ADVANCED FUSION SYSTEMS

Ultra Fast Surge Arrester
UFSA EMProve®

December 4, 2024

Revision 7

Ultra Fast Surge Arrester EMProve® - Description

- E1 Simple Definition: E1 is a brief but intense electromagnetic field that induces high voltages and current transients when coupled into electrical conductors. This coupling mechanism is the same way electromagnetic transients from indirect lightning couple into to cables. E1 causes most of its damage by causing electrical breakdown due to the high voltages exceeding equipment ratings.
- The EMProve® is a protection device designed to shunt E1 induced current pulses to ground, while limiting the residual transient voltage to levels below the assets BIL rating. Without this protection the equipment will experience high voltage transient levels exceeding hundreds of kilovolts.
  - This operation is similar to LSAs shunting lighting currents to ground
  - Lightning transients can exceed Megvolt levels with rise times around 8 uS
  - EMP transients can exceed 300 kV with rise times around 20 nS
- The UFSA EMProve® device will protect equipment from induced E1 current pulses induced from potential out of sight origins that could be 10's of miles away
- The UFSA EMProve® device will protect equipment from E1 current pulses induced from a HEMP event provided the device is installed in compliance with the manufacturer guidelines. Installation inside of a Faraday type structure is an added consideration and may be necessary to increase asset preservation from radiated transients from a nuclear or high-altitude event.
- The 6 kV (4160 V) to 15 kV, 18 kV (under development) intermediate device spectrum was chosen as the first EMProve® market because this range is extremely common within industrial facilities and 15 kV particularly is very common to national grid connections

Medium Voltage One at a Time Protection - You Have to Start Somewhere

- High Value Assets (Transformers, Generators, Pumps, Motors, etd)
- Long Lead Time Components
- High Consequence Loss vs. Recovery Event:
  - Pipeline
  - Chemical
  - Refining
  - Nuclear
  - Tunnel
  - Railroad
  - Transit
  - Offshore Wind
  - Medical
  - Foundry

Point of USE and Supply Protection

- Building Points of Entry
- Generator (Prime/Backup)
- Transformer
- Data Center
- Motor
- Chiller/Evaporator
- Water/Waste Pump
- Tunnel Fan
- Tunnel Boring Machine
- Underground Facility
- Bulk Collection Bus Point
- Inverter Station

EMProve® – Basic Operation

- During normal power grid operations, the EMProve® has an extremely high impedance, thus drawing very low current, typically less than 20 uA at power frequency (60 Hz)
- In effect, under normal conditions, the EMProve® is an open circuit
- When the E1 voltage pulse is detected, the EMProve™ will activate within 6 nS and shunt more than 97 % of the current pulse to ground, then return to its high impedance state within a fraction of the power sine frequency, protecting the equipment.
- After the current surge, the EMProve® will then return its original high impedance state quickly, so upstream or downstream circuit protection devices won’t trip

EMProve® – General Outline

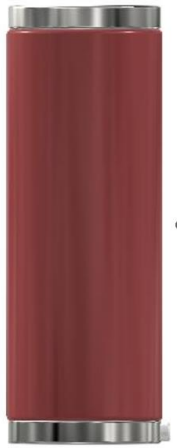


Fig 1 6 kV

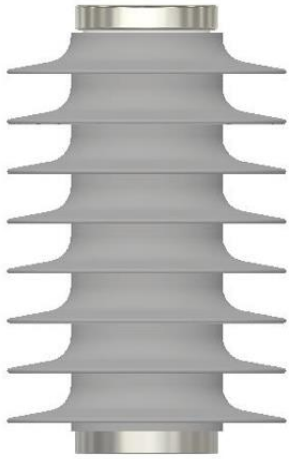


Fig 2 6 – 15 kV

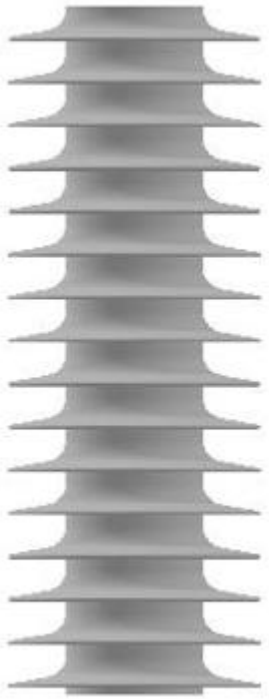


Fig 3 18 – 36 kV

Indoor EMProve™
Pollution degree from Very light to Light

Outdoor EMProve™
Pollution degree from Medium to Heavy

EMProve® – Specifications UFSAXXE1-x

- Intermediate class rated device
- 6 kV class device 10 kV device 15 kV device
- MCOV = 5.1 kV MCOV = 8.4 kV MCOV = 12.7 kV
- Bypass current rating = 2500 amps (tested in excess of 5000 amps)
- Housing BIL rating of 110 kV (tested to 130kV)

Ultra Fast Surge Arrester EMProve® - Dimensions

- The EMProve® is intended to be installed on the phase conductors and neutral within 1 m (3.28 feet) of the protected equipment
- EMProve® is 9 inches (228.9 mm) long, 3 inches (76.2 mm) diameter, approximate weight is 5.5 US pounds (2.49 kg) – indoor unit, 6.8 US pounds (2.86 kg) outdoor unit
- Top and bottom have 2 NEMA compliant threaded holes for electrical connections, allowing for bus bar mounting or for wire connections with proper bracing

EMProve® – Setup and Installation

- Identify equipment, points of entry, or junctions that need protection from EMP
- UFSA must be installed as close to the asset as possible, similar to typical lightning arrestor installations
- The EMProve® comes in two configurations, indoor and outdoor
- The indoor UFSA is suitable for installation in equipment housings and inside buildings where pollution degree levels are very light to light, where the outdoor EMProve™ is suitable for pollution degree of medium to heavy
- Outdoor EMProve® units may be used in indoor installations where space allows
- The EMProve® must not be used as a structural member for any other device or equipment
- Protection of a complete facility should include a full site study to offer an approach to protect against EMP

EMProve® – Third Party Test Results

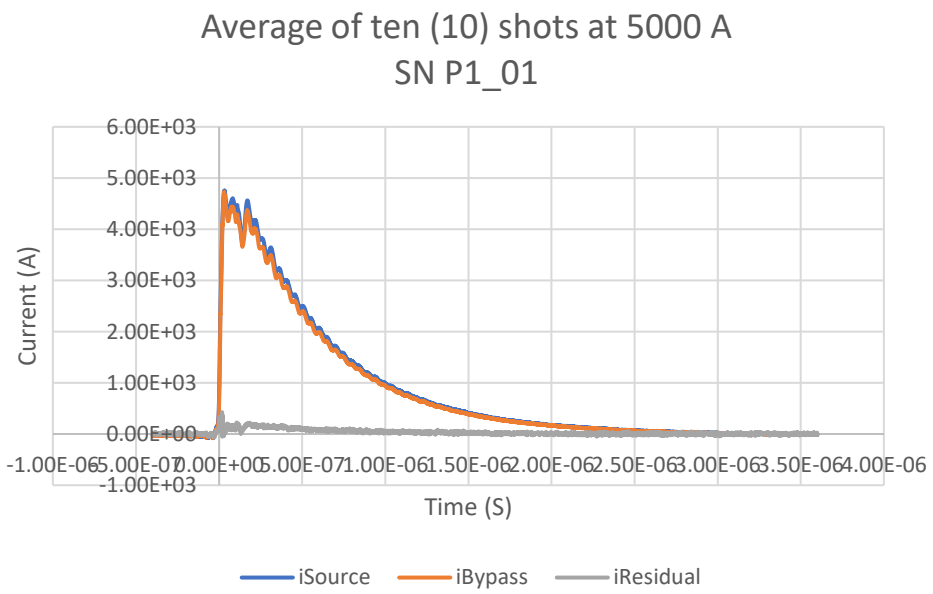
- Tested to MIL-STD-188-125 at the Boeing Little Mountain Test Facility
  - Unit shunted >97 % of the injected current 5 kA peak
- Partial Discharge Test tested to IEC60270 by Doble Engineering
  - Units passed with no PD activity detected with background level of 5 pC
- Lightning Short Circuit Current Tests on the UFSA Arrestors by Lightning Technologies, an NTS Company in Pittsfield, MA
  - Lightning tests were performed on test power line in the presence of a commercial LSA, a UFSA, and a transformer/load. Tests were performed with transients applied with different rise times to evaluate the relative responses on the interconnected parallel elements. Short circuit current rise times included approximately 100 µs, 10 µs, and 1 µs. Tests were performed with up to 5 kA applied to the Arrestors, depending on the generator circuit configurations. The protection circuits had a cut in voltage of around 25 – 30 kV, therefore, the test voltage charge was limited to 80 kV.
  - Finally, tests were performed to try to break the unit, with multiple discharges up to 30 kA (test system equipment limitation). There were no signs of degradation of the intended function as deduced from Megger tests before and after shots.
- Sandia/Idaho National Lab testing
  - Phase 1 - “Due no harm” phase 1 – Installed 10 kV rated device on coop community grid system to confirm no harm or issues to the grid. Product installed Feb 2022, still running with no issues after 1.5 years
  - Phase 2 – Inject normal and abnormal faults into INL dedicated test grid. 15 kV device operated as intended and no issues arose.
  - Phase 3 – Once pulser is available, inject E1 pulses into active grid with UFSA installed.

EMProve® – Third Party Test Results

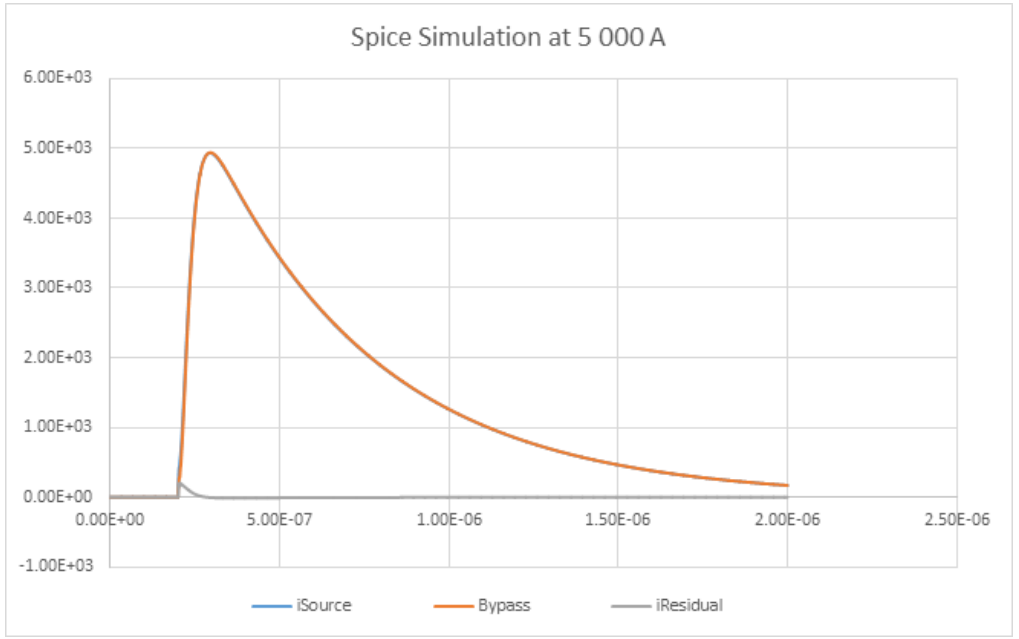
- BIL tested to IEEE C37.06 chopped wave by Neeltran, Inc.
  - Unit passed 130 kV – Insulated Body
- Accelerated Life Test (ALT) using Coffin-Manson model by New England Halt Labs

- The chamber temperature extremes are as low / high as –35°C and +150°C.
- Test Plan: -35C to 80C. 438 Cycles. Ramp Time 0.2C/min. Cycle Time 9.58 Hours.
- Test Goal: Achieve 10 Years to Wear out as per the graph below:

EMProve® – Bypass Current Results



Actual Test Data Collected at LMTF



Simulated Performance Data

EMProve® – Internal Test Results (UFSA15E1-x)

- MIL-STD-188-125 testing was also performed internally on many samples of the EMProve® with similar results to the Boeing test results
- Endurance / Robustness testing was performed in house prior to third party ALT testing, where the EMProve® unit under test was subjected to 8.66 kV_{RMS} (phase to ground of 13.8 kV) while being subjected to 3 kA surges (15 J per surge) from a Marx generator every 6 seconds:
  - Unit subjected to 400 E1 current surges greater than the Mil-188-125 standard

EMProve® – Future Development

- The 6kV, 10kV, and 15kV intermediate devices were chosen first to allow for quick adaptation in as many locations as possible
- Future plans are to expand the EMProve® family:
  - 18 kV model is under development and available in 2024 Q1
  - 36 and 72 kV will follow 18 kV development
- Collaboration with academia
- Offshore/Wind applications