POSSIBILITIES OF INTEGRATING RENEWABLE GENERATION TO THE DISTRIBUTION GRID BY FAULT CURRENT LIMITERS

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ABSTRACT

Over the last decade an evolution towards higher power requirements on distribution networks has to be stated. Due to additional connection of decentralized power generation in terms of renewables, the referred short circuit current (I_{SC}) values for some network segments were steadily increasing.
The actual network structure is based on a unidirectional power flow, assuming a centralized power generation. The electricity is transmitted via point-to-point or simple ring structures at the high voltage transmission grid and radial or point-to-point structures in the Medium Voltage Distribution Grid. Medium and low voltage distribution grids are not intended to handle a bi-directional power flow, created by the integration of renewable electricity generation. Tu guarantee a stable operation of the grid, the grid voltage must kept stable the balance between power supply and consumption has to been managed. In consequence the increased short circuit level might push installed equipment to its physical limits. Therefore new technologies like fault current limiters might be one of the solutions. [1]

INTRODUCTION

To overcome this bottleneck, different approaches seem possible. One is extending the network capability, i.e. the replacement or upgrading of existing switchboards to higher ratings, the most costly variant.
The application of fault current limiters could be an alternative. Such limiters can be used to restrict the contribution to the I_{SC} by a local generator. Busbars connected to several generators, reaching an I_{SC} load above the rated level can be split into independent segments with the help of a current limiter. In case of a failure the current limiter is blocking the failure current and is segmenting the busbar into physical parts, able to handle the effective I_{SC} per segment.
Besides the reduction of the short circuit levels, a fault current limiter might show also additional features to increase the efficiency of installed assets, as discussed in this paper, with focus on the possibilities to integrate renewables.
Criteria, like limitation factor of the first peak, low operating impedance, high fault impedance, self-activating, fail safe, multiple operation, low service and maintenance cost will be explained at the example of different limitation technologies in comparison with an inductive shielded superconducting fault current limiter.

This technology is based on the perfect diamagnetism, meaning that a magnetic field will be expelled from the inner of a superconductor or even a ring of it. The paper will discuss the principle and the generic design concept of the iSFCL, including tests on a mock-up. To cope with the integration of renewables the field trial at Stadtwerke Augsburg will be shown. Here the device will act twofold. Firstly as a grid coupler between the utility network and a dedicated generator test plant with intermitted energy generation. Vice versa the iSFCL will also act as generator protection for the test plant.

CRITICAL INDUSTRIAL NETWORK

Using the example of a critical industrial customer with a high level of service continuity, the different possibilities of fault current limitation are explained.
In a industrial plant, the generator infeed is going to be extended from five to seven generators, see **Fig. 1**, supplying a 132 kV busbar system.

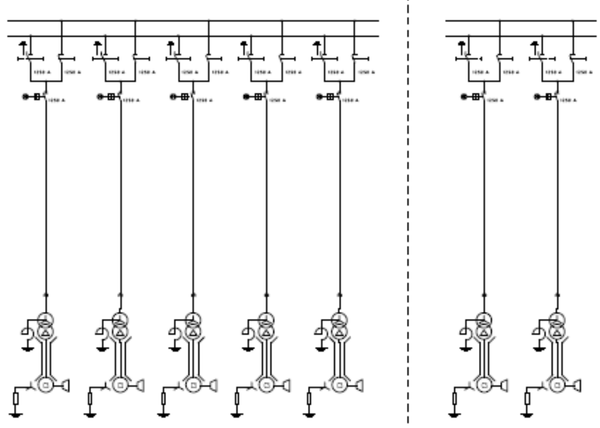

Fig. 1: Example of single line of an industrial plant

After stepping down, first to 33 kV and then to 6.6 kV, medium voltage switchboards are installed at this sub busbars. Here are bus couplers foreseen, too.
Now it has to be checked, if the existing switchboards are still able to cope with the increased infeed of 7 generators.

CONVENTIONAL SOLUTION

Network Analysis

The method of demonstrating the breaking capability of the switchboard is based on a comparison of the thermal stress of the short-circuit arc between the contacts of the vacuum interrupter after its opening operation. The contacts of the vacuum interrupter must thermally withstand

the arc duration till the last pole clears. Only the worst case short-circuit currents with the highest asymmetrical breaking currents - I_{basym} - are considered.
The instantaneous value of the short circuit current level I_{sc} is used to calculate the thermal stress of the short-circuit current. The dc component at the appropriate opening time is determined by following equation:

$$\%dc = 100 \cdot \frac{I_{dc}}{I_b \cdot \sqrt{2}}$$

The resulting thermal stress of the arc in each short circuit scenario is compared with the corresponding tested value the switchboard as shown in **Fig. 2**. This test was performed with a 12 kV / 31.5 kA breaker as installed at the industrial network, with a DC component of 28%.

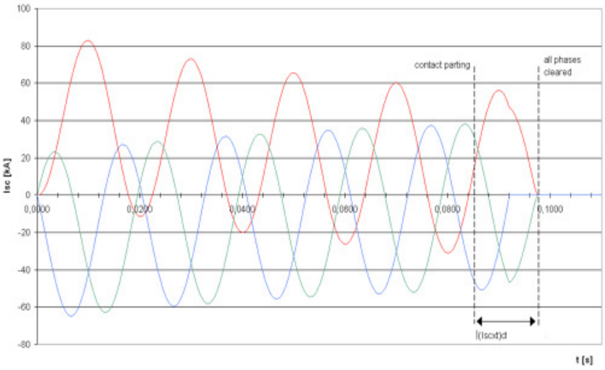

Fig. 2: reference test with a 12 kV switchboard

This reference measurement results in a short-circuit arc stress of $\int (I_{SC} \cdot t)dt = X[As]$. Now this value can be compared to the expected stress resulting from the generator lead. The actual situation with 5 generators leads at a minimum opening time of 45 ms to a DC component of 49%. The simulation of this scenario at the maximum asymmetrical breaking current is presented in **Fig. 3**. The expected short-circuit arc stress $\int (I_{SC} \cdot t)dt = X[As]$, which is lower than the tested one (X<Y).

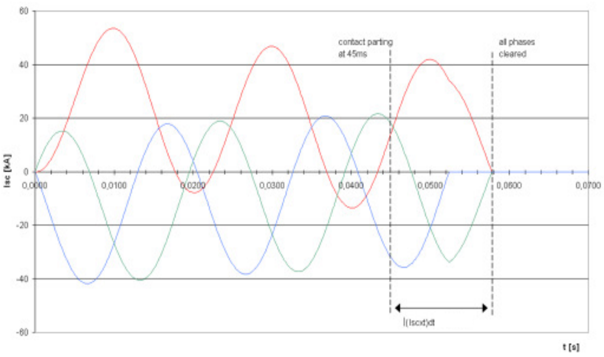

Fig. 3: scenario with 5 generators

This analysis was repeated with the extension of the plant to 7 generators in service. Here we receive a DC component of 49.2% at a minimum opening time of 45 ms. The resulting opening operation at maximum asymmetrical breaking current is shown in **Fig. 4**. In this scenario, the expected short-circuit arc stress $\int (I_{SC} \cdot t)dt = Z$ is higher than the tested one.

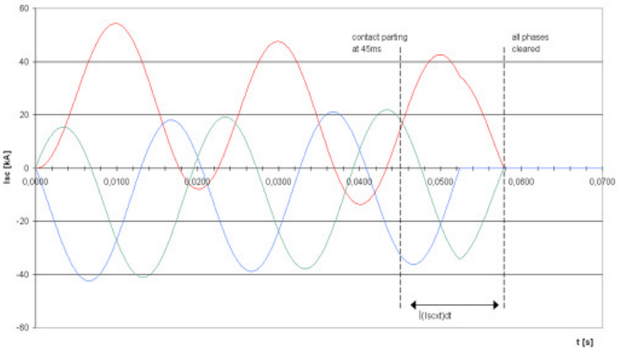

Fig. 4: scenario with 7 generators

In the described network expansion, it was not possible to handle the increased power infeed with the installed equipment. To stay with the same equipment, installing a fault current limiter is a suitable solution. Such fault current limiter will reduce the first peak of the short-circuit fault current, so that the stress for the installed equipment afterwards is significant reduced.

POSSIBILITIES OF INSTALLING NEW TECHNOLOGIES

As the energy sector is a very conservative business, a single advantage might not be sufficient to bring a new technology to market. Therefore one can define objectives which fault current limiters should meet. A major aspect is the already mentioned limitation of the first current peak. Beside that, the device should show low operating impedance, high fault impedance, self-activation at network faults, fail safe, multiple operation, and low life cycle costs.
Table 1 shows a comparison of conventional solutions like current limiting fuses (A), the pyrotechnic fault current limiter (B), the air core reactor (C) and power electronic based devices (D) [2]. For all these devices severe drawbacks in terms of the necessary features can be stated. This is a clear reason why these technologies have only gained a limited market success.

Requirement	A	B	C	D
Limitation	+	+	+	+
Low operating impedance	-	+	-	-
High fault impedance	+	+	+	+
Self activation	-	-	+	-
Continuous operation at internal failure	-	-	-	-
Multiple operations	-	-	+	+
Costs	+	-	+	-

Table 1: Comparison of different current limiter technologies (A-fuses, B-Pyrobreaker, C-reactor, D-PE)

The iSFCL concept

As the state of the art fault current limiter are not able to fulfil all defined requirements, a new concept of fault current limiter was requested; the so called inductive shielded superconducting fault current limiter (iSFCL). The concept of this superconducting fault current limiter is based on the principle of the perfect diamagnetism, meaning that in superconducting state the magnetic field is expelled from the superconductor. This effect was first discovered by Meißner and Ochsenfeld in 1933, **Fig. 5**.

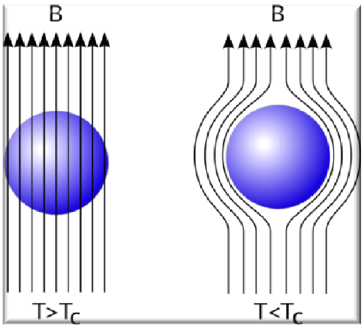

Fig 5: Schematic of Meißner-Ochsenfeld effect

Transferring this effect to a ring made of superconducting material means to expel the magnetic flux from the volume covered by the ring. In case that an iron core is placed inside the ring, any magnetic field induced into this iron core is screened by the Meißner-Ochsenfeld effect.
Forcing the superconductor to change from superconducting to normal conducting state, would allow the magnetic field to enter the iron core and to generate a magnetic flux. In case of coupling this magnetic flux with a normal conductive secondary winding would enable the induction of a counter voltage limiting the driving current of the primary winding.
There are three critical parameters to switch from superconducting to normal conducting state: the critical temperature, the critical magnetic field and the critical current density, whereas it is sufficient to move one parameter above his critical level. .
The investigation of the inductive shielded superconducting fault current limiter was based on a long-term research co-operation between Schneider Electric and Alstom Grid (both former AREVA T&D) together with Bruker High Temperature Superconductors (BHTS).

The iSFCL design

The iSFCL is based on a transformer-like set-up with an iron core, copper primary winding and a superconducting winding with a parallel by-pass winding, placed inside a cryostat.
Beside the assembly of an iSFCL, **Fig. 6** also shows the supply of the cryostat with liquid nitrogen. The primary winding is acting as the main current lead of the circuit outside of the cryostat. So the cryogenic losses are dramatically reduced in comparison to so-called resistive type of current limiter, where the main current path goes directly through the superconductor. In such a case major losses are released at any cryogenic bushing and as well inside the superconductor. The losses in the superconductor are due to the alternating current leading to magnetization losses at each change of the polarity of the current.

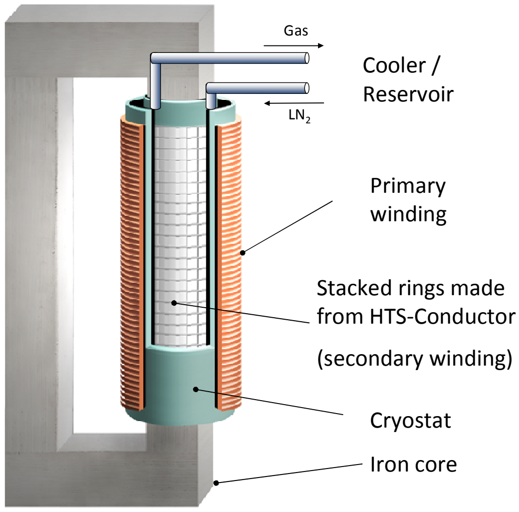

Fig. 6: Schematic outline of a single phase of an iSFCL

In normal operation the magnetic field is expelled from the superconductor. That means that the magnetic flux, generated by the primary winding, is not able to penetrate the iron core. Therefore the iron core doesn't provoke any magnetization losses and the iSFCL shows very low impedance to the network. In case one of the critical parameter – preferably the critical current density (J) – is forced above the critical point, the superconductor will change into the normal conduction state. The magnetic field will enter the iron core and large impedance is inserted into the network.

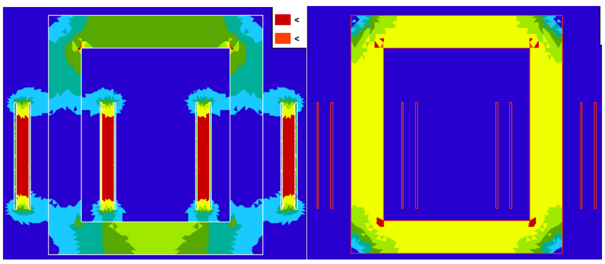

Fig 7: Operation Principle of the iSFCL
a) Superconducting State b) Resistive State

As the superconductor is based on a YBCO (Ytterium-Barium-Copper-Oxide)-Ceramic, this ceramic will show a very high intrinsic electrical resistivity in normal conductive state. Changing from superconductive to normal state

would dissipate so an amount of energy into the ceramic material that it would be damaged or even destroyed. To prevent this, a normal conductive bypass made out of steel is taking over the induced current in the normal state.
Fig. 7 shows a simulation of the flux density distribution in superconducting and resistive state.

Potential integration sites in networks

In medium and low voltage networks, there are several opportunities of installing such new kind of fault current limiters. Those can act as generator protection, network coupling, integration of distributed power generation, or for protection of parallel infeed of critical consumers (**Fig. 8**).

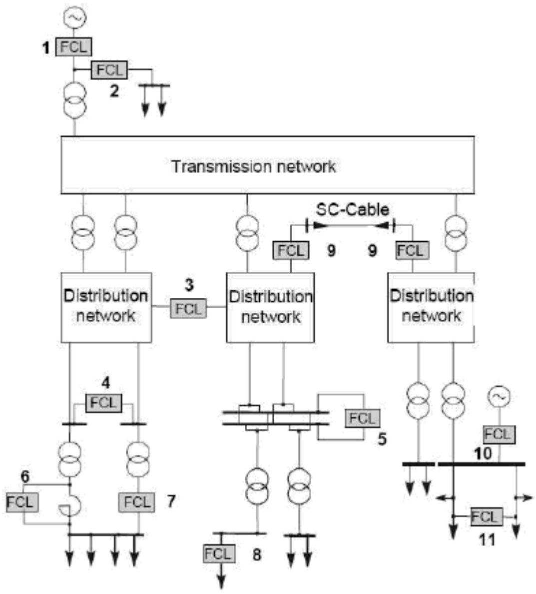

Fig 8: Overview of potential installation sites based on [3]

Advantages and disadvantages

Referring to the discussed plant of **Fig. 1**, some of the above described installation options can be found there as well. The major advantage is given for the installation in the line of infeed from a group of generators; in our case a segmentation into two groups might be useful. All seven generators can be connected to grid and in case of a failure stress for this equipment is limited in such a way , that an expansion is not necessary.

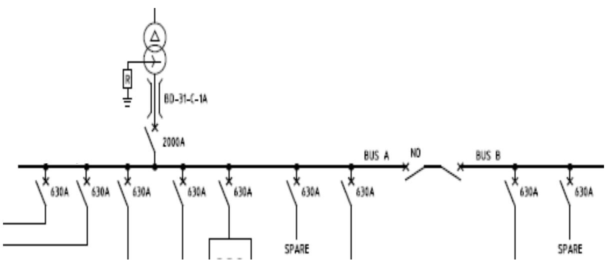

Fig 9: Busbar segment at 33 kV level

As shown in **Fig. 9**, there is the possibility in the conventional grid structure to use the iSFCL for coupling of busbar segments. Busbars, i.e. with several generation infeeds, reaching an I_{SC} load above the rated level can be splitted with a current limiter. In case of a failure the current limiter is blocking the failure current and is segmenting the busbar into parts, able to handle the I_{SC} per segment.

CONCLUSION

Based on a generic showcase of an industrial power grid application, it was shown, that a current limiting technology could enable an extension of the generation capacity without upgrading the grid. Doing a network simulation gave a clear intention how to evaluate the limits of the installed switchgear. To choose the right limiting technology a comparison of different conventional limiter technologies was done. Based on the parameters: limitation, low operating impedance, high fault impedance, self-activation at network faults, fail safe, multiple operation, and low life cycle costs it could be stated that none of the conventional technologies fulfill all requirements. A potential solution was presented with the principle and the generic design concept of the iSFCL. Based on the consequent usage of the Meißner-Ochsenfeld-Effect, a current limiter technology was presented; able to overcome technical drawbacks. The iSFCL can be stated as fail safe and guarantees multiple operations. As the main current path is no longer inside the cryostat the thermal losses are significantly reduced. In case of a failure of the cryostat, the iSFCL will switch into the limiting stage and will stay in operation.
On the example of a real industrial network, the installation of an iSFCL was compared to a conventional limiting possibility. The advantages and many potential installation sites have been discussed. In such networks, the iSFCL is also able to act twofold: for example as a grid coupler and secondly as generator protection related to the infeed.

ACKNOWLEDGEMENT

This work is co-founded by the German Ministry of Trade and Industry, project number 03ET1003A.

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