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FAULT CURRENT LIMITERS FOR DISTRIBUTION NETWORKS —STATE OF THE ART AND DEVELOPMENT PROJECTS

Ograniczniki prądu zwarciowego dla sieci rozdzielczych — współczesny stan wiedzy i projekty nowych rozwiązań

P. BEHRENS EUS GmbH
A. CIELEIT E.ON Engineering
M. GINZBURG EUS GmbH
E. K. STACHORRA EUS GmbH
Gelsenkirchen, Germany

Abstract: **The authors describe the numerable possibilities that fault current limiters (FCL) offer as power quality devices in distribution networks. The different techniques of FCL are explained, the experiences of existing solutions are illustrated, and new developments as well as their expected fields of application are shown.**

Streszczenie: **Autorzy opisują liczne możliwości, jakie stwarzają ograniczniki prądu zwarciowego (FCL) jako urządzenia wpływające na poprawę jakości energii w sieciach rozdzielczych. Wyjaśnione są różne techniki FCL, przytoczone zostały doświadczenia uzyskane na podstawie istniejących rozwiązań. Przedstawiono również nowe opracowania jak też spodziewane obszary ich zastosowań.**

Key words: fault currents, fault current limiter, high temperature superconductors, power electronics, power quality, superconducting fault current limiter

Słowa kluczowe: prądy zwarciowe, ogranicznik prądu zwarciowego, nadprzewodniki wysokotemperaturowe, energoelektronika, jakość energii elektrycznej, nadprzewodzący ogranicznik prądu zwarciowego

1. INTRODUCTION

The liberalization of the European energy market demands an effective use of the existing distribution networks. So far usual long planning periods become shorter, investment decisions become more and more uncertain. At the same time the local demand for high power quality is increasing. Therefore a high short-circuit power is often desired while the necessary reinforcement of the grid is considered as too expensive. However the customers who need the high power quality do not represent the majority. This leads to individual solutions for improving the power quality where it is needed [1].

On the other hand, the power quality can be disturbed by new customers that have strongly fluctuating loads or decentralized generation which cause a deterioration of the power quality. Hence voltage dips, harmonics, inter-harmonics, and flicker have to be kept in reasonable limits [2].

A good way to improve power quality by means of increasing the short-circuit power and to avoid larger construction measures in the grid is to use fault current limiters (FCL). As a consequence, FCL are looked on as a useful alternative. An increase of the short-circuit power in the distribution network causes a smaller internal resistance in the grid which results in a more stabilized voltage.

The application-possibilities are varied. Partly they are already in use, partly they are just starting to be taken in consideration. One reason for this is that not until now fault-current limiter types are being developed that have enough rated power for more profitable applications. On the other hand this development is furthered by the liberalized marked that makes the power utilities look for inexpensive and quickly realizable alternatives to simply reinforcing the grid. So far usual long-term planning is now often considered as too inflexible and too expensive.

2. FIELDS OF APPLICATION

At the moment FCL are used mainly in industrial distribution networks and in the public low voltage distribution networks [3]. Here their primary task is to couple the grids during normal operation and to separate them in case of a short circuit in less than 5 ms.

In Figure 1 different possible fields of application are shown. Three of these applications are already in use: The extended throttle concept is frequently realized with the pyrotechnic i_p-limiter as well as the connection of powerful motors. These cases have mostly been realized in industrial networks. In Germany the connection of wind turbines to the low-voltage

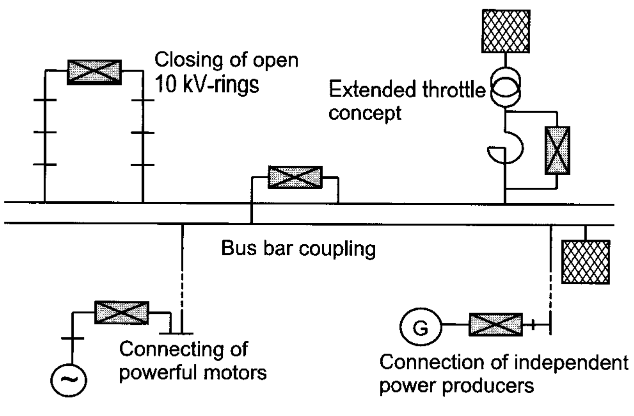

Fig. 1. Fields of application for fault current limiters

grid is frequently realized with the power electronic FCL LimSoft®.

For the power utilities different applications on medium voltage or even high voltage would be interesting. On medium voltage the coupling of bus bars or the protection of transformer feedings are considered as good applications for superconducting FCL [2]. Actually any FCL would be welcome that can easily be switched back to normal operation after release. Another typical medium-voltage application would be the coupling of open 10 kV-rings. Other interesting applications would be the connection of powerful motors or the use of transformers with smaller short-circuit impedance. These applications would always help to avoid or to delay expensive extension measures in the distribution network.

On high voltage the power utilities are especially interested in the coupling of 110 kV-network groups. This would help to avoid additional feedings from the 220 kV-level.

Not every task can be fulfilled of any FCL. Figure 2 shows a differentiation between fault current limiting devices and fast switches. If only a limiting of the short circuit current is desired then limiting concepts are the best solution. They allow further operation of the network.

3. EXPERIENCE WITH EXISTING FCL

Two types of FCL are currently available: the pyrotechnic i_p-limiter (ABB Calor Emag) [4] and the power electronic FCL LimSoft® [5], [6].

Pyrotechnic i_p-limiter

The pyrotechnic i_p-limiter is the only FCL that operates on medium voltage today [4]. In case of a short circuit current the contact is already blasted open by means of a detonator when the current is still rising. The current commutates on a high-voltage fuse being in parallel to the usual current path. The fuse is taking care of the current limiting and the arc-quenching.

Usually it is only desired to limit the short-circuit current, but not to shut down the line unselectively. In these cases a current-limiting reactor is used in parallel to the fault-current limiter. During normal operation this reactor is shorted out by the fault current limiter. In this way the coil does not cause any grid reactions during normal operation.

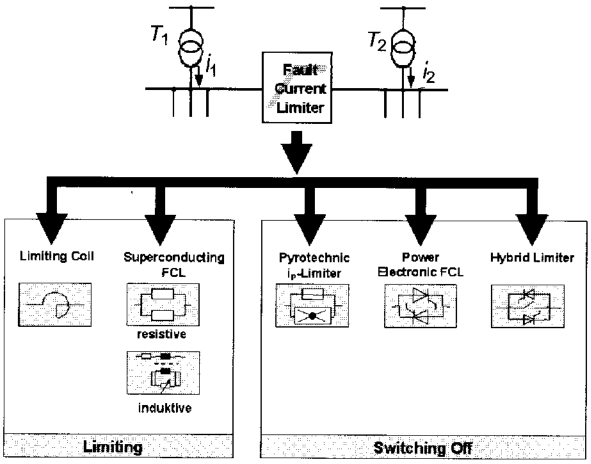

Fig. 2. Limiters and fast switches

The pyrotechnic i_p-limiter is commonly used. It is the FCL with the highest rated power currently available. The main disadvantage of this technology is the fact that the detonator has to be changed manually after each circuit breaking before the i_p-limiter can go back to normal operation. Furthermore, this technology is not inherently safe and difficult to test on its functionality. However the experience has shown that this FCL is the only available solution for many applications today.

Power Electronic FCL LimSoft®

The power electronic FCL LimSoft PE® is operating on low voltage [5], [6]. Its main current path consists of two antiparallel thyristors per phase with parallel connected quenching circuits. The supervisory system measures the time characteristics of the voltages and currents and additionally calculates the rate of rise of the phase currents. As a result the available input quantities will be combined to a release criterion which is only fulfilled by fault currents. In case of a release the current is quenched within a few milliseconds.

The power electronic FCL LimSoft PE® has been used mainly for the connection of wind farms to the distribution grid. The power utilities had worried that the tolerable short circuit power could have been exceeded by the wind power plants. The installation of a fault current limiter was in all of these cases the precondition for mounting the wind farms.

Other Limiting Concepts

Apart from these there are other fault-current limiting concepts, such as current-limiting reactors, fuses and switch gear. But these are either reactive, such as the current-limiting reactors, or they are too slow , such as the circuit breaker or they are rated for lower currents, like fuses.

4. FCL IN DEVELOPMENT

In Figure 3 the prospective voltage range and current range of different FCL are shown.

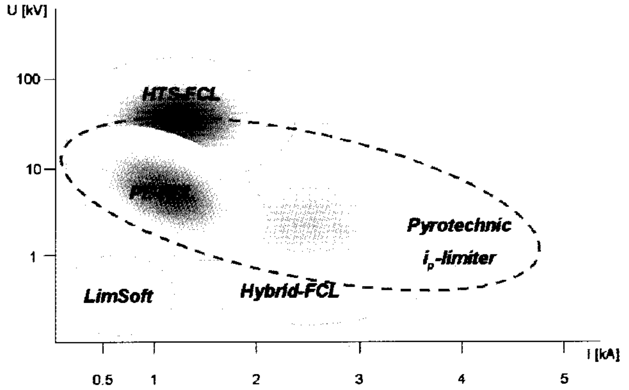

Fig. 3. Voltage and current range of different types of FCL

It is obvious that the pyrotechnic i_p-limiter covers a large scale of the prospective area. However the fact that the detonator has to be exchanged manually makes this FCL unattractive for many applications. Hence other types that are either switchable or that can switch back to operation automatically are being developed. These are power electronic FCL for medium voltage, hybrid solutions or superconducting FCL.

Power Electronic FCL for Medium Voltage

At the moment one project on a power electronic FCL on medium-voltage is in development. The new semiconductor valves IGCT (integrated gate commutated thyristor) make this possible. Partners in this project are E.ON, EUS, Nordex, RWE and Siemens. The first prototype is expected to be built into the distribution network in 2002 [7].

Hybrid FCL

The projects concerning the development of a hybrid-FCL are rather promising. A hybrid-FCL has both a mechanical switch and a power electronic circuit [5], [8].

With higher currents the thermal losses in the power electronics of a pure power electronic FCL become intolerable. Furthermore the size of such a FCL gets too large. Here a hybrid FCL is more advantageous. During normal operation the current flows over the mechanical contact. This way no losses occur in the power electronics which additionally saves the cooling facilities. Hence the unit becomes more compact. In case of a fault current the current commutates on the power electronic circuit where it is quenched within a few milliseconds. That's how the mechanical switch has enough time to strengthen the clearance between the contacts.

So far no prototype of this kind of FCL has been tested in a distribution network.

Superconducting FCL

Advantages of all superconducting devices are their low reactions on the grid during normal operation as well as their quick reactions when desired, even with high rated powers. The disadvantages are the still high costs as well as the partly extremely high magnetic fields. The latter have to be considered with respect to personal protection.

It is recommended to run superconducting devices together like transformers or cables together with FCL. However since most of these devices will be integrated into a complete network, this will probably not be the rule.

Two types of superconducting current limitation are currently in development: the inductive and the resistive current limitation.

Inductive HTS-FCL

In case of the inductive (or shielded-core) current limitation the superconductor is not placed in the current path, but it is indirect-coupled with the grid like a transformer [9], [10]. The current limitation is done by an increase of the magnetic field. ABB used BSCCO 2212 for their prototype. The small heat development during current limitation is an important advantage. The large size and the weight are rather disadvantageous, since they have the dimensions of a transformer with comparable rated values. Since the shielded-core HTS-FCL does not need any current leads it might be interesting for high current applications.

The mixed inductive-resistive limiting FCL is built in the same way as the inductive limiting FCL. But here the superconductor is limiting not only inductive, but also resistive.

Resistive HTS-FCL

The resistive limiting FCL is used directly in the current path. The impedance is increased as a result of the raise of the current density. This causes a temperature rise in the superconductor which leads again to a stronger increase of the electrical resistance. Due to different materials different concepts have been developed. The main concepts are the thin layer FCL and the bulk material FCL [11], [12]. A general advantage of the resistive HTS-FCL is its more compact size and weight in comparison to the inductive HTS-FCL. The sensitivity of resistive HTS-FCL about developing hot spots is rather disadvantageous. Therefore all projects that develop resistive HTS-FCL consider a shunt layer in order to bypass hot spots.

Siemens tested a thin layer FCL-model based on a metallic (i.e. gold) shunted YBCO thin layer on a monocrystalline sapphire substrate [11]. The advantage of the thin layer FCL is the fast release and the short recovery time. The thin layer FCL is very quickly back to operation. On the other hand the production of the thin layer superconductors is rather expensive.

The bulk material FCL has a less complex structure than the thin layer FCL. At the moment two projects are working on this technique: The working group around ACCEL and ABB. The group around ACCEL containing RWE, E.ON, FZ Karlsruhe, Nexans, ATZ, EUS, and ACCESS is working on a grid demonstrator which is expected for 2002 [12]. ABB has recently presented a single-phase 6.4 MVA demonstrator [13].

The bulk material is easier and more inexpensive in production. Examples are melt-cast processed BSCCO 2212 and melt-textured YBCO [14], [15]. Since bulk material is much thicker than the thin layer material the reaction time is slower. The limiting characteristic is softer and therefore is with less reactions on the grid which is rather positive. On the other hand the recovery times are longer.

5. IMPROVING POWER QUALITY

The development of new fault current limiters for higher voltage levels will make it possible to substitute conservative fault current limiting devices such as current-limiting reactors. This will decrease the reactions on the grid caused by these chokes.

A high short-circuit power causes a more stable voltage. This decreases voltage dips, harmonics, inter-harmonics, and flicker.

New FCL are expected to have softer limiting characteristics, that means they are expected to have lower overvoltages than today's current limiting devices.

Fault current limiters will enable new grid structures with a better supply redundancy in the future. This will lead to a better supply reliability for the customers.

6. OUTLOOK

The FCL that are currently being developed will not compete with each other as much as expected. Each concept has its special area of application as well as voltage and current range. It is rather a question of whether the particular concepts will be able to gain acceptance against the present planning practices. This will depend on the prices that will be achieved. Especially in the area of the superconducting fault current limiter the prices will be determined by the possibilities of the superconductor production.

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Petra Behrens
was born in Oldenburg, Germany, on September 30, 1970. She studied electrical engineering at the RWTH Aachen and received her diploma in 1996. Since 1997 she is employed by the EUS GmbH Gelsenkirchen in Germany. Petra Behrens works on research and development projects concerning software and simulation in the field of distribution networks and power quality.

Antje Cieleit
was born in Soest, Germany, on February 28,1970. She studied electrical engineering at the University of Paderborn, department Soest and received her diploma in 1993. Since 1993 she is employed by Veba Kraftwerke Ruhr AG Gelsenkirchen, which merged in 1998 in PreussenElektra. After the next merger in 2000 she is now working for E.ON Engineering GmbH Gelsenkirchen in Germany. Antje Cieleit works on electrical calculations, for example short-circuit current and load flow calculations from 24V up to 400kV.

Elmar Stachorra
was born in Gladbeck, Germany, on October 10 ,1963. He received the degree in Electrical Engineering from the Ruhr-University of Bochum, in 1994. He joined EUS GmbH, Gelsenkirchen, Germany in 1995 as development engineer. Today he is head of the department Power Quality. Elmar Stachorra is engaged in researches on power quality analysis, electrical power systems reliability und development of PQ-devices (e.g. active filters, multifunctional energy storage systems and high fault current limiters based on power electronic devices and superconductive materials).

Michael Ginzburg
was born in Charkov, Ukraine, on June 29, 1962. He studied electrical engineering at Charkov Polytechnical Insitute and received his diploma in 1985. From 1985 until 1992 he was employed by the reseach Institute of Charkov Electro-Mechanical Plaint. Since 1995 Michael Ginzburg works at the EUS GmbH Gelsenkirchen, Germany as development engineer and project manager at the field of Power Quality (power electronic and fault current limiting).