THE USE OF THE COMPUTER PROGRAM ATP FOR STUDYING ELECTRICAL TRANSIENTS IN INDUSTRIAL POWER SYSTEMS

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Abstract - It is showed the use of the program ATP, PC version of the Electromagnetic Transients Program (EMTP), in the study of electrical transients in industrial power systems. Several studies are showed in systems existing in oil refineries and offshore platforms.

Studies of transient overvoltages are presented in 480 V systems being grounded or not. These studies, executed in platforms, are compared with tests performed . It's also presented overvoltages caused by switching, energization and de-energization of a electrical system of two tied platforms.

Several studies are performed in the electrical system of a refinery: capacitor banks switching causing undesirable occurrences, line-to-ground faults in feeders and their consequences in others feeders and inrush currents of capacitor banks operating isolated or back-to-back.

1. INTRODUCTION

We see, in Brazil, the use of the Electromagnetic Transients Program (EMTP) for studying electrical transients only in the electric energy systems of the large power companies. We know a little about this use in the industrial power systems. In the beginning of 1992, we started studying the utilization of the program ATP, PC version of EMTP, in the electric systems of the oil industry. We see a large utilization of the ATP in the electrical systems existing in the oil refineries and offshore platforms from PETROBRAS, the oil company of Brazil.

Our first utilization was in an electrical system of one offshore platform situated in the Campos Basin, which is responsible for almost 70% of the national production of oil in Brazil. In these platforms, the 480 V system is solidly grounded. Due the high values of the ground-fault currents in this type of system, causing fortuitous material damages and even human, we began studying the grounding of this system through high resistance. One platform was chosen as pilot, we changed its grounding system and performed a few tests.

We use the ATP for studying transient overvoltages in the 480 V system being ungrounded or grounded through high resistance. The electrical system was modelled with its 13.8 kV generation, cable, 13.8-0.48 kV transformer and 480 V cable. The results were compared with tests done and with the existent literature about this subject.

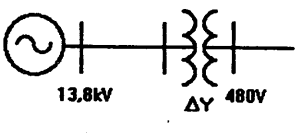
Other case studied was the electrical tie between two offshore platforms through one submarine cable with 7 km of length. They were studied overvoltages caused from switching of the system and transient overvoltages caused by ground faults.

We also used the ATP in several studies in an oil refinery, such as capacitor banks switching causing undesirable occurrences, line-to-ground fault in one feeder and its consequence in another feeder and inrush currents of capacitor banks, with the possibility of puting reactors in the circuits that feed the banks.

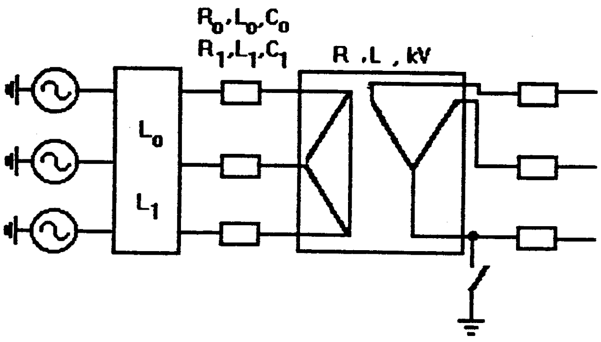
2. TRANSIENT OVERVOLTAGES

Our first experience with the ATP was a complement to the paper presented by Bordignon and Diógenes in the First Meeting of Electrical Engineering of PETROBRAS [1]. In this paper it was analysed the change of the 480 V system of offshore platforms from solidly grounded to grounded through high resistance. Results of field tests of transient overvoltages that appear during intermittent arcing ground faults are also presented in this paper. We use the ATP for studying transient overvoltages due to intermittent arcing ground faults varying the 480 V system grounding from ungrounded to grounded through high resistance.

Figure 1 shows the typical system studied. Regarding to the ATP simulation, we must be careful in chosing the time step which must be lower than the travel time of the lines modelled through distributed parameters. In the industrial case, low values of the travel time (τ) appear in the cables. In our system, we found τ of positive sequence equal to 21.5 μs and τ of zero sequence equal to 20.4 μs, for the 480 V cable. We used a time step of 20 μs and a time of simulation of 25 ms. We also found difficulties to determine the values of resistance, inductance and capacitance of positive and zero sequences of the 480 V cable. These values were obtained from T&D [2].



(a) One-wire diagram



(b) Modelling

FIGURE 1 : Sample system

We intended to simulate the study of overvoltages due to intermittent ground faults, that is, repetitive momentary contacts between one line and ground. This phenomenon is presented in Beeman [3], which is showed in figure 2, for ungrounded systems.

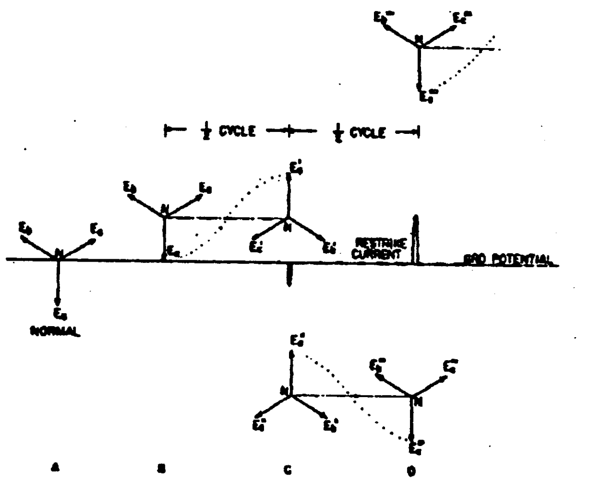


FIGURE 2: Overvoltages on ungrounded systems due to repetitive momentary contact between one line and ground

For simulating the arcing faults, we use the artifice of opening and closing of ground switchs in one of the phases. In a determined instant, we close the first switch simulating the first arc. This switch is opened when the fault current reaches zero occurring then the first arc extinction. A second switch , in parallel with the first that remains open, is closed when the voltage in this fault phase reaches a maximum. It is the simulation of the second arc. Again when the fault current reaches zero, this second switch is opened, so the second arc is extinguished, and a third switch is closed, also in parallel, when the line voltage reaches a maximum, so simulating the third arc, and then successively.

In figure 3, comparisons made regarding waveform only are showed among the simulations done by the ATP with results presented in [1]. The similarity between the waveforms seems to show a good modelling obtained by the ATP. In this case, the system was high resistance grounded.

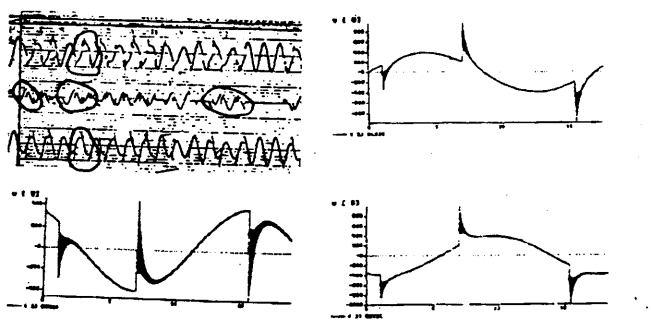


FIGURE 3: Comparison between waveforms: real x simulation. High resistance grounded system. (left lower is the faulted phase)

Figure 4 shows computer outputs with the ungrounded system. Figure 5 presents the numerical results after 3 successive faults, with different grounding. The results show how the overvoltage decreases as the system goes from ungrounded to high resistance grouded. If we compare these results with the field, we observe that for the case of high resistance, the numerical values are close. The same does not occur to the ungrounded system which presents lower fields results. The computer results are closer to the ones found in the literature about this matter.

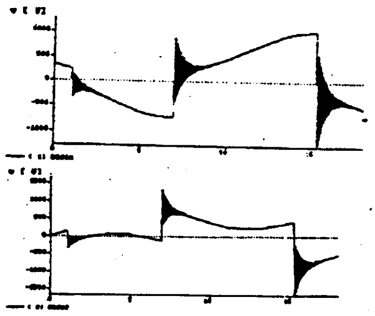


FIGURE 4: Computer outputs. Ungrounded system. (faulted phase is the upper)

type of grounding	phase a (V)	phase b (V)	phase c (V)	maximum p.u.
ungrounded	1255	1639	1644	4.2
138 kΩ	1229	1603	1634	4.2
69 kΩ	1204	1582	1613	4.1
554 Ω	470	979	997	2.5
277 Ω	452	964	983	2.5
138 Ω	422	938	957	2.4
27.7 Ω	435	786	806	2.1

FIGURE 5 : Phase voltages maximum values (after three sucessive faults)

3. ELECTRICAL TIE BETWEEN TWO PLATFORMS

Figure 6 shows other system studied through the ATP. It is a electrical tie project between two 2 platforms through a submarine cable with 7 km of length. Due to the impossibility of using traditional lightning arresters in platforms, because of the explosion risk, our concern was the calculation of switching and transient overvoltages. Again, in the industrial power systems modeling, we were careful in determining the time step Δt. We found, for the cable, τ of positive sequence equal to 58 μs and τ of zero sequence equal to 50.9 μs. Once again, we made use of T&D, [2], in order to determine the zero sequence values of the cable.

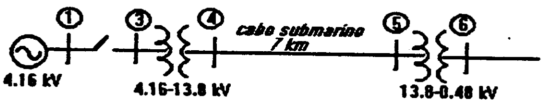
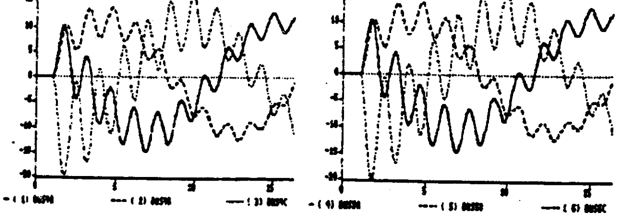


FIGURE 6: System studied. Electrical tie between two offshore platforms

We elaborated the following studies to determine the voltages in the begining of the cable, 4.16-13.8 kV transformer secondary, bus 4, and end of the cable, 13.8-0.48 kv transformer primary, bus 5.

a) system energization:

Figure 7 shows the phase voltages at buses 4 and 5 for a system energization with the loaded system. We found a maximum phase voltage of 1.78 p.u.. In this simulation, the contacts of the breaker close simultaneously. We made others simulations: unloaded system and contacts of the breaker not closing simultaneously. The maximum value found was 1.96 p.u. (unloaded system and contacts closing at the same time).



(a) bus 4 (b) bus 5

FIGURE 7: System energization. Phase voltages at buses 4 & 5. Loaded system.

b) ground fault at bus 5:

Figure 8 shows the phase voltages at faulted bus for a ground fault at bus 5. The maximum voltage found was 1.26 p.u..

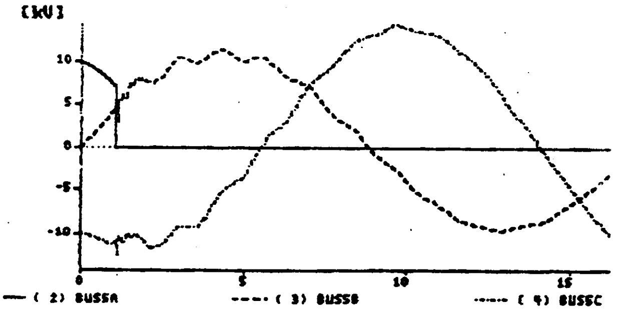


FIGURE 8: Ground fault study. Phase voltages at bus 5

c) system de-energization:

A new study performed was the system de-energization presented in figure 8, that shows phase voltages at bus 4, for the loaded system. The maximum phase voltage found was 0.97 p.u.. For the unloaded system, we found a maximum value of 1.38 p.u. (figure 10). We see, in the figure 10, the trapping phenomena. As the system is unloaded, the charge is trapped in the cable.

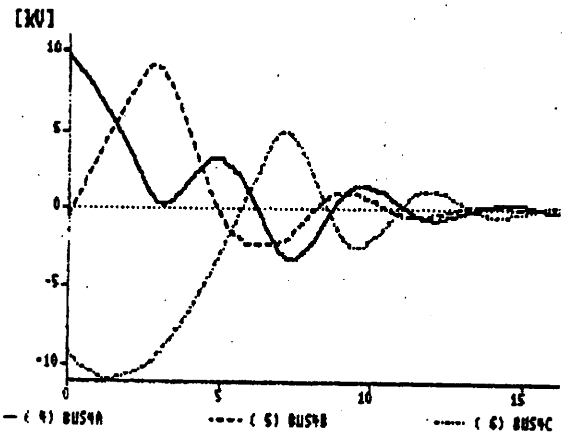


FIGURE 9: System de-energization. Phase voltages at bus 4. Loaded system..

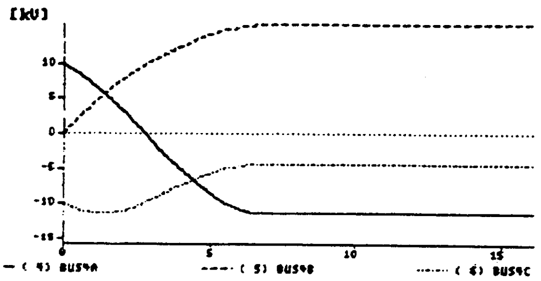


FIGURE 10: System de-energization. Phase voltages at bus 4. Unloaded system..

4. STUDIES PERFORMED IN A REFINERY

The ATP was used in several studies in an oil refinery. Figure 11 shows the one-wire diagram of the studied system. The first studies started with the purpose of understanding some abnormal occurrences in the operation of the capacitor banks such as the energization of a bank causing tripping of the other and the misoperation of neutral relays of transformers or the de-energization of a bank also with undesired consequences

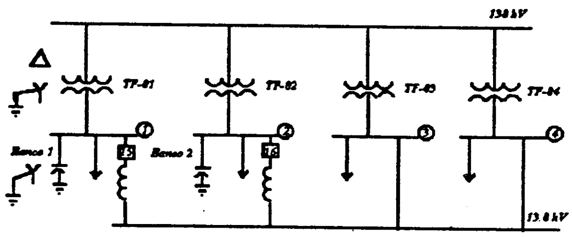


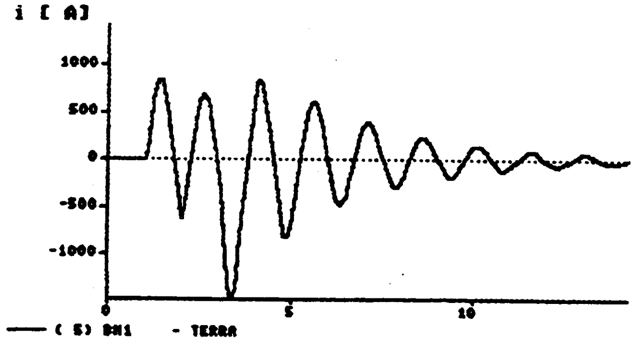
FIGURE 11: Sample system

a) undesired occurrences:

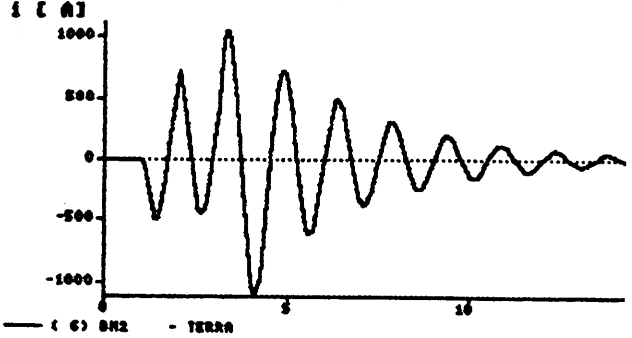
One of the occurrences seen in the field was that when bank 1 is energized, being bank 2 operating and the tie breakers closed (breakers 15 and 16), bank 2 is tripped through its 50GS protection and there is a misoperation of the 50GS protection of the proper bank 1 and a neutral relay of the transformer 3. The computer outputs seen in figure 12 show that these consequences can occur. About our simulation in these studies, we would like to say:

1. We used an artifice to determine the 50GS relay currents, which are proportional to the sum of the 3 line currents. We created an element, a little value of resistance, between the neutral of the Y connection of the bank and the ground, and obtained the current in it which is the sum of the 3 line currents.
2. The currents of the transformer neutrals are zero when simulating the energization of the capacitor bank, with simultaneous closing of the contacts of the breaker, which feeds the bank. The results showed in these studies occur from the no simultaneous closing of the contacts where is a difference of 1 ms in the closing of each contact.

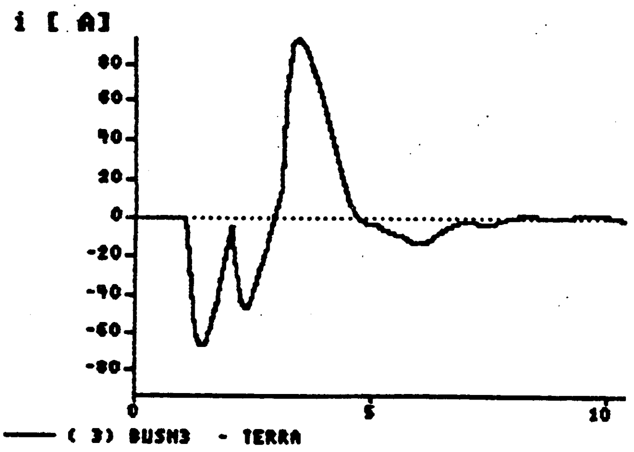
Having these results, the project engineer will be able to take decisions such as to change the protection, to make temporization, to analyse the grounding system,etc.



(a)50GS relay primary current. Bank 1.



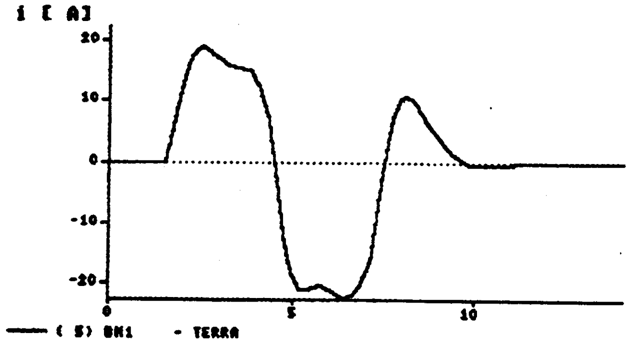
(b)50GS relay primary current. Bank 2



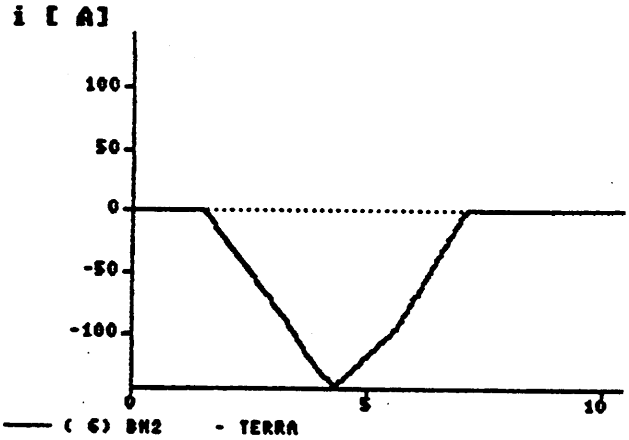
(c)transformer 3 neutral current.

FIGURE 12: Capacitor bank 1 energization with bank 2 operating and tie breakers closed.

Another occurrence could be observed when bank 2 is tripped, being the bank 1 operating and the tie breakers closed, was the misoperation of the 50GS relay of the bank 2 and the neutral relay of the transformer 3. Figure 13 shows these computer results. It is seen that due to the grounding banks, there is circulation of current in the ground.



(a)50GS relay primary current. Bank 1



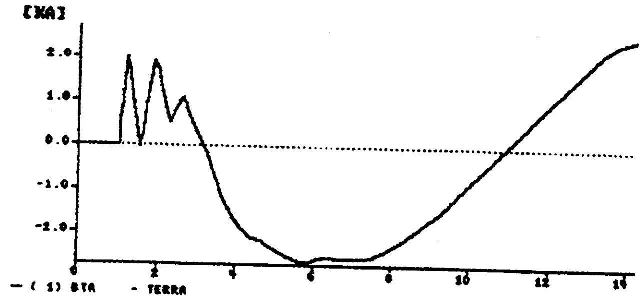
(b)50GS relay primary current. Bank 2.

FIGURE 13: Capacitor bank 2 de-energization with bank 1 operating and tie breakers closed.

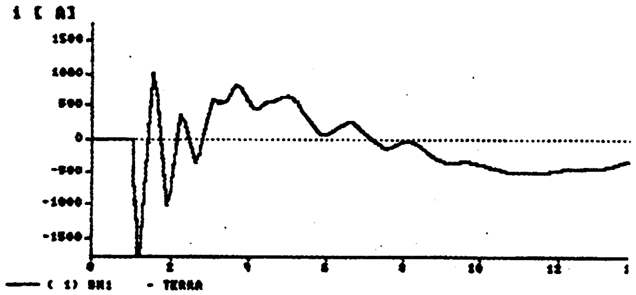
b) ground fault study

Another study performed was a line-to-ground fault in one 15 kV feeder and the consequences in the system. It was seen the acting of the 50GS protection of the capacitor banks and of others feeders too when this fault occurs. The ATP simulation is showed in figure 14. Again, the project engineer has proper data to take decisions.

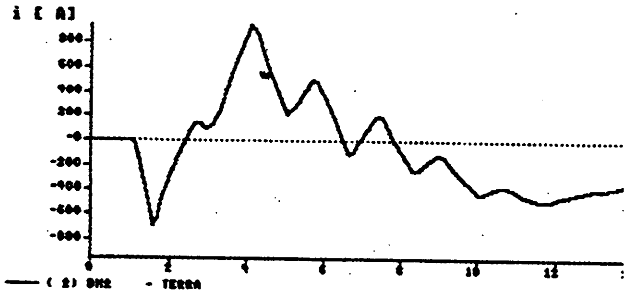
Again, we had the same problems of modelling: difficulties for obtaining the cable values and low values of τ in the cables. The artifice to determine the current in the 50GS relays was an additional problem. We used distributed parameters to model the faulted feeder and used lumped parameters to model the feeder which we wanted to observe the fault effects.



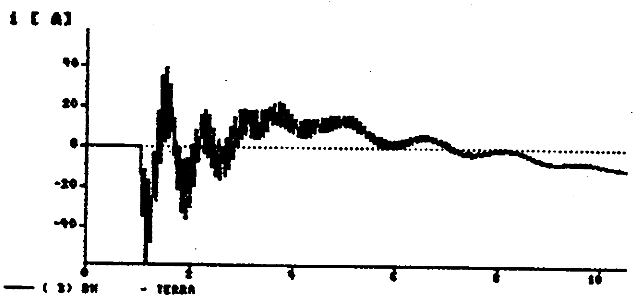
(a)Ground-fault current



(b)50GS relay primary current. Bank 1.



(c)50GS relay primary current. Bank 2.



(d)50GS relay primary current. Feeder observed.

FIGURE 14: Ground fault at a feeder.

c) new capacitor bank:

The inclusion of a new 5,400 kVAR capacitor bank, at bus 4, has originated more studies with the ATP. To select the circuit breaker for this bank, we use the ATP to find the transient inrush current and frequency. Figure 15 presents the isolated bank switching being found the values 3,806 A (peak maximum value) and 500 Hz. As the resistance of the bank was not modeled, there is no current decaying.

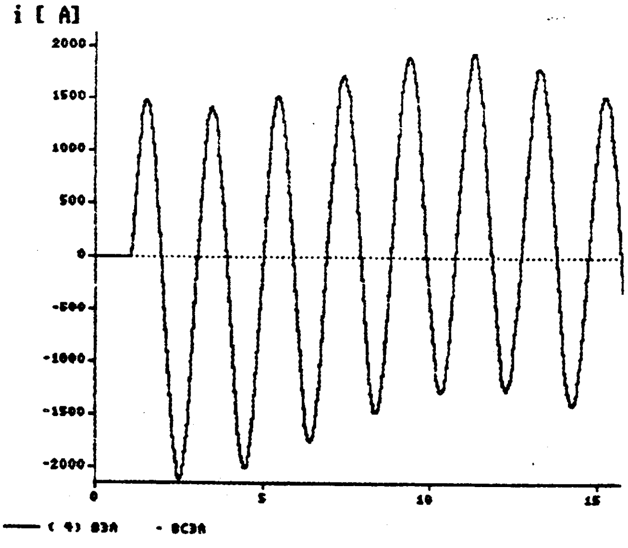


FIGURE 15: New capacitor bank energization. Isolated switching. Only one line current showed.

We found 4240 A (maximum peak) and 1000 Hz when the new bank is switched back-to-back, that is, with bank 1 and bank 2 operating, without modeling the resistance of the banks. Figure 16 shows the simulation with modeling the resistance. In this case, we found a lower value of the current, 3490 A, but the same frequency, 1000 Hz. Due to the lack of further information about the value of the banks resistances, we used a typical value found in [2]. We used a resistance value which represents resistive loss in the bank equal to one third of 1% of the bank kVAR.

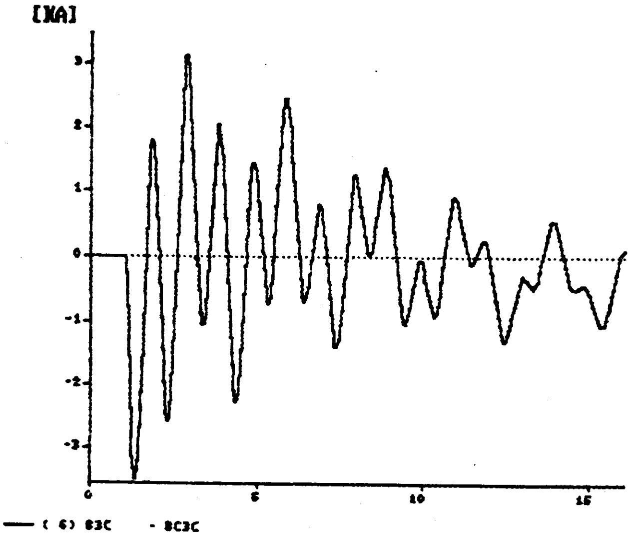


FIGURE 16: New bank energization. Back-to-back switching. Only one line current showed.

As we found a high value of current frequency, we simulated the addition of reactors in the circuits that feed the banks. We included the inductance within the capacitor bank itself, a typical value of 5 μH, and varied the reactor values included in the bank circuits. For a value of 100 μH, we found 3,190 A and 875 Hz..

5. CONCLUSION

More and more we see computer programs originally restricted to the use of the electrical systems of the large power companies, being used in the industrial power systems. We started with the steady-state programs: short-circuit, load-flow. We moved to dynamic regimes: dynamic studies, stability, transients.

In electrical transients, we see the EMTP as an important or even compulsory tool in the studies made in industrial power systems. Studies of system modifications, ties, non-understandable situations, equipment selection, can be performed with this tool.

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