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We have used finite element approach in our computer program "CABLE", made in University of Ljubljana (5). The versatility of this program is very large: quayed structure, any cable arrangement (substation with flexible bus bars, aerial line, chording structure (insulators, towers...)). This program can also include an aerial line section (6). In the first part of the paper we study a broken conductor load and compare our calculations with experiments.

Computer tool seems to be well adapted to this problem: you can make or buy it for a very low cost and you have no more any restriction for studying very complex geometry. Parameters study and you have no more any restriction for span length, insulator spacing, length of each part, span length, insulator spacing etc... without numbers time. You can easily modify it is quickly done for some additional CPU time every large: quayed structure, any cable arrangement (5). The versatility of this program is very large: quayed structure, any cable arrangement (substation with flexible bus bars, aerial line, chording structure (insulators, towers...)). This program can also include an aerial line section (6).

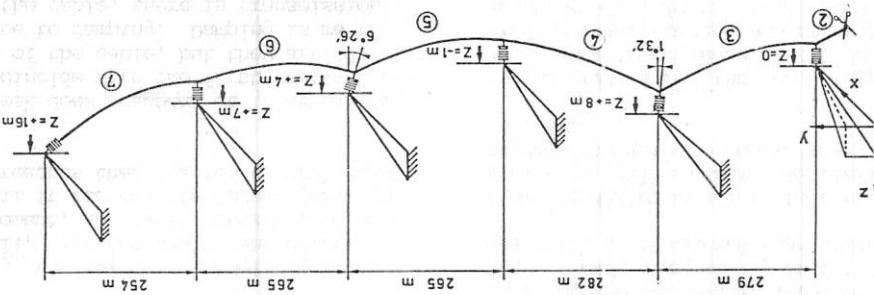
Some experimental studies have been already published on reduced scale model (1) and full scale (2,3). Unusually such tests are very costly and not versatile. Analytical approach or simulation of the probability of failure and design cost is much higher than maximum values for peak tension. But these data are not sufficient because the simulation of these peaks is also of some importance. We hope to give them some help.

The aim of our work is to predict future time evolution of displacements and tensions in all the sections in order to perform the risk analysis.

The section in which probabilities and design costs need sufficient knowledge of the probability of failure and the nature of the failure causes the most problems. The load wedge of the section in question is to determine the risk analysis.

The solution of the problem is to give them some help.

Fig. 1 Aerial Line section



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J. ROBERT

S. MANGIONE

SUMMARY

SIMULATION OF OVERHEAD LINE DYNAMIC BEHAVIOR DUE TO MECHANICAL AND ELECTRODYNAMIC STRESSES

In the second part electrodynamic load on a 20 KV compact little submittted to a 8 kA three-phase short-circuit are studied. Interested readers will be able to find other applications on 150 and 400 KV substations and lines (5, 7, 8). Model basic equations are given in appendix.

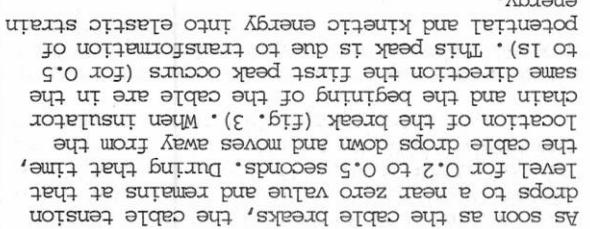
2. BROKEN CONDUCTOR LOAD

2.1 General approach

Fig. 1. We always have an evolution of the tension in the cable next to insulator as in fig. 1. In the second part electrodynamic load on a 20 KV compact little submittted to a 8 kA three-phase short-circuit are studied. Interested readers

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Fig. 2 Classical time evolution of mechanical tension in the cable next to break (see § 2.2 for dotted line).



This effect gives rise to a travelling wave, which partially lift the cable until it reaches its lowest position (fig. 4) until it reaches its second peak (fig. 4) note that dynamic energy to the cable, there is transmission with power. After some minutes the tension will reach a steady final value.

The second peak does reappear at intervals of time which coincide with the first vertical part of the second peak at the cable, but they are of lower importance due to damping. Damping is mainly internal to the cable, but they are of lower importance due to damping, but they are of lower importance due to damping. Damping is mainly

Fig. 2 to 4 give results of calculations for cable drop is much more high (fig. 4). Let's note that dynamic drop at rest position was calculated 3.9 m and measured (2) 3.84 m. Let's note that dynamic drop at 910 N and measured (2) 930 N. Cable lengthed 910 N and measured (2) 930 N. Cable in this case final tension in span 3 was calculated

to break. Final equilibrium after cable break can be easily done with a static calculation suspending one more traction on one side at insulator next to break.

One could even imposed says instead of tensions. This is made very easily in our "ABE" program. That means we have to find unsaturated length of cable between anchoring points in order to respect imposed horizontal tensions in each span. First step of calculation is to find initial position of all the section without cable break.

This case has been tested by EPR (2). Initial horizontal tension in span 3 is 21330 N. This causes a non vertical insulator chain. That means a non some imbalance for some spans which causes a non zero torsion and remains at that level for 0.2 to 0.5 seconds. During this time the cable drops down and moves away from the location of the break (fig. 3). When insulator drops to a near zero value and remains at that level for 0.2 to 0.5 seconds. During this time the cable breaks, the cable tension

as soon as the cable breaks, the cable tension

cent to the cable break. Longitudinal forces mainly on the tower adjust the peaks after release cause strong torsion and

Fig. 4 Classical time evolution of mid-span next to break (vertical component)

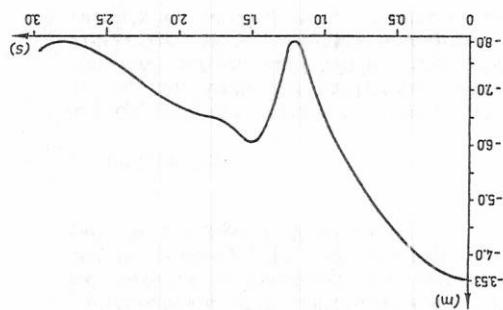
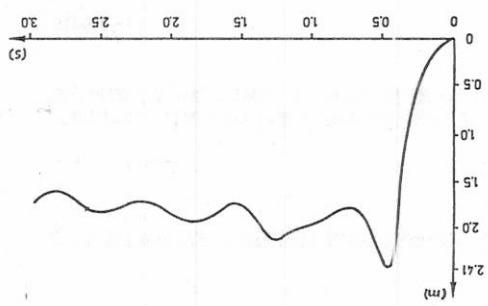


Fig. 3 Classical time evolution of the bottom of insulator chain next to break (vertical component)



KA a maximum of 11.8 kN per phase. Security F.G.H. without ice-load and have found for 8 tions they come back together very closely. The authors of (6) have made some tests in 0.54 m to 2.7 m. After short-circuit eliminates the distance between conductors goes up from even electromechanical load. In the same time to 3 to 4 times the initial value for the given when they move away the tension increases up once more away due to short-circuit force, etc. During short-circuit conductors move first away from rest position and the distance between

maximum rises to 20 kN instead of 16 kN. Lutton in the two other phases is similar but tension in the bottom phase versus time. Evolution shows the evolution of the mechanical

spacings was replaced by transverse spacer. For numerical calculations start constant. For duration and 30 ms for the time 1 second of three phase width maximum asymmetry, 8 kA rms, is three times 6.4 ms. Spacing mass is 3.2 kg. Short-circuit section is 5340 N at -5°C with added load of 6.4 m with ACSR conductor 50/8 mm². Conductor tension shows the geometry of the span and the intermediate spacer. Span length is 4 times 29 (Fig. 6).

Fig. 7 shows the deformations on new 20 kV compact line design last CTRD (June 1985) (6) has given some information on how 20 kV compact line design

phase short-circuit. Fig. 8 on classical 3.2 20 kV compact line submitted to 8 kA three-phase short-circuit. Some seconds by inertial effect. We already have some experience in effect of increase of mechanical tension (due to forced vibration caused by magnetic field) and instantaneous movement (due to forced vibration caused by inertial effect). The main problems caused by short circuit are some deformations caused by inertial effect.

We already have some years. But what happens during compact line design have increasing interest from some years. What happens during short-circuit?

3.1 General approach

3. ELECTRODYNAMIC LOAD

model like the one presented in this paper. Natural choice of up to date engineers is low cost numerical calculations with appropriate splitted, experimental tests are very simple. Analytical approach must be of course very sim-

plex, say or tension, span length, inclined

sulator length and weight, cable characteristics of numerous parameters (anchoring structure, loads causing failure, deformation is depending on the probability of failure and the utilities and designers need sufficient knowledge to perform the risk analysis the cascading failure are extremely expensive but

which allow slippage of conductors under impact, like break-away cross arms, clamp releases results in the loss of components easily repeated transmission line systems so that failure not the answer. One approach could be to design over-design of all towers to prevent failure is cascading failure are extreme but

2.3 Conclusion 1

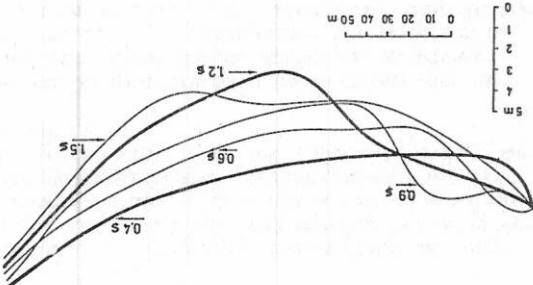
span 3 and 4. The first time of appearance chording point of the span 3 at insulator between other spans is to modify real stiffness of another peak (thick line). Influence of transition of second peak (thin line) was two hours CPU on DEC 2050 (1 mips).

Compaction time for this case (3 seconds of observation for all the section) was two hours the first clearly explains the time of apparition

in fact only the two first peaks are of some choice.

After discretization in space which explains our results on Fig. 5. We have already spoken about. The wave is visible below the propagation of the travel wave is folded parameteric second order elements in order to for the spans 4 to 7 (only 4 second order cable elements). Span 3 was discretized with 14 limit to discrete this is mainly due to discretization in space which was limited after discretization increases this is mainly due to discretization in space which explains our results on Fig. 5.

Fig. 5 Propagation of travelling wave in the span 3 (in a vertical plane)



On Fig. 2 conformation with experiment is remarkable until 1.5 seconds. Calculations in continuous line. On Fig. 3 next to break, displacement of the span (Fig. 4). Tension (span 3 next to break), displacement of the bottom point of insulator (Fig. 3) and mid point of the span (Fig. 4). Tension (span 3 next to break), displacement of the bottom point of insulator with experiment is remarkable until 1.5 seconds. Calculations in continuous line.

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Cables are very often used for their flexibility, low weight small cost, etc... But their flexibility, low weight non linear. Easy solution can be found by the proposed model in our software "CABLE" included in the CAE program developed in our laboratory, Lisbon, Portugal. Now it is highly non linear. Easy solution can be found by the proposed model in our software "CAFE" included in the CAE program developed in our laboratory, Lisbon, Portugal. Nov. 1968 (in portuguese).

Numerous components have to be taken into account (insulator chain, anchoring structure, spacers, etc.). In consequence the solution obtained is not over nor under designed.

Practical applicability of our model is very large. Of course not only dynamic but also very complex static calculations can be performed. Numerous experiments have been done in the past (5,8) and always in a very satisfactory way.

General conclusions

Electrodynamic forces due to short-circuit cause very strong effect on supporting structures and also spacers. In full scale tests you can only simulate some few cases and for a very high cost. Why not stimulate a lot of cases on a well proved numerical model for a low cost?

3.2 Conclusion 2

We could have tested the combined effect of short-circuit and after some time the rupture of the ice (due to shock and heating) but that's another case.

Let's note that heating is very important due to small cross section: after 1 second of fault to the temperature has increased of about 35°C. This effect partially explains the very big instantaneous interphase distance observed (2.7 m).

Fig. 7 Time evolution of mechanical tension in the bottom phase for a 3-phase short-circuit 8 kA.

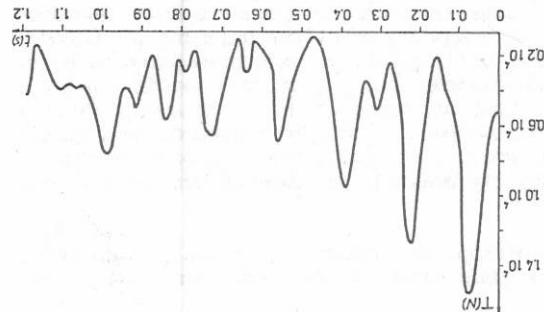
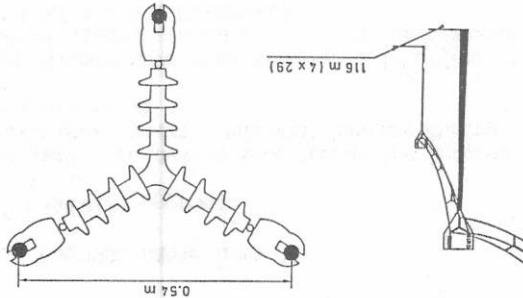


Fig. 6 20 KV compact line design and the interphase spacer used.



With 20 kV calculated on the same line with a load, security factor goes down to 1.06. Moreover there is some risk of secondary fault due to close come together after proper effort. In addition of the fault.

The solution of the system equations is obtained by taking discrete time elements using second by second by step direct integration methods.

Constitutive law given by $N = EA^0(g-a(0-E^0))$

Where E is the variation of the Green's measure (strain) and N the tensile force in the cable.

$$\int_0^t [(-P_0 A_0 \dot{u}_1 + f_1' + f_{NC}') \dot{u}_1 - N \ddot{u}_1] ds = 0 \quad (4)$$

Carrying out the variation of these expressions the equation (3) becomes the virtual work equation that can be applied to transitions problems:

- 1. : cable length without strain
- 2. : potential energy ($\text{gravity}, \dots$)
- 3. : external conservative loads
- With U_1 : cable strain energy

$$U = \text{total potential energy} : U_1 + U_2$$

where t : cable kinetic energy

where t_1 and t_2 are times at t_1 and t_2 , the lagrangian forces of the system. We add the electrodynamic action is stationary regarding the real trajectory $\dot{u}_1 = 0$ at times t_1 and t_2 , the virtual motion's principle of least action that in a way \dot{u}_1 kinetically admissible and in such a way variate system undergoing displacement variations. Hamiltonian formulation of the motion equations rather than reference to the previous instant.

We have chosen the so called fully Lagrangian approach (initial configuration) at any instant rather than reference to the previous instant.

2. Flexible cables elastodynamic

Internal and external damping may also be negligible as these values have a small effect upon the maximum values of the response which occurs as the damping co-efficients are also very large.

The flexional and torsional stiffnesses of cables may be neglected as these parameters have a very low influence of the phenomenon owing to the magnitude of the forces. Moreover it is difficult to obtain realistic experimental data for them.

The three phase faults and a realistic assessment of the movement (laplace's law), phase-to-phase or counterphase mechanisms, cables of various sizes, electromechanical forces caused by currents, and insulator drops (rigid or semi rigid), concentrated masses (pantographs, gravity and wind, and conductor head towers, insulator supports (giant), cables and their anchoring structures (giant), towers, the elasticity and inertia of the cables, the computation of large displacements of the system to take into consideration in current flow.

1. Mechanical considerations (5,9)

APPENDIX HYPOTHESES AND MODEL EQUATIONS

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