A Tested Method for Mitigating Arc Flash Hazards in Existing LVMCC

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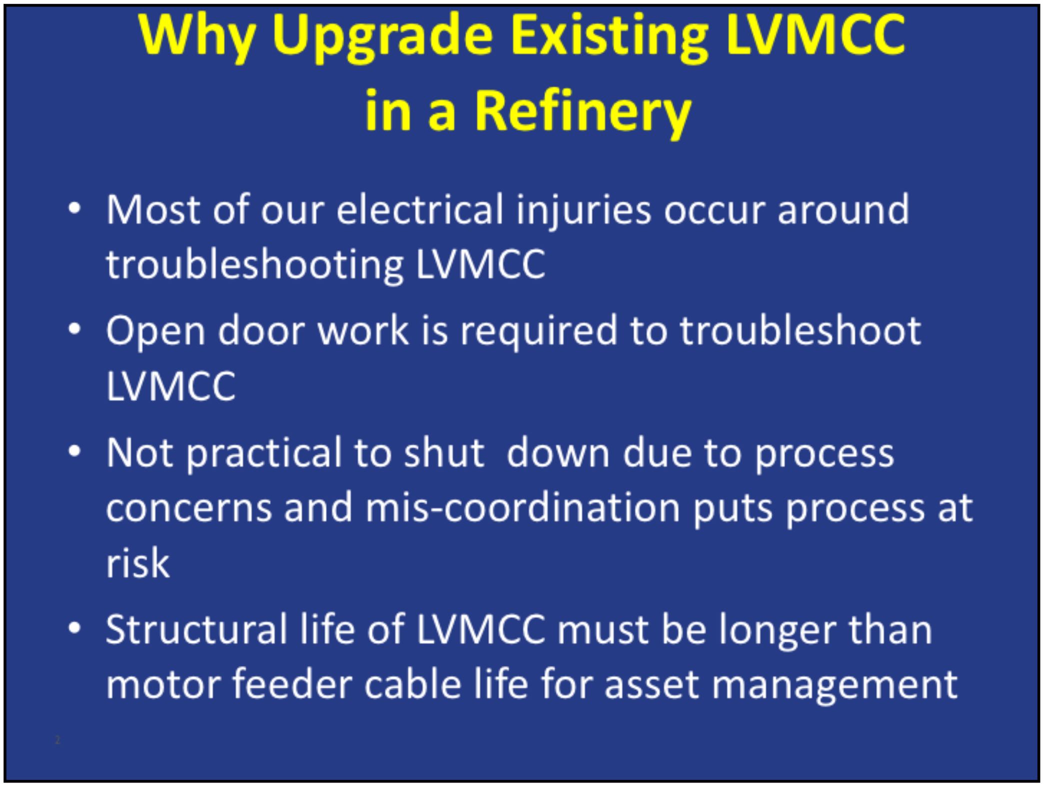
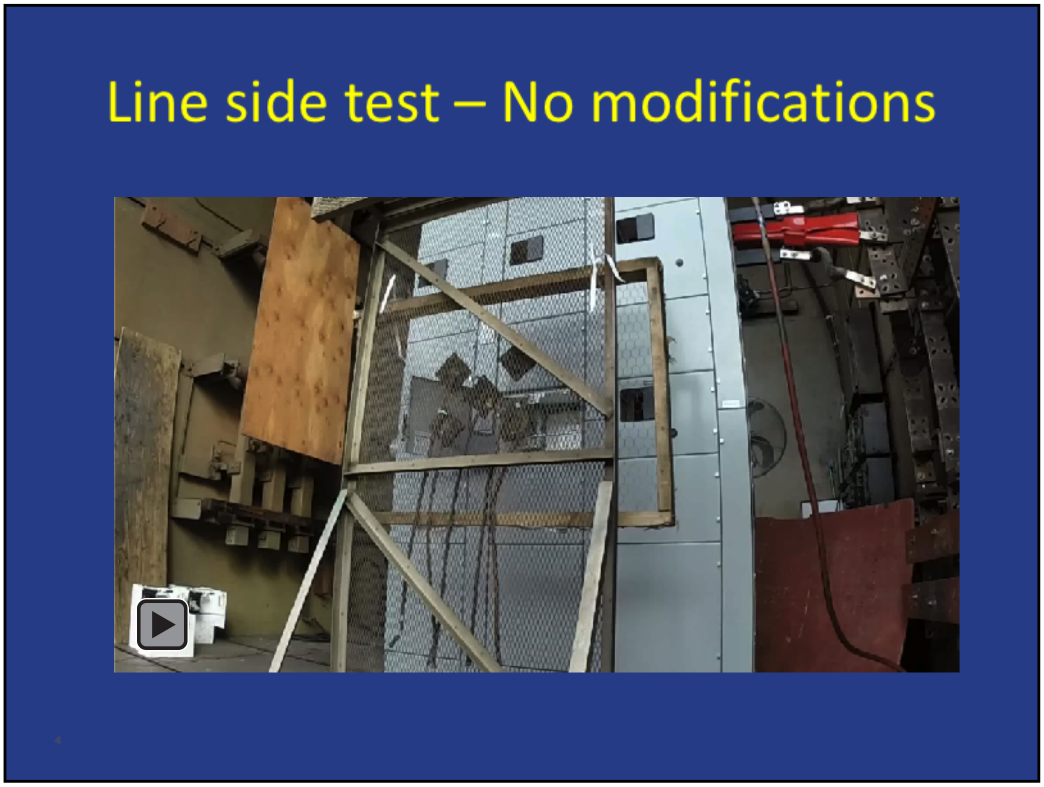


Also, there is a extremely large installed based of LVMCC, all similar in design and function, ranging from new to old, simple to complex. The LVMCC structures have an extremely long life – basically steel and copper. The component can be changed and upgraded as needed, The true cost of the system is the installed cables, which could be many times the value of the LVMCC. Trying to remove old and re-install new LVMCC is a high risk proposition when the risk of damaging existing cables in pulling back and re-installing operations are done. Moving around 15-30 year old cables is a high risk activity, replacement could result in greatly increased costs and downtime.

Load Side Test - without the 4’ of wire

This test was conducted to verify the open door results of a load side fault. Fine-strand bare #10 SIS wire was connected in a short-circuit between the three load terminals.

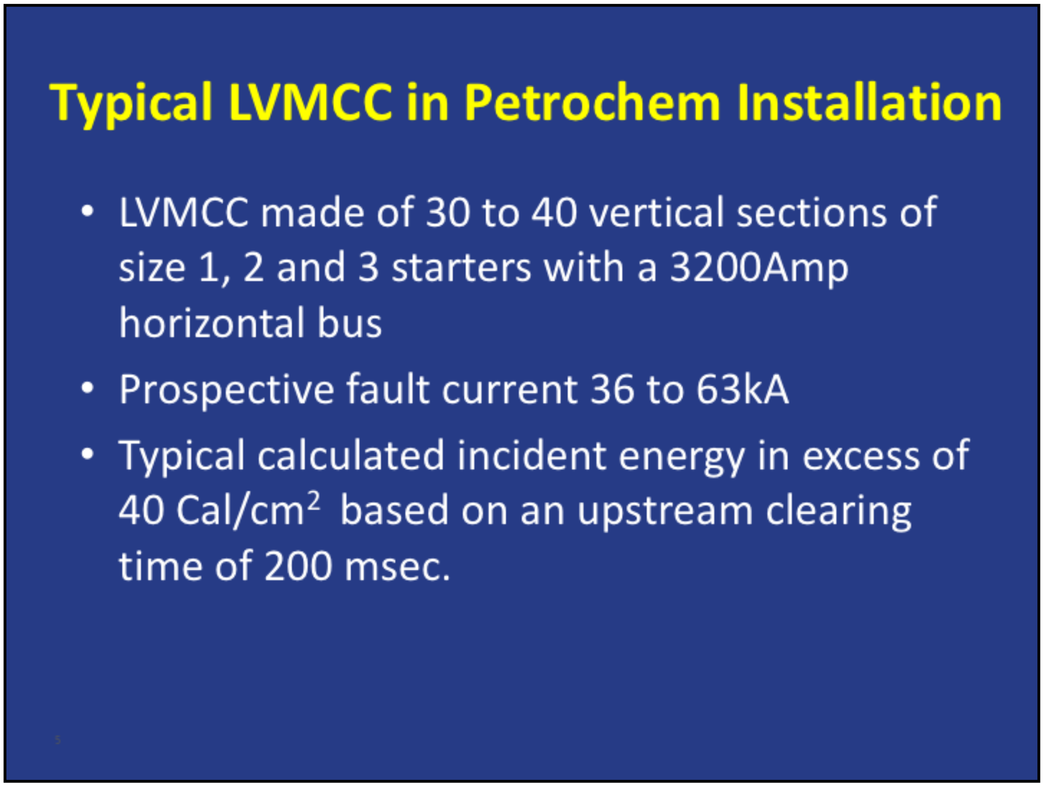
The test current was 65kA, the fault was cleared by the MCCB in 6mS. It is evident there is little or no arc-flash exposure in this configuration.



Five calorimeters placed at 18" from front of open door to measure heat energy from fault through open door. The configuration is bare #10 fine-strand SIS wire in a short circuit in the line side breaker terminals (see Slide 16), simulating a fault that could occur by a technician mistake measuring incoming voltage or expulsion of a lead wire during a load side fault. The fault current for this test was 50kA.

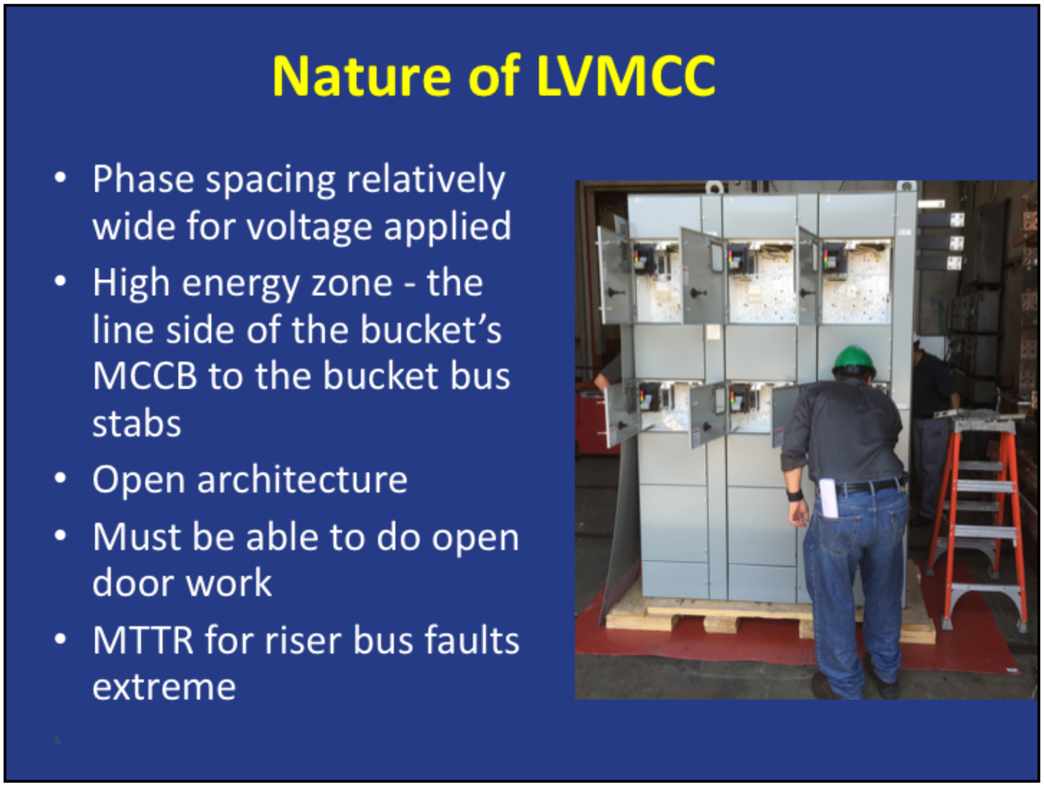
Arc begins at the breaker and within ½ cycle propagates to rear bus through the bucket stab assembly and is cleared by Main Backup Breaker in 300ms. The calorimeter readings were in excess of 40 cal/cm^2. The fault caused vaporization of approximately 12 inches of copper riser bus, resulting in heavy contamination of adjacent structures.

An fault of this nature would have significant safety impact on the technician working with the door open to troubleshoot a problem and result in a long MTTR,



For the systems we are talking about this is a set of 1500kVA to 2500MVA transformers in a main tie main configuration. The arc flash values for this configuration could be 40-60 cal/cm^2 and in excess of 80 cal/cm^2 with the tie breaker closed and a typical 200msec clearing time.

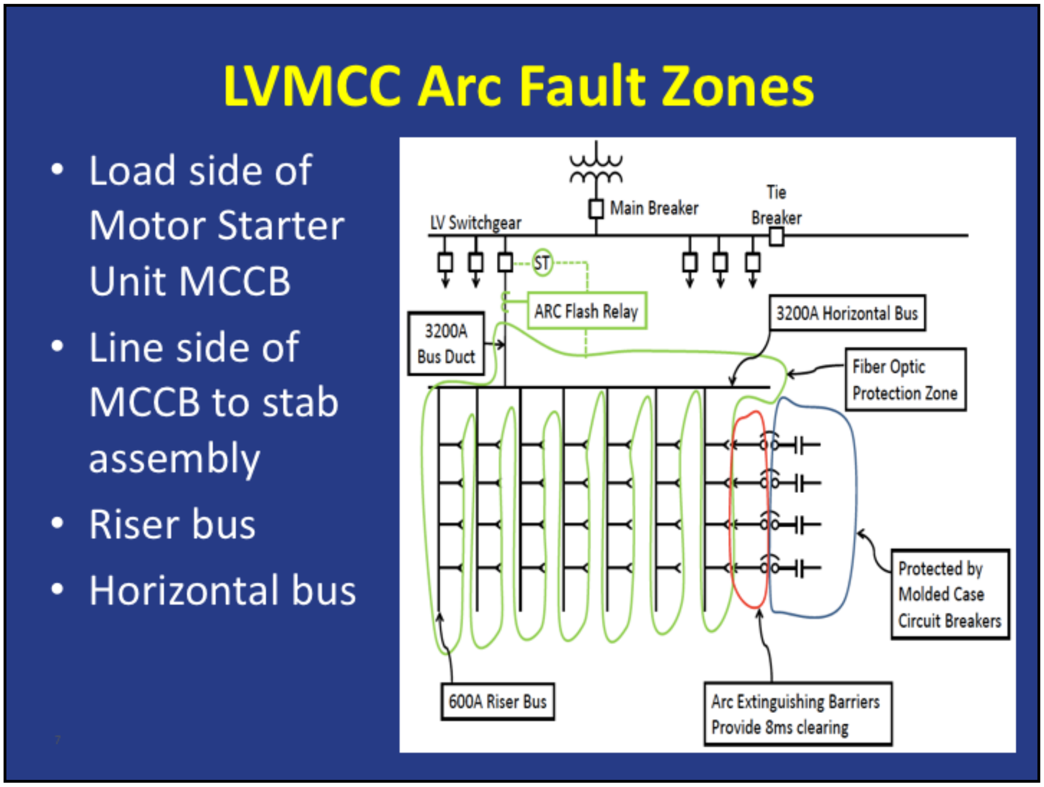
Another consideration is that typical LVMCC is the power source for critical process equipment, such as instrument air compressors, lube oil pumps, elevators, etc. An attempt to protect one electrician working on the LVMCC by instantaneous tripping could put 20-30 people working in the process area in extreme danger.



LV MCC has many of the features of metal enclosed equipment – the compartments are not a grounded enclosure, the bus zone is one big box, the area we call the high energy zone is not tested for fault withstand as a part of the certification process. Standard certification tests evaluate the performance of the assembly based on the MCCB clearing the fault with 4 feet of wire short-circuited on the load side of the MCCB. No evaluation of a line side failure is conducted in standard certification testing.

The design of the LVMCC allows a high degree of flexibility in application, can be reconfigured (if needed) in the field. The buckets have interlock defeaters that allow opening the doors with a common screwdriver, allowing access to live parts. ALL manufacturers state in their instructions that the equipment must be de-energized to maintain. In process applications, as we have stated, this is impractical or impossible, so most technicians do open door work, exposing themselves to hazards. Utilizing high calorie rated PPE is not practical due to the small access spaces. 40 calorie leather gloves are not practical working in a 3-4 inch wireway.

In the event of a high energy fault, the resulting fault vaporizes copper and causes insulation material to carbonize. Some applications are mounted where only front access is available, making removal of faulted sections difficult. Shipping splits from manufacturers are typically three sections wide, removal or cleaning of affected sections leads to long MTTR.



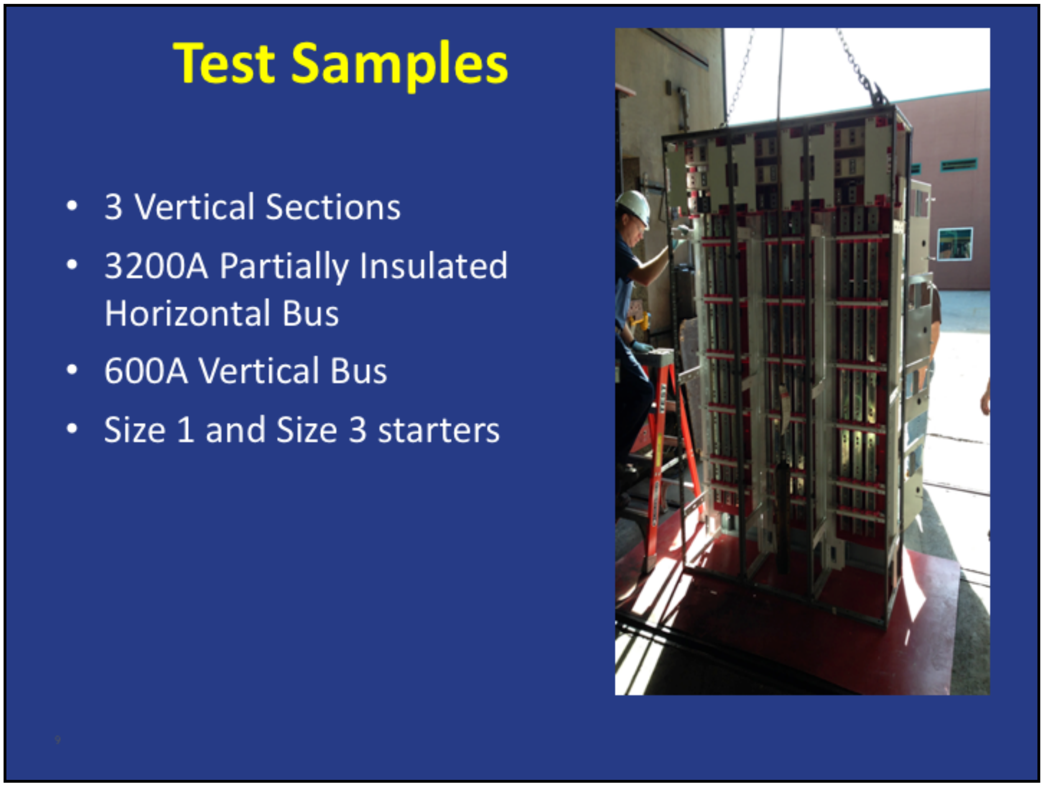
LVMCC is considered metal enclosed in design, meaning it does not have steel barriers between compartments or areas. In the simplest terms, it is one big box of components, wireways and busbars. It is true, however, that there is segregation between units and structures with a common rear area. Therefore we determined to look at the assembly on a “source of fault” basis. (i.e. where could a mistake or situation lead to a fault occurring?) That is what generated these areas –

- Within the bucket on load side of disconnect device (Operator error or component failure)
- Within the bucket on line side of disconnect device (Operator error, component failure, energized conductor ejection during interruption)
- Riser bus (Propagation from bucket faults above, stab failure, vermin, water, insulation failure, loose connection, faults rooting away from source)
- Horizontal bus (Insulation failure, water, loose connection, faults rooting away from source)

LVMCC Fault Physics

- #10 fine strand ignition wire generates enough free electrons to establish a plasma
- Fault stability a function of geometry, distance, fault energy, and driving voltage
- Very hard to restrike - free electrons don't just sit around in space after the plasma field collapses
- Fault energy has a hard time lasting as a diffused arc due to low driving voltage and resulting cathode anode energy zones

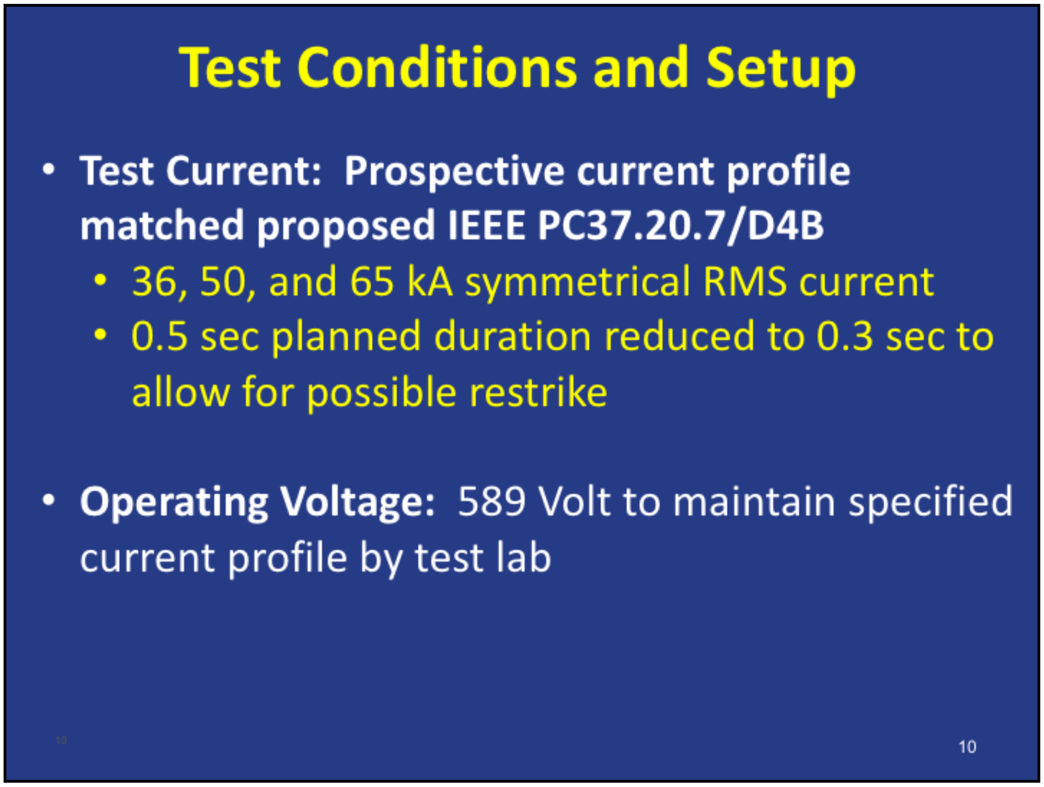
In all the test sequences, no evidence of arc restrike occurred. This is primarily due to the actual construction restraints are ampacity (thermal capacity) due to the higher amperage ratings. The bus spacing is well beyond the voltage gap requirements per kV to allow airflow within the structure to meet standard temperature rise requirements.



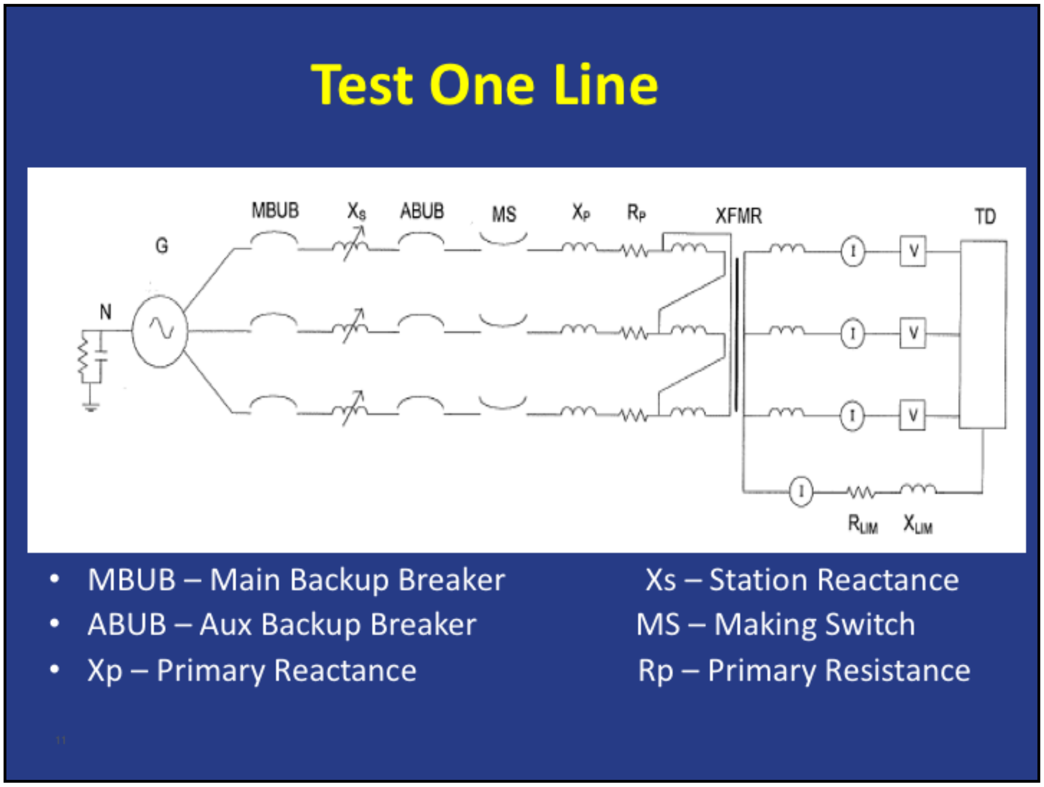
30A, 60A and 225A breakers were tested to verify ampacity was not a factor in the trials, which proved to be true.

The reason we use the term “partially insulated” is because the ends of the bus was not insulated. This is common among manufacturers of this type of equipment, allowing shipping splits for large lineups.

No difference between insulated and un insulated riser bus with the high number of exposed points of connection exposed for bucket stab locations



This was much worse than real life for a 480V system with the test voltage at 589V. As mentioned in Slide 8, the arc physics dictate that the duration where any free electrons are present is extremely short. Reducing the duration time actually makes the available energy the best case condition for arc restrike on this system configuration.

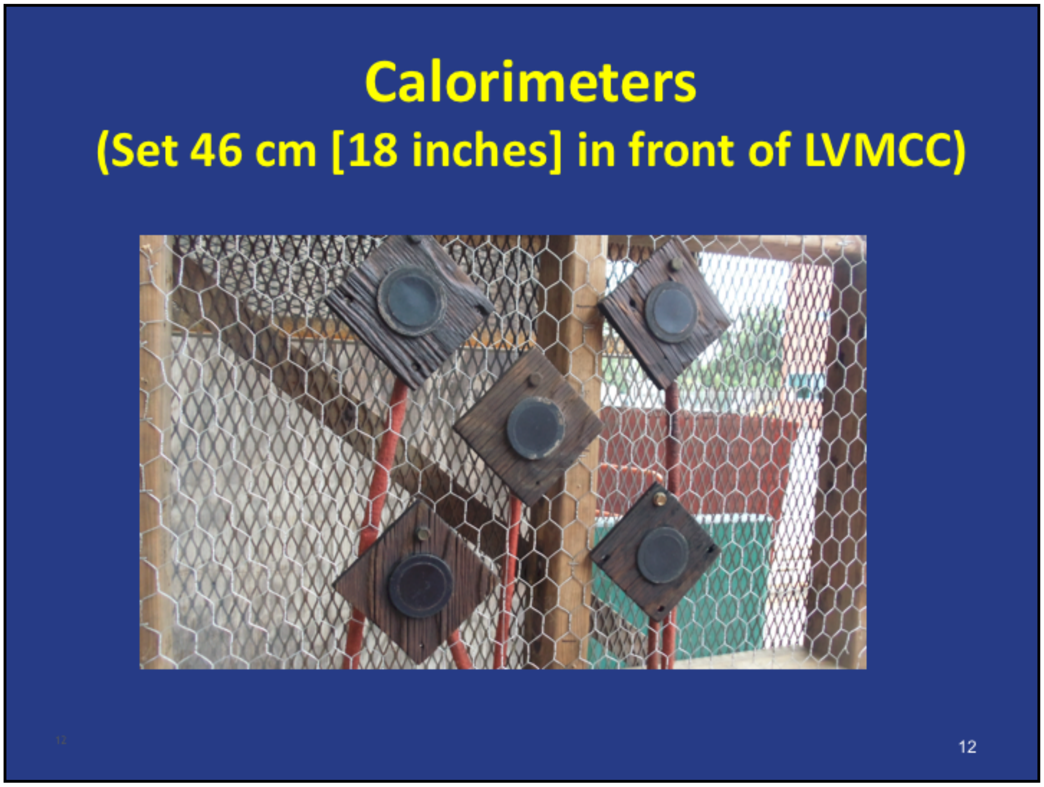


Driving voltage significantly higher than 480V giving a true worst case scenario.

Explanation of the the one-line diagram:

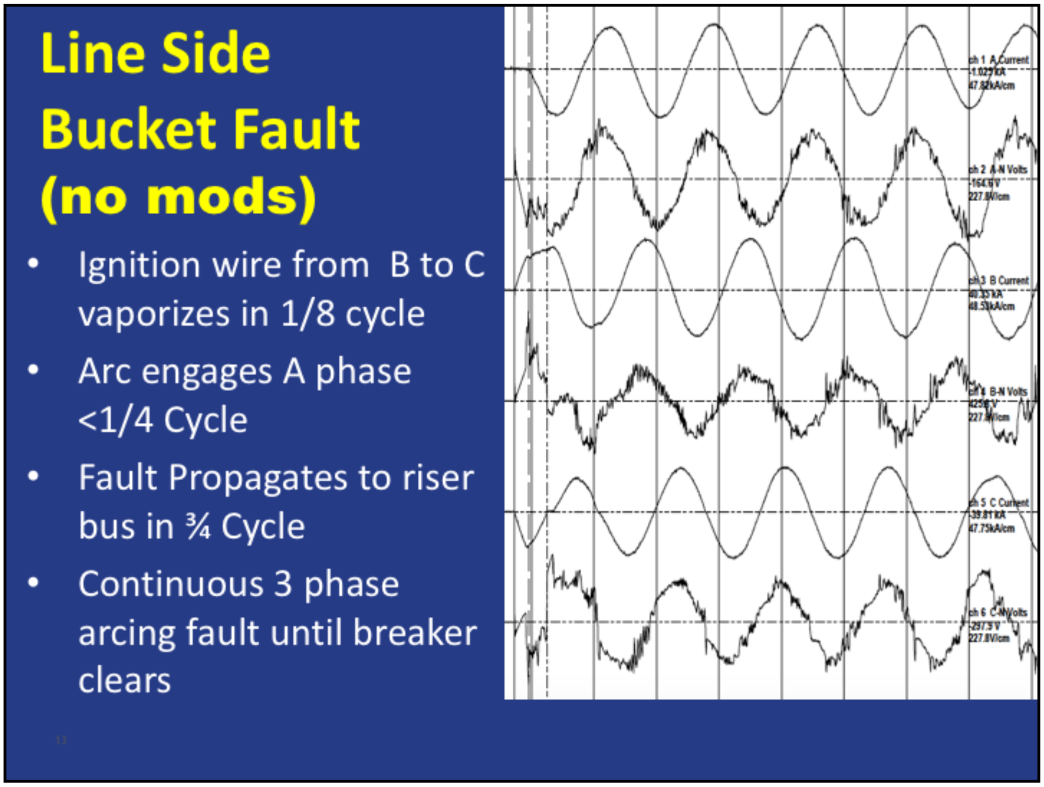
-TD is the Test Device (480V MCC with Three vertical sections)
-Voltage and Current meters on all three phases, current meter on neutral
-System is calibrated before the tests to verify available fault current per C37.20.7.
-HRG and solidly grounded tests with R_{lim} and X_{lim}
-Delta to Wye Isolation transformer
-MBUB – Main Back Up Breaker
-ABUB – Auxillary Back Up Breaker
-X_s _ Excitation Control
-$X_{p,}$ R_p _ Test Station reactor
-Generator gets up to speed for available fault current. Once generator has available power, it isolates itself from power grid and the Making Switch (MS) is closed.
-Modifications in Test Device are to clear the fault without any other devices operating, leaving LVMCC bus energized. Main backup breaker to clear the circuit in 300ms in the event of a restrike, or to end the test.

- Not a single restrike occurred in over 20 tests.



Purpose was to monitor the heat energy in calories. Mounted 18 inches from face of structure.

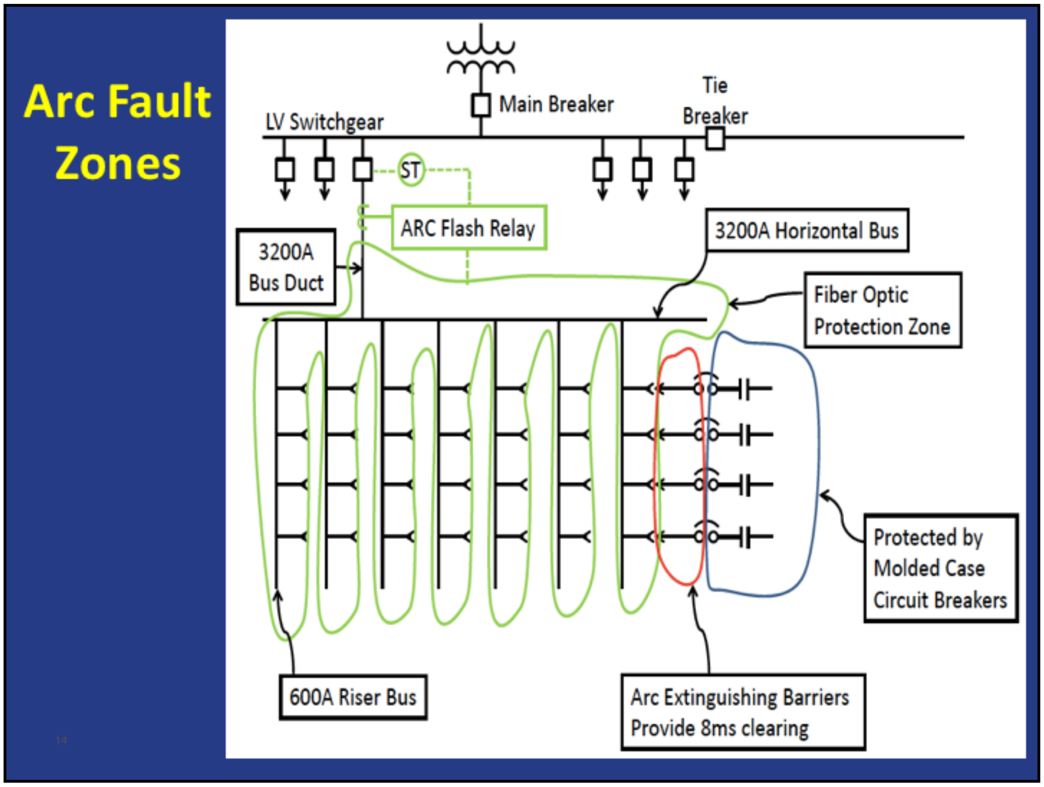
No attempt was taken to monitor noise or light.



Waveform layout from top - A current, A-N Voltage, B current, B-N Voltage, C current, C-N Voltage
Fault was initiated B-C phase, vaporized and initiated A phase within 1/8 cycle
Propagates to rear bus in ¾ cycle where it continued until Main Backup Breaker de-energized circuit

This would model a typical LVMCC failure in a plant application without modifications. The result would be catastrophic equipment damage, resulting in process interruption and significant downtime.

This type fault was indicated in the second video, Slide 4



MCCB did show degradation for this close in fault but still performed well. This had to be confirmed since the UL testing requires the addition on the 4feet of rated wire to assure the feeder wire is protected by the components under test. In typical troubleshooting activities, the components are accessed at the terminals, creating the possibility of a close in fault condition.

The line side test is not part of the normal UL tests. It was included in our testing because the line terminals are accessible and energized when the MCCB is in the off position and the door is open, creating a potential shock and arc flash hazard.

Bucket Fault Upgrade Goals

- Develop retrofit self-extinguishing barriers
- Reduce measured max. incident energy exposure below 1 cal/cm^2
- Allow open door troubleshooting and maintenance
- Fast install
- Reduce the shock hazard likelihood

These were goals established by the team for the testing program.

While this looks great in a photo, measuring voltage is the most simple task done during troubleshooting activities. Wearing the same PPE, how easy would it be to access to the terminal blocks or starter contact blocks?

Wearing the hood, visibility is hampered. The gloves would inhibit dexterity in smaller parts. With the tested modifications outlined in this paper, the same technicians could utilize 8cal HRC2 PPE with voltage rated gloves and face shields, hard hats and ear protection, allowing safer working conditions for the tasks to be performed.

Technically, this photo indicates activity that is not covered by the manufacturers operation and maintenance instructions, which require de-energizing the equipment prior to access – something not practical in process operation.

Bucket Upgrades

- Top MCCB cap secured with HD cable tie
- Proper torqueing of MCCB terminals
- Braided shields connected to Ground

Proper torqueing of MCCB terminals (stop ejection of lead wires under fault conditions)
Shielded line side jumpers to ground (stops fault propagation between phases or if lead wire is ejected under fault conditions and eliminate shock hazard)
Sealed entry to stab assembly (stops a fault within the bucket from propagation to riser bus)

The breaker cap and copper braid were the simplest solutions using commonly available parts

Bucket Upgrades

- Sealed clamshell prevents propagation to rear riser bus
- Stab alignment pre-insertion important

We did find several instances where stab alignment caused issues under fault conditions. Improper insertion can break the clamshell support or deform one side of the stab. We have also witnessed the stab assembly missing the riser bus completely only contacting the outside of the stab – making it electrically conductive but totally ineffective under fault conditions leading to bus compartment failure.

When sealing the clamshell, a centering jig to assure proper alignment is recommended.

Test Configuration for Line Side Bucket Faults

- Fine strand bare connecting 10-32 lug bolt extensions
- Test sample left energized to permit any possible re-ignition

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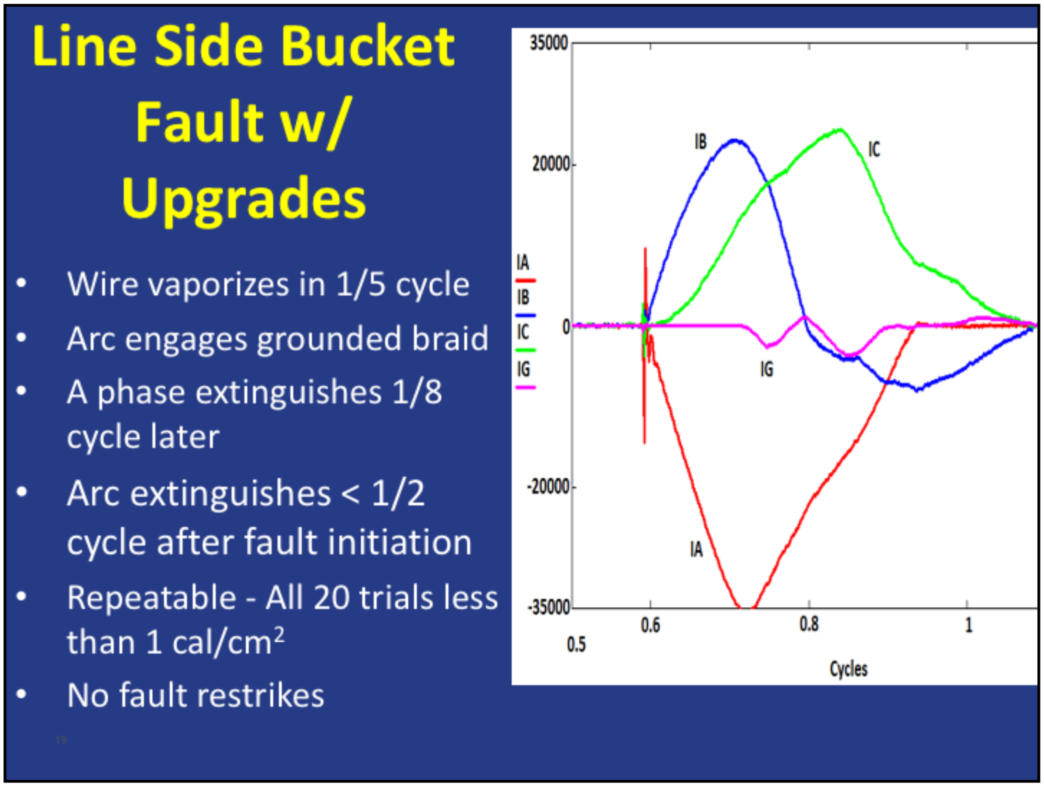
Lugs on line side of breaker were drilled and tapped to accept 8-32 screws to provide access for wrapping fine strand #10 SIS bare wire to short-circuit terminals for test.

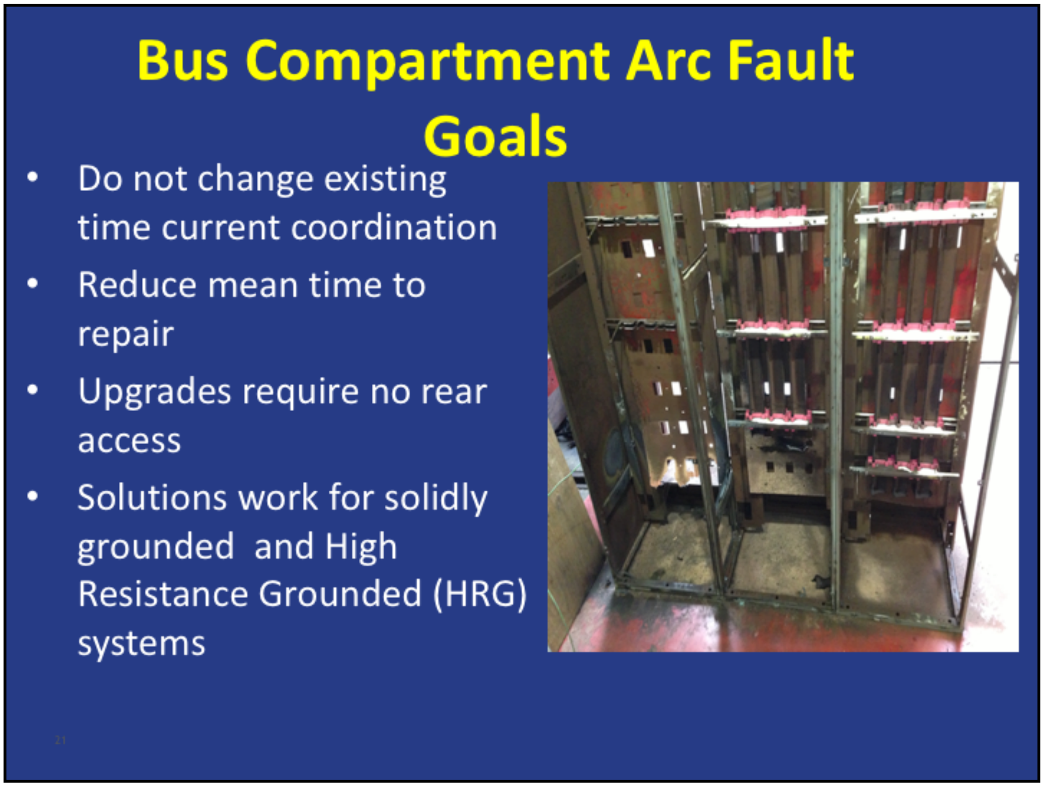


This profile was typical of all 20 tests after modifications were made to buckets.

Test Observations

- Sealed stab assemblly clamshell prevents propagation to rear riser bus
- Breaker cap prevents arc development at breaker terminals
- Braided shield forces short path ground faults

One question that is asked concerns the thermal impact on the MCCB with the breaker cap installed. Manufacturers do not publish any derating factors in their application literature and the true heat sink is the connected devices and cables on the load side of the breaker. The damage shown above is somewhat exaggerated due to the connection method used to install the ignition wire. Note that all hardware vaporized during the fault, potentially leading to the corner of the breaker cracking. The shield wires would have eliminated any potential propagation between phases by their short path to ground, reducing any fault propagation between phases to a ground fault.



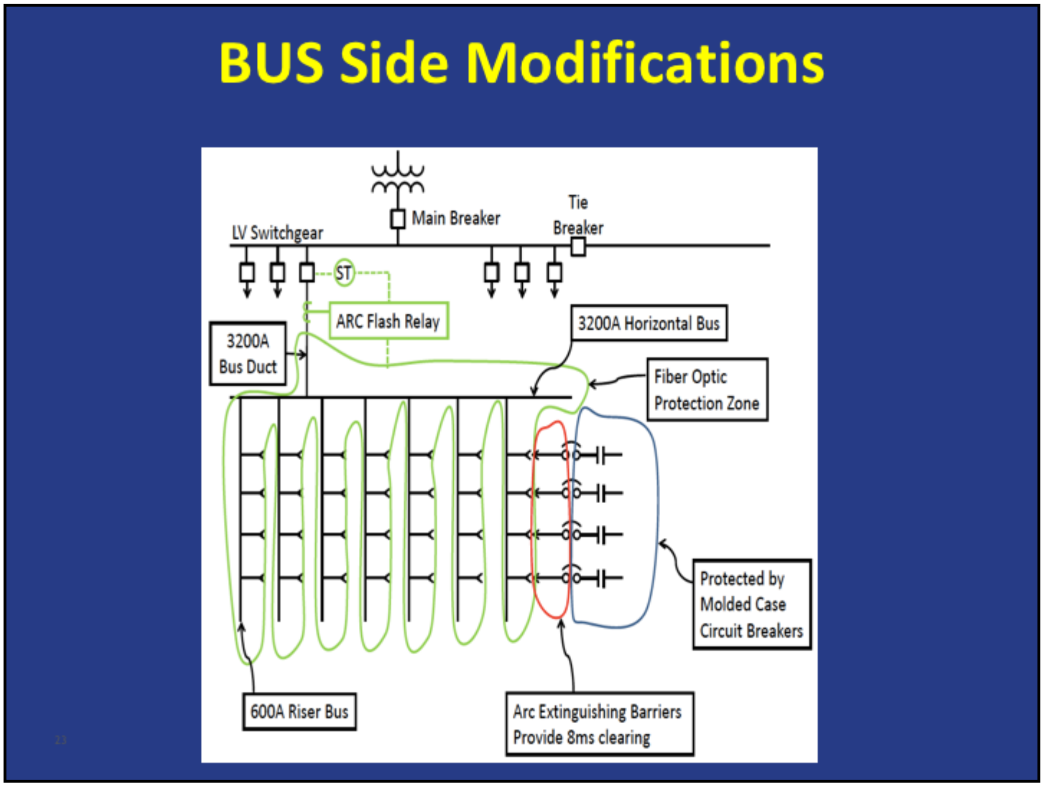
After completing the bucket modifications, we felt that we could isolate any type of fault inside the bucket to remain inside the bucket. The sealed clamshell prevented a bucket fault from propagating to the riser bus.

Now the concern shifted to what would happen IF there was a stab failure, vermin intrusion, loose connection or other sources that would cause a bus compartment failure. The team did not believe adding instantaneous tripping through the addition of maintenance switches or trip unit upgrades was the answer, as it would require updating system studies, additional training, plus an instantaneous trip might help protect the electrician working on the LVMCC, it would cause a process flare condition, potentially gravely endangering workers in the process area. So the goal was established to not impact the existing time-current coordination, but decrease the tripping time for arc fault calculations if and only if there was a true bus fault condition.

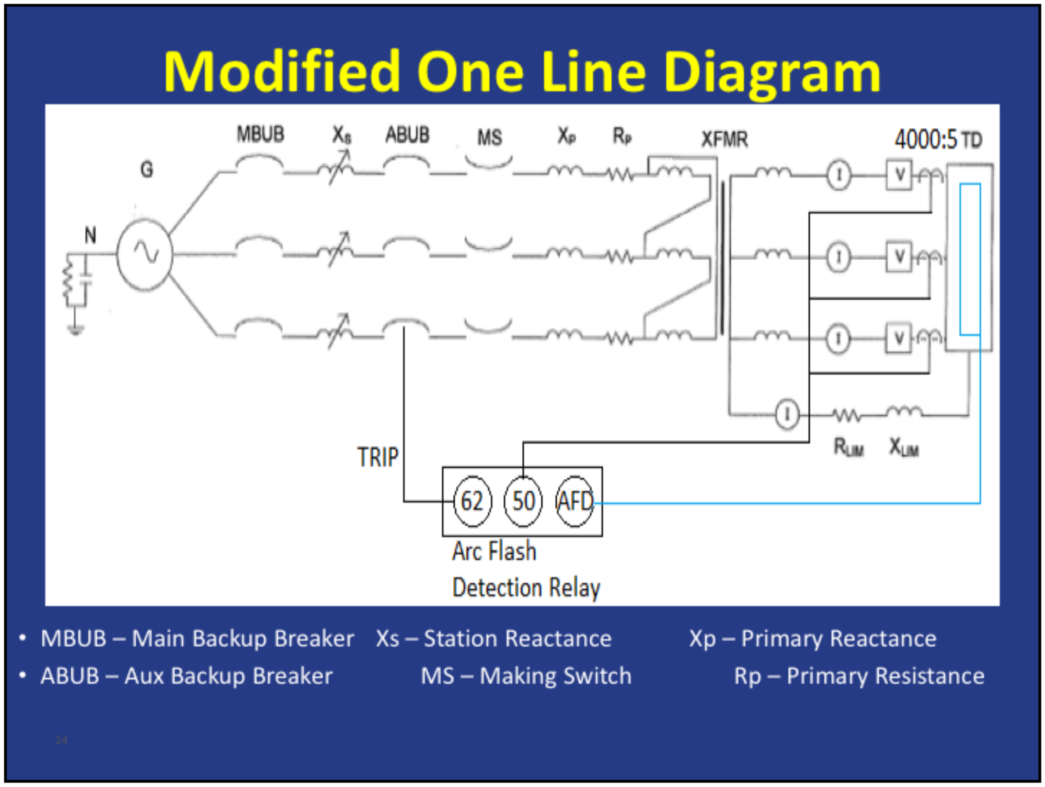
It was also critical that the upgrades can be done from side access, as many LVMCC are mounted against the wall.

Because many petrochem facilities utilize HRG grounding and well as solidly grounded, we had to verify the upgrades worked on both systems.

The #10 fine-strand bare SIS was installed by wrapping it through and around the stab assembly, creating a direct short circuit at the riser bus. This allowed the test plan to evaluate the arc flash relay application performance.

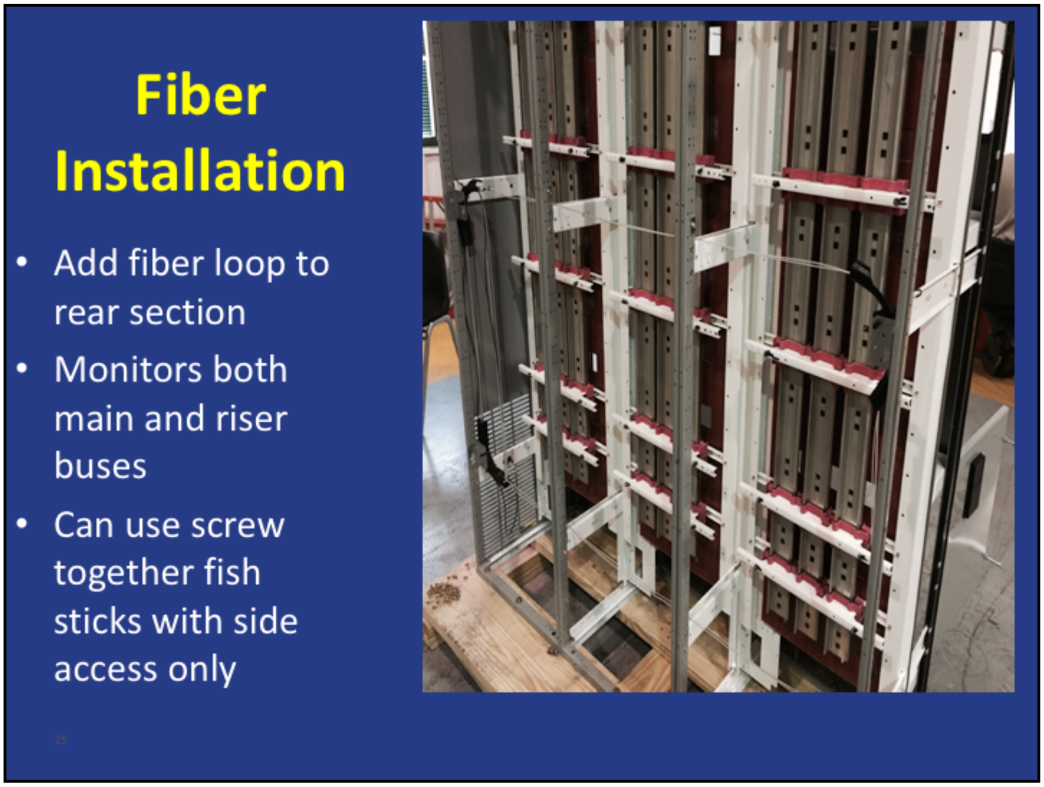


By adding the fiber optic sensors in the rear compartment, we were able to sense any light emitted by an arcing fault. By adding an Arc Flash Detection Relay (AFDR), current transformers on the feeder conductors, and a shunt trip device on the feeder breaker, we were able to create a separate static monitoring system independent of the existing time current coordination settings, yet trip extremely fast when both light and current are detected.

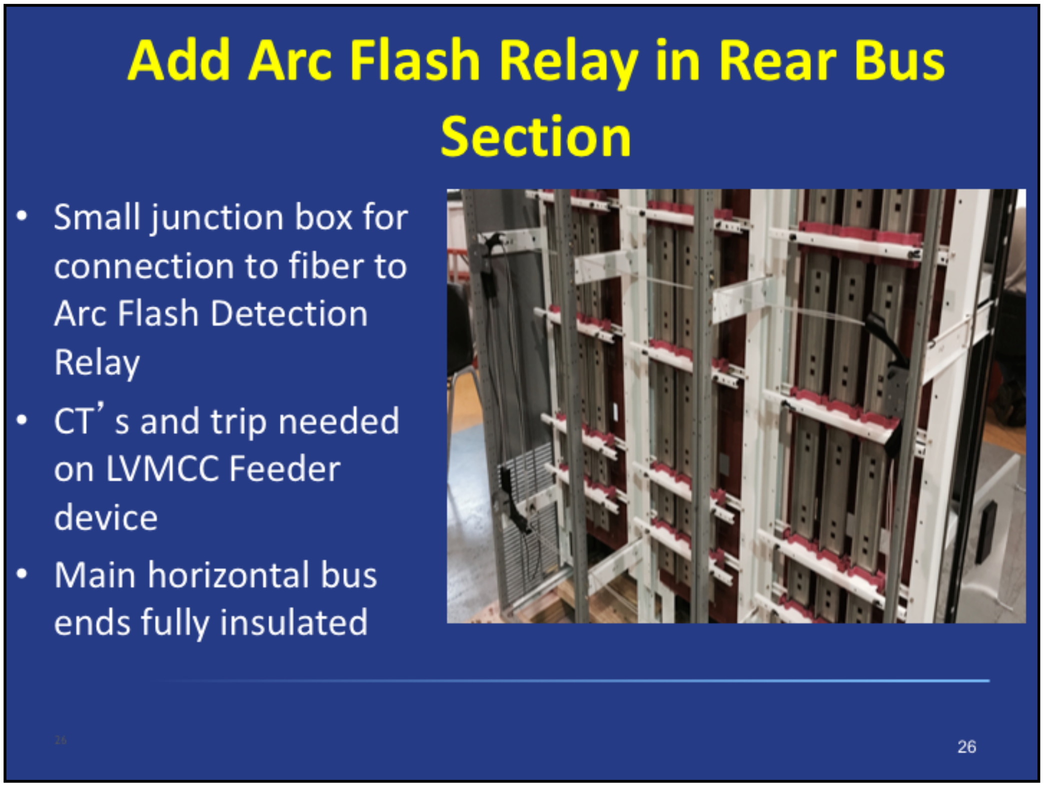


The testing scheme remained the same except for the addition of the AFDR, the CT's, and the trip circuit to the Auxiliary Backup Breaker. The ABUB was used so the MBUB could clear any potential re-strike. All arc faults in the bus section of the LVMCC emitted enough light to provide a maximum light magnitude in both relays. In fact, even when the light detecting fiber loops were not replaced and allowed to be coated with smoke residue from the previous trials, the light from the arc fault was still enough to provide a maximum light magnitude reading on both relays. The light magnitude recorded never approached the minimum pickup settings of the relays for a fault initiated in the bucket, effectively proving the bucket modification performance.

The 62 function was added to latch the light signal due to the extremely short duration to make sure the relay would trip if the current signal was present. The delay time was set at .03.

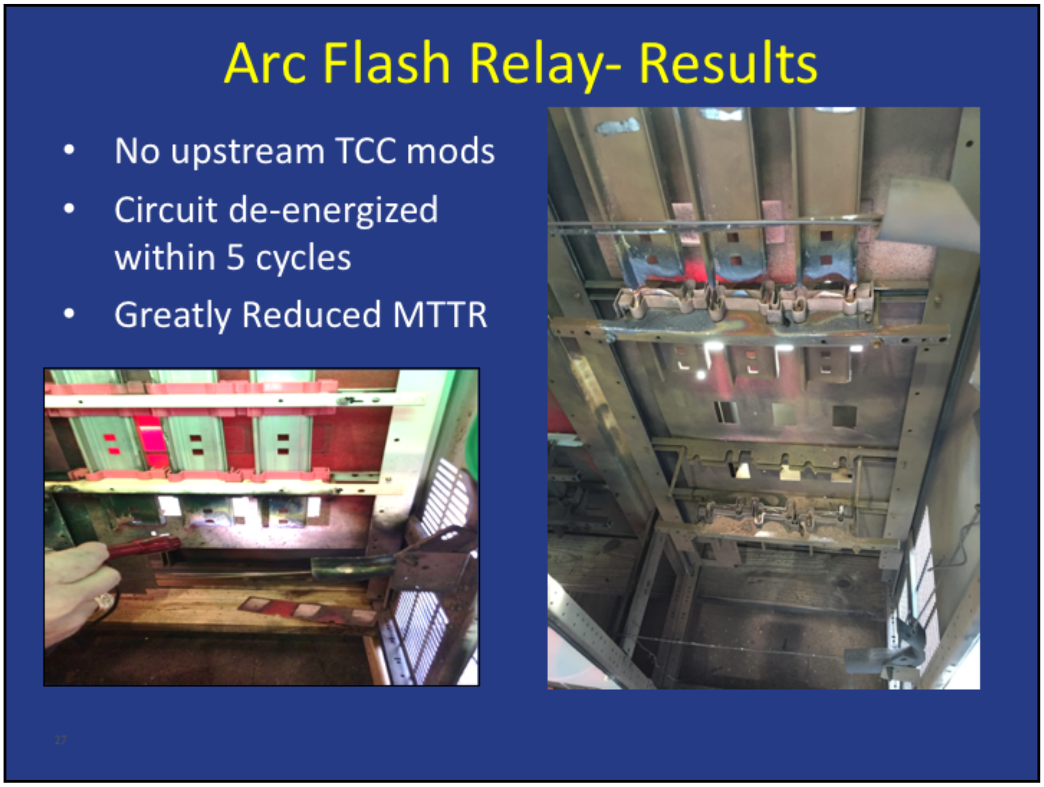


The fiber loop was installed in the middle of the rear compartment above and below structure braces. To avoid crimping or breaking the fiber loop, common PEX bend supports were installed where bends were made in the loop. Due to the available space, the use of screw together fish sticks can reach from end to end of large lineups by using the brackets for support. This allows side access to install the fiber loop.



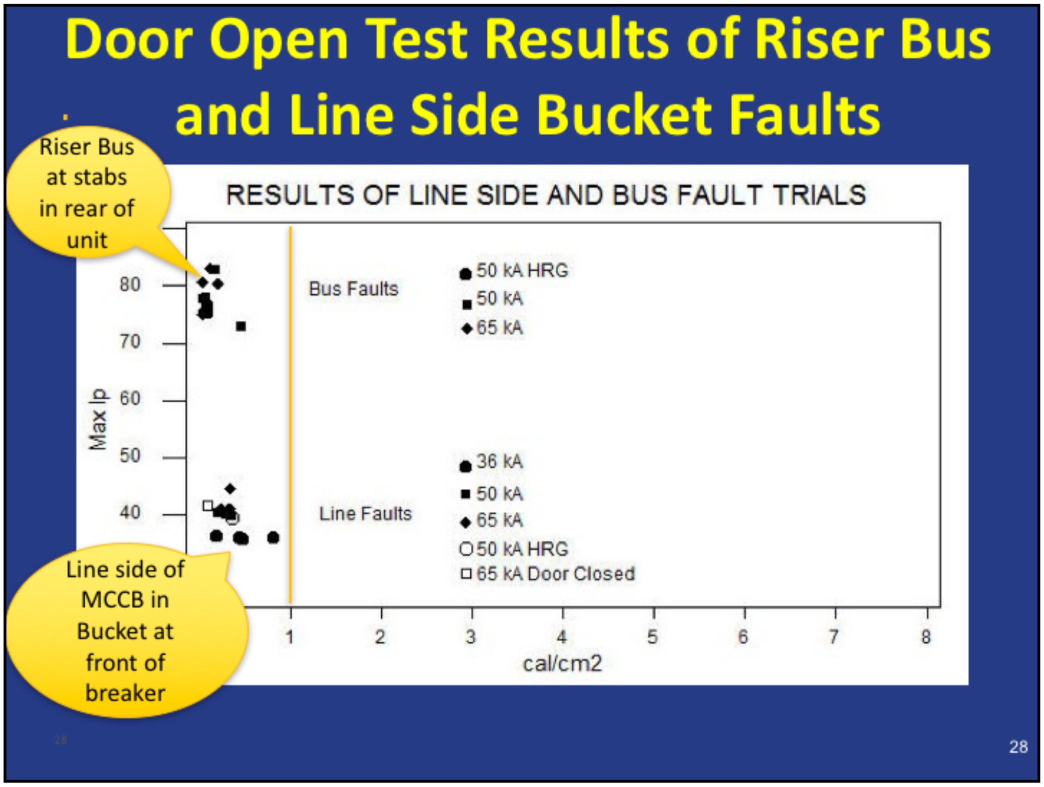
To connect the fiber to the AFDR, a transition from bare fiber to jacketed fiber is required. This is accomplished through adding a small junction box in a wireway, on top of the LVMCC, or other suitable location. A conduit with the jacketed fiber is routed to the AFDR panel.

Insulating the ends of the main horizontal bus is required as the faults witnessed typically flow away from the source and can root to the adjacent metal cover or support. Manufacturers do not typically install insulation on the ends of the LVMCC bus, as it is assumed additional structures could be added. Adding insulation to the bus ends will not allow a bus fault to engage the metal structure. It is worth noting that some manufacturers actually add a small extension to their new arc flash LVMCC offerings to keep this phenomenon from occuring.



These photos are the actual riser buses after faults. The photo on the right shows a rear compartment with the riser bus after three trials. The area that appears blue towards the top of the photo is indicative of the copper vaporization under fault conditions after the AFDR modifications were done. Test preformed in previous trials before the modifications were developed typically vaporized 9-16 inches of riser bus. After developing and installing the AFDR modifications, this was the typical result – the riser bus didn't completely burn through, the left hand side actually had to be cut with a cut-off wheel and copper vaporization was limited to less than two inches as indicated in the photo. This greatly reduces the area of contamination after a fault, reducing the MTTR. During the trials, we could remove the access panels, cut the riser bus, disconnect the source splice plates, megger the bus (typically 11MOhms) , install the next test device and attach the access panels in less than one hour. We did have rear access to do this, but the point is that in a critical situation the time is greatly reduced. In a real world setting you could say getting back online in days instead of weeks.

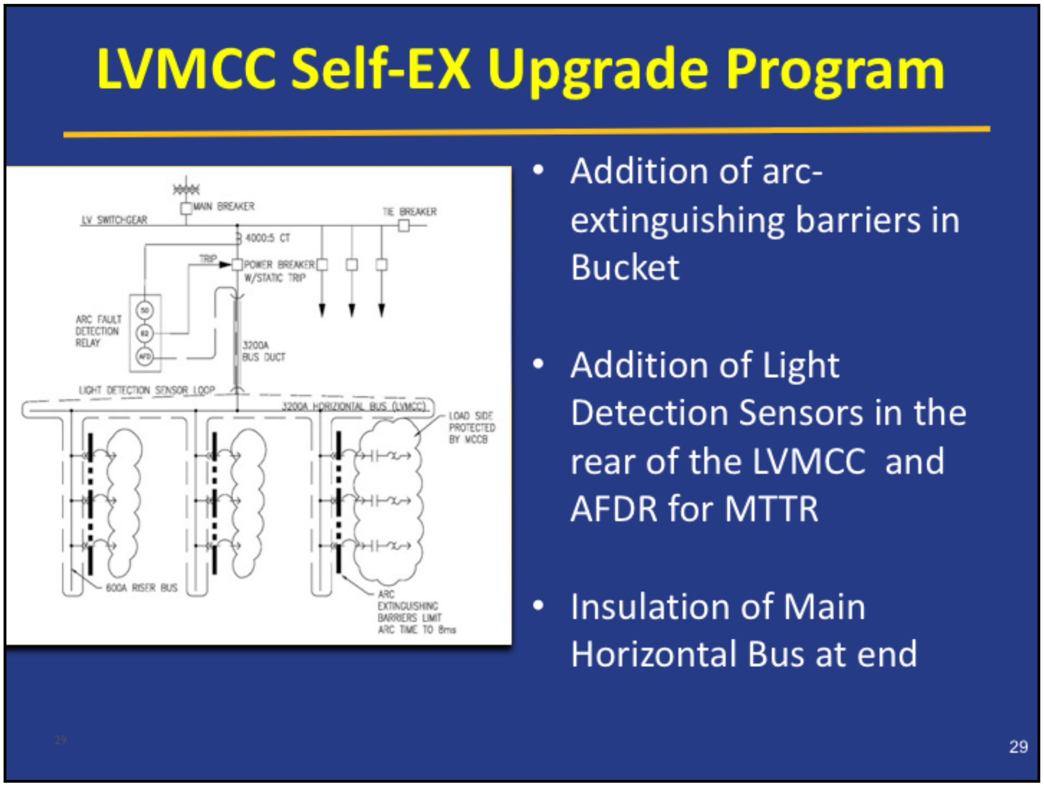
The photo on the left is indicative of the discussion on the previous slide, where a fault in section two resulted in indication of the arc rooting at the last support in section three – the most distant point in the bus structure from the source. While not catastrophic in nature, it should be noted this phenomena exists when doing MTTR repairs as there could be damage in structures distant from the faulted section.



This chart is the summary the calorimeter readings for all tests. The Y axis is the Ip values as the tests did not complete three cycles to calculate rms current, therefore Ip values were used. The X axis is the observed average calorimeter readings. Line faults are the short circuits created on the line side of the circuit breaker as shown in Slide 19. as you can see, the available fault current or grounding had little impact on the actual cal/cm_2 values. The 65kA Door Closed test was an added trial where we could evaluate the open door with modifications versus the typical test with the door closed. As you can see, the values are very similar, proving the effectiveness of the modifications. Also note as stated previously, none of the bucket faults caused the AFDR to operate – they were completely self extinguishing, isolating the failure to that particular bucket without interrupting service to the LVMCC.

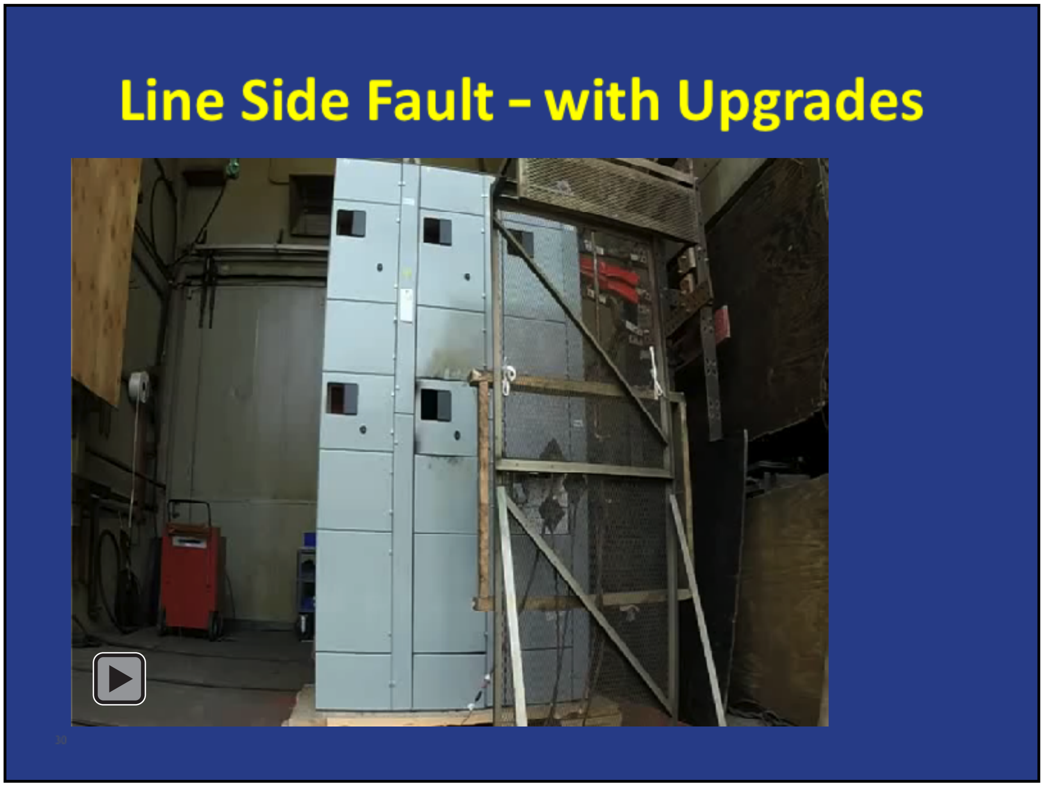
Riser Bus faults were initiated as shown on Slide 23 and did involve AFDR operation. All trials resulted in total light saturation of the AFDR light sensing circuit, regardless of position within the structure of the fault. There were 3 trials per each kA rating. As indicated, the grounding system had little impact on cal/cm_2 output. It should be noted that in the bus fault trials, the fault energy has space in the rear that allows the gases to expand without expulsion through the front of the LVMCC, which helps reduce the cal/cm_2 measured in front of the LVMCC.

In summary, the modifications WORK.



Another representation of the installed modifications and AFDR. The system only allows the AFDR to operate in the presence of both current and light – a true indication of equipment failure which would require service interruption. It was also proven that a fault within the bucket stays within the bucket and will not cause nuisance and dangerous interruption to critical plant processes by propagation to the rear compartment.

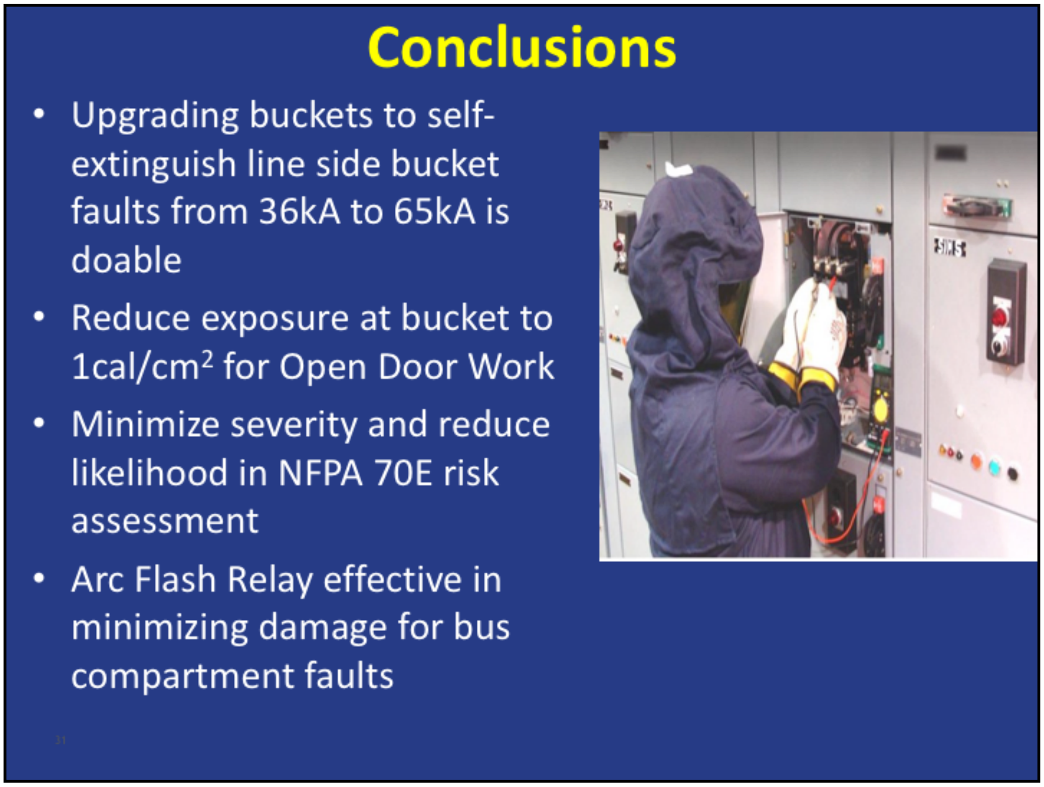
Of note, it is also possible to add a second channel to the fiber optic sensor and place the fiber within non-segregated bus duct that would indicate a failure within the bus duct, lowering the MTTR to repair.



This is the combined result of the modifications in a Line Side fault. This is a 65kA fault, duration 9ms , the average calorimeter reading was .32 $cal/cm_{2.}$

If you will refer back to Slide 21, the bare SIS and the 8/32 hardware vaporize, which is indicated by the sparks seen around 01:59 of the video.

An electrician in proper HRC2 PPE would survive this type of fault with little injury (besides needing a new pair of underwear)



The program was a success and we were able to meet our desired goals. Considering the installed base of LVMCC in the field that is older than 5 years, this program will offer owners a way to enhance their asset management plan while increasing the level of safety for their employees with minimum impact to their present safety procedures.

Please note that these modifications do not cover all LVMCC maintenance activities, such as removing and stabbing buckets. Fully rated PPE to the present arc flash values is required for these activities.

On buckets where the modifications are preformed, a supplemental label is affixed that notes that open door troubleshooting is allowed with 8 calorie HRC2 PPE and appropriate accessories..

The goal is to get people out of heavy, cumbersome PPE into their standard electrical PPE with the knowledge the equipment will not generate a deadly level of arc flash energy in the event of a fault.

THE END