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# Design Strategies for Arc Flash Hazard Mitigation in Metal-Enclosed Power Capacitor Banks and Harmonic Filter Banks

This technical note provides background information on arc flash hazard mitigation as it applies to metal-enclosed power capacitor banks and harmonic filter banks and what hazard mitigation features and options are available from NEPSI when applying, specifying, and purchasing this equipment.

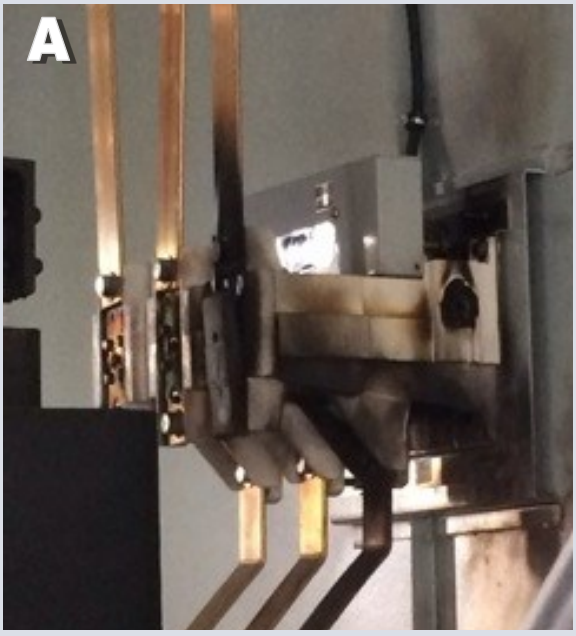
## Background

While safety and equipment standards to help mitigate injuries and damages caused by arc faults have been evolving for switchgear since the late 1990s, tens of thousands of accidents still occur each year involving a wide range of electrical equipment. NEPSI is taking a proactive approach to manufacturing safer equipment, by applying tried and tested switchgear arc flash mitigation methods to their medium voltage metal-enclosed capacitor banks and harmonic filter banks, reducing their arc flash hazard and improving their safety.

Arc flash hazard mitigation is the process of minimizing the level and exposure to an arc flash event or reducing the probability that an arc flash event will occur at all. There is no one-single-solution to the arc flash phenomenon and the risk can never be eliminated completely. However, if multiple strategies are employed, the damages and safety concerns associated with arc flash hazard can be significantly diminished.

Even though metal-enclosed capacitor bank application, relative proximity to load, maintenance requirements, electrical standards, and degree of hands-on worker contact with the equipment are different from those of switchgear, the fundamentals of the mitigation strategies commonly applied to switchgear can also be applied in design and application of capacitor banks.

When purchasing and applying metal-enclosed capacitor banks it is important to weigh the cost of arc flash





Similar to switchgear, metal enclosed capacitor banks and harmonic filter banks can experience arc flash faults from component failure (picture A showing a vacuum contactor failure), improper equipment operation through human error, lack of maintenance, etc. These faults may result in significant heat and pressure build up (as evidenced in picture B showing warped doors) within the enclosure and represent an arc flash hazard to workers near the equipment.

mitigation against the risk and cost of the hazard. NEPSI encourages the use of multiple mitigation strategies, building in additional protections and redundancy to break the chain of events that often leads to failure.

To this end, NEPSI offers multiple equipment features, strategies and options to reduce equipment arc flash hazard. The following sections and tables describes three broad strategies employed by NEPSI for arc flash hazard mitigation: reducing arc flash energy associated with an arc flash event, reducing the exposure during an event, and reducing the probability that an arc flash event will occur.

## Reducing Arc Flash Energy

The incident energy associated with an arc flash event is directly related to the current that flows during the arcing fault and the time that current is allowed to flow. Employing mitigation strategies that reduce either of these two parameters may lessen arc flash hazards and equipment damage (Table 1).

Using current limiting fuses is a well-known method for fast clearing of high fault currents and reducing through-fault current. These fuses are standard in all of NEPSI's metal-enclosed capacitor banks, installed on every capacitor in NEPSI's equipment. These fuses are able to reduce and extinguish high current arcing faults (no matter where they are in the capacitor bank) in as little

**Table 1** – *Strategies That Reduce Arc Flash Energy*

| Strategy | Description / Comments | Effectiveness | Budget Cost Adder * | Standard NEPSI Option |
|---|---|---|---|---|
| **Current Limiting Fuses for protection of each capacitor** | Protects the capacitor from case rupture and protects against capacitor terminal faults. Limits the magnitude and duration of arcing faults to 4mS for high current faults. Can take as much as 60mS at 20X its rating and therefore is only a partially effective strategy. | ★★★ | Included as standard $0 | ✓ |
| **Main Incoming Current Limiting Fuses** | Installed in the main incoming compartment. Is limited to smaller banks with lower current ratings where fuses are available. Partially effective as noted above for capacitor fusing. | ★★★ | ~$4000 | |
| **ABB UFES System** | Ultra-Fast Earthing Switch – Removes arcing fault in approximately 4ms, resulting in significantly less equipment damage, increased worker safety, less equipment downtime. Can be considered an insurance policy for your equipment. | ★★★★★ | ~$25,000 | |
| **Maintenance Switch** | Enable instantaneous settings on capacitor bank feeder breakers (and stage breakers when present) to reduce trip times when workers are near the equipment. The switch also inhibits all stage switching to reduce probability of arc flash event from switch failure or switch restrike while workers are nearby. | ★★ | $300 + Field Programing of feeder relay by customer | |
| **Arc-Flash Detection Relays** | Fast tripping through use of arc-flash detection relay. Trip signals are sent in as little as 2mS resulting in significant reduction in energy levels when compared to conventional overcurrent relays. The total clearing time is hampered by breaker which can take on the order of 45 to 75mS to operate. | ★★ | ~$4000 | |
| **Bus Differential Relays** | Fast tripping – on order of 4mS. Also hampered by breaker operating time. | ★★ | ~$4000 | |

* Budget cost adders are based on typical capacitor banks and harmonic filter banks sold by NEPSI.

as 4mS. When bank ratings permit, the entire capacitor bank can be equipped with optional main incoming current limiting fuses.

Whereas current limiting fuses act to reduce the magnitude and time associated with high fault currents, they do not always function as well in the low current region of the fuse. For faults in this region, high speed protection provided by arc flash detection relays, bus differential relays, or maintenance switches enable "fast" protection while workers are in the vicinity of the capacitor bank are an effective mitigation strategy. These strategies can be effective for fast detection of arcing faults, but are hampered by circuit breaker clearing times, which are on the order of 40ms to 50ms.

ABB's Ultra Fast Earthing Switch (UFES) breaks the arc flash chain of events quickly to reduce the damage associated with longer circuit breaker clearing times. The UFES system's ultra-fast earthing switch in combination with an arc flash detection relay extinguishes arcing faults within 4mS (total time, from arc ignition to arc extinction). With such fast arc extinction times, equipment damage and the resulting downtime is minimized and operator safety is improved. It can be seen as an insurance policy for your capacitor bank.

## Reducing Exposure to Arc Flash Event

Table 2 provides strategies to reduce the exposure to an arc flash event. Most of these strategies involve physically moving workers away from the capacitor bank, or moving the capacitor bank away from workers, and is based on the knowledge that the arc blast dissipates at a rate which approximates the inverse-square

**Table** 2 – *Strategies That Reduce Exposure to an Arc Flash Event*

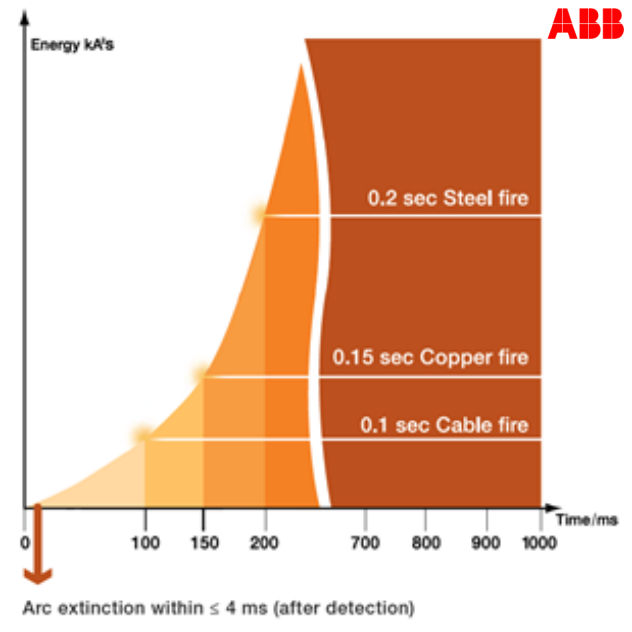
| Strategy | Description / Comments | Effectiveness | Budgetary Cost Adder * | Standard NEPSI Option |
|---|---|---|---|---|
| **Locating equipment outside in substation** | Arc blast dissipates at a rate which approximates the inverse-square rule for distance. Keeping workers away from the capacitor bank is a sure bet way to ensuring their safety. Save on E-house space and improve worker safety: install the outdoor rated equipment, outdoors. | ★★★★ | Included as standard $0 | ✓ |
| **Delayed Switching** | Programmed pushbuttons that delay closing of switches and breakers so operators have time to leave the area before capacitor switches/breakers operate. | ★★★ | Included as standard $0 | ✓ |
| **Remote Switching & Racking** | Remote switching and remote racking of breakers or the use of pendant stations allow for remote operation outside of the arc flash danger zone. | ★★★★ | ~$10,000 for Breaker, ~$5000 for disconnect switch | |
| **Remote Protection & Control System** | Remotely mounted control and protection systems allow for remote programming and viewing of capacitor bank protection and controls; keeping workers away from the equipment. | ★★★★ | ~$2000 | |
| **Arc Resistant Enclosure** | A reinforced, compartmentalized enclosure with arc vents flaps that contain and redirect arc blast away from workers. Type 1 and Type 2 designs are available from NEPSI. Key disadvantage is equipment damage is not minimized. Meets IEEE Std. C37.20.7 requirements. | ★★★ | ~$5000 | |

* Budget cost adders are based on typical capacitor banks and harmonic filter banks sold by NEPSI.

rule for distance. That is, if you double the distance from the arc, the energy level is divided by 4. Increase the distance by 4 times, and the energy level drops to 1/16$^{th}$, and so on. Distance from the fault is a key hazard mitigation strategy and quite appropriate for capacitor banks bank applications. Unlike switchgear, capacitor banks require very little hands-on work and therefore can be placed in a more remote location and virtually forgotten. Putting the capacitor bank outside in the switchyard, away from workers, and remotely mounting the control and protection system away from the capacitor bank is a sure bet way to improving worker safety.

In addition to moving the capacitor bank away from workers, the potential for arc flash exposure can be reduced by designing and constructing the capacitor bank enclosure in a manner similar to arc-resistant switchgear as set forth in IEEE Standard C37.20.7-2007, *IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38kV for Internal Arcing Faults*. This helps to ensure worker safety by containing and redirecting (away from workers) the effects of an arcing fault within the enclosure. Using the same rating system as provided in the standard, NEPSI's metal-enclosed capacitor banks can be built to provide protection from internal arcing faults to workers standing in front of the enclosure (Type 1), or to provide safety anywhere around the perimeter while the bank is in normal operation (Type 2).

The arc resistant enclosure helps protect workers around the equipment, but does not reduce the intensity or duration of the internal arcing fault. It contains the "blast" and redirects it away from works, but the internal damage can be significant, requiring re-work or replacement before it can be put back into service. For this reason, options that reduce arc-flash damage, such as the ABB UFES system and those that keep distance between the workers and the equipment are more favorable choices for arc flash hazard mitigation.




ABB's UFES system nearly eliminates arc flash hazard and equipment damage by extinguishing arcing faults in less than 4 ms (after detection).

## Reducing Probability of an Arc Flash Event

Preventing an arc flash event from occurring in the first instance is the best and only way to completely eliminate arc flash hazards. Although not theoretically possible, NEPSI strives to do just that.

Through our ISO9001:2008 quality system, NEPSI collects and logs all customer complaints, component failures, and equipment failures. This information is used to develop corrective action and preventative action plans (CAPA) for each and every complaint and failure, improving the reliability and quality of our product, customer satisfaction, and an overall reduction in arc flash events.

Our quality system has identified arc flash events are often related to component failures (i.e. switches, reactors, fuses, etc.), the use of outdated design practices, poor installation and commissioning, and poor maintenance practices. Table 3 lists items that NEPSI has identified as ways to reduce the probability of an arc

**Table** 3 – *Strategies that Reduce the Probability of an Arc Flash Event*

| Strategy | Description / Comments | Effectiveness | Budgetary Cost Adder * | Standard NEPSI Option |
|---|---|---|---|---|
| **Key Interlocks** | Key interlocks dictate sequence of operation and control entry into electrical equipment, reducing likelihood of human error. | ★★★ | Included as standard 0$ | ✓ |
| **Proper Choice of Capacitor Switching Device** | Proper choice of capacitor switching device reduces probability of pre-strike and re-strikes; both of which can cause flashover in capacitor banks. | ★★ | Included as standard 0$ | ✓ |
| **Fuse Failure Protection** | Protection against fuse failure due to fuse overload and fuse damage; a leading concern for protection against flash overs in metal-enclosed capacitor banks. See NEPSI technical note titled: An Alternative to Neutral Unbalance Protection Systems in Un-grounded Wye Capacitor Banks at nepsi.com. | ★★★ | Included as standard 0$ | ✓ |
| **Lightning Arresters** | Prevention of flash-over due to transient over-voltages. Note: The use of lightning arresters does not ensure a flashover from an over voltage event will not occur. | ★★ | Included as standard 0$ | ✓ |
| **Windows** | Windows for viewing ground switch, disconnect switch, blown fuse indicators, and condition of internal components of capacitor/harmonic filter bank help reduce likelihood of human error and allow for viewing condition of internal components. | ★★ | Included as standard 0$ | ✓ |
| **Condensation Control with Heaters** | Reduce tracking and damage from tracking by reducing condensation buildup. | ★★ | Included as standard 0$ | ✓ |
| **Rodent screens** | Prevents rodents from entering enclosure and causing faults. Standard for all openings in NEPSI equipment. | ★★ | Included as standard 0$ | ✓ |
| **Signage** | Prevent operational errors with bilingual warning, caution, and danger signs as well as operational protocol signs. | ★★ | Included as standard 0$ | ✓ |
| **Detailed installation, commissioning and maintenance instructions** | NEPSI knows that a properly installed, commissioned, and well maintained capacitor bank is key to preventing equipment failure. To this end, NEPSI has developed extensive bilingual manuals, online how-to videos, technical notes, online calculators all with the intention of reducing equipment failure. | ★★★★ | Included as standard 0$ | ✓ |
| **Glow Tubes** | "Glow Tubes" – medium voltage indicators manufactured by Voltage Vision is one sure way to answer the question: *Is there voltage*? Install on terminals of capacitor bank to prevent inadvertent contact. | ★★★★ | ~$600 | |
| **Split-wye current detection for blown fuse detection systems** | NEPSI always recommends split-wye neutral current detection as opposed to neutral voltage detection as NEPSI has seen an increase in flash overs due to switch/breaker restrike when a PT is used in the neutral of the capacitor bank (stay away from neutral PT's). | ★★★ | Lower Cost Alternative to PT | |
| **Insulated Bus Bars** | Reduce probability of flash over by insulating main bus and bus joints. | ★★★ | ~$2400 | |

**Table 3 (continued)** – *Strategies that Reduce the Probability of an Arc Flash Event*

| Strategy | Description / Comments | Effectiveness | Budgetary Cost Adder * | Standard NEPSI Option |
|---|---|---|---|---|
| **Increasing Component Ratings** | Increasing component ratings increase their margin and come at a fraction of the cost of the equipment. Consider increasing voltage rating of capacitor, current rating of filter reactors, voltage/current rating of capacitor switching device. | ★★★ | Varies with equipment rating (low) | |
| **Removable air filters while in operation** | Provisions that allow for the removal and replacement/cleaning of air filters when in operation, reduces the likelihood of failure due to poor ventilation. | ★★ | Included as standard 0$ | ✓ |
| **Increasing BIL Level** | Increasing BIL level by one step is one simple way to reduce the probability of a flashover. | ★★ | ~$1000 | |
| **Protection that detect imminent faults** | Thermal sensing relays, overload relays, harmonic voltage and harmonic current sensing relays and others not mentioned can all serve to detect an imminent fault before it occurs. | ★★ | Varies with equipment | |
| **Infrared Inspection Port** | Allows for infrared inspections without having to remove panels or open doors. Provides early detection of developing faults. | ★★★ | ~600 per port | |
| **Ultrasound Inspection Port** | Allows for consistent ultrasound inspection without having to remove panels or open doors. Provides early detection of developing faults. | ★★★ | $400 per port | |
| **Smoke Detectors** | Install smoke detectors to detect impending faults. | ★★★ | ~$300 | |
| **Partial Discharge Monitoring** | Detect impending faults through online or offline partial discharge monitoring | ★★★ | ~ $ Varies | |

* Budget cost adders are based on typical capacitor banks and harmonic filter banks sold by NEPSI.

flash events.

One of the more notable items identified by NEPSI includes the reduction in flash overs due to current limiting fuse failure with the use of SIBA's blown fuse detection system; a protection philosophy pioneered by NEPSI and now a de facto standard amongst most metal-enclosed capacitor bank suppliers.

By way of another example, we have reduced the probability of flash overs due to switch/breaker restrikes by replacing the voltage transformer in the neutral of our capacitor banks with a current transformer; a simple more cost effective form of protection that also decreases the likelihood of flashovers from over-voltages.

Reduction in failures can also be accomplished through simple cost effective design changes, such as increasing equipment insulation level by one step, increasing the voltage rating of the capacitor, or simply insulating the over-head bus.

Then there is maintenance; NEPSI has further Improved the maintainability of the equipment and the early detection of faults through the use of IR ports, smoke detectors, ultrasound inspection ports, partial discharge monitoring, and the ability to change filters when the equipment is live.

## Conclusion

In order to be most effective, the consulting engineer/designer needs to conceptualize multiple mitigation strategies at the beginning of the design stage, not after the purchase. Properly specified gear (including built-in redundancies), purchasing from a reputable and experienced manufacturer, proper implementation and commissioning, and ongoing maintenance are key to reducing the arc flash hazard of metal-enclosed capacitor banks and harmonic filter banks.

Mitigation techniques range from very simple to complex and costly, however a thoughtful combination of these techniques can have a significant impact in reducing the risks associated with complex electric power equipment. By offering both standard and optional strategies, NEPSI strives to create the safest and most reliable equipment available, where failure of any one link in the arc flash chain of events can be mitigated to reduce the likelihood of total equipment failure and worker injury.