TECHNICAL AND APPLICATION GUIDE

ArcLimiter™

Arc flash mitigation solution for low voltage equipment using UFES (ultra-fast earthing switch)

Many industries are facing internal or external deadlines to implement arc flash (AF) mitigation solutions within their facilities. ABB now offers ArcLimiter™, an arc flash mitigation solution that is unique in the industry. It solves the LV arc flash problem at the MV or LV system level.

Table of contents

ArcLimiter™ Introduction

Many industries are facing internal or external deadlines to implement arc flash (AF) mitigation solutions within their facilities. ABB now offers ArcLimiter™, an arc flash mitigation solution that is unique in the industry. It solves the LV AF problem at the MV or LV system level. Many industries have internal distribution system configurations as shown in Figure 1. The REA and UFES are ABB product additions to this typical configuration that comprise the ArcLimiter AF mitigation solution.

Abbreviations used in this document

AF:	arc flash
AWG:	American Wire Gage
CLF:	current limiting fuse
FLA:	full load amperes
LV:	low voltage
MV:	medium voltage
PSE:	primary switching element
QRU:	quick release unit (of the UFES)
REA:	ABB's dedicated arc flash detection relay
SCC:	short circuit capacity
SUS:	secondary unit sub, MV-LV
51G:	AC inverse time earth overcurrent relay (residual method)

This solution is appropriate for:

- Light and heavy industrial
- Commercial facilities
- Educational campuses
- Any facility applying primary loop fed transformers with fused MV switches (36 kV limit), new or existing applications
- Facilities having MV to LV transformers in the range of 750 KVA – 5000 KVA

To prove this solution concept, tests were performed at a third-party test laboratory. During an actual LV arc flash event (performed per IEEE C37.20.7), the REA detected and responded to the AF event, sending a closing signal to the UFES. The REA is advertised to detect and close its output trip contact within 2.5 milliseconds (ms). With the current setting at 1.5x the CT primary rating and the light detection adjustment at mid-range, this third-party test proved the REA responded within 1 ms.

This response placed negligible voltage on the transformer primary, extinguishing the LV arc flash quickly (approximately 4 ms). Test results indicate the incident energy level peak was 0.5 cal/cm2, which is well below the AF threshold of 1.2 cal/cm2, where PPE is required.

A note on the CLF application is in order. A fuse will become current limiting when the magnitude of amperes through it is large enough to fully interrupt in ¼ cycle or less, i.e., the fault waveform's peak is never reached. In general, for each application with an applied UFES and MV E rated fuse, the applying engineer needs to obtain the SCC (in amperes) available at the upstream MV BUS. The MV E rated fuse will reach its current limiting threshold (¼ cycle interruption) when the ratio of SCC to fuse full load ampere rating is 25 times at a minimum. If the ratio is less than 25, the fuse will take many cycles to fully interrupt. With the UFES closed, the MV BUS is now at zero volts, negatively impacting plant operations.

LV starters can drop out while we are waiting for full fuse interruption. The CLF interruption time determines when the MV BUS returns to nominal operating voltage.

Consider the following two examples for illustration (in either case, the LV AF problem is solved equally well):
- System SCC= 10,000A; CLF is a 150E; ratio of the SCC to the fuse FLA rating is 67. Fuse will interrupt in ¼ cycle. Operations should not be impacted.
- System SCC= 4,600A; CLF is a 200E; ratio is 23. Fuse will interrupt in cycles. Operations could be impacted and the plant needs to be informed upfront.

Post testing analysis revealed that MV system grounding has an impact on overall system behavior in case of an AF and applying a UFES. This application note addresses system grounding configurations and how to technically apply the UFES, minimizing any reliability issues for customers' plants. Each MV grounding method is addressed.

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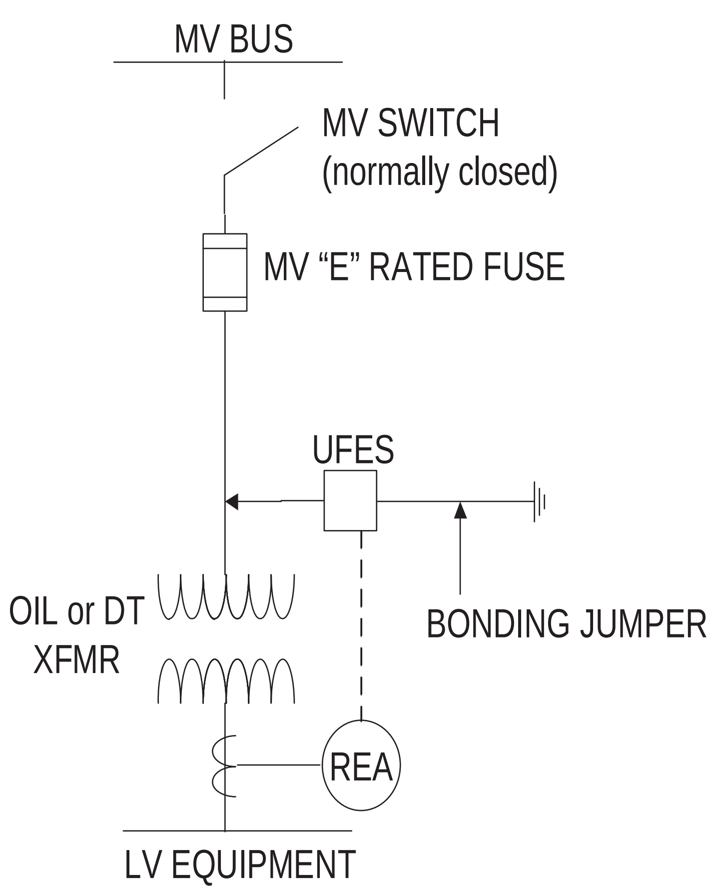
01 Internal distribution system configuration



Solidly grounded MV systems

On a solidly grounded MV system, the ArcLimiter application for LV arc flash mitigation is proven very effective by test.

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02 solidly grounded MV system

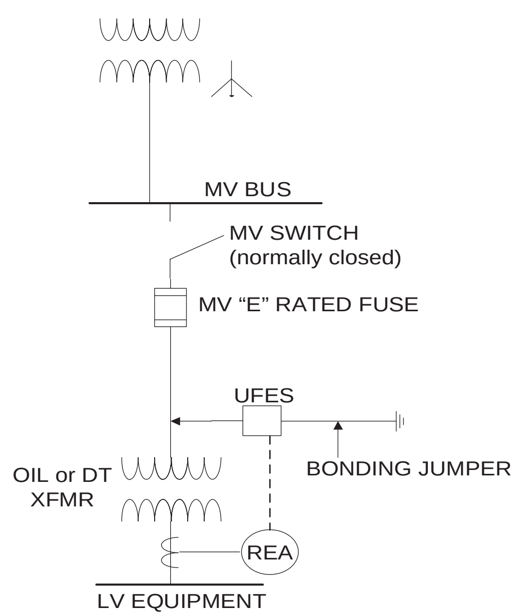
On a solidly grounded MV system, shown in Figure 2, the ArcLimiter application for LV AF mitigation is proven very effective by test. The UFES closes all three phases to ground simultaneously with some minor contact bounce. At this point, the LV AF is over.

Depending upon UFES closing time and phase sequence, phases A and B fuses melt in 1 ms (MV system voltage recovery starts) with full CLF interruption by 1.5-2 ms. The actual CLF interrupting time is dependent upon the MV system fault availability (many times referred to as SCC). The higher the SCC, the faster the CLF interruption, the shorter duration of the fault induced voltage dip, the less impact on other on-going operations.

When phases A and B CLF fully interrupt, the entire phase C current briefly appears as a zero sequence current on the traces. The only path for fault current is through the phase C fuse, to UFES phase C PSE, to transformer grounded neutral. Since there is no impedance in that path, the fault current flow is high, only limited by the transformer's short circuit impedance.

Since phase C is delayed by 120 degrees, about 5 ms (assuming a 60 Hz system), in order for the phase C fuse to melt, those amps will not flow via phases A and B fuses, which are already open, but back to the source neutral. The UFES to ground bonding jumper can be small thermally, approximately #2 AWG, since it only has to carry current for 5 ms.

Upon UFES operation, all three fuses should be replaced, since the phase C fuse may be damaged by microsecond internal arcing, along with all three PSEs.



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Low resistance/grounded MV systems

If the MV system is not solidly grounded, but low resistance neutral grounded, the application of the ArcLimiter solution needs to change.

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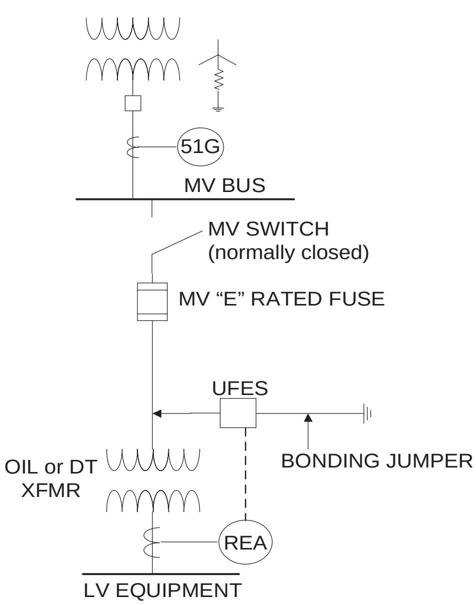
03 MV system is not solidly grounded, but low resistance neutral grounded
—
04 Path for fault current is through the phase C fuse, to UFES phase C PSE, to the transformer's neutral, but is now limited by the source neutral return path's resistance

If the MV system is not solidly grounded, but low resistance neutral grounded (Figure 3) the application of the ArcLimiter solution needs to change. The UFES closes all three phases to ground, simultaneously, when triggered. At this point, the LV AF is essentially over.

Depending upon UFES closing time and phase sequence, phase A and B fuses melt in 1 ms (MV system voltage recovery starts) with full CLF interruption by 1.5-2 ms (SCC dependent). When phase A and B CLF clear, the entire phase C current appears as a zero sequence current on the test traces. There is a large reduction in phase C fault current once phases A and B CLF open.

The only path for fault current is through the phase C fuse, to UFES phase C PSE, to the transformer's neutral, but is now limited by the source neutral return path's resistance (Figure 4).



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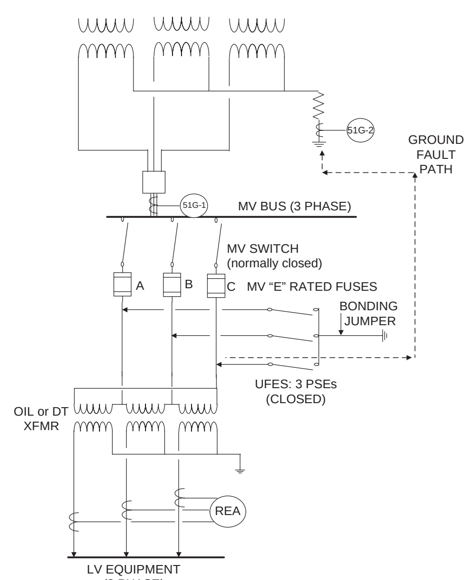

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Low resistance/grounded MV systems

Typically, in industrial plants, that ground fault value can be limited to 200-600 A and in power plants up to 1200 A. Phase C could remain energized to the transformer primary for an extended time and since most of the plant's SUS are delta-wye, all three transformer phases have the same evenly applied potential. Since there is no potential difference between the delta windings, there is no current flow, therefore, there is no induction to generate secondary potential. With no supporting secondary potential, the LV AF collapses in microseconds.

However, a sustained bolted line-to-ground phase C fault on a low resistance grounded system will be detected and tripped by the upstream 51G-1 or 51G-2 protection relay "x" seconds later. Review the ground return path in Figure 4. This action shuts down the entire MV BUS resulting in poor reliability for customers' plants. The 51G-1 or 51G-2 will be faster than a sustained high ground fault value (say 1200 A) through the CLF.

To prevent this reliability issue, the MV SWITCH should be installed (or retrofitted) with a shunt trip activated by one of the QRU1's trip out contacts

Phase A and B CLF will still interrupt in about the same timeframe, about 1-2 ms, since they are in series through the closed PSEs. Phase C may not interrupt. The upstream 51G-1 or 51G-2 will not see ground current within its pick up range.

Upon UFES operation, all three fuses should be replaced, since the phase C fuse may be damaged by microsecond internal arcing, along with the three PSEs. The UFES to ground bonding jumper can be small thermally, approximately #2 AWG, since it only has to carry current for 5 ms.

High resistance/grounded MV systems

If the MV system is high resistance neutral grounded, the application of the ArcLimiter solution needs to change.

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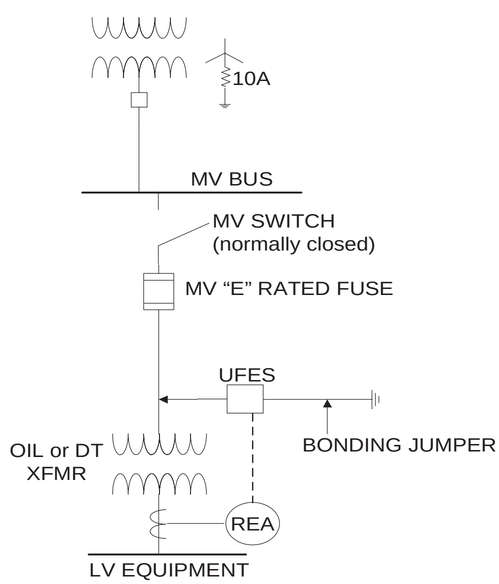
05 MV system is high resistance neutral grounded
—
06 Path for fault current is through the phase C CLF to UFES phase C PSE to transformer's neutral, but is now very limited by the source neutral return path's resistance

If the MV system is high resistance neutral grounded (Figure 5) the application of the ArcLimiter solution needs to change. These types of systems are typically applied in older industrial plants, feeding a process. A single line to ground fault does not cause major damage and the MV switchgear breakers usually do not have ground fault protection. Indications of a ground fault are usually detected via installed voltmeters. The operating process continues as a plant benefit.

The UFES closes all three phases to ground simultaneously. At this point, the LV AF is essentially over. Depending upon UFES closing time and phase sequence, phase A and B CLF melt in 1 ms (MV voltage system recovery starts) with full CLF interruption by 1.5-2 ms (SCC dependent). When phases A and B CLF clear, the entire phase C current (now very limited) appears as a zero sequence current.
The only path for fault current is through the phase C CLF to UFES phase C PSE to transformer's neutral, but is now very limited by the source neutral return path's resistance (Figure 6).



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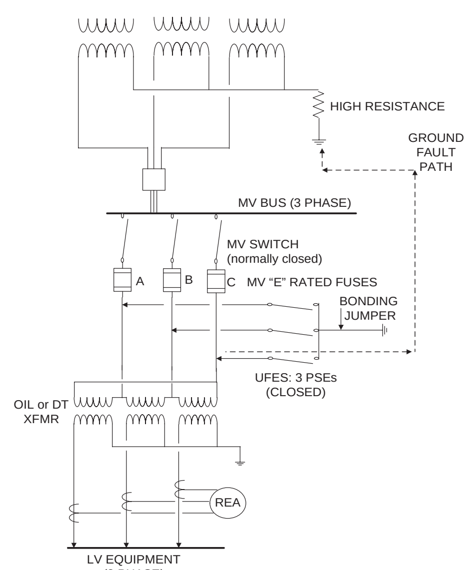

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High resistance/grounded MV systems

Typically, in industrial plants, the maximum high impedence ground fault current flow value is limited to 10 A. Phase C could remain energized to the transformer primary for an extended time and, since most of the plant's SUS are delta-wye, all three transformer phases have the same equally applied potential. Since there is no potential difference between the delta windings, there is no current flow, therefore, there is no induction to generate secondary potential. With no supporting secondary potential, the LV AF collapses in microseconds.

However, having a sustained bolted line-to-ground phase C 10 A fault will activate the plant's ground fault alarm system. Maintenance would be chasing the wrong problem. To prevent this nuisance alarm, the MV SWITCH should be installed (or retrofitted) with a shunt trip activated by one of the QRU1's trip out contacts.

Two of the CLFs will still interrupt in about the same timeframe, about 1-2 ms, Phase C CLF may not interrupt. This prevents the false ground fault alarms.

Upon UFES operation, all three fuses should be replaced, since the phase C fuse may be damaged by microsecond internal arcing, along with the three PSEs. The UFES to ground bonding jumper can be small, approximately #2 AWG, thermally, since it only has to carry current for 5 ms.

Ungrounded Delta MV systems

If the MV system is delta ungrounded, the application is very similar to high resistance grounded systems.

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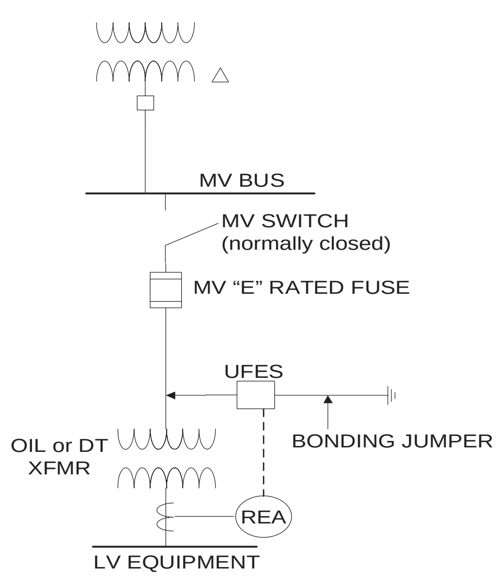
07 MV system is delta ungrounded
—
08 After phases A and B CLF clear, there is no phase C current since the ground return path is open

If the MV system is delta ungrounded (Figure 7) the application is very similar to high resistance grounded systems. These types of systems are typically applied in older industrial plants feeding a process.

A single line to ground fault does not cause any increase in ground current to flow except from inter-electrode capacitance. The MV switchgear breakers do not have ground fault protection. Indications of a ground fault are usually via installed voltmeters. The operating process continues as a plant benefit.

When triggered, the UFES closes all three phases to ground simultaneously. At this point, the LV AF is essentially over. Depending upon the UFES closing time and phase sequence, phase A and B fuses melt in 1 ms (MV voltage recovery starts) with full CLF interruption by 1.5-2 ms (SCC dependent). After phases A and B CLF clear, there is no phase C current since the ground return path is open. See Figure 8.



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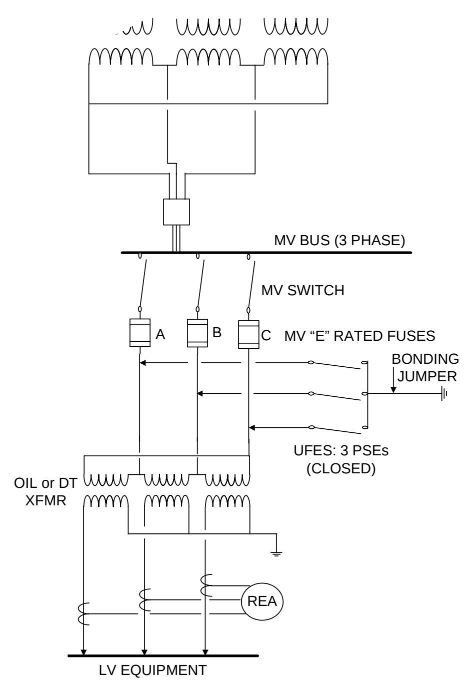

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Ungrounded Delta MV systems

Phase C could remain energized to the transformer primary for an extended time and since most of the plant's SUS are delta-wye, all three transformer phases have the same equally applied potential. Since there is no difference in potential between the delta windings, there is no current flow, therefore there is no induction to generate secondary potential.

However, having a sustained bolted line-to-ground phase C fault will activate the plant's ground fault alarm system. Maintenance would be chasing the wrong problem.

To prevent this nuisance alarm, the MV SWITCH should be installed (or retrofitted) with a shunt trip activated by one of the QRU1's trip out contacts.

Two of the CLFs will still interrupt in about the same timeframe, about 1-2 ms, Phase C CLF may not interrupt. This prevents the false alarms.

Upon UFES operation, all three fuses should be replaced, since the phase C fuse may be damaged by microsecond internal arcing, along with the three PSEs. The UFES to ground bonding jumper can be small thermally, approximately #2 AWG, since it only has to carry current for 5 ms.

Summary of ArcLimiter™ solution MV application scenarios

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Summary Table

<table>
<thead>
<tr><th>Solidly grounded MV system</th><th>Low resistance grounded MV system</th><th>High resistance grounded MV system</th><th>Ungrounded Delta MV system</th></tr>
</thead>
<tbody>
<tr><td colspan="4">AF is detected
UFES closes all three phases to ground simultaneously
LV AF is over
Phases A and B fuses melt in 1 ms & fully interrupt (MV system voltage recovery starts)
CLF interruption within 1.5 - 2 ms (SCC dependent)</td></tr>
<tr><td>Phase C briefly appears as a zero sequence ground current</td><td colspan="2">Phase C appears as long-term flow of zero sequence ground current</td><td>Phase C will remain energized to the transformer primary for an extended time</td></tr>
<tr><td>Phase C CLF interruption is delayed about 5 ms</td><td colspan="3">Phase C CLF interruption is delayed almost indefinitely</td></tr>
<tr><td rowspan="4">Too short a time for ground relay pick up</td><td>Sustained line-to-ground phase C fault tripped by the upstream 51G relay

Trips entire MV BUS resulting in poor reliability for the plant</td><td>Sustained line-to-ground phase C 10 amp fault activates the plant’s ground fault alarm system</td><td>Sustained line-to-ground phase C fault will activate the plant’s ground fault alarm system

Maintenance would be chasing the wrong problem</td></tr>
<tr><td colspan="3">Remedy: Install MV shunt trip activated by QRU1</td></tr>
<tr><td colspan="3">Two CLFs still interrupt in about the same timeframe, about 1-2 ms</td></tr>
<tr><td>Prevents upstream 51G from tripping</td><td colspan="2">Prevents the false ground fault alarms</td></tr>
<tr><td colspan="4">Upon UFES operation, all three fuses should be replaced, since the phase C fuse may be damaged by microsecond internal arcing, along with spent PSEs</td></tr>
<tr><td colspan="4">The UFES to ground bonding jumper can be small thermally, ~#2 AWG, since it only has to carry current for 5 ms</td></tr>
</tbody>
</table>

MV-LV transformers fed by MV breaker

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09 MV system is not solidly grounded, but low resistance neutral grounded

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10 Path for fault current is through the phase C fuse, to UFES phase C PSE, to the transformer's neutral, but is now limited by the source neutral return path's resistance

The MV system may have the configuration shown in Figure 9. The MV system grounding does not enter into this application discussion because the feeder breaker will be shunt tripped at the same time as the UFES. Once the breaker is open, all phase and ground current flow stops. The ground relays have a chance to time out or pick up but do not as the ground fault is cleared by the breaker prior to this happening.

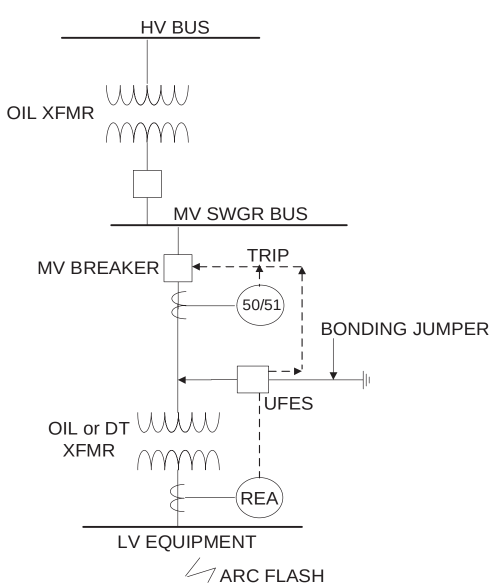
UFES type equipment (high speed ground switches) have been applied for many years on LV and MV systems to reduce arc flash incident energy levels. They are effective but there is a concern among some liquid-filled transformer manufacturers that solving an arc flash problem with a UFES may actually be creating a problem at the transformer. If the upstream HV-MV transformer is older and/or has aged insulating paper, the high current-induced magnetic vibrations could damage the insulating paper causing a turn-turn transformer fault.

Figure 10, from IEEE C57.109, "IEEE Guide for Liquid Immersed Transformer Through-Fault Current Duration," is a visual representation of an assumed sustained bolted fault on the transformer's secondary reflected to the primary windings. The "X" axis is in units of times transformer's full load amps (base, not top). The "Y" axis, in seconds, is the time duration capability of the transformer to thermally and mechanically withstand a sustained secondary bolted fault. The lower portion of the curve is the mechanical damage area, considered the area of most concern from a protection viewpoint.

The graph's purpose is to assist in the coordination of the transformer's primary protective devices. Even though the transformer is designed to withstand this long-term bolted fault level, the fault time duration is dependent upon the device 51 protective relay settings and breaker interrupting time frame or primary fuse interruption. The protective device time-current-curve must be positioned left of the transformer's damage curve.

In order to minimize the through-fault duration, the UFES's shunt trip contacts should trip direct (by-passing the 50/51 protection relay) to the upstream MV breaker as in Figure 9. This direct trip action also minimizes the fault produced voltage dip duration; a benefit to operating processes.

Upon UFES operation, all three PSEs should be replaced. The UFES to ground bonding jumper can be small thermally, approximately #2 AWG; the zero sequence current will be zero.



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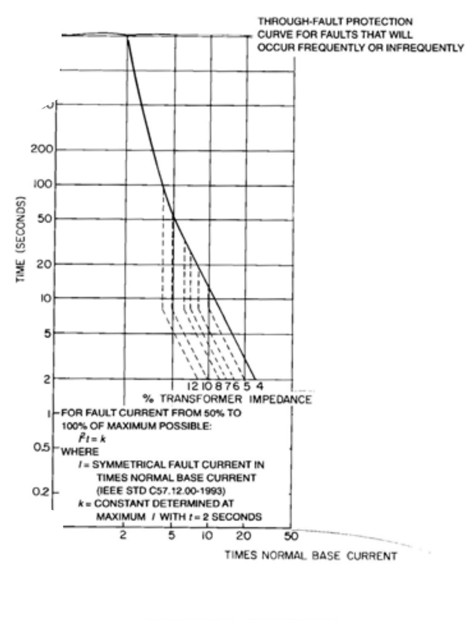

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ArcLimiter™ solution application at LV system level

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11 MV system is not solidly grounded, but low resistance neutral grounded

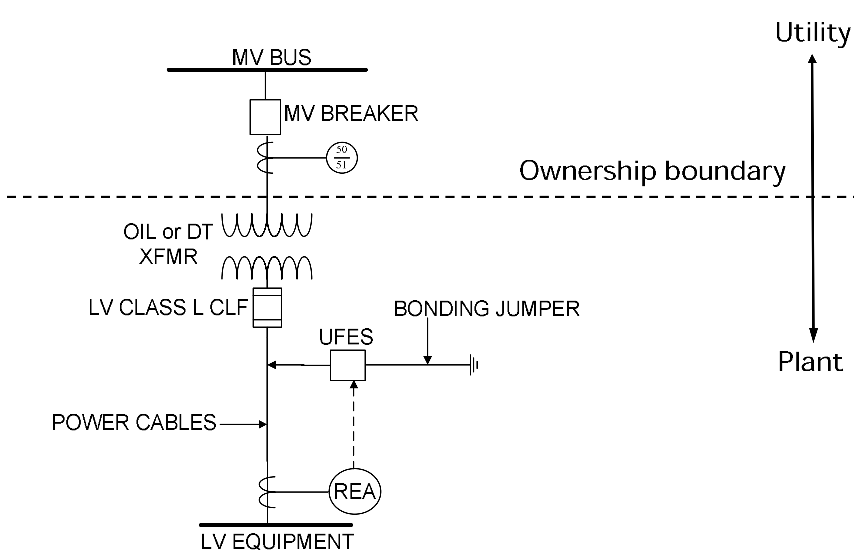
If the customer does not own the MV line connected to their transformer or the local utility does not want additional products added on their MV service line to the customer's site, we can apply ABB's ArcLimiter solution to the LV transformer side with the same arc flash mitigation effectiveness and possibly lower installed costs. This approach should also improve MV power quality during an AF event.

Note that in Figure 11, the CLF is now relocated from the MV side to the LV side of the transformer. These LV CLFs are not as long, but much wider, so changes in mechanical installation must be considered. Connect the CLF directly to the transformer's secondary LV bushings. The CLF's load terminals should connect to the LV busduct or main load cables routed to the LV switchgear. The PSEs should be connected from the CLF's load terminals to ground. The QRU100 controller can be mounted in the LV switchgear or the transformer's secondary air terminal. As in the previous applications, the REA101 needs to have communications to the QRU100. This approach will have less negative impact at the MV level.

LV fault magnitude
Once the PSEs close, the transformer and CLF will see a bolted LV fault collapsing any LV equipment AF. That transformer LV through-fault of 52kA will be reflected to the MV primary as (1 / %Z) * FLA. Example: 80% of the MV-LV transformers are 2500KVA base rated. Per ANSI, energizing the transformer will produce an inrush of 12*FLA for 0.1s. If the transformer has an impedance of 5.75% or 9%, the inrush will be (1 / 0.0575)*FLA = 17.4*FLA. Slightly higher than typical inrush. For the 9%Z version, the inrush will be (1 / 0.09)*FLA = 11.1*FLA. Slightly lower than typical inrush.

Through-fault duration
A 2500KVA transformer has a top rating typically at 3333KVA (3990FLA at 480V). Therefore, a 4000A (or 5000A) class L CLF needs to be applied. If a Mersen A4BQ 4000A (or 5000A) is applied, that through-fault will last 0.029s or 1.7 cycles (0.148s or 8.9 cycles). The reflected through-fault could be higher than typical inrush but may last for less time duration. The mix of transformer KVA vs. CLF sizes vs. CLF response time is not that large. Each application will have to be evaluated and the area FAE(s) can help here.

Grounding
Similar to the MV applications, most LV applications for industrial plants have high Z (5A limited) grounded systems. Upon PSE closure, two of the CLFs will open, the third CLF will be damaged but stays intact. The ground alarm will activate.



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Available UFES ratings

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UFES primary switching element type U1

Electrical maximum characteristics for each voltage category (different types available)						
Rated voltage (ms)*	kV	1.4	17..5		27	36
Rated power frequency withstand voltage (rms)	kV	5	42		60	70
Rated lightning impulse withstand voltage (peak)	kV	12	95		150	170
Rated frequency	Hz	50/60	50/60		50/60	50/60
Rated short-time withstand current	kA	100	50	63	40	40
Rated peak withstand current	kA	220	130	165	104	104
Rated duration of short-circuit	s	0.5	3	2	3	3
Rated short-curcuit making current	kA	220	130	165	104	104
Mechanical properties						
Dimension (diameter x height)	mm (in)	~137 x 210 (~5.4" x 8.3")				
Closing time	ms	< 1.5				
Contact bounce time	ms	0				
Service life expectation						
Number of closing operations		1				
Mechanical	years	up to 30				
Micro gas generator	years	up to 15				

* 40.5 kV on request

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