SolidGround™

GIC & EMP Neutral Blocker

Power Grid protection against Solar Storms (**GMD**) and EMP **E3**

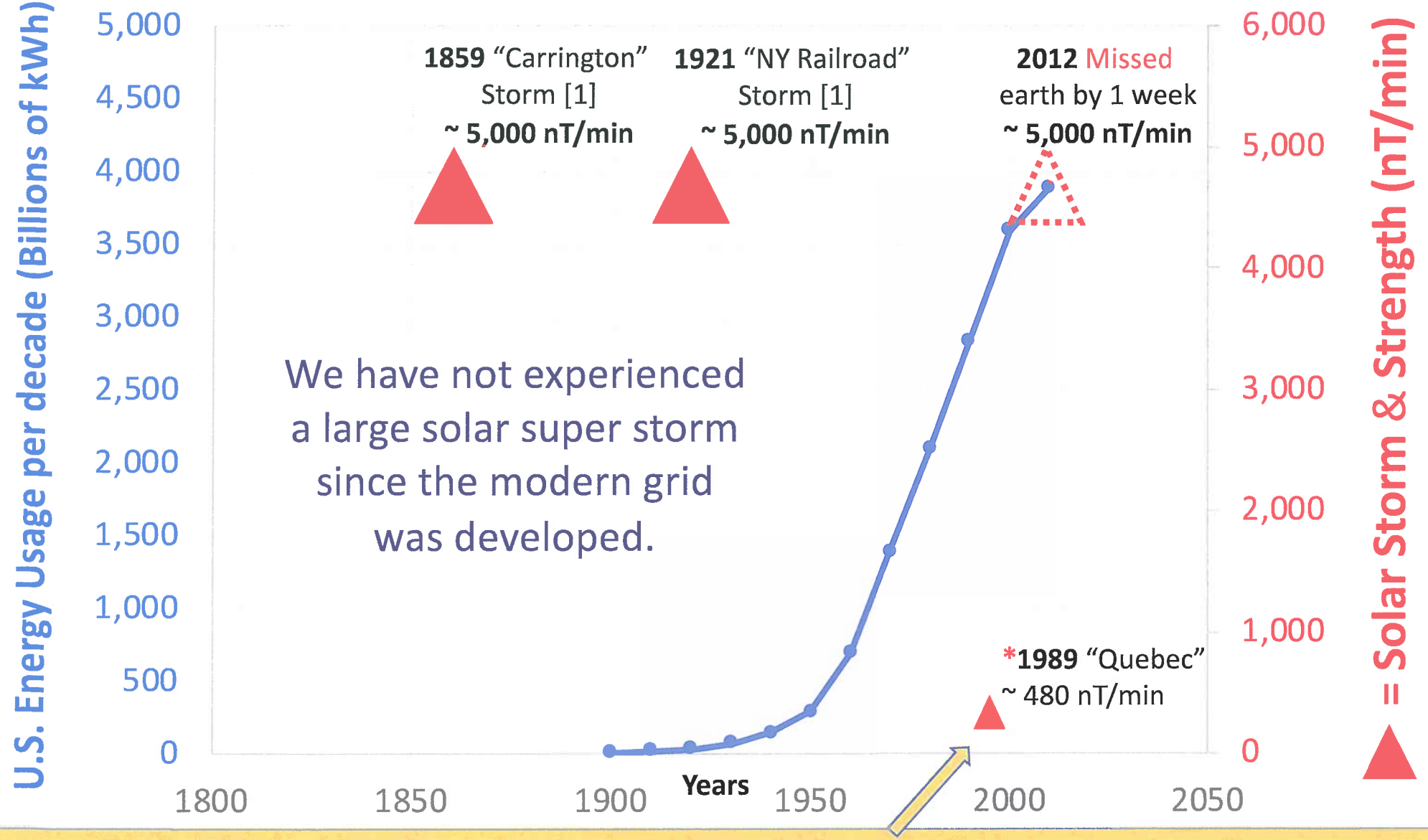
➢ ***Perfect record on the U.S. Grid for over 3 years operating 33 times***

✓ **SIMPLE CIRCUIT** ensures the transformer neutral is Grounded 100% of the time

- GMD model **Easy to upgrade** in the field at any time for **EMP E3** Protection – no wasted dollars
- Spark Gap Multi-Fault Capability
- Can operate in "Passive Mode"

Power and productivity for a better world™ ABB

U.S. Electrical Grid Development vs. Solar Storms



*1989 storm collapsed Quebec's grid costing ~ **$13.2 Billion** in economic loss (Lloyd's) **SolidGround™ would have prevented this** and is a complete solution to protect the U.S. grid from solar super storms (like 2012) which could have cost in the $trillions.

Not just a large Solar Storm issue

Common low-level Solar Storms produce **GIC** (DC Current) which invades the AC Power Grid at the High Voltage level generating **Harmonics** which travel into the distribution causing Customer Equipment Damage and Business Interruptions:

- **Several $Billion** in business losses ***each year*** in the United States (2000-2010) due to common low-level solar storms.
  - Caused by Induced Poor Quality Power
    i.e. **GIC related Harmonics**

AGU PUBLICATIONS

Space Weather

RESEARCH ARTICLE

Assessing the impact of space weather on the electric power grid based on insurance claims for industrial electrical equipment

C. J. Schrijver[1], R. Dobbins[2], W. Murtagh[3], and S. M. Petrinec[1]

[1]STAR Lab, Lockheed Martin Advanced Technology Center, Palo Alto, California, USA, [2]RAA Engineering Technical Strategy & Team, Zurich Insurance Corporation, Schaumburg, Illinois, USA, [3]Space Weather Prediction Center, NOAA, Boulder, Colorado, USA

Abstract Geomagnetically induced currents are known to induce disturbances in the electric power grid. Here we perform a statistical analysis of 11,242 insurance claims from 2000 through 2010 for equipment losses and related business interruptions in North American commercial organizations that are associated with damage to, or malfunction of, electrical and electronic equipment. We find that claim rates are elevated on days with elevated geomagnetic activity by approximately 20% for the top 5% and by about 10% for the top third of most active days ranked by daily maximum variability of the geomagnetic field. When focusing on the claims explicitly attributed to electrical surges (amounting to more than half the total sample), we find that the dependence of claim rates on geomagnetic activity mirrors that of major disturbances in the U.S. high-voltage electric power grid. The claim statistics thus reveal that large-scale geomagnetic variability couples into the low-voltage power distribution network and that related power-quality variations can cause malfunctions and failures in electrical and electronic devices that, in turn, lead to an estimated 500 claims per average year within North America. We discuss the possible magnitude of the full economic impact associated with quality variations in electrical power associated with space weather.

1. Introduction

Large explosions that expel hot, magnetized gases on the Sun can, should they eventually envelop Earth, effect severe disturbances in the geomagnetic field. These, in turn, cause geomagnetically induced currents (GICs) to run through the surface layers of the Earth and through conducting infrastructures in and on these, including the electrical power grids. The storm-related GICs run on a background of daily variations associated with solar (E)UV irradiation that itself is variable through its dependence on both quiescent and flaring processes.

The strongest GIC events are known to have impacted the power grid on occasion [see, e.g., *Kappenman et al.*, 1997; *Boteler et al.*, 1998; *Arakn Enmmez et al.*, 2002, *Kappenman*, 2005; *Wik et al.*, 2009]. Among the best known of such impacts is the 1989 Hydro-Québec blackout [e.g., *Boklúv*, 2002; *Béland and Small*, 2004]. Impacts are likely strongest at middle to high geomagnetic latitudes, but low-latitude regions also appear susceptible [*Gaunt*, 2013].

The potential for severe impacts on the high-voltage power grid and thereby on society that depends on it has been assessed in studies by government, academic, and insurance industry working groups [e.g., *Space Studies Board*, 2008; *FEMA and NOAA*, 2010; *Kappenman*, 2010; *Hoppgood*, 2011; *JASON*, 2011]. How costly such potential major grid failures would be remains to be determined, but impacts of many billions of dollars have been suggested [e.g., *Space Studies Board*, 2008; *JASON*, 2011].

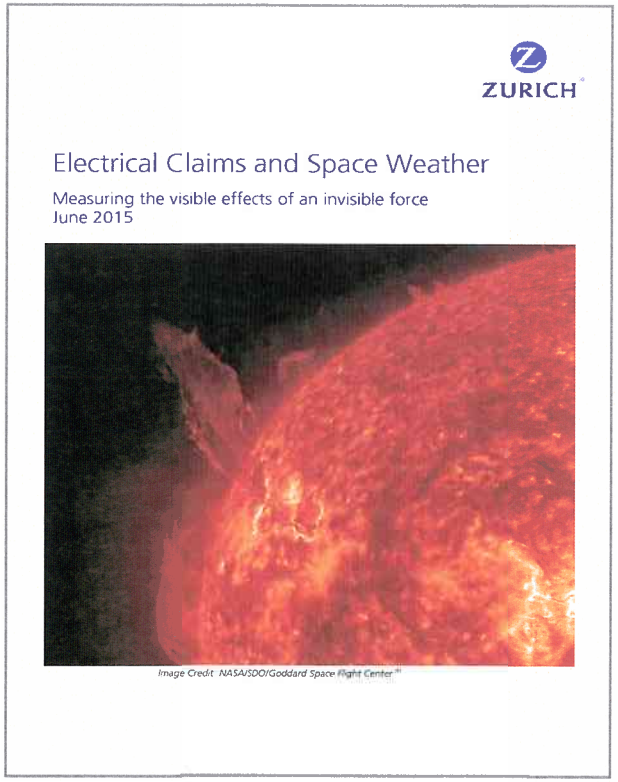
Noncatastrophic GIC effects on the high-voltage electrical grid percolate into financial consequences for the power market [*Forbes and St. Cyr*, 2004, 2008, 2010] leading to price variations on the bulk electrical power market on the order of a few percent [*Forbes and St. Cyr*, 2004].

Schrijver and Mitchell [2013] quantified the susceptibility of the U.S. high-voltage power grid to severe, yet not extreme, space storms, leading to power outages and power-quality variations related to voltage sags and frequency changes. They find, "with more than 3σ significance, that approximately 4% of the

SCHRIJVER ET AL. ©2014 The Author. 487

Electrical Claims and Space Weather: Zurich, June 2015

Insurance Study By Lockheed/Zurich/NOAA:
C. J. Schrijver, R. Dobbins, W. Murtagh, and S.M. Petrinec
Space Weather Journal, 2014



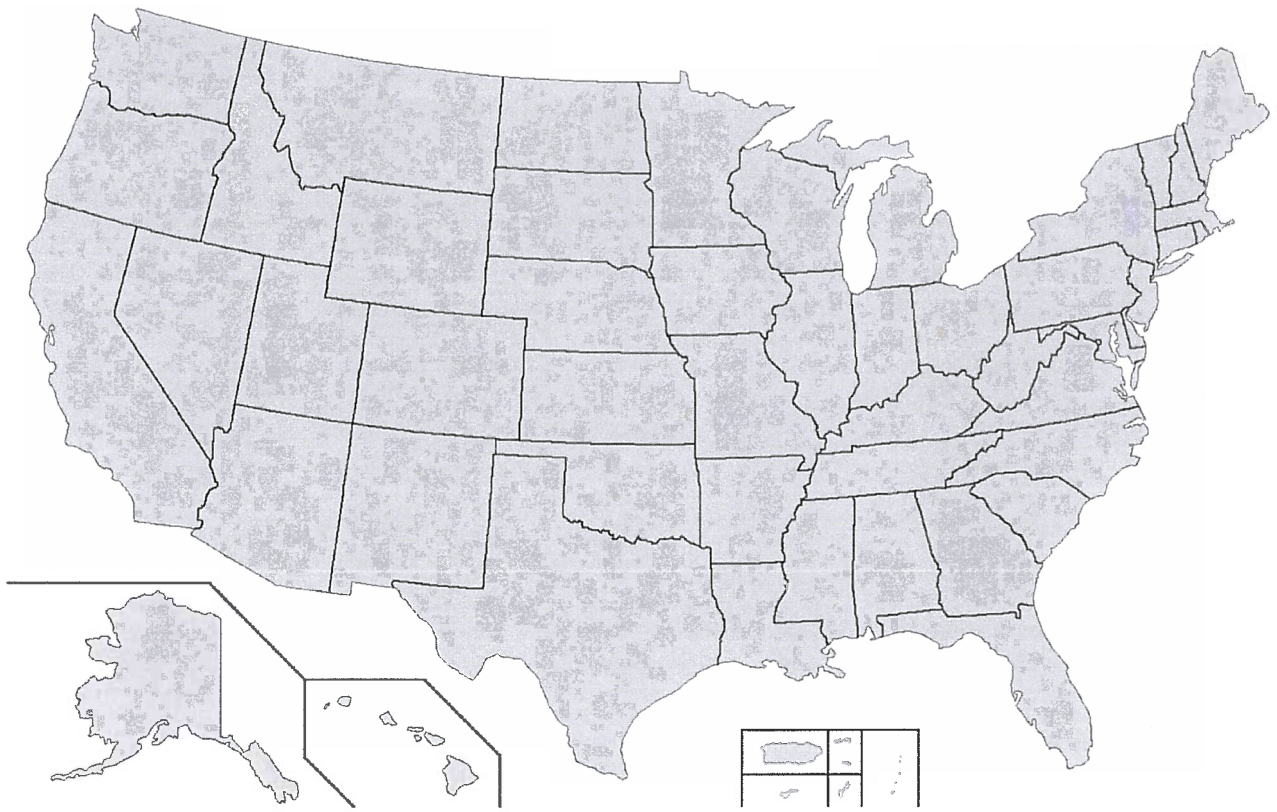
ZURICH

Electrical Claims and Space Weather

Measuring the visible effects of an invisible force
June 2015

Image Credit: NASA/SDO/Goddard Space Flight Center

"The overall fraction of all insurance claims statistically associated with the effects of geomagnetic activity is ≈ 4%."



"...we are potentially looking at an average impact on the order of $10 billion per year..."

"Assessing the impact of space weather on the electric power grid based on insurance claims for industrial electrical equipment", Lockheed/Zurich/NOAA , Space Weather Journal, 2014
"Electrical Claims and Space Weather", Zurich, 2015

Janney

Janney Report – January 18 - 2018

Grid Resiliency From Electromagnetic Threats; the Infrastructure Plan Provides an Opportunity for Substantial Investment

Billions of dollars from the new Tax Act now available to redeploy into power grid resiliency investments.

"Hardening will likely require a phased approach... focusing initially on protecting the largest, most important transformers..."

*"...the entire 5,000 [HV Transformers] could be outfitted with state-of-the-art, field tested and proven technology such as **SolidGround™** GIC/EMP neutral blockers..."*

How do small amounts of
GIC (DC current) on our **AC** power grid
cause $billions in losses to the
U.S. economy each year?

GIC induced

HARMONICS

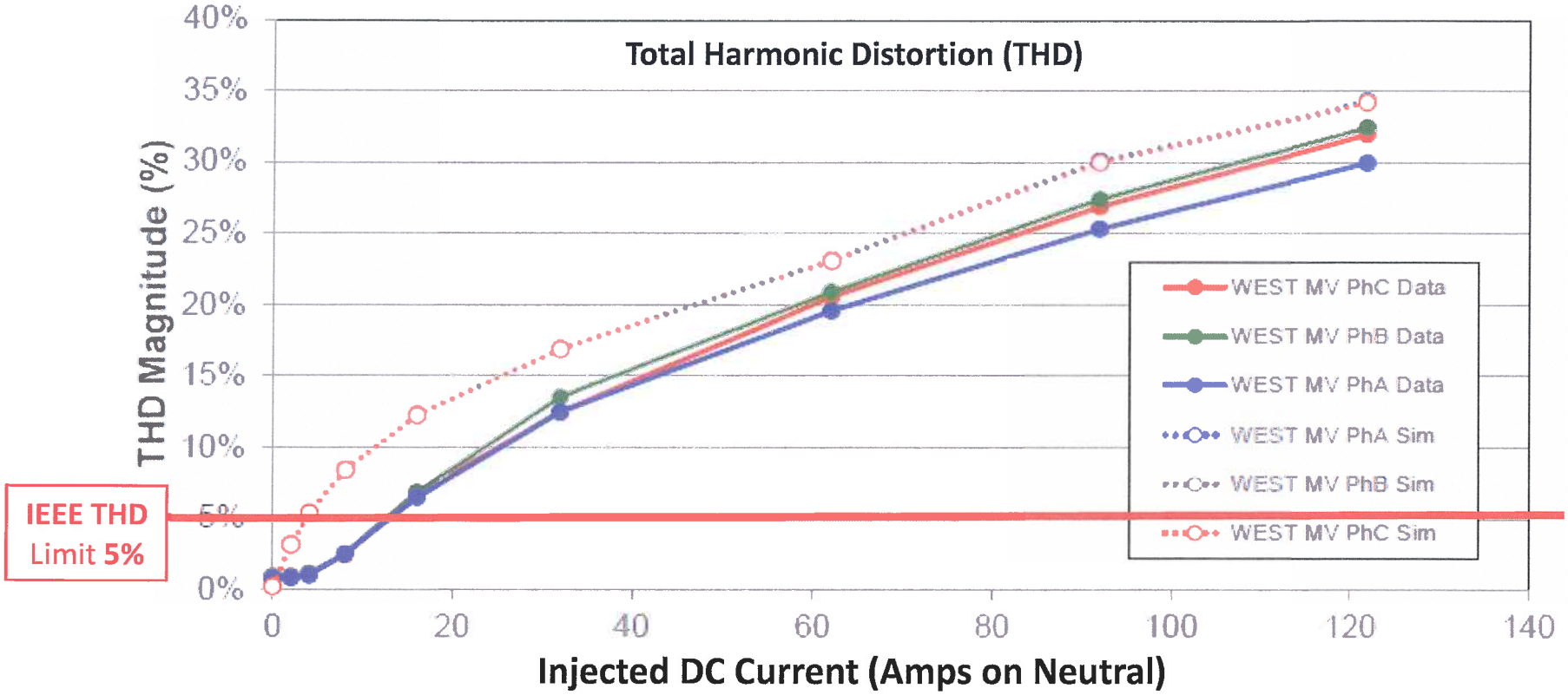
IEEE 519 – 2014 Total Harmonic Distortion

Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $< V \leq 69$ kV	3.0	5.0
69 kV $< V \leq 161$ kV	1.5	2.5
161 kV $< V$	1.0	1.5[a]

[a]High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

Secondary Harmonic Trends



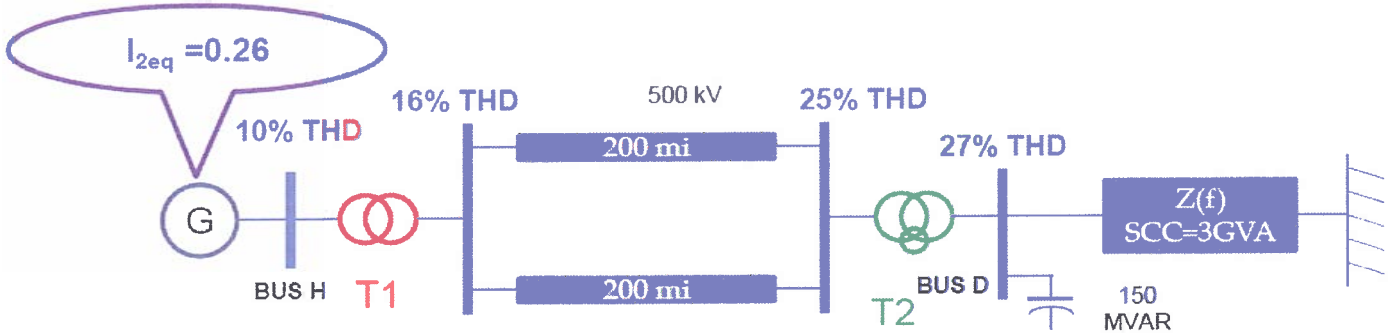
- At only 5 Amps DC per phase the IEEE 519 Std. of 5% Total Harmonic Distortion was exceeded. This data helps explain why small amounts of GIC (DC current) in our AC power grid cause major problems *each year*. As Total Harmonic Distortion increases, business interruptions increase as well as the risk of damage to customer equipment.
- **E3** can induce DC currents of hundreds to thousands of Amps per phase (EMP Commission)

*Graph above is from the U.S. Defense Threat Reduction Agency (DTRA) test results measured on the Idaho National Laboratories Grid in 2012.

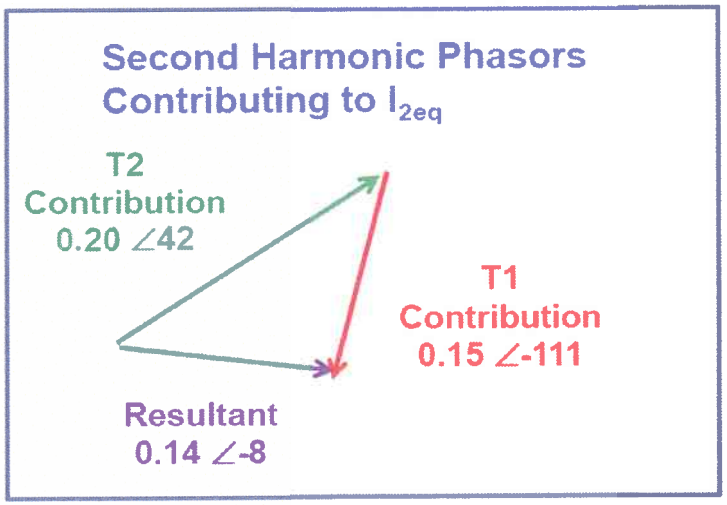
GIC (DC current) **invades the AC grid at the high voltage level** (longer lines/larger loop antenna, less resistance) and induces **Harmonics** which build as they travel into the lower voltage distribution network towards load.

***See example below how Total Harmonic Distortion (THD%) can increase**

Example Case With Iterative Solution



- Dominant contributor to generator I_{2eq} is a transformer 200 miles away!
- Results would have been 65% more severe if non-iterative harmonic analysis used

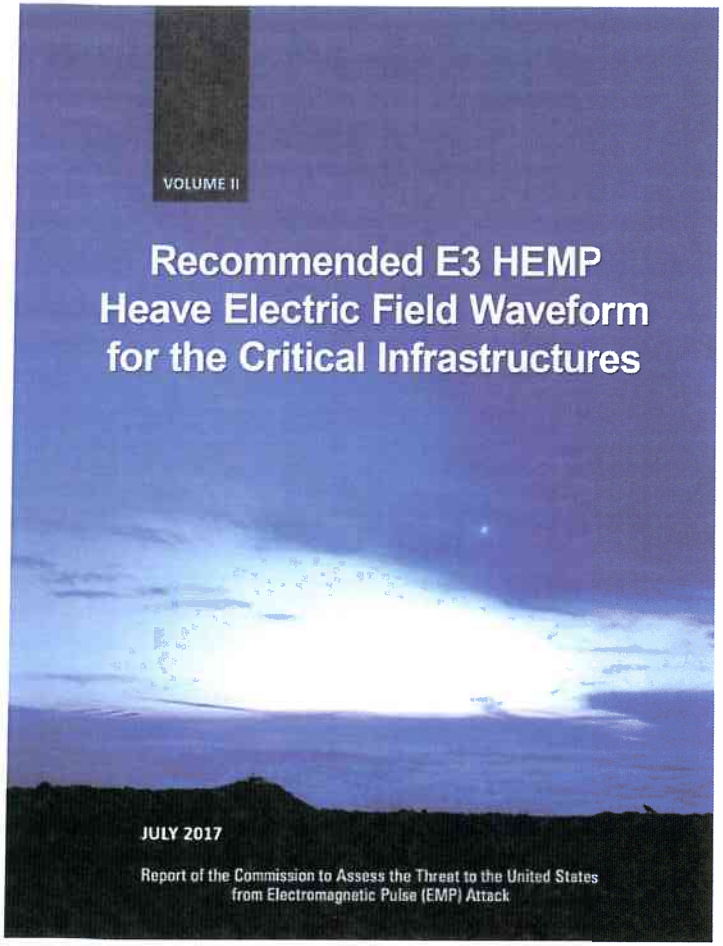


WESC

43

Source: "**GMD Impacts on Generators**", Reigh Walling, pes-psrc.org

April 2018: Declassified EMP **E3**B Field Strength - **85 V/km**



"A realistic unclassified peak level for **E3** HEMP would be **85 V/km**... **102 V/km** for locations nearer to the geomagnetic equator..." (p. ix, 1)

"...**E3** HEMP measurements are evaluated from two high-altitude nuclear tests performed by the Soviet Union in 1962." (p. 1)

"This report does **not** [emphasis added] claim that the values suggested here are absolute worst-case field levels..." (p. 4)

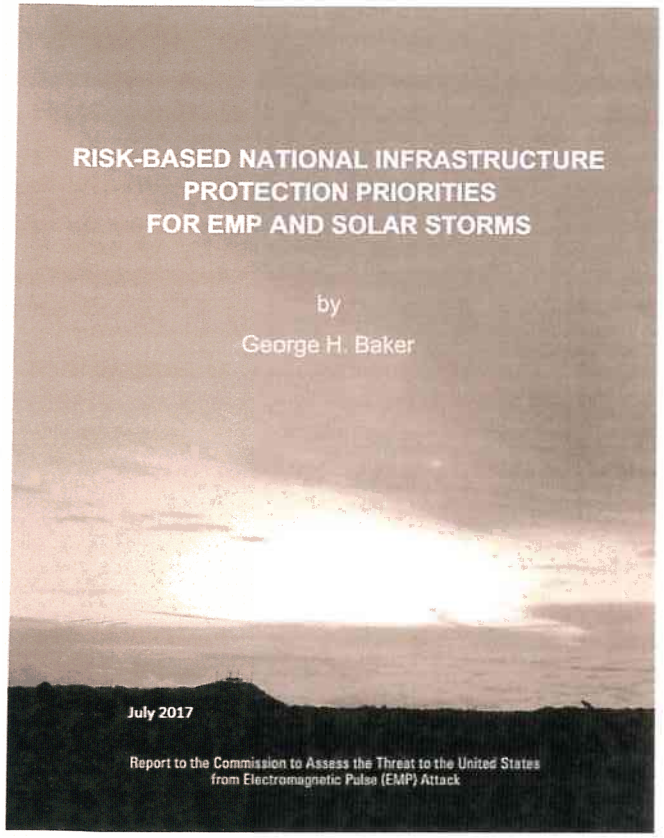
GMD vs. EMP **E3** Characteristics

Parameter	GMD	EMP **E3**
Anticipated Very Large Disturbances	4,800 nT/min	> 4,800 nT/min
Anticipated Very Large Geo-Electric Fields	20 - 50 V/km	> 85 V/km
Induced Grid Currents (Neutral **DC** Current)	800 – 2,700 Amps [1]	6,750 Amps [2]
Rise Time	10 – 100 Seconds	< 0.1 Second (Blast Wave) [2]
Total Impact Duration	1 – 12 days	1 – 300 Seconds [2]

1. PowerWorld™ Modeling of Wisconsin ATC Power Grid, May 18, 2016
2. "The Late-Time (**E3**) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid", James Gilbert et. al. Metatech-R-321, January 2010

E3 can have a higher Field and faster Rise Time but **GMD** has a much longer Impact Duration (3000x)

June 2018: U.S. Department of Defense cleared the EMP Report to the Commission for open publication



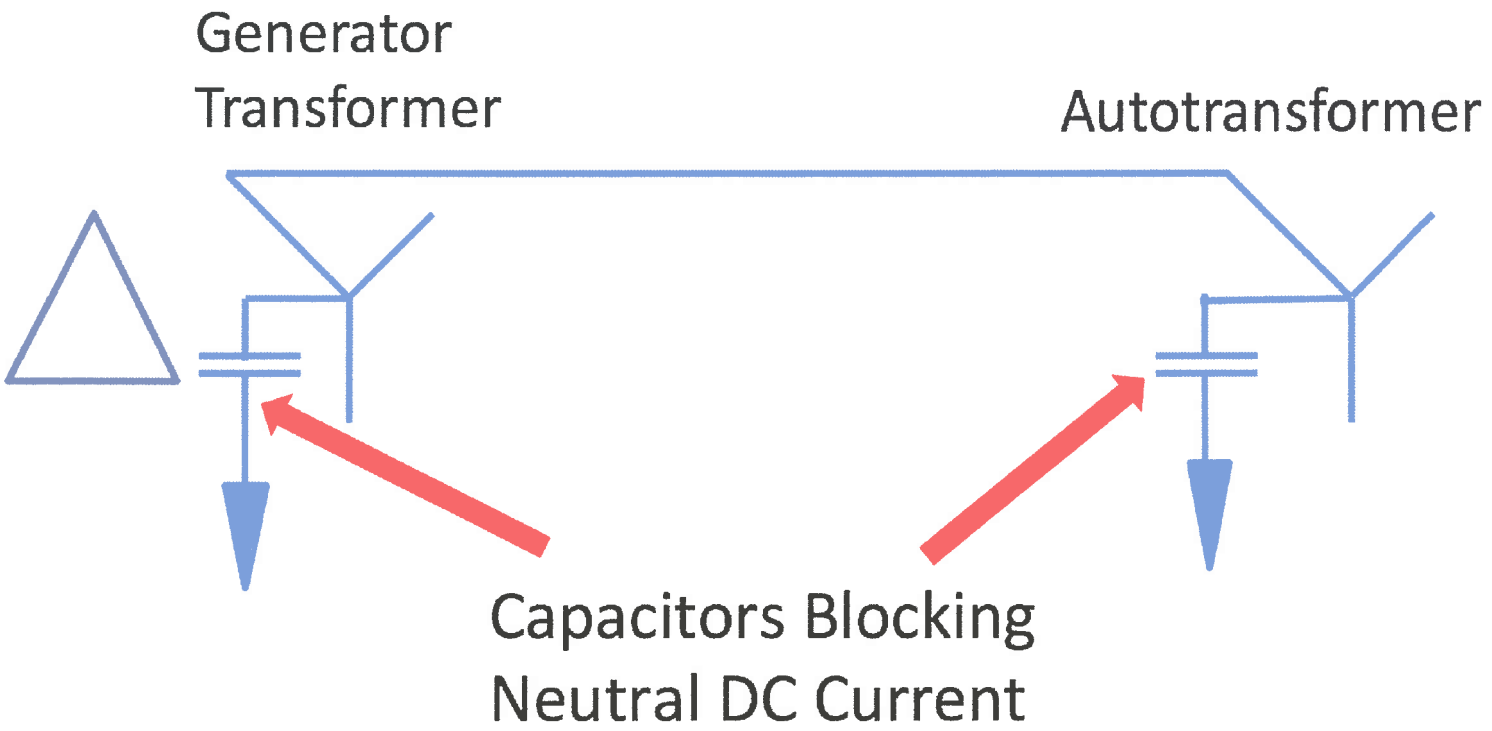
"EMP **E3**...induces currents of 100s – 1000s of amperes in long conducting lines (a few kilometers or greater) that damage components of the electric power grid itself as well as connected systems." (p. 3)

"We have empirical evidence that EMP and solar storms damage transformers within the electric grid..." (p. 8)

"**Installation of blocking devices in the neutral to ground connections of transformers** will significantly reduce the probability of damage from solar storms and... EMP **E3**." (p. 8) [emphasis added]

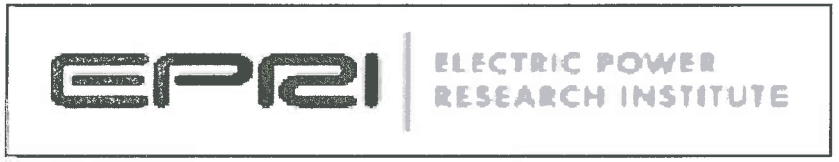
The most effective way to block GIC and EMP E3 induced DC currents:

- Capacitors placed in the neutral to ground connection of Transformers (**Neutral Blocking**)



Capacitors block DC current (GIC) while allowing AC current to flow

Brief History of Neutral Blocking



Electric Power Research Institute (EPRI)

1983: "A capacitor in the neutral of transformers was determined to be the most effective and practical blocking device."

-EPRI EL-3295, Project 1770-1 "Mitigation of Geomagnetically Induced and DC Stray Currents"

1992: "...inserting blocking devices in neutral leads appears to be the most logical and effective means of preventing GIC flow."

"...the use of ordinary capacitors is the best option for a GIC neutral blocking device." [emphasis added]

-EPRI TR-100450 "Proceedings: Geomagnetically Induced Currents Conference"

Concern: Having capacitors in the Neutral 100% of the time prevented utilities from maintaining a solid metallic ground

Emprimus worked with many utilities and EPRI to design the requirements for SolidGround™:

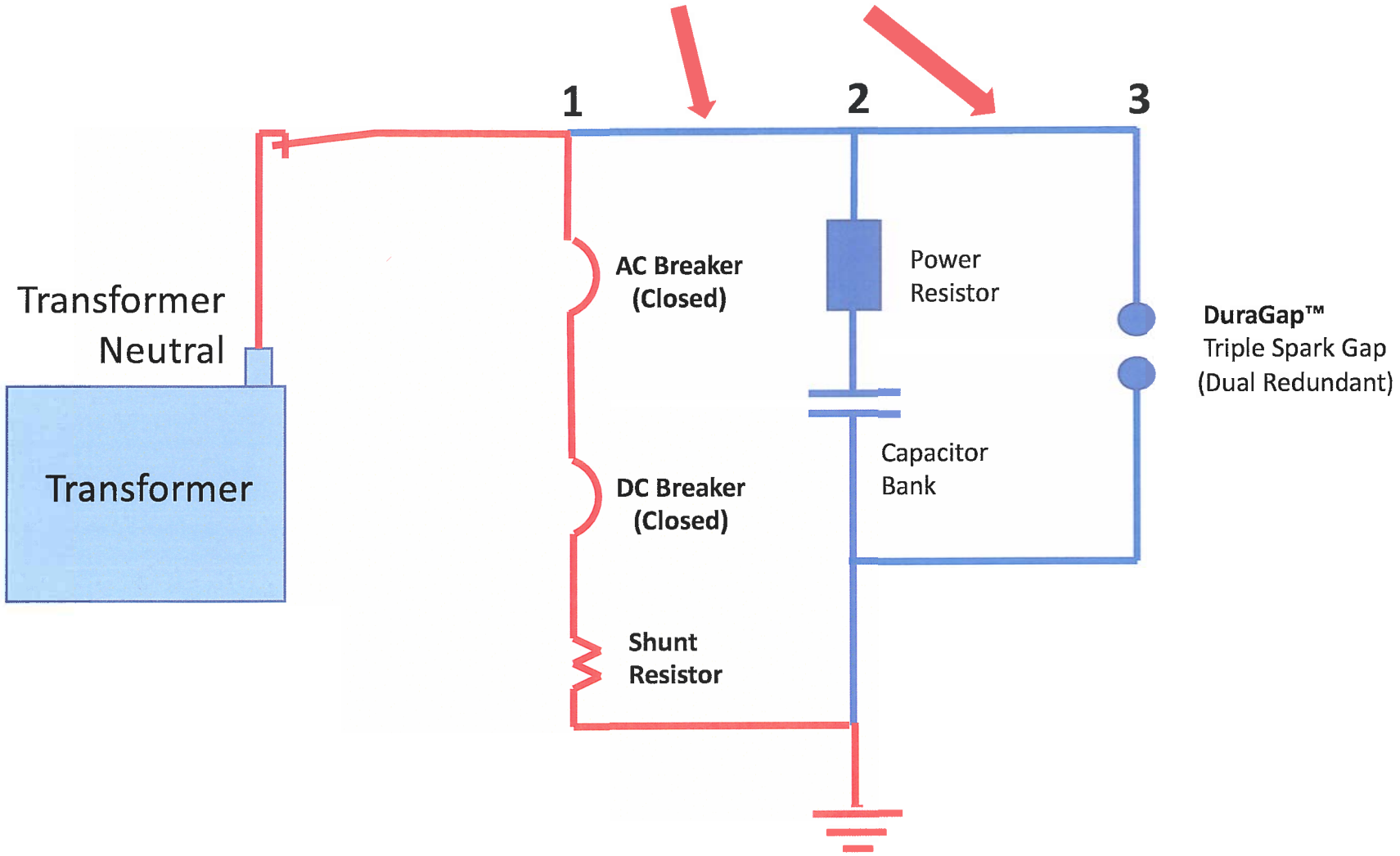
- ✓ Grid safe, Robust design, ABB & SEL **Standard Components**
- ✓ **Grounded neutral 100% of the time**: 3 parallel paths to ground (no switch between paths) ensuring it is always grounded
- ✓ **Solid Metallic Ground > 99.9% of the time** when no GIC or EMP induced currents are detected
- ✓ Fully **Automatic** (blocking only when necessary) with the ability to operate as a **Passive Device** (continuously in blocking mode)
- ✓ Automatically directs current through a **low impedance** capacitor bank which **blocks DC current** "effectively grounding" the transformer only when needed to protect against GMD/EMP
- ✓ Robust **Spark Gap** - capable of **>20 faults** with **no readjustment**

SolidGround™ Requirements continued…

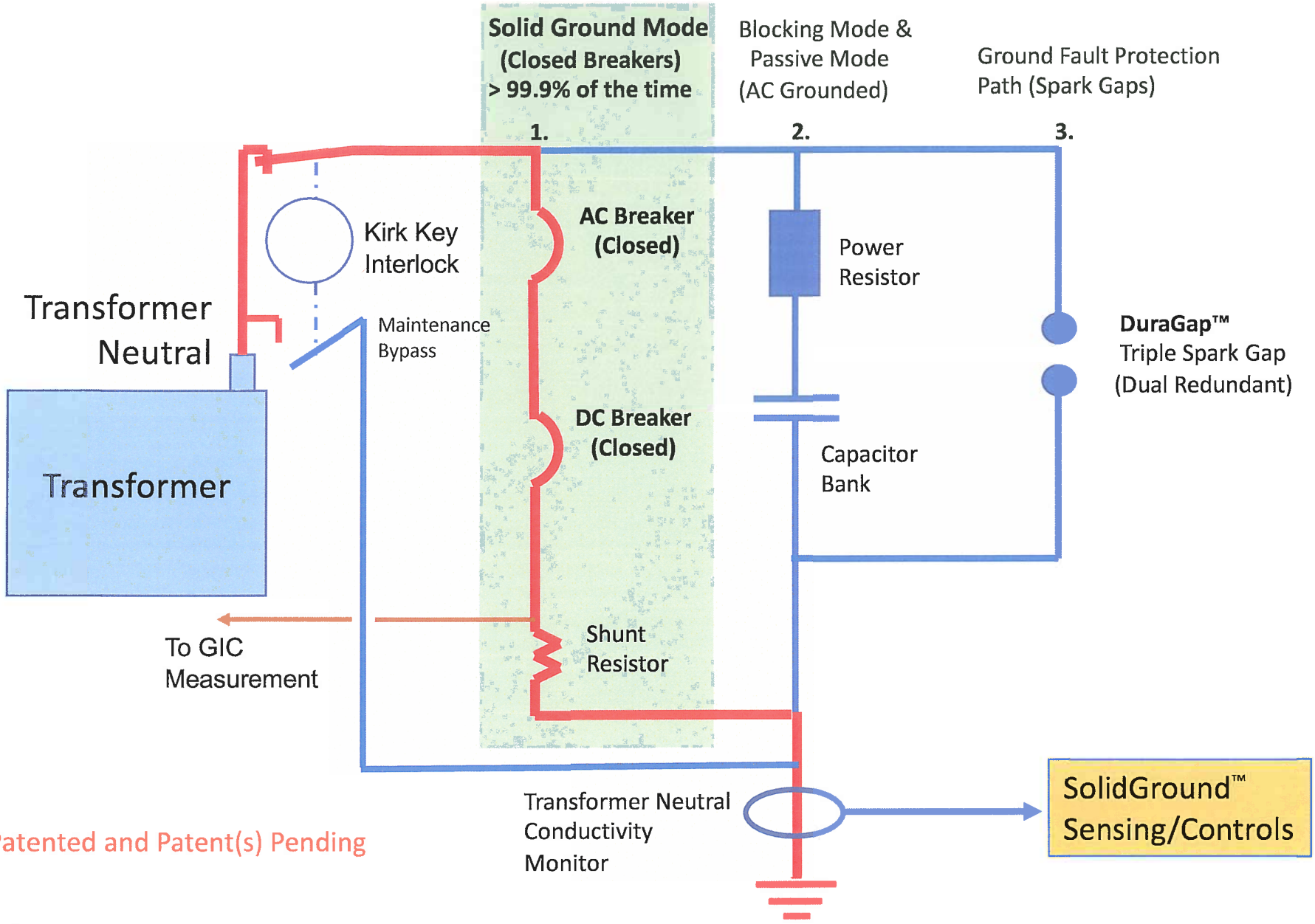
- ✓ **Voltage Safety Switch** Protects HV Transformers against voltages that exceed the withstand of transformer neutral insulation
- ✓ Utilizes a **DC Breaker** in the neutral to safely break DC Current
- ✓ No adjustment of relay settings, **No unintended consequences**
- ✓ Communicates with **SCADA** (Supervisory Control & Data Acquisition) continuously monitoring E1, DC current & Harmonics
- ✓ Continuous **Self Diagnostics**, **Little to no maintenance**,
- ✓ Meets all applicable electrical/mechanical requirements/codes
- ✓ Protects HV Transformers, Generators and HV Circuit Breakers
- ✓ **Works on all HV Transformer designs**: **GSUs, Auto & HVDC** Converter Transformers

SolidGround™ SIMPLE DESIGN

NO SWITCH between the 3 parallel paths to ground, ensuring the transformer is **Always Grounded 100% of the time**



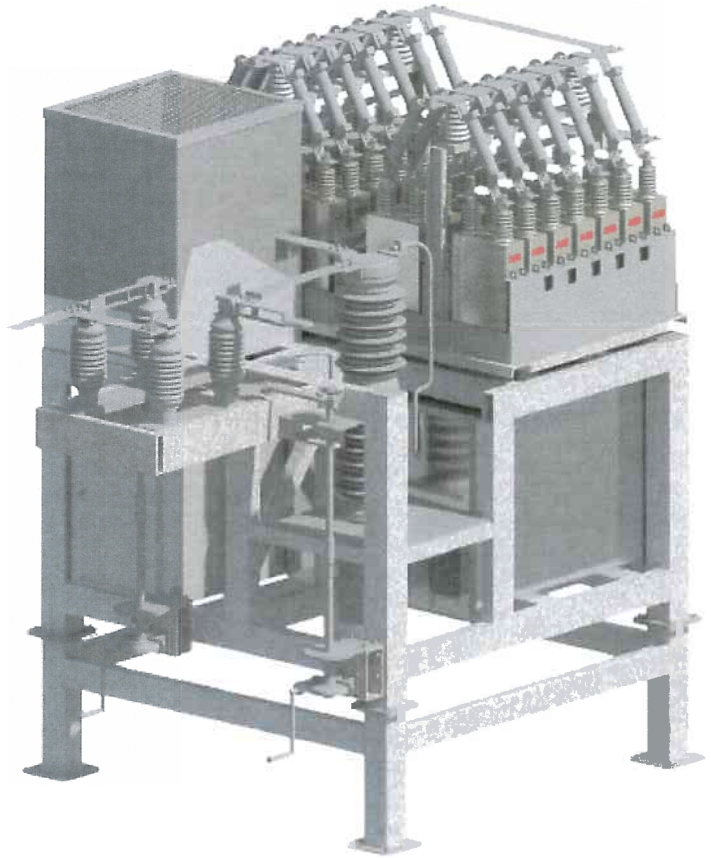
SolidGround™ Circuit Diagram

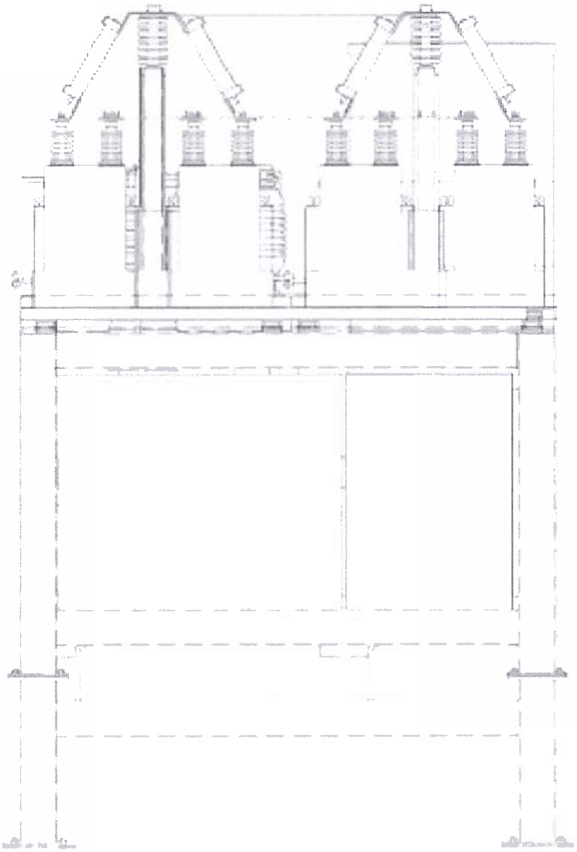


*Patented and Patent(s) Pending

SolidGround™ Standard GMD Model

- ✓ Protection up to **8 kV DC**, 2 Ohm which is sufficient for a 100 year "Carrington" level solar super storm (estimated to be ~20 V/km)
- ✓ **Easy to upgrade <u>at any time</u>** to protect against higher **EMP E3** fields **(>35 kV DC)**





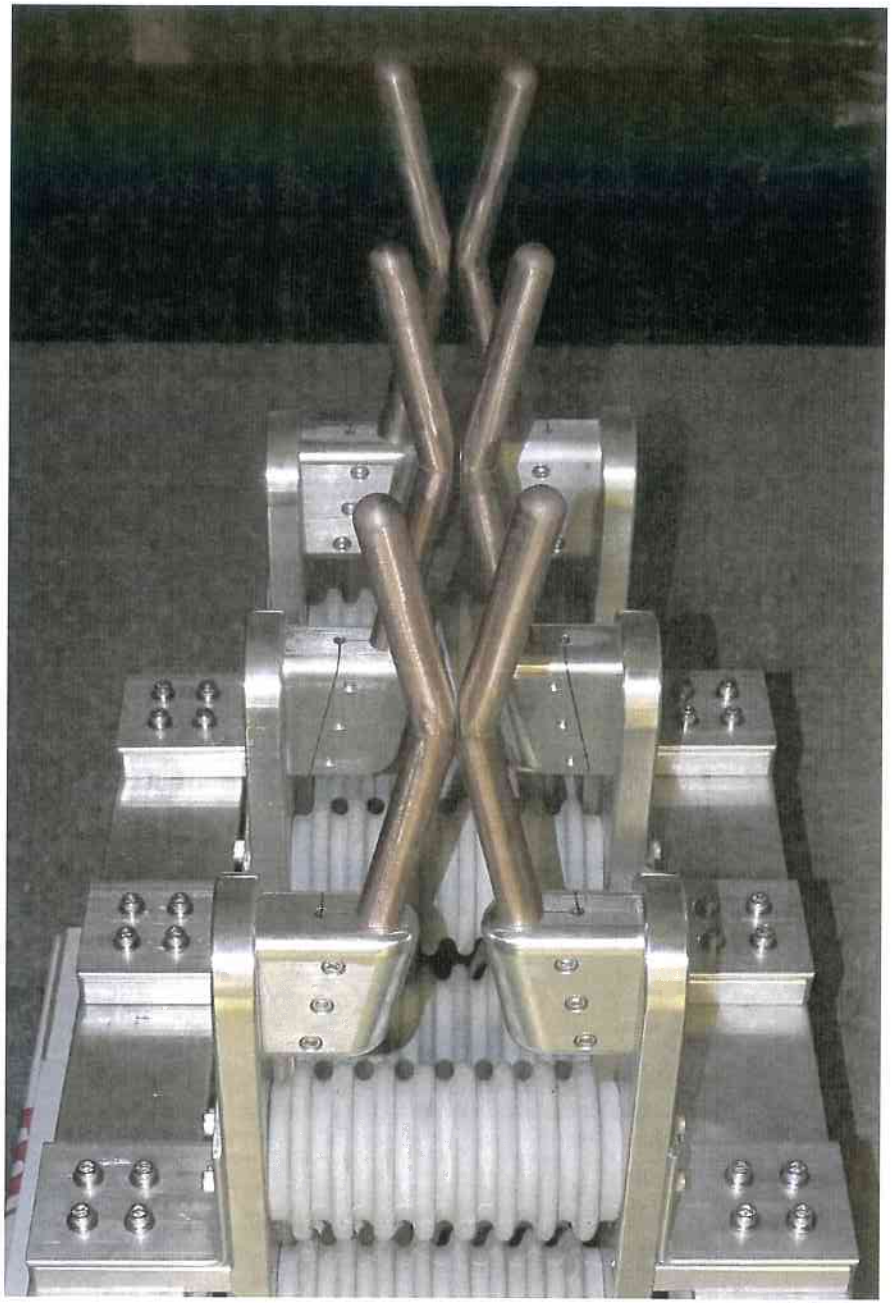
SolidGround™ Overvoltage Protection

DURA.GAP™

- **Passive Device** no electronics, **EMP Proof**
- **Dual Redundant** (Triple Spark Gap)
- **Simple** and **Reliable** overvoltage protection for **repeated high faults** with **no readjustment or cool down required**
- Robust, patented **gap preserving design** with adjustable breakdown voltage
- At KEMA, DuraGap™ easily carried **20 faults** (8 cycles) - 56 kA Peak each (20 kA RMS) **No increase in breakdown voltage**
- Preferred by utilities over the MOV (EPRI)

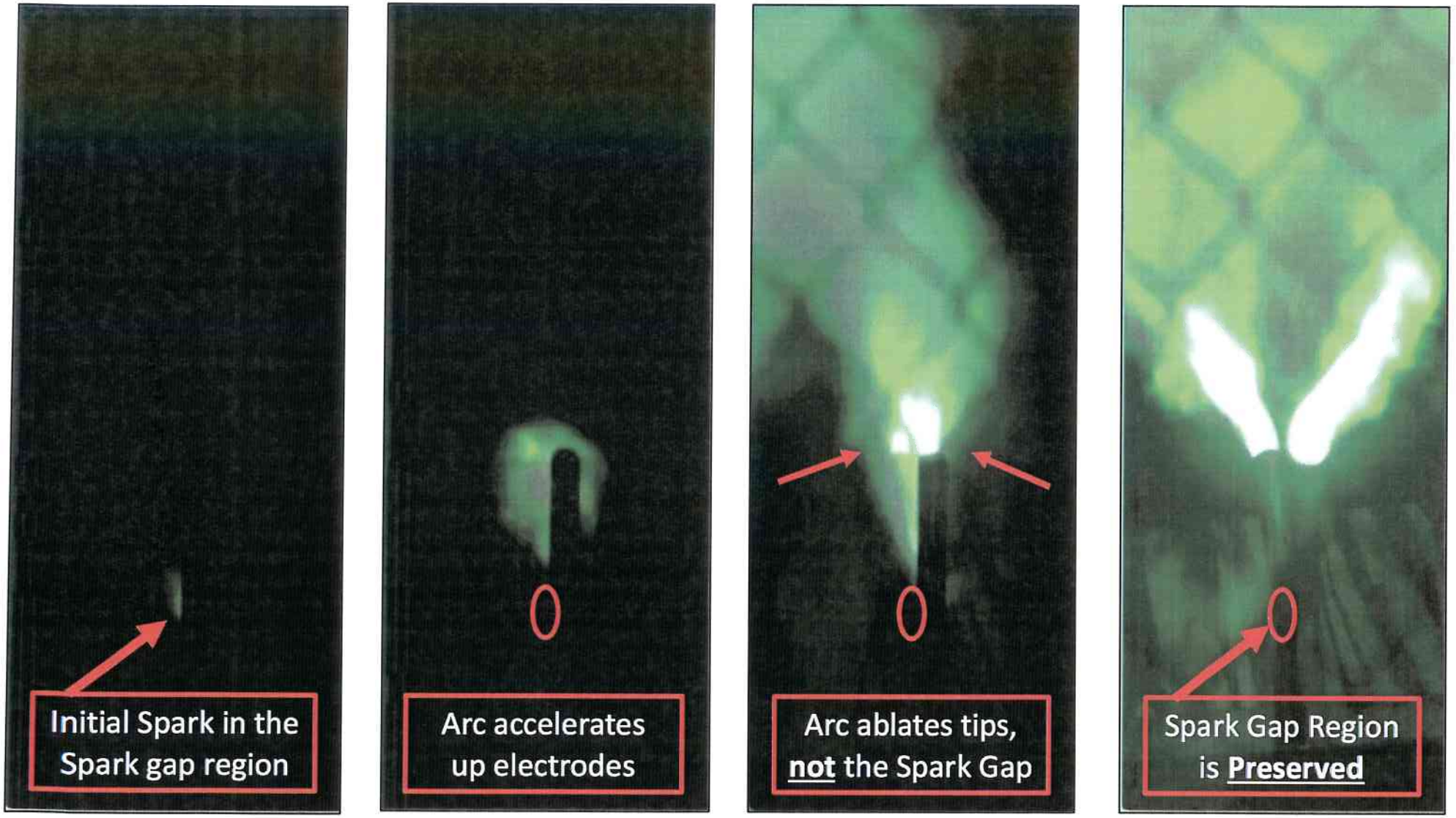
Note: Fault current = neutral return current

***56/20 kA rating can be increased**



empRIMUS

DURA.GAP™ ➤ *The closest thing to a copper wire ground*



Images show how the **gap preserving design** works: in **~ 1 millisecond** (1/16th cycle) **Lorentz Force** from the fault current **pushes the destructive arc up the electrodes** away from the spark gap region to the tips of the electrodes, preserving the spark gap.

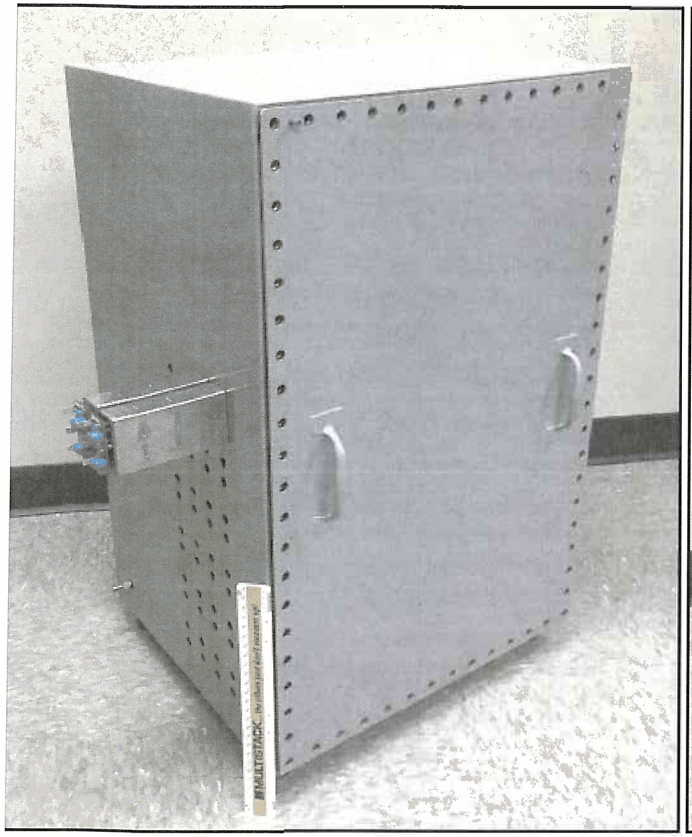
SolidGround™ EMP Model Upgrade(s)

1. **E1, E2 & IEMI Shielding** and **Filtering** for SolidGround™ Electronics
2. **Modular Capacitor Bank** "add-ons" for very high **E3** Fields (**>35 kV DC**)
3. **EMP.Alert**™ - continuous EMP **E1** monitoring and triggering device
4. **Passive Mode**: SolidGround™ is placed in "Blocking Mode" 100% of the time.

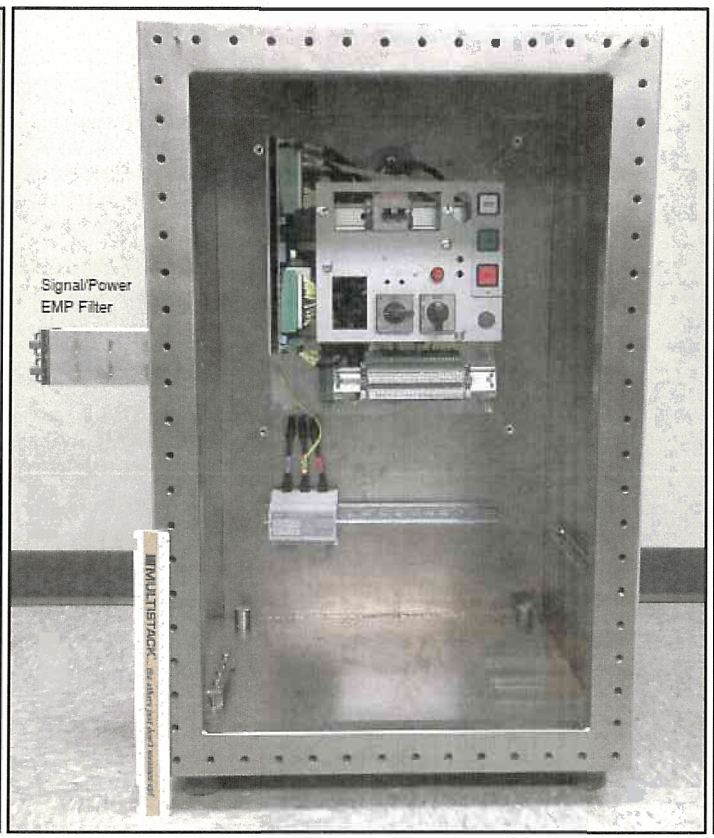
SolidGround™ 1. Shielding & Filtering

AC Breaker Electronics

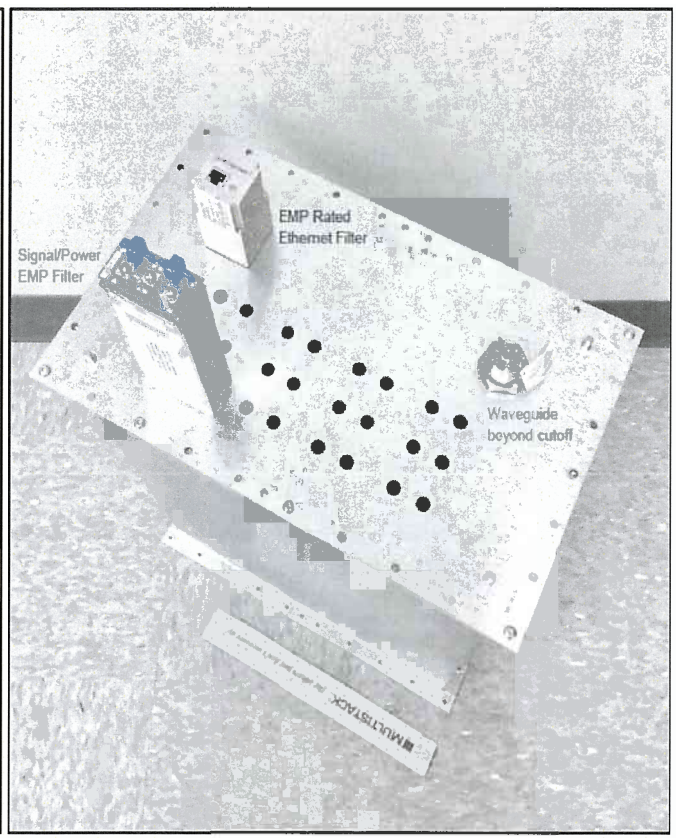
Schweitzer (**SEL**) Control Electronics



External View



Internal View

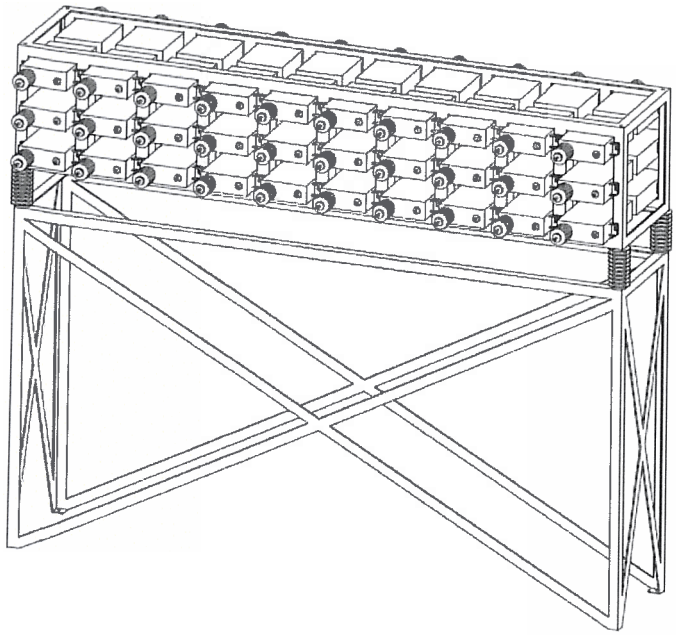


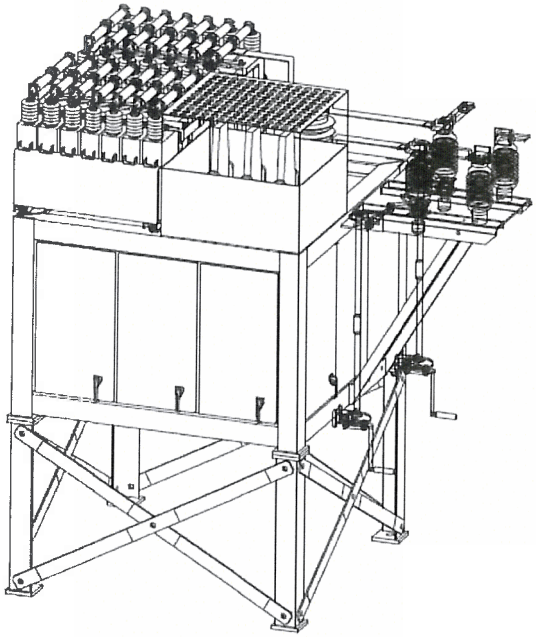
External View

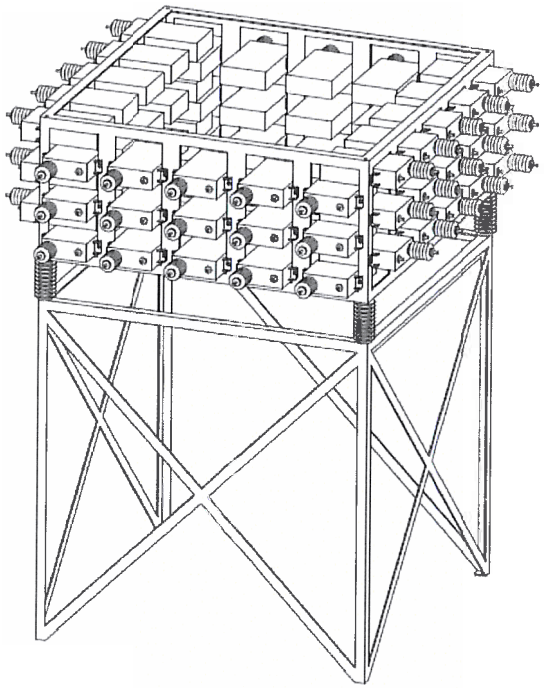
emPRIMUS

High Level EMP E1, E2 and RF Weapon Protection

SolidGround™ 2. Modular Capacitor Banks







- ✓ Protection against **very high** EMP **E3 Fields**
  - **>35 kV DC**, 2 Ohm
  - Variety of layouts to fit any space

SOLID GROUND SG-28E
EMP VERSION
2GHV035808A0002

Comments: -			Order: -	Scale: 1:200	Format: A1
Prepared: 2016-04-06 C Daehler	Based on: -			Units: mm	
Reviewed	Responsible department: PPHV/USTRA				Language: en
Approved	Document kind: Drawing		SOLID GROUND		Page: 1 of 2
ABB	The information contained in this document has to be kept strictly confidential. Any unauthorized use, reproduction, distribution or disclosure to third parties is strictly forbidden. ABB reserves all rights regarding intellectual Property Rights.		Document id: 2GHV035808		Revision: A
ABB Technology Ltd	© Copyright 2015 ABB				

SolidGround™ 3. E1 Detection & Triggering

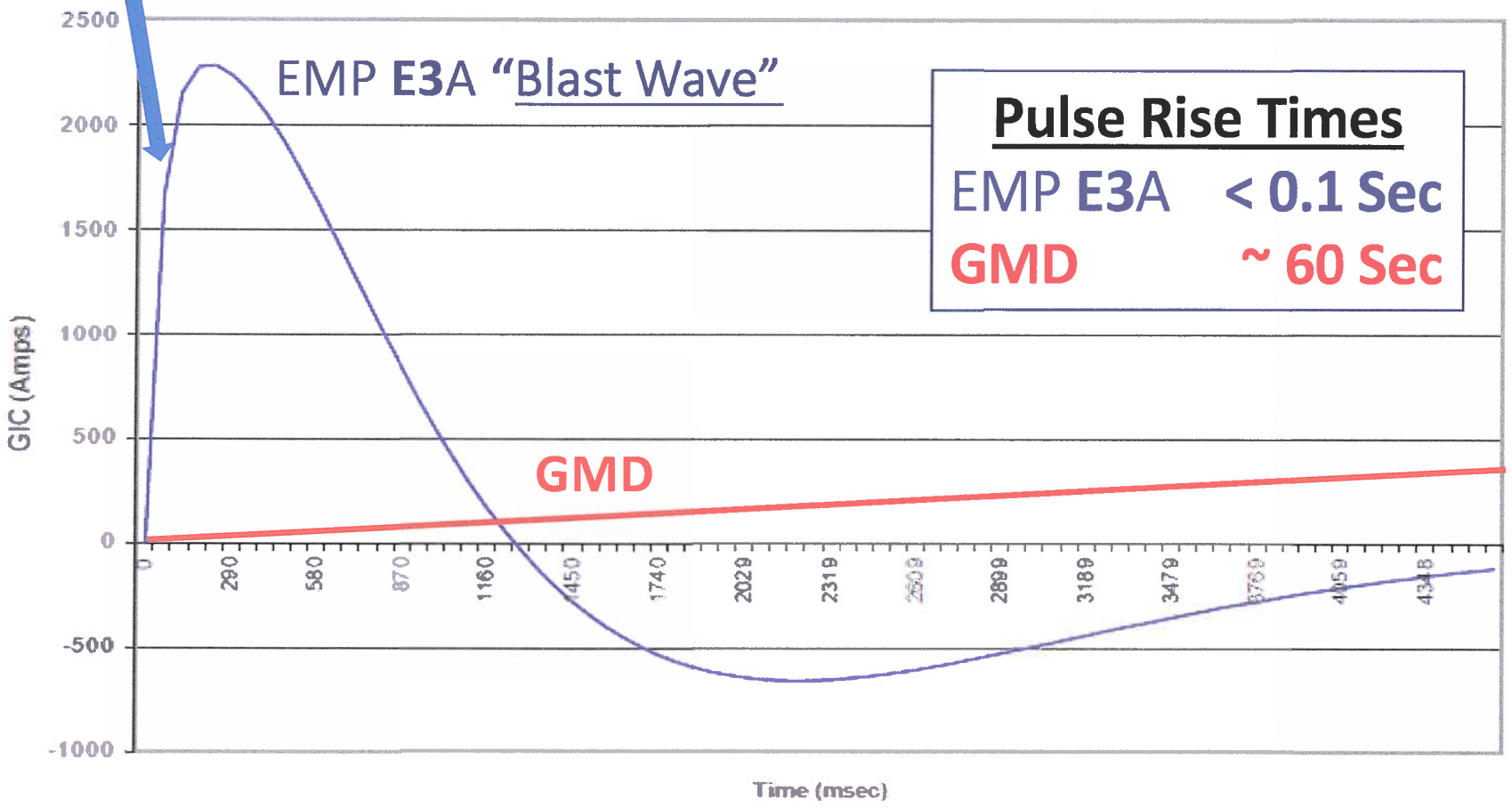
EMP.ALERT™

- Patented Compact/Robust design with **Wide dynamic range**: **(<100 V/m to 100,000+ V/m)**
- Non-Consumable w/ Electronics Shielded and filtered from **E1**
- **Two Models Available**
  1. Specific **E1** frequency range: (**10 MHz to 150 MHz**)
  2. **IEMI** frequency range: (**100 MHz to 10 GHz**)

EMP.Alert™ is the only known product capable of **detecting E1** in nanoseconds, **triggering breakers to safely operate** in milliseconds switching SolidGround™ into "Blocking Mode" *and* opening strategic HV breakers to instantly create "Microgrids" in order to isolate or de-energize portions of the power grid, all **before E3** Pulse Arrives.

EMP **E3**A Blast Wave vs. **GMD** Pulse

E3A Rise Time **too Fast** for Normal **DC** Detection then Protection



Source: "The Late-Time (**E3**) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid", James Gilbert et. al. Metatech-R-321, January 2010

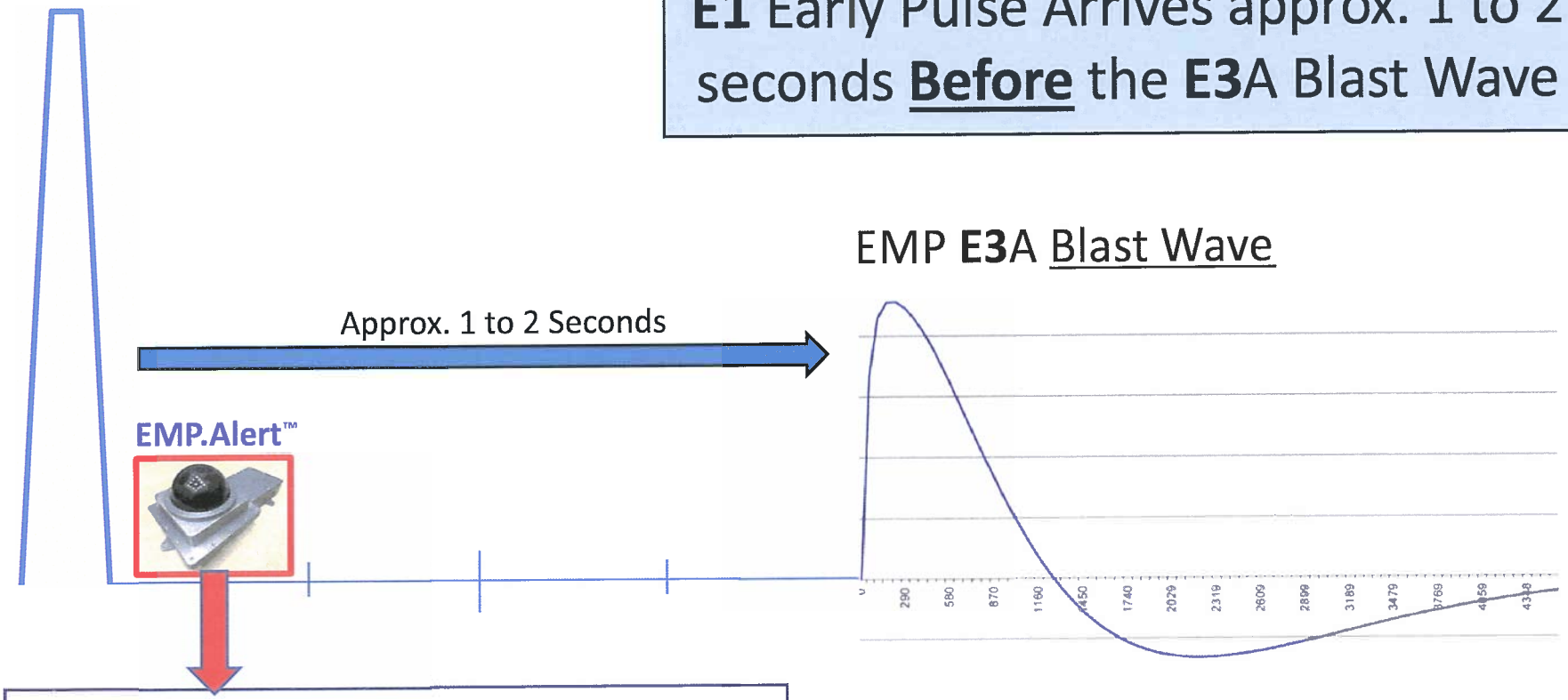
E3A Rise Time is Much Faster (600x faster) than **GMD**

Solution for **E3**A Fast Rise Time Issue

EMP **E1** Early Pulse

E1 Early Pulse Arrives approx. 1 to 2 seconds **Before** the **E3**A Blast Wave

EMP **E3**A Blast Wave



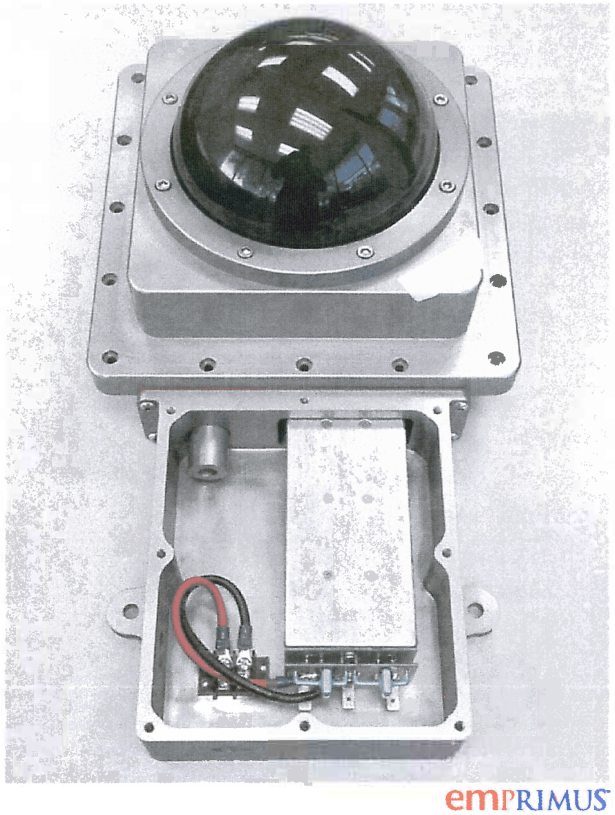
E1 is detected, automatically triggering SolidGround™ into "Blocking Mode" in Less Than 0.25 Seconds after nuclear detonation, **before** the **E3** pulse arrives

EMP **E1** Early Pulse Triggers **SolidGround™** into "Blocking Mode" **before** the **E3**A Blast Wave arrives

EMP.ALERT™

2017 National Defense Authorization Act (NDAA)

Energy Savings and EMP Provisions



✓ EMP.Alert™ meets the criteria of

SEC. 319 EMP AND GMD MITIGATION RESEARCH AND DEVELOPMENT

"(3) …**feasibility of rapidly isolating** one or more **portions of the electrical grid** from the main electrical grid."

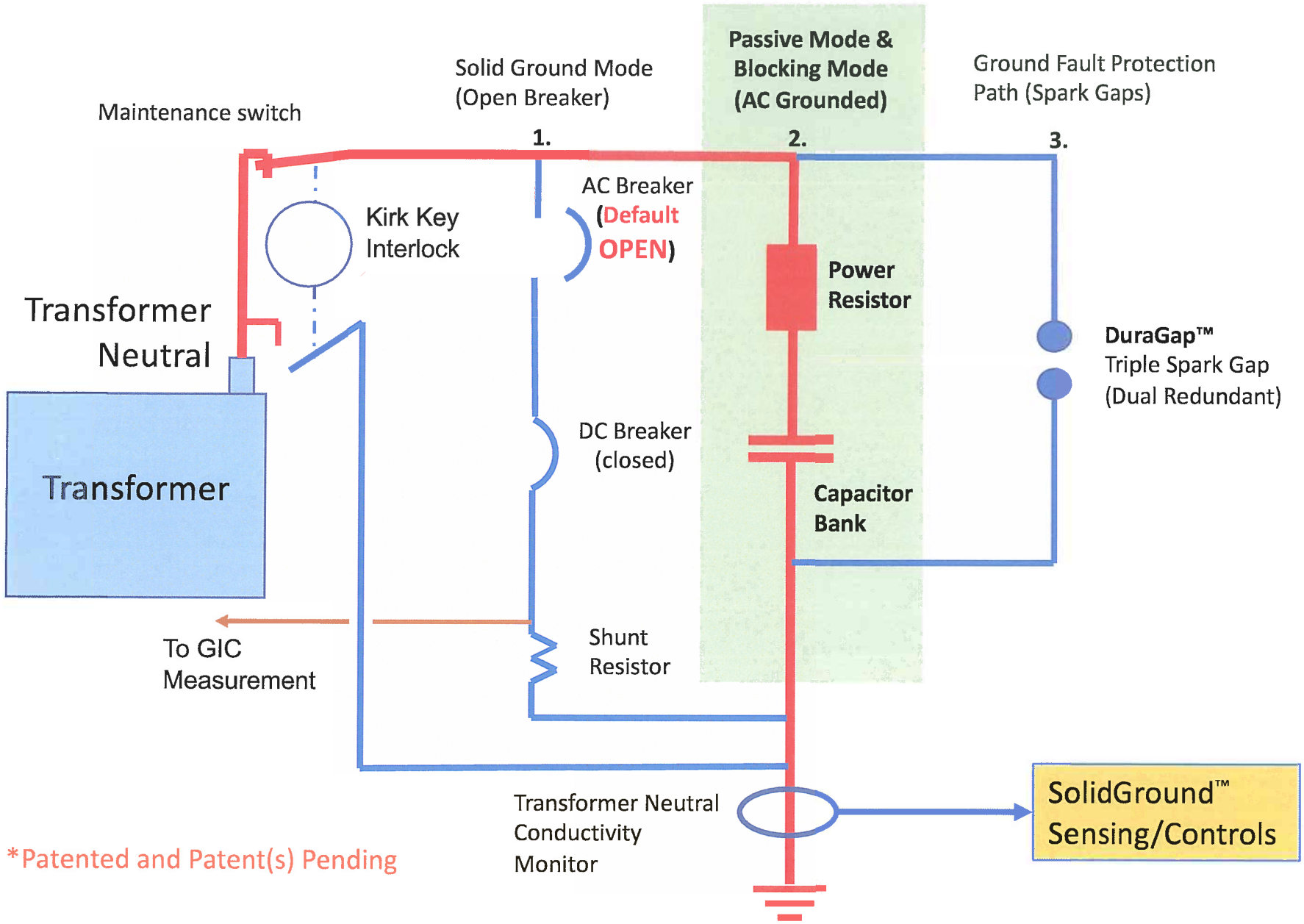
"(6) …**feasibility of a real-time alert system to inform** electrical grid operators and other stakeholders **within milliseconds of a high-altitude nuclear explosion.**"

4. "Passive Mode"

If preferred by the utility, SolidGround™ can be operated as a **Passive Device**:

- ✓ Does *not* require **DC** (GIC) or **E1** detection/triggering
- ✓ SolidGround™ is placed in "Blocking Mode" continuously, directing current through a low impedance capacitor bank "**effectively grounding**" the transformer during normal operation
- ✓ Automatically bypasses capacitors, solidly grounding transformer with DuraGap™ only for very short periods when necessary, such as during a fault

SolidGround™ Passive Mode Circuit



*Patented and Patent(s) Pending

Operating Procedures are not sufficient

Utility Operating Procedures

- *Procedures do **not** decrease the amount of GIC entering the grid*
- *Require hours (not minutes or seconds) after a GMD warning and are susceptible to human error.*
- *Expensive and result in loss of efficiency in power generation and transmission "Uneconomic Dispatch"*
- *NOAA warnings cannot predict GIC or which procedures will be effective*
- *Low-level GMD events are currently causing $Billions in economic loss each year to the U.S. (Zurich/Lockheed)*

Vs.

SolidGround™ Neutral Blocker

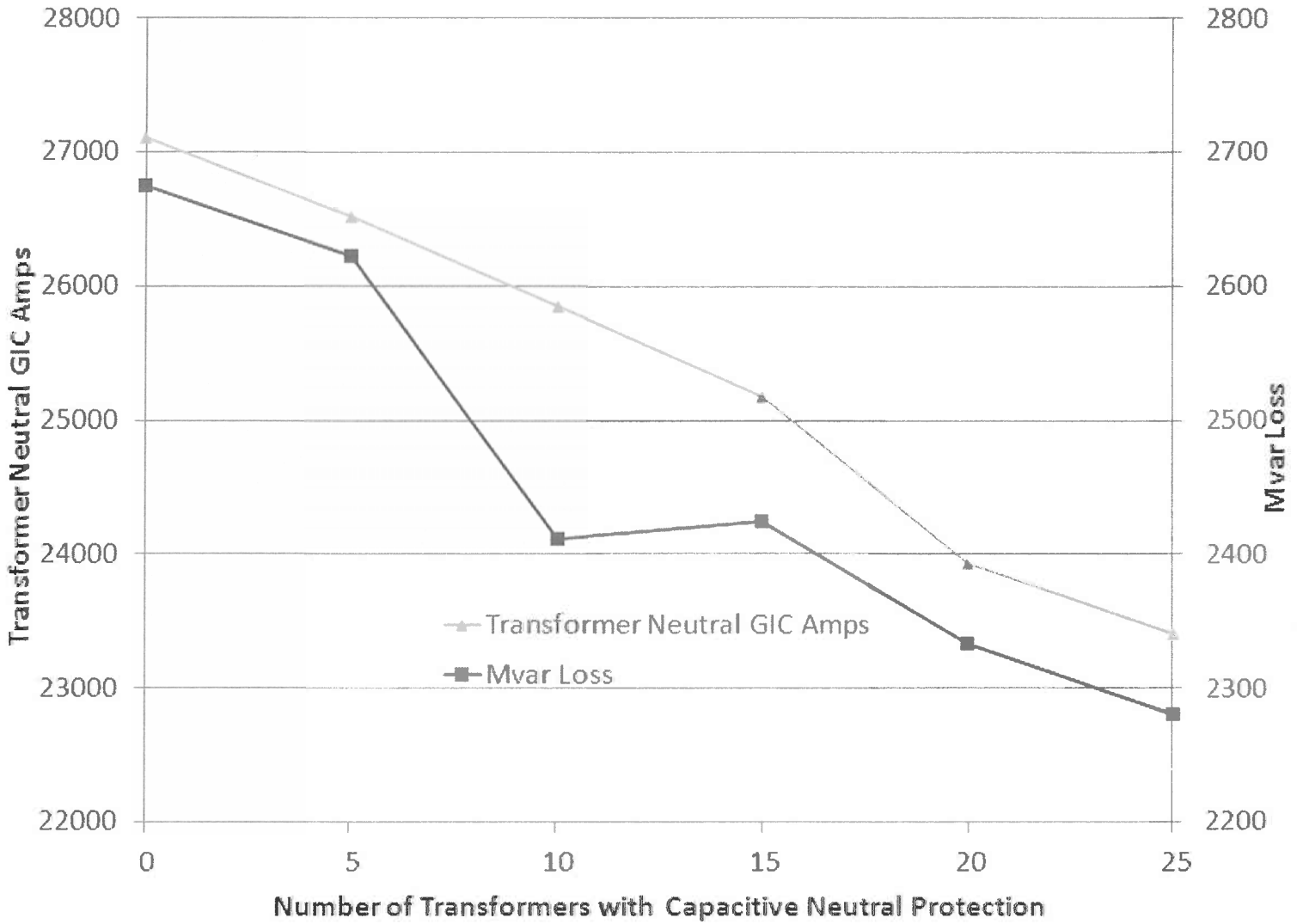
- *Automatically **blocks GIC** from entering the grid and **prevents** the generation of damaging **harmonics***
- ***Operates in milliseconds** when GIC is detected. Not dependent on GMD Warnings from NOAA/MISO. Not susceptible to human error*
- ***Decreases MVAR consumption** during GMD events allowing utilities to operate without losing efficiency.*
- ***Perfect track record** over the last 3+ years blocking GIC every time it was detected in the ATC (Wisc.) Grid*

***GIC must be blocked** to ensure reliable high quality power*

Must block DC Current (GIC) to prevent:

- **Voltage Collapse** (Long term Black Out over large areas)
  - Mis-operation of SVC Capacitor Banks - Inability of capacitor banks to switch on and off with constant GMD field polarity changes
- **Damage to Large Power Transformers (LPTs)**
  - Thermal *and* Harmonic damage
  - Very long lead times (up to 2 years) to build
  - Transformers are custom built
- **Damage to AC Breakers**
  - Mis-operation of controls
  - High Voltage AC breakers are unable to interrupt high DC Current
    - Black Sky hazards such as Hurricanes and 1,000-year floods are more localized and do not produce DC current therefore AC Breakers are able to operate as designed. This is not the case with GMD and EMP E3.
  - ➢ **AC Breakers attempting to open in the presence of DC current can arc and be permanently damaged.**
    - Loss of Breakers make black start capability vastly more difficult
- **Damage to Generators**
- **$Billions in business losses *each year* due to Harmonics** (as documented by Zurich, Lockheed & NOAA).

SolidGround™ decreases Total GIC & MVAR Losses – ATC Wisconsin Pw Grid



SolidGround™ Validated

Simulation and Modeling
Extensively studied by the University of Manitoba and **EPRI**

University of Manitoba

EPRI Electric Power Research Institute

Report #3002002985, March 2014

High Ground Fault Current Testing at KEMA Labs
Passed repeated high current fault testing

Defense Threat Reduction Agency · United States of America

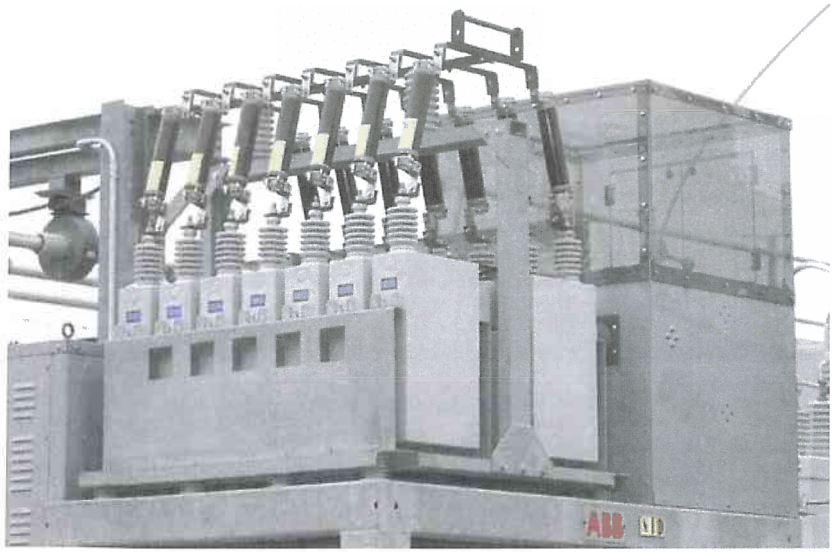
DoD/DTRA Idaho National Laboratory
Live Grid EMP E3 Experiment
SolidGround™ met all performance requirements. Detected and blocked injected DC current.

American Transmission Company co-authored & presented a paper at MIPSYCON on the ongoing performance of **SolidGround™** (over 3 years) on the Wisconsin power grid.

"SolidGround™ is ready for deployment"

- Automatically operated **33 times** performing as designed without issue, **blocking GIC** during multiple solar storms (as of 12/2018)
- No "Whack-a-Mole" - successfully blocked **GIC** at substation with no GIC increases elsewhere
- Little to no maintenance
- **No unintended consequences** to the power grid

SolidGround™ Summary



- **Blocks GMD** and EMP **E3** induced **DC currents**
- **Prevents** generation of Damaging **Harmonics**
- Fully **Automatic**, operates as an **Active** or **Passive** Device
- **Always provides a solid metallic *and* effective AC ground**
- Protects Transformers, Generators and Circuit Breakers (“*backbone of our grid*”) allowing utilities to operate through Solar Storm events without loss in efficiency.
- Scalable, **Voltage Safety Switch** allows protection of an entire Grid against Solar Super Storms and EMP **E3**
- Stabilizes Grid, Reduces existing GIC stress on equipment
- Major components are industry standard, high quality, provided by **ABB** and **Schweitzer (SEL)**.
- SCADA controls with continuous monitoring of **DC** currents and EMP **E1** (Harmonic detection optional)
- Reduces Total Network GIC and MVAR Consumption
- No Adjustment of protection relay settings required

SolidGround™ Fully Operational

Currently operating on the U.S. Grid

AMERICAN TRANSMISSION COMPANY

Fully Operational on ATC Wisconsin Grid Protecting a 300 MVA 345kV / 138kV Transformer

ATC's SolidGround™ has operated **33 times** since being installed (successfully blocking **GIC** during multiple **Solar Storm** events)

SolidGround™

For more information please contact

Gale Nordling: gnordling@emprimus.com

Thanks for Your Attention

ABB Power and productivity for a better world™

emPRIMUS