Comparison of Traditional and Thyristor-controlled Fault Current Limiters for Medium Voltage Application

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Abstract - **EMTP simulation was applied to find the best solution in solving the problem, how to decrease the dynamic and steady state short circuit current in an industrial network, where two, originally radial suppy systems had to be interconnected in order to increase the voltage stability and the reliability of service, without increasing the short circuit stress of the network elements (circuit breakers, busbars, e.t.c.). Three kind of possible solutions were examined and the optimal one was found causing negligible overvoltage and ensuring acceptable short circuit current. Results of EMTP studies performed on a medium voltage power supply system of an industrial power plant are presented.**

Keywords: fault current, limiting, thyristor, simulation, overvoltage, EMTP, medium voltage, industrial network.

I. INTRODUCTION

Proliferation of sensitive loads such as computers, programmable drives and controllers in industrial networks requires more reliable power supply. The reliability can be increased by interconnecting the normal and backup feeders, or closing the tie breaker in twin-buses substations. Both operations improve the power quality of the supply by lowering the flicker level, increasing the voltage stability, reducing the voltage sag and the voltage drop [1].

In order to keep the short circuit level of the system below the component withstand level, buses are generally connected through series reactors acting as static limiters. When quick segmentation of the network in case of fault is needed, dynamic short circuit limiters should be applied. Two kinds of such devices can be considered: the traditional exploding-type and the solid-state fault current limiter.

The paper introduces the operating principle of different kind of fault current limiters and modeling aspects of them using the ATP version of EMTP [2] and ATPDraw for Windows [3]. In these studies the operating characterisitics of traditional and thyristor-controlled dynamic fault current limiters have been investigated in a real size network.

II. SHORT CIRCUIT LIMITING METHODS

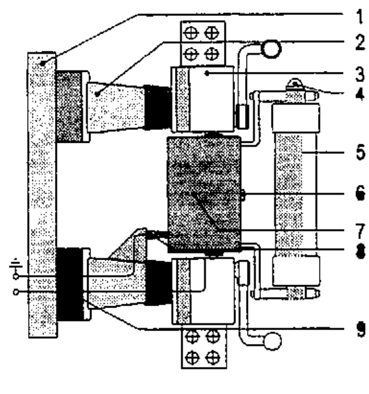
The limitation of the short circuit current magnitude is very important from the point of view of the rated short circuit power of existing equipments. The shorter is the clearing time the less is the dynamic stress caused by the short circuit current. However a current breakdown before its zero crossing will cause enormous overvoltage on the system. This problem on the medium voltage distribution network is solved with the known compromise: the short circuit current is limited by series reactors, causing steady-state voltage drop.

However in some special cases the ultra fast limitation of the developing short circuit current would be essential. Ultra fast operation means here a time interval of 2-4 ms. There is a known method to solve this problem introduced on medium voltage networks, called dynamic fault current limiter (DFCL), or I_S Begrenzer [4] in German.

As it is shown in Fig. 1, this device includes an exploding fuse in the path of high current (part 7 in Fig. 1). After this part exploded, the high current flows through a medium voltage fuse (part 5) composing this way a resistive circuit and the current will be cut off by the fuse, causing a relatively low overvoltage due to the resistive circuit.

To get a reliable sensing of the development of the short circuit current special current transformers and di/dt sensors are used. The disadvantage of the dynamic short circuit current limiter is, that after each operation a maintenance is necessary to replace the blown parts. However the parts to be replaced are very expensive. If there is a relative high probability of the faults on the network, the application of DFCL does not seem economical.

The alternative method could be to connect a solid state fault current limiter (SSFCL) instead of the DFCL to achieve better economical and technical parameters [5].



1 base	6 indicator
2 insulator	7 exploding capsule
3 connection	8 spring contact
4 indicator	9 impulse transformer
5 HV fuse	

Fig. 1 - schematic description of the conventional, exploding-type fault current limiter [2]

III. SYSTEM STUDIED

As it was mentioned in section II, medium voltage distribution cable network feeders are connected usually via short circuit limiting reactors to the busbar of the substation. However in some cases series reactors have to be omitted from some reason which is out of scope of this paper. In these cases DFCL application can help in sense of the dynamic short circuit current limitation, and makes unnecessary to invest money to increase the short circuit withstand capability of buses, breakers etc.

The disadvantage of the DFCL is the time necessary to replace the blown elements in order to be ready for operation again. (The exploded capsule and the high voltage fuse are to be changed.) The price of a capsule can not be neglected as well.

Because of these disadvantages, the operation of DFCL must be based on a very sophisticated sensor system to avoid misoperations. The introduction of SSFCL can be advantageous even in these simple cases because of the fast recovery ability, and lack of maintenance after every operation.

The network studied in the paper is more complicated than the above mentioned simple one. The industrial plant as seen in Fig. 2 is fed via two transformers connected to a twin busbar transfer substation.

The power plant is separated into two radial systems, and they can not be interconnected if both transformers are in operation, because the short circuit withstand level of some busbars and circuit breakers would be exceeded when a three-phase-to-ground fault appears.

IV. PROBLEMS TO BE SOLVED

A) Voltage fluctuation

System 2 supplies a high power dynamic load (rolling mill drives). The voltage fluctuation exceeds 4% on the 10 kV side of the substation, causing problems at sensitive loads. The question was how to decrease the voltage fluctuation about to the half of the original value.

B) More reliable power supply

The voltage outage is permitted for a short time while the protections operate and the fault is located. Of course the shorter is this period the better is the power quality. Because of the radial supply systems, practically there is no interaction between System 1 and System 2. In case of emergency the two radial systems can be interconnected, however by means of continuous parellel operation would provide a more reliable supply.

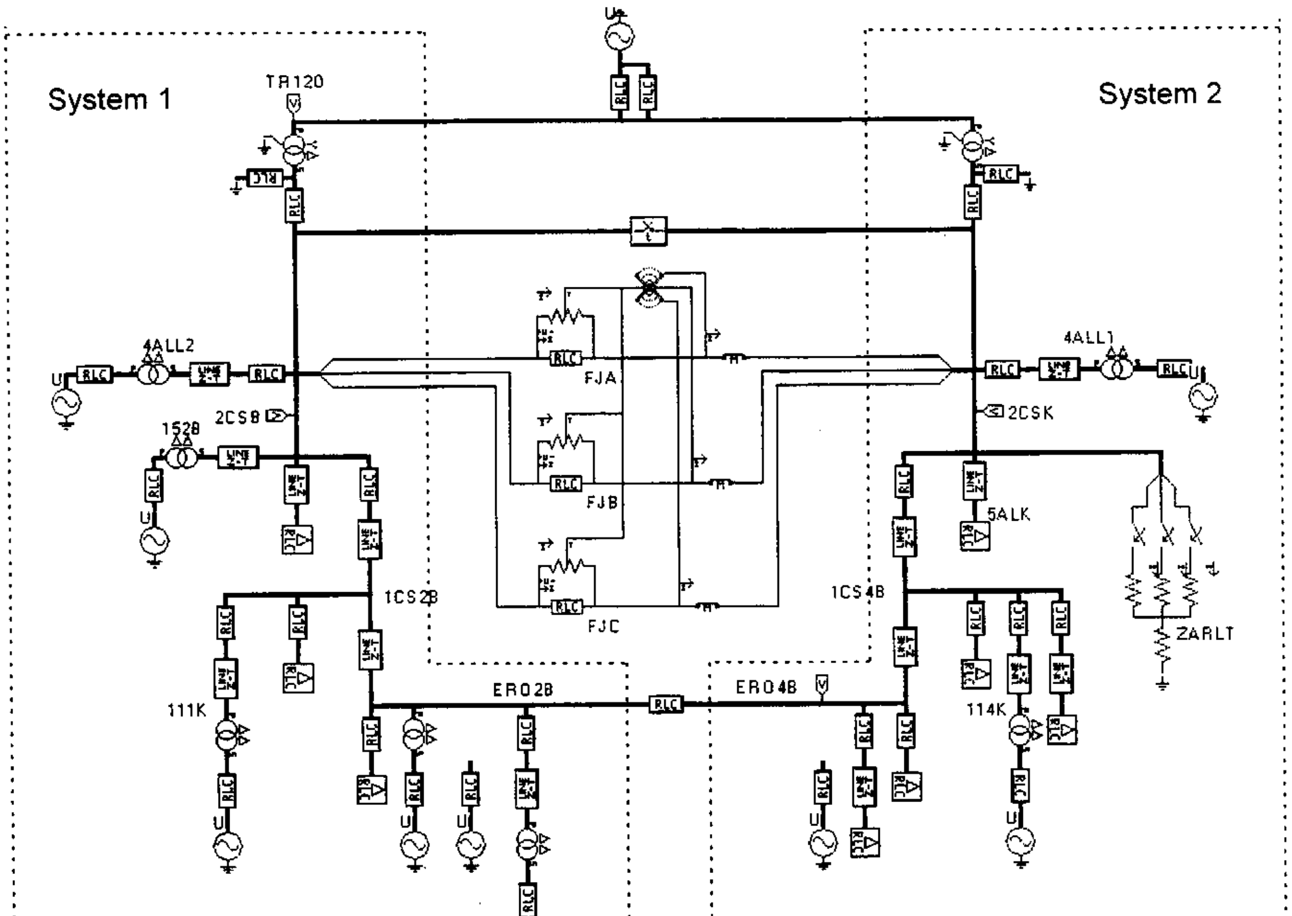


Fig. 2 - Power supply system of the studied industrial plant

One possible solution for the above problem is the SVS, the other possibility is to increase the short circuit withstand level of the substation. The idea was to solve both problems with one intervention.

The most promising alternative were if the two radial systems are steadily interconnected via series reactor, and in normal mode the DFCL or some kind of SSFCL were connected in parallel with the reactor as it is seen in Fig. 2. In order to find the most proper solution, a detailed EMTP model of the energy supply system has been built.

V. EMTP MODEL AND THE GOAL OF THE STUDY

The goal of the simulation was to determine the parameters of the reactor and the main characteristics of the voltage and current transients, when different kinds of short circuit limiters operate.

The reactor and the dynamic fault current limiter parameters have been selected according to the following conditions:

- the short circuit power has to stay under the allowed value in steady state regarding any kind and any location of faults along the system
- the voltage drop across the reactor should be the possible minimum during short circuit
- the highest fault current on the reactor and longest clearance time of the protection has to be considered
- the overvoltage caused by the limiter should comply with the level given by the overvoltage protection
- in case of SSFCL to find the most economical solution

The most important components of the EMTP model are described next. The medium voltage underground cables which are connected to the busbars via or without reactors have been represented by three-phase constant parameter, transmission lines. The reactors were modelled by lumped R-L-C branches. Mutual coupling beetween reactors and their capacitances has been neglected. The buses are supplied by two Y/Δ connected transformers delivering energy from the utility's 120 kV network, and by several medium voltage generators in the own power plant of the factory. Transformers have been represented by a 3 phase saturable transformer model, however the magnetizing branch has been neglected. Loads were simulated either by delta coupled RL branches or by a sub-transient Thevenin equivalent of large motors. Generators and motors were connected to the busbars via artificial Δ/Δ transformers, to ensure the exact representation of its zero sequence impedance. Description of the DFCL and SSFCL models will be given later.

VI. OPERATING CHARACTERISTICS OF DYNAMIC FAULT CURRENT LIMITERS (DFCL)

The operating principles of conventional limiter has been studied first in a simple case, shown in Fig. 3. As a first approximation, DFCL can be represented by a variable resistance, which describes the melting of the fuse:

if $I>I_m$ and $dI/dt > D_m \rightarrow R(t)=a\,(t - t_0)^b$, otherwise $R = 0$, where t_0 is the moment of operation of the limiter, a and b are device dependent constants, I_m and D_m are predefined margins which specify the operating conditions.

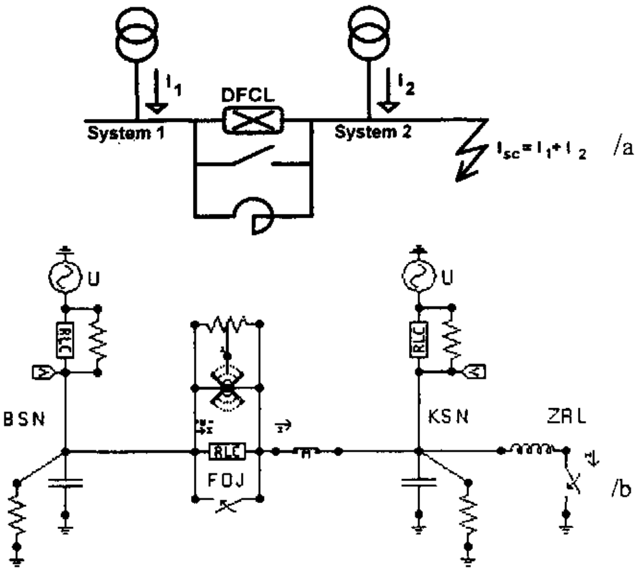


Fig. 3 - Single phase sheme for testing the model of the conventional limiter. a/ study case, b/ EMTP model

Such a variable resistance can be easily realised in ATP and ATPDraw as a MODELS [6] object.

Table 1 - Description of DFCL model in MODELS

```
MODEL EXPFUSE
INPUT CURA
DATA I_MARG, DIDT
VAR  RES, T_EXPL, FCURA, DCURA, FDCURA
VAR  F_CURA, D_CURA
OUTPUT RES
INIT
   T_EXPL:=0
   HISTDEF (FCURA):=0
   HISTDEF (FDCURA):=0
   HISTDEF (F_CURA):=0
ENDINIT
EXEC
FCURA:=(0.96*prevval(FCURA)+CURA)  -- filtering
F_CURA:=FCURA/25          -- rescaling * 1/(1-q)
DCURA:=deriv(F_CURA)
FDCURA:=(0.95*prevval(FDCURA)+DCURA)  -- filtering
D_CURA:=FDCURA/20000    -- *1/(1-q),*1/1000 [A/ms]
IF T_EXPL=0
   THEN RES:=0
     IF ABS(F_CURA)>I_MARG AND ABS(D_CURA)>DIDT
     THEN T_EXPL:=T
     ENDIF
   ELSE RES:=5.0E+5*(T-T_EXPL)**1.7
ENDIF
ENDEXEC
ENDMODEL
RECORD EXPFUSE.RES       as      RES
RECORD EXPFUSE.F_CURA    as      F_CURA
RECORD EXPFUSE.D_CURA    as      D_CURA
```

When the current reaches the pre-defined amplitude and steepness, the DFCL capsule explodes and the quickly increasing resistance redirects the fault current into the reactor. Since the evolving short circuit current always has a path to flow through a relatively low impedance (first through the capsule, then through the high voltage fuse and finally on the current limiting reactor), no significant overvoltage appears.

The time functions of the System 1 and 2 busbar voltages are shown in Fig. 4 - in case of DFCL is used to decrease the dynamic short circuit current.

The time functions of the corresponding currents are shown in Fig. 5.

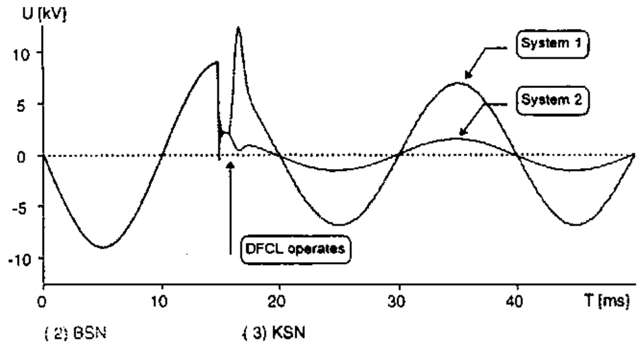


Fig. 4 - Pre-fault and post fault busbar voltages and transients caused by DFCL operation

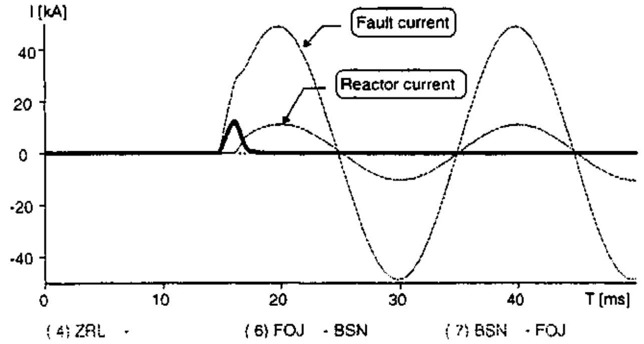


Fig. 5 - Symmetrical fault current of the reactor (thin line) and of the limiter (thick line)

The operation characteristics of DFCL device has been further investigated in a three phase model of the energy supply system of the factory. This scheme has already been shown in Fig. 1. Fig. 6 shows the main busbar voltages in case of a close-in three phase short circuit on System 2. System 1 and 2 are assumed to be interconnected via a tie breaker. As it can be seen, the voltage collapses in both system during the clearing time of relay protection.

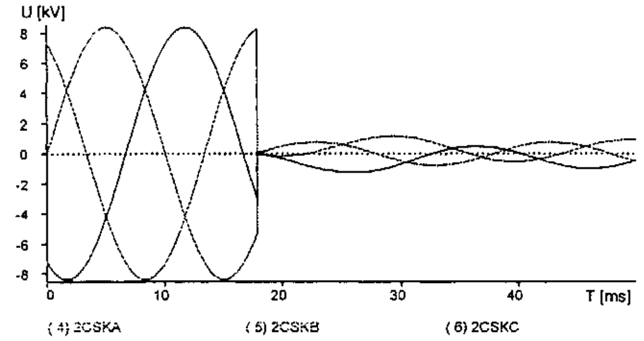


Fig. 6 - Three phase fault, no DFCL applied

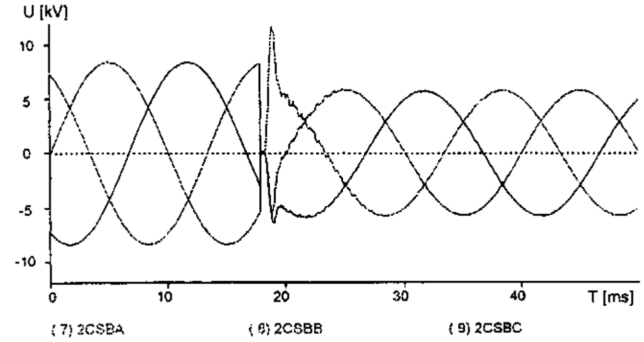


Fig. 7 - Three phase fault, with DFCL operation

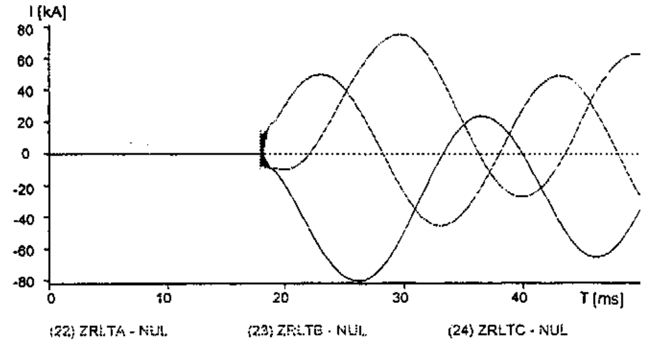


Fig. 8 - Short circuit fault current

Fig. 7 shows much lower voltage sag at System 1, when buses are interconnected via DFCL and a parallel connected current limiting reactor. The time functions of the corresponding currents are shown in Fig. 8.

VII. OPERATION CHARACTERISTICS OF SOLID-STATE FAULT CURRENT LIMITERS (SSFCL)

Two kinds of solid state custom power devices have been taken into consideration as promising alternatives of the conventional fault current limiter. These devices were:

a) antiparallel thyristor composed SSFCL and

b) GTO thyristor composed SSFCL.

One of the purpose of this work was to develop a simple study system that can demonstrate the operation of these devices and can be used at constructing the real size equipment in the future. Fig. 9 shows the single phase model of the antiparallel thyristor controlled SSFCL. The GTO thyristor controlled device is shown in Fig. 10.

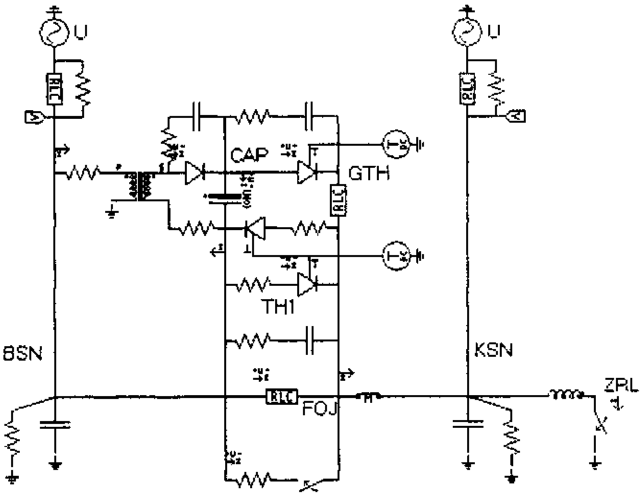


Fig. 9 - Single phase EMTP model of the antiparallel thyristor based SSFCL

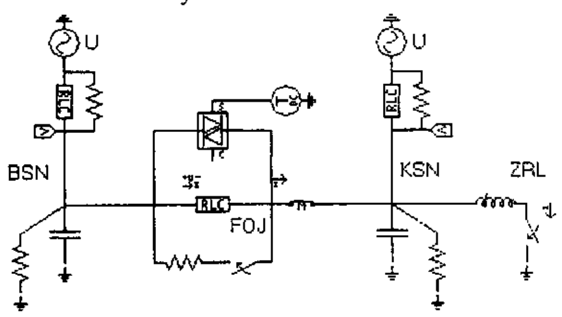


Fig. 10 - Single phase model of the GTO based SSFCL

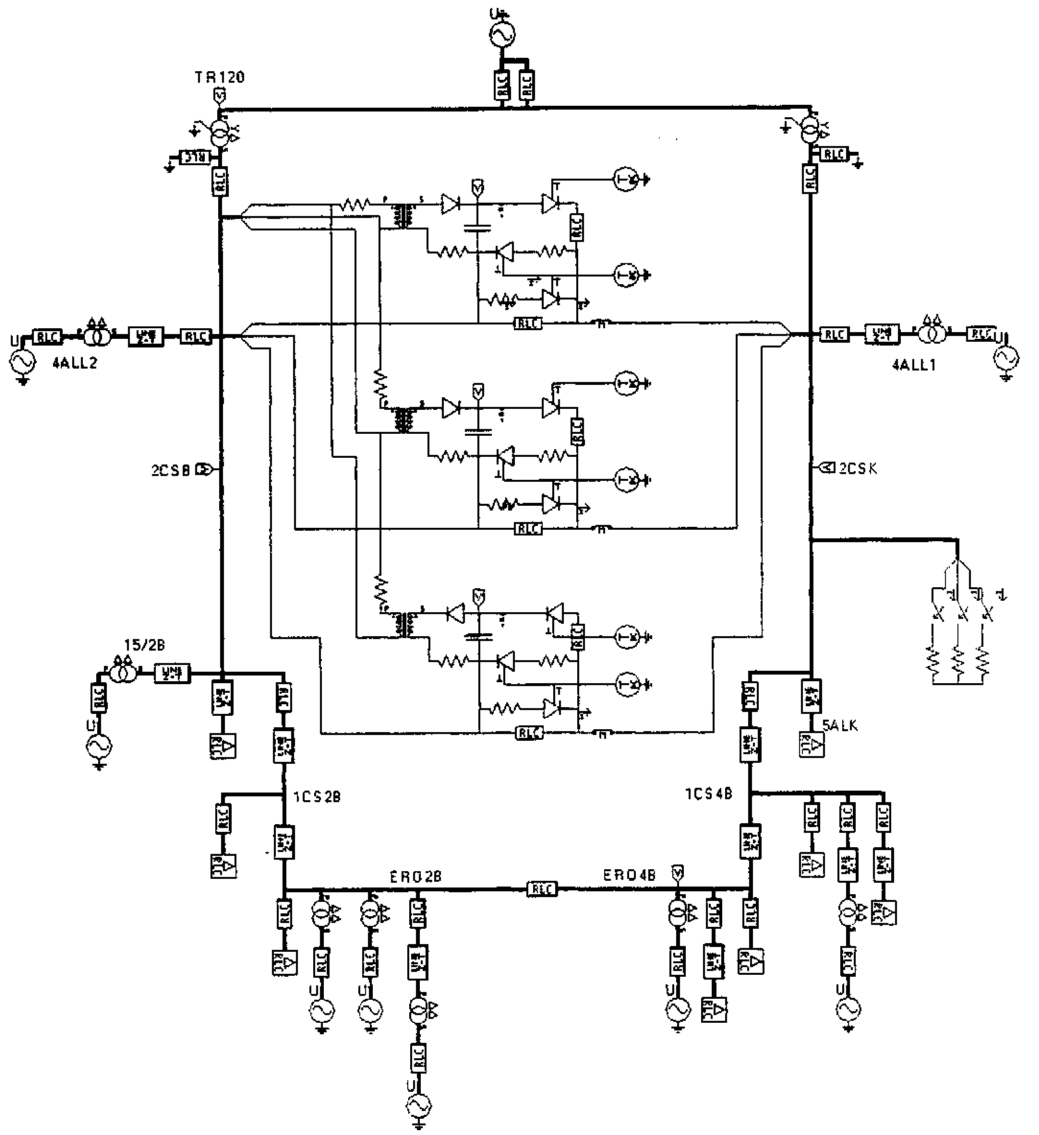


Fig. 11 - Three phase model of the simulated network completed with the SSFCL circuit

Description of operation of the complete SSFCL circuit shown in Fig. 11 is out of scope of this paper. Here only a brief overview of the operation of the single-phase SSFCL models shown in Fig. 9 and Fig. 10 are given.

Each phase of the SSFCL consists of either an antiparallel thyristor arrangement or a GTO thyristor. The main thyristors (TH1 and TH2) are fired continuously till short circuit is not detected, when firing of main thyristors are stopped. At the same time the extinguishing thyristor (GTH) is fired and TH1 thyristor commutates with that one due to the impulse current produced by the charged capacitor (CAP). Then the current extinguishes in the thyristor branch at the next transient current zero, and current of the reactor connected parallel with the main thyristors starts to increase.

Both SSFCL device would cause very high overvoltages without a damping resistor. This resistor must be connected in parallel with the reactor and semiconductors, as well. The damping resistor will be switched off by a vacuum circuit breaker within some power frequency period.

The main circuit of the GTO thyristor based SSFCL seems more simple than the thyristor based, but the firing circuit in this case is much more complicated than it was taken into account in this study.

Table 2 - Current and voltage stresses of semiconductors in the SSFCL circuit

	DFCL + fuse + reactor	SSFCL + fuse + reactor	SSFCL + resistance + reactor	SSFCL + reactor
Overvoltage crest factor	1.5 pu	1.0 pu	1.0 pu	2.1 pu
Inst. value of current in moment of breaking	10 kA	5 kA	5 kA	5 kA

The importance of the proper damping resistor in SSFCL circuits is demonstrated in the next figures. Without such a resistor the voltage stress of semiconductors and other circuit components would be significantly higher. The results of this optimization study are shown in Fig. 12-14, where different kind of SSFCL circuits have been simulated, assuming such a damping resistor connected to the circuit, or running the case without that. Table 2 summarizes the voltage and current stresses of semiconductors obtained in the study.

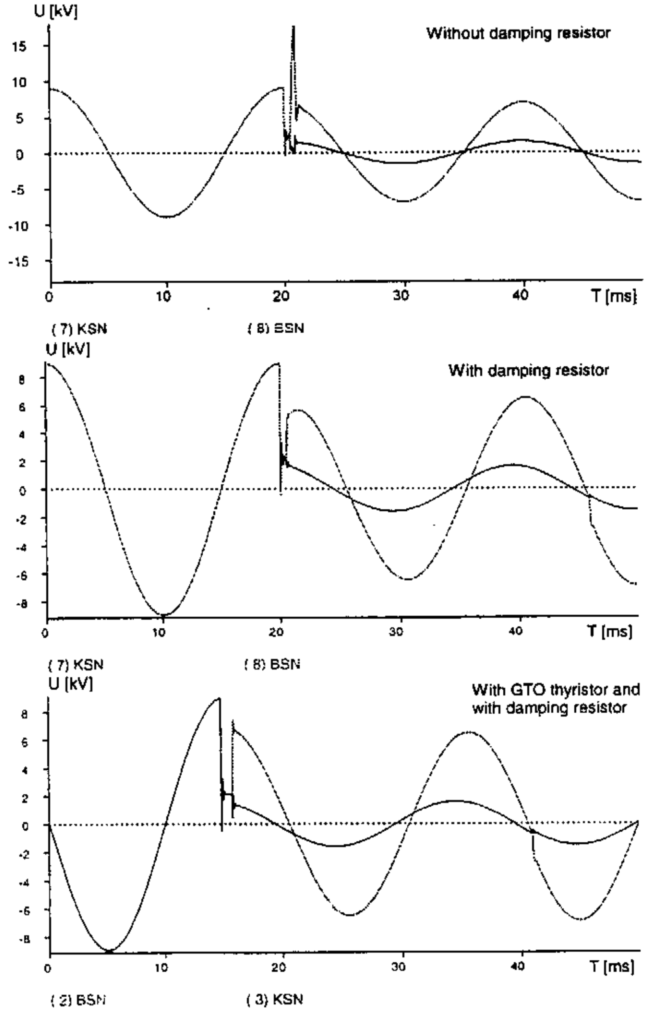


Fig. 12 - Busbar voltages when SSFCL operates with or without a 0.5 Ω damping resistor

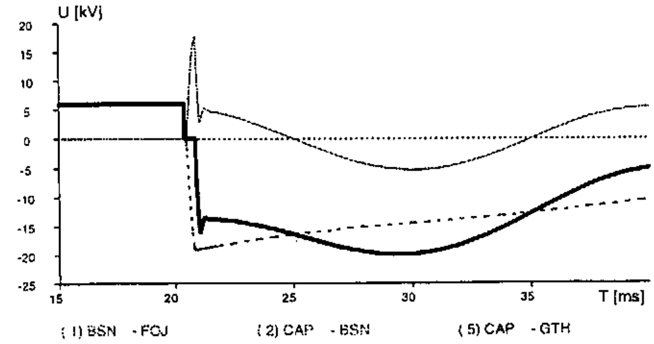


Fig. 13 - Voltage stress of the main thyristor (thin), the extinguishing thyristor (thick) and the capacitor (dotted) without damping resistor

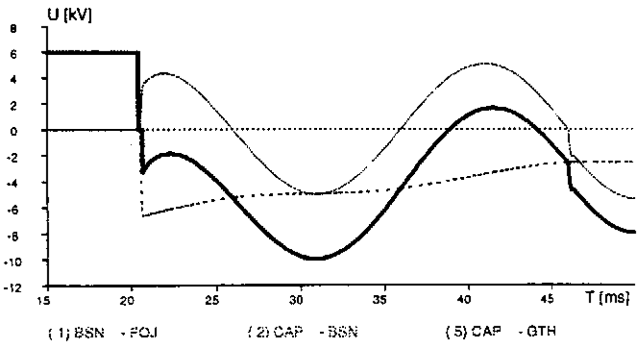


Fig. 14 - Voltage stress of the main thyristor (thin), the extinguishing thyristor (thick) and the capacitor (dotted) with a 0.5 Ω damping resistor

VIII. CONCLUSIONS

EMTP simulation was applied to find the best solution in solving the problem, how to decrease the dynamic and steady state short circuit current in an industrial network, where two, originally radial suppy systems had to be interconnected.

Parallel connection of radial feeders with dynamic fault current limiter increases the voltage stability of the system and the reliability of service, without increasing the short circuit stress of the network elements.

Three kind of possible solutions with conventional and thyristor controlled dynamic limiters were examined and the optimal one was selected.

The main difference between the investigated limiters from the point of the operation is the value of the crest factor of the voltage transient when the fuse blows or the thyristor and the GTO thyristor is switched off.

Both semiconductor based limiter would cause very high overvoltages without a damping resistor. This resistor should be connected in parallel with the semiconductors.

IX. ACKNOWLEDGEMENT

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