INCREASING POWER GENERATION CAPACITY IN MESHED ELECTRICAL GRIDS - GRIDON'S FAULT CURRENT LIMITER SUCCESSFULLY SUPPRESSES MULTIPLE NETWORK FAULTS DURING TWO YEARS IN SERVICE

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ABSTRACT

After two years of operation of a 10MVA device in a live substation, and installation of a 30MVA device, saturated core fault current limiters (FCL) with immediate recovery capability are now a well-established field proven technology and commercially available products. This paper discusses the working environment and performance through normal and fault conditions of GridON's 10MVA fault current limiter in the UK. It demonstrates the ability of these novel devices to perform robustly through multiple consecutive long duration fault events, and recover instantly when the faults clear, enabling fail-safe connection with absolute no interruption to current flow in transformer and generator feeders. The FCL is built using standard power transformer technology (superconducting-free), and provides very low insertion impedance in normal operation, and high fault current reduction.

INTRODUCTION

Early in 2013, GridON has installed a 10MVA fault current limiter (FCL) in a primary distribution substation operated by UK Power Networks, in Newhaven, East Sussex, UK. Through its two years of operation to date, the FCL has been suppressing high fault current levels generated in multiple occasions. The introduction of GridON's FCL into this substation enabled operating the network with 3 transformers in parallel, while previously only two could operate in parallel due to excessive fault levels.

GridON's FCL is of the saturated core type, and is built in standard transformer technology, without the usage of exotic materials such as superconductors. This enabled the FCL to be installed and commissioned quickly, and made its maintenance simple and familiar to the network operator.

Figure 1 - 10MVA FCL installed in the UK

The 10MVA FCL has been in operational service for the past two years, proving to be fully reliable and benign to the network under normal operating conditions, with very low voltage drop, requiring no down time, and exhibited extremely effective performance in limiting the fault current during multiple network fault events, including multi-consecutive faults.
The FCL has been fitted with online monitoring equipment to enable analysis of its behaviour in both normal and fault regimes. Normal behaviour has been analysed continuously, while fault events on the network triggered precision transient waveform recordings. These waveforms were then analysed offline to determine the electrical performance of the FCL as well as fault level reduction in the network due to the FCL presence.
Prior to the FCL installation, the network has been fully modelled in a power-systems-analysis software by E.ON Technologies who provided engineering consultancy to this project. This enabled simulating load flow and fault scenarios in any location in the network. It also enabled introducing a simple model of the fault current limiter, to enable analysis of the same with the FCL present in the system.
In analysing the fault limiting performance of the FCL in the paper, the data recorded by the monitoring equipment in the field was compared against test results from the FCL comprehensive testing database. As the location of the field fault is readily available from the operator for each fault event, a similar fault has been modelled in the power-system-analysis software model, and these simulation results were also compared against the data recorded from the monitoring equipment. The field results, test results and network simulation results all showed good correlation among them, and demonstrated the FCL operating as designed and tested.

Figure 2 - 30MVA FCL installed in the UK

GridON has already installed a second FCL rated 30MVA for Western Power Distribution in the UK, with specifications that are far more demanding than the first unit (2000A overload current, over 50% initial fault peak reduction).

FCL LOCATION IN THE NETWORK

The FCL is located on the LV side of a 33/11kV transformer. This substation has 3 transformers, each rated 10MVA. Before the FCL was put into service, it was necessary to run the substation with the bus split due to fault levels which exceeded the switchgear ratings.
The transformer feeder location was chosen for the FCL installation as it was the most convenient location in this substation, minimizing installation costs and outages.

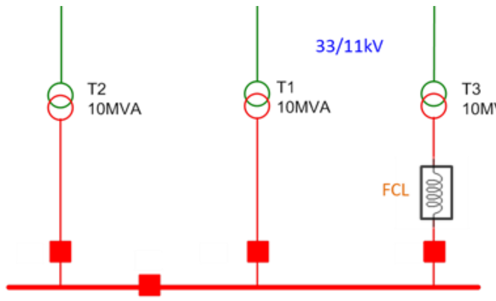

Figure 3 - FCL location in the network

The feeder location puts demanding requirements on the FCL compared to other potential locations. 1) The FCL needs to carry the fully rated current under normal conditions with low impedance, and be able to carry overload current for a specified duration. 2) It needs to reduce (limit) the fault current and not interrupt it, as interruption would cause difficulties in locating the fault. 3) It needs to recover to normal load immediately after the fault clearing (instantaneous recovery). 4) Since the FCL can only limit the contribution of fault current from one transformer, it needs to provide significant fault current reduction to enable meaningful reduction of the overall fault current in the substation. 5) Due to protection grading, it may take as long as 3 seconds for the feeder protection to trip, and so the FCL needs to be able to carry the fault current for up to 3 seconds without being damaged. The ability of a saturated core FCL to carry the fault current through its entire duration of few seconds is highly advantageous, as it simplifies the network operation, and does not require special running arrangements associated with other types of fault current limiters requiring special recovery actions after a short period into a fault event.

OPERATION IN NORMAL CONDITIONS

Operational data was gathered from the FCL continuously in order to analyse its impact on normal network operation. The data shows that throughout the field operation period, the network voltage profile has not notably changed; the voltage drop across the FCL was less than 1%. Significantly lower than what a current limiting reactor with similar performance would drop. Harmonic distortion data was also gathered, and compared to the data gathered before the FCL was installed. No measureable increase in harmonic distortion was observed.

OPERATION IN FAULT (SHORT CIRCUIT) CONDITIONS

Throughout the FCL's operation period the substation has experienced multiple fault events. The 11kV distribution system is solidly grounded, and consequently single phase to earth faults create substantial fault currents. A fault event is followed by tripping of an outgoing CB, which removes the fault from the substation bus. Sometimes, the faulted location may be on a customer's network, and would then be typically removed from the network by a secondary substation's breaker. In many occasions, the tripped feeder breaker is reconnected to the network after some time, in order to isolate the exact location of the fault. Such reclosing may be done to a healthy line, or to a line that is still faulted. In the latter case – a second fault event would be inflicted on the network within minutes to an hour after the initial fault event. Where auto-reclosers are used, the interval between the first fault clearing and reclosing to the faulted line may be in the order of only a few seconds [1]. These considerations emphasize the importance of the FCL's ability to recover immediately after a fault, and be ready to either allow the normal current to run into the healthy line, or being ready to limit another fault current in case of reclosing to a faulted line. The ability to recover to normal load within milliseconds – offers the best flexibility to the network operation in response to faults. At the same time – immediate recover offers the best availability figures and minimal interruption (actually zero added interruption time) to the customers.
Typically when a fault current limiter is placed in a network, it is done to enable the network to continue running with underrated equipment. This means that the FCL has to provide its guaranteed current reduction in a failsafe manner, as there is no backup for its correct operation during a fault event. In other words – if the FCL fails to limit the fault current as required, it will expose the rest of the equipment to fault current levels beyond its rating. Operators therefore specify that FCLs be failsafe under all circumstances. Saturated core FCLs are by nature failsafe, as their operation is based solely on overcoming of a DC bias flux by the fault current AC flux. Even complete loss of DC bias does not prevent the saturated core FCL from providing its guaranteed current limiting capabilities.

Since its field installation, the FCL operated through multiple network fault events, including consecutive faults, of multiple types (Phase to earth, phase to phase and 3 phase faults). The examples shown here are of two consecutive fault events.

The following two fault events occurred shortly one after the other. The first event started as a phase to phase to earth fault, and evolved into a 3 phase fault. The fault was cleared after about 750msec (Figure 7) when the faulted location was disconnected from the network by a circuit breaker. This was followed by switching actions on the network in an effort to isolate the fault. During these efforts, the same CB closed onto the faulted section of the network, resulting in another fault, which was a 3 phase from the start. This second fault was also cleared after about 750msec. In these particular fault events, two transformers were connected in parallel: T2 was connected directly to the bus, and T3 was connected to the bus through the FCL.

First fault event

Figure 4 shows the initial evolvement of the first fault event as measured by the online monitoring system of the transformer without the FCL (T2).

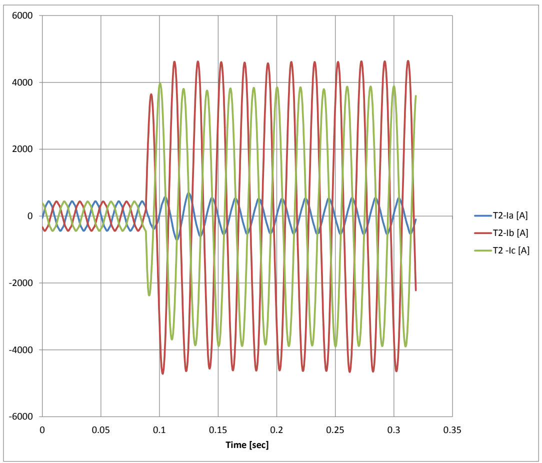

Figure 4 - T2 Currents - Fault 1 start

The fault event starts as a phase to phase to earth fault. Phases B and C are faulted while phase A remains un-faulted. Figure 5 shows the further evolvement of the fault into a 3 phase fault after 630msec, again on transformer T2 which does not have the FCL.

This also shows the clearing of the fault by one of the station breakers and resumption into normal load. These two figures are indicative of the prospective fault level, i.e. the fault current without an FCL in circuit. The overall duration of the fault event from its inception until its clearing was 760msec. The fault current level from this transformer is 3.3kA RMS.

At the same time, similar data was captured from T3, which has the FCL connected at its tail. Figure 6 shows the currents through T3 and the FCL in series with it. It can be seen that the currents through this branch are significantly reduced by the FCL, to a level of 1.3kA RMS. The FCL limits both the phase to phase and the 3 phase fault currents.

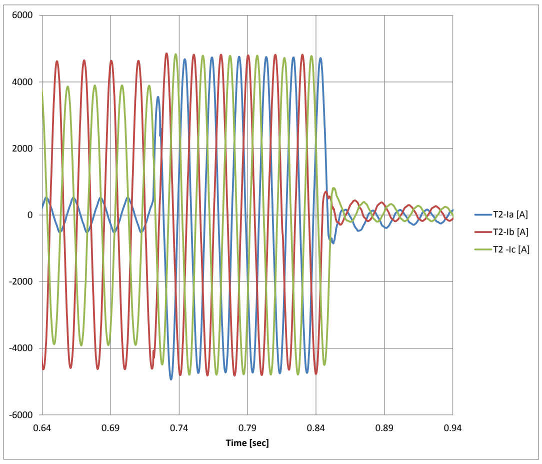

Figure 5 - T2 Currents - Fault 1 end

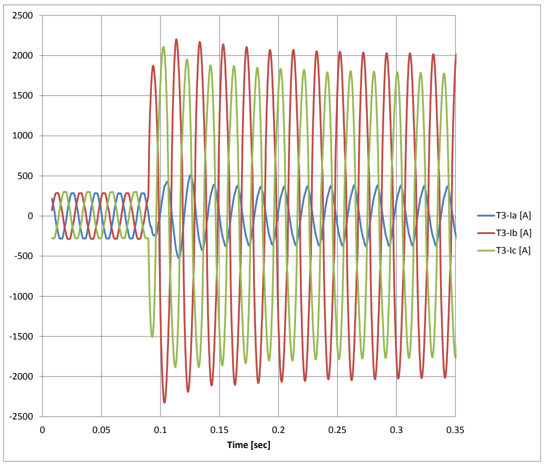

Figure 6 - T3 & FCL Currents - Fault 1 start

It can be seen from Figure 6 that the FCL reacts instantly to the rising fault current, and provides current limitation from the very first peak. The FCL then carries the fault current throughout the entire duration of the fault until it is cleared as can be seen in Figure 7.

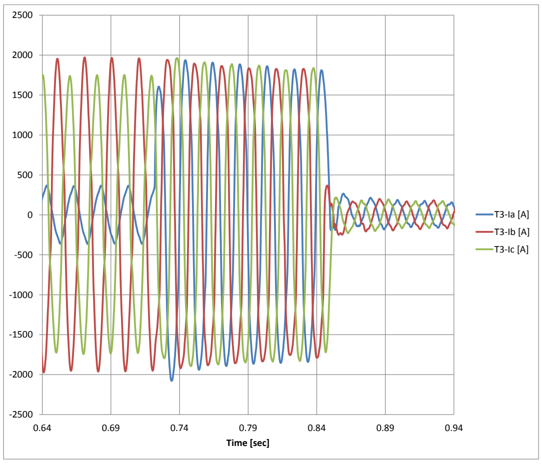

Figure 7 - T3 & FCL Currents - Fault 1 end

It can also be seen that once the fault is cleared, the current from T3 and the FCL goes back to its normal level instantly, allowing the continued and uninterrupted power flow from this branch, thus increasing network availability.

Based on this measured data, network simulations were performed in order to estimate the current reduction by the FCL. This is not straightforward from the measured data, because increasing the impedance of one of two parallel branches causes the fault current to increase in the lower impedance branch. Analysis of the measured data shows that the FCL impedance during the fault has increased around 8-fold from its normal state impedance to provide the current limitation. The fault impedance of the FCL has been introduced into the power-system-analysis simulation model, and it has shown that the effective reduction of the fault current through the FCL branch was 36%, which is very well correlated with short circuit tests that were carried out prior to installation on site.

At the end of this event, the current through the FCL went back to normal level immediately after the fault was cleared as can be seen in Figure 7. This is done completely passively, without any decision or switching mechanisms and the FCL is immediately ready for subsequent fault operation. From the network operator view point, the network behaviour through this event was in every respect indifferent to the FCL existence in the circuit. The FCL required no attention or handling following this event.

Second fault event

Shortly after the clearing of the first fault, another fault occurred on the same location in the network, as a result of switching activity whose purpose was to locate and isolate the fault. Since the FCL has recovered instantly from the previous fault, it was ready to limit the next fault once the outgoing feeder breaker closed back onto the faulted section.

Figure 8 shows the beginning of the second fault event as measured through the transformer without the FCL (T2). It is a 3 phase fault from the start, and it is cleared by one of the station breakers 740msec after its inception, while the substation resumes normal load instantly. The fault current level from this transformer is again 3.3kA RMS like in the first fault event.

Figure 9 shows the currents through T3 and the FCL in series with it. Again the currents are reduced significantly compared to T2, to a level of 1.2kA RMS. The FCL limits the fault current from the first peak, and then carries the fault current throughout the entire duration of the fault until it is cleared as can be seen in Figure 10. Once the fault is cleared, the current from T3 goes back to its normal level instantly.

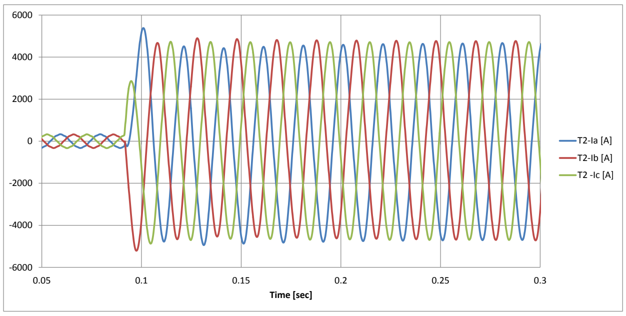

Figure 8 - T2 Currents - Fault 2 start

It should be noted, that if the feeder protection would have failed and a backup protection would need to be operated, the FCL could carry the entire fault current even up to 3 seconds, and still recover instantly after the fault would have been cleared, giving the operator maximum flexibility in the network operation.

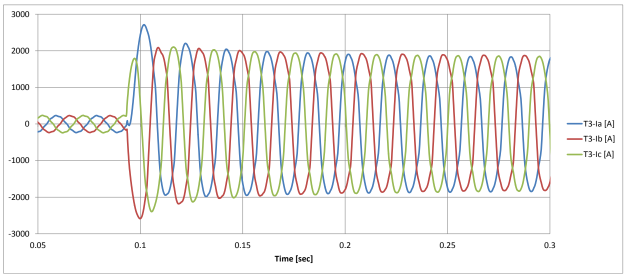

Figure 9 - T3 & FCL Currents - Fault 2 start

Analysis of the measured data has been introduced into the power-system-analysis simulation model, and it has shown that the effective reduction of the fault current through the FCL branch was 35%, which is very well correlated with short circuit tests that were carried out prior to installation on site.

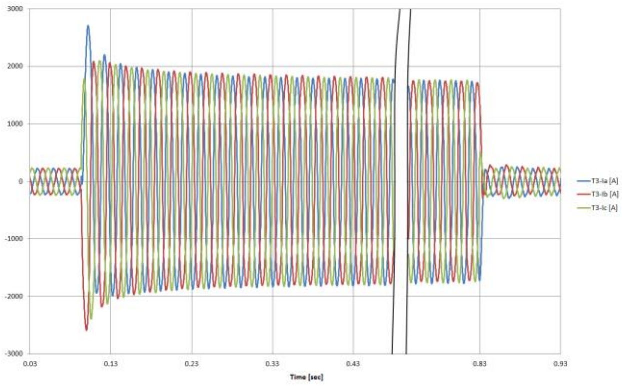

Figure 10 – T3 & FCL currents – Entire Fault 2

At the end of this event, the current through the FCL went back to normal level immediately after the fault was cleared as can be seen in Figure 10. This is done completely passively, without any decision or switching mechanisms and the FCL is immediately ready for subsequent fault operation. From the network operator view point, the network behaviour through this event was in every respect indifferent to the FCL existence in the circuit. The FCL required no attention or handling following this event.

Comparison of the FCL behaviour in both fault events shows that the its fault limiting performance is consistent and repeatable, as expected due to the fact that the two fault events occurred on same location in the network.

CONCLUSIONS

Data gathered from GridON's saturated core fault current limiter during two years of operation in a live substation show the maturity and readiness of these FCLs for widespread adoption in distribution, transmission and industrial grids. The device exhibited fault current reduction of 35-36% as designed, through consecutive long duration fault events, enabling the connection of three transformers in parallel rather than two. Upon fault clearing, the FCL instantly recovered back to normal load, enabling the uninterrupted operation of the network. The operator's protection system behaved exactly as expected, and has not faced any spurious alarm signals. In normal operation, the FCL presented very low impedance to the network, significantly lower than a current limiting reactor, improving power quality and network availability and security of supply, owing to the parallel connection of three transformers. The FCL has not required any care following the multiple fault events, enabling the network operator to maintain well-known operating practices with reduced fault levels.

GridON's technology has already proven to work in higher rated power and fault limiting requirements (over 50%). Being based on conventional transformer technology, the commercially ready FCLs are scalable to all voltage and power ratings.

ACKNOWLEDGMENTS

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REFERENCES

[1] Conseil international des grands réseaux électriques. Comité d'études A3, 2012, *Application and Feasibility of Fault Current Limiters in Power Systems – CIGRE Working Group A3.23,* CIGRE, Paris, France