor.